Growth of capelin in relation to zooplankton biomass in the Barents Sea

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Abstract

Growth of capelin in the Barents Sea stock has been found to vary considerably both between years and between different parts of the distribution area. The aim of this paper is to compare such growth variations with measured abundance of zooplankton within the capelin feeding area.

In the period 1979-1984 a north-south transect in the Barents Sea was studied one to four times during summer. A negative relationship between the plankton biomass and the density of capelin along the section was evident. During the summer feeding migration the largest capelin, primarily the oldest, but also the largest individuals of each age group, were found in the front of the north-ward migration. Here they form a capelin front, which can be seen as eating its way through the plankton distribution. Length and weight of capelin were positively correlated with plankton density along the section.

From 1987 to 1994, zooplankton abundance has been recorded on several stations taken along the track of an acoustic survey for capelin during September. The mean annual individual growth in weight of capelin was found to be positively correlated with average zooplankton density. The strongest relationships were found between one year old capelin and the smallest zooplankton size fraction, and between three years old capelin and the largest size fraction of plankton. Capelin length, weight and condition factor were also to some degree correlated with plankton density, although significant results were found for only some combinations of capelin age group and zooplankton size fraction.

1.0 Introduction

The data stem from scientific surveys of the Barents Sea in the period 1979 to 1994. During the period 1979 to 1984, data on plankton and capelin were sampled one to four times during the summer period each year along a section in the central Barents Sea - "Section I" (Fig. 1)

During the period 1987 to 1994 data were sampled in the autumn period at annual multipurpose surveys, with main aim to map the geographical distribution, size and composition of the Barents Sea capelin stock. These surveys, therefore, cover the whole distribution area of the capelin towards the end of its feeding season. Another aim of the surveys were to map the abundance and distribution of plankton.

The aim of the present paper is to analyse zooplankton density data and capelin growth parameters to search for possible relationships between those variables.

2.0 Materials and methods

2.1 Capelin data

Random samples (100 specimens) of the capelin caught in trawl hauls (mostly pelagic) were analysed individually, and length and weight were measured. The age was determined by inspection of otoliths. Based on length and weight, a condition factor (CF) was calculated, equalling

$$CF = \frac{Weight \cdot 1000}{(Length)^3}.$$ (EQ 1)

Trawl stations, in general, give no information on capelin biomass or density. Such information was gathered using an echosounder/echo integrator system (Bodholt et al. 1989), following standard procedures for acoustic surveying (Dommasnes and Røttingen, 1985; Foote, 1991).To compare the data on size and condition of individual capelin from trawl catches with capelin density, the amount of capelin inside subareas with size 2 degrees longitude by 1 degree latitude was determined using the acoustic method. The amount of capelin of each age group inside each subarea was derived by applying weighting factors to each of the samples included in the subarea. The capelin data sampled along section I during 1979-1984 were treated differently. Here, no biomass estimate of capelin was available, since an area coverage was not attempted. In this case, the mean acoustic density of capelin was determined along 30 nautical miles intervals of the section, and mean values of capelin length, weight etc. from the nearest trawl station (trawl stations were taken at irregular intervals along the section) were allocated to each interval.

2.2 Plankton data

The zooplankton samples were collected with a $1m^2$ MOCNESS (Wiebe et al. 1976) or Juday nets. The MOCNESS is a plankton trawl equipped with 8 nets for sampling in different depth intervals. It was towed obliquely or stepwise horizontally from near bottom to surface. The depth intervals varied in size but the height were usually between 25 and 100m. The filtered volume

also varied, usually about 200 m^3 was filtered by each net. The catch was subsampled and as a rule 1/2 was used for dry weight analysis. The sample was sieved through 2000μm, 1000μm, and 180μm plankton sieves to obtain three different size fractions of the biomass. Larger medusae and ctenophores were removed prior to sieving, and the volume converted to dry weight, assuming 3% dry weight content. The >2000μm size fraction typically contained medusae, chaetognaths, amphipods, pteropods, and a few large copepods. The mid size fraction (1000-2000μm) was dominated by the copepods *Calanus finmarchicus* and *C. glacialis* in copepodite stages IV-V, while the 180μm fraction contained smaller copepods and early copepodite stages of *C. finmarchicus*. Also juvenile pteropods could be numerous here.

The samples from the different size fractions were transferred to aluminium vessels and dried at 70°C for 24 hours. Early samples taken before 1991 were burned in oven at 450°C to obtain also ash free dry weight (A.f.d.w.). Later samples were not burned, but the dry weight was converted to A.f.d.w. (= 0.8*dry weight), assuming 20% ash content to be able to compare with older data.

Based on dry weight in mg and filtrated volume in m^3 the original data are expressed as mg*m^{-3}. For the statistical analysis the data were recalculated to give A.f.d.w. as g*m^{-2} from near bottom to surface and from 100m to surface. Because most of the MOCNESS hauls were starting about 30 m or more from bottom, it was assumed that the concentration of zooplankton found in the deepest haul was also representative for the depth layer not covered above the bottom. In case of intermediate layers not covered, the values were estimated as averages of values below and above. Thus the biomass below 1m^2 can be expressed as the sum of biomass per m^3 multiplied with the height of the water column covered by each net (I_n) in part of or the whole water column:

$$Afdw_{sqm} = \sum Afdw_{cbm} \cdot I_n \qquad \text{(EQ 2)}$$

3.0 Results

3.1 Section I

The section (Fig. 1), or a part of it, was covered one or more times per year from 1979 to 1984. Zooplankton biomass was recorded from Juday net hauls, and most years length, weight and density of capelin were recorded from pelagic trawl hauls and from an acoustic survey along the section.

3.1.1 Relationship between capelin density and total zooplankton biomass

In 1980 this section was covered twice, in June and July. In June, the density of plankton was highest in the middle part of the section, between latitudes 75° and 76°. The mean density was 15.9 g/m^2, ranging from 5 to 25 g/m2. The density of capelin was low, ranging from 1.6 million individuals/nm^2 in the south to almost 0 north of 76°N. The second coverage revealed a much higher density of plankton ranging from 13 g/m^2 south of 75° N to 80 g/m^2 at the northernmost station at 75°30N. The density of capelin showed a similar pattern, increasing from less than 10 million individuals/nm^2 south of 75°N to 35 million individuals/nm^2 at 75°30 N.
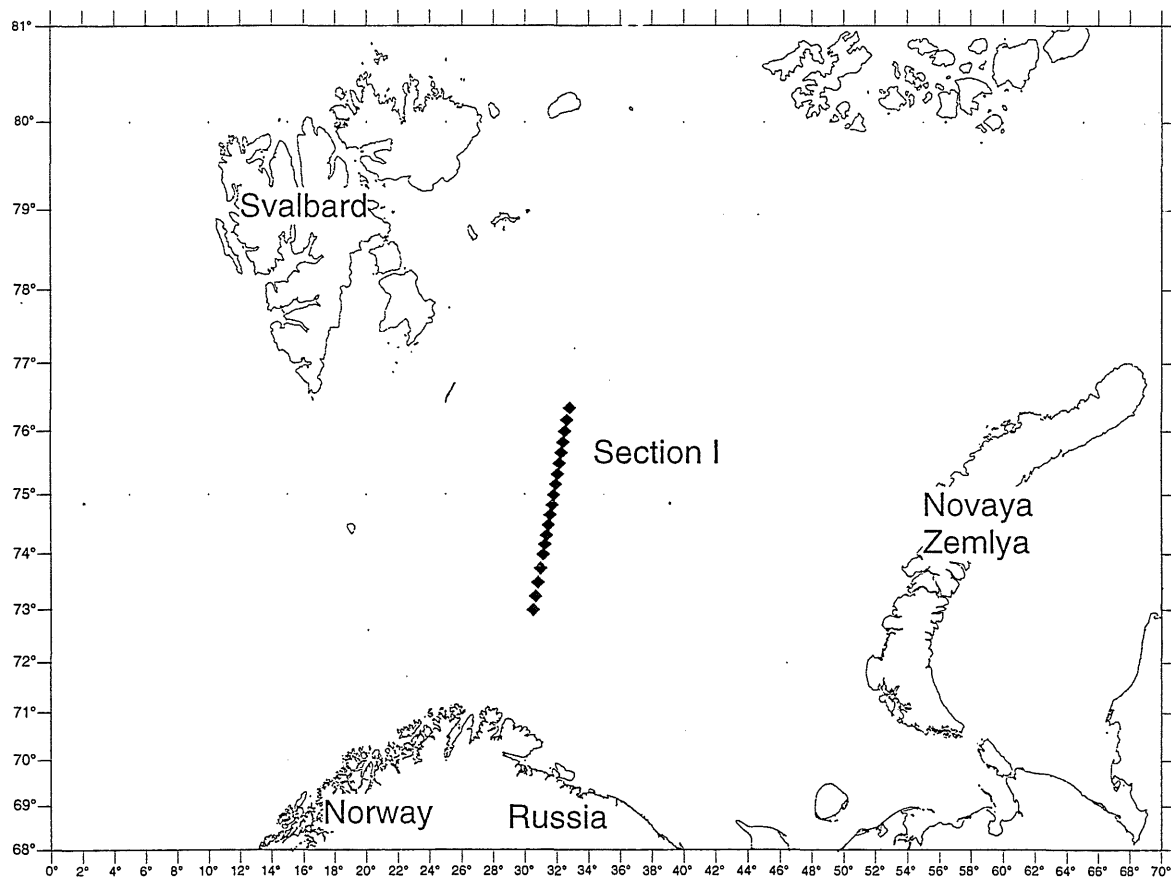
Figure 1. Map of the Barents Sea with the location of Section I shown

In 1981 an extensive study was undertaken, and section I was covered four times, in May, June, July and August (Fig 2). The northernmost station of each coverage of the section was taken near the receding ice edge, so different but partly overlapping parts of the section was covered each time. Generally, the plankton density was increasing from May to July, but was lower in August. The capelin density was generally low except in August, when densities of above 80 million individuals/nm^2 was recorded between latitudes 76° and 77°. In May, no relationship between plankton density and capelin density was evident (r^2=0.005, p=0.94). Low plankton biomass in the southern part of the section corresponded to high fish density, while a second minimum in the plankton density from 73°30' to 74°00' corresponded to low fish densities (Fig 2a). In June, however, there was a clear opposite trend in the distribution of plankton and capelin (r^2=0.37, p=0.01). During this period, the northern limit of the capelin distribution ("the capelin front") had moved northwards to about 74°N, and the plankton biomass increased to high levels just north of this latitude (Fig 2b). Unfortunately, the capelin distribution was not recorded during the July coverage of this section. The plankton biomass was generally highest from 75°30' to 76°30', but with lower biomass around 76°00' (Fig 2c). Based on the position of the capelin front in June and in August, it seems reasonable that the local minimum of zooplankton biomass may have been be associated with the capelin front in July. In August, the capelin front had reached about 77°10' (Fig 2d), and there were generally low concentrations of plankton south of 78°00'. In this case, there was a clear drop in plankton biomass between 76°20' and 77°10', where the highest concentration of capelin was detected. A linear regression of capelin density versus plankton density revealed a negative, although not significant relationship (r^2=0.18, p=0.075).
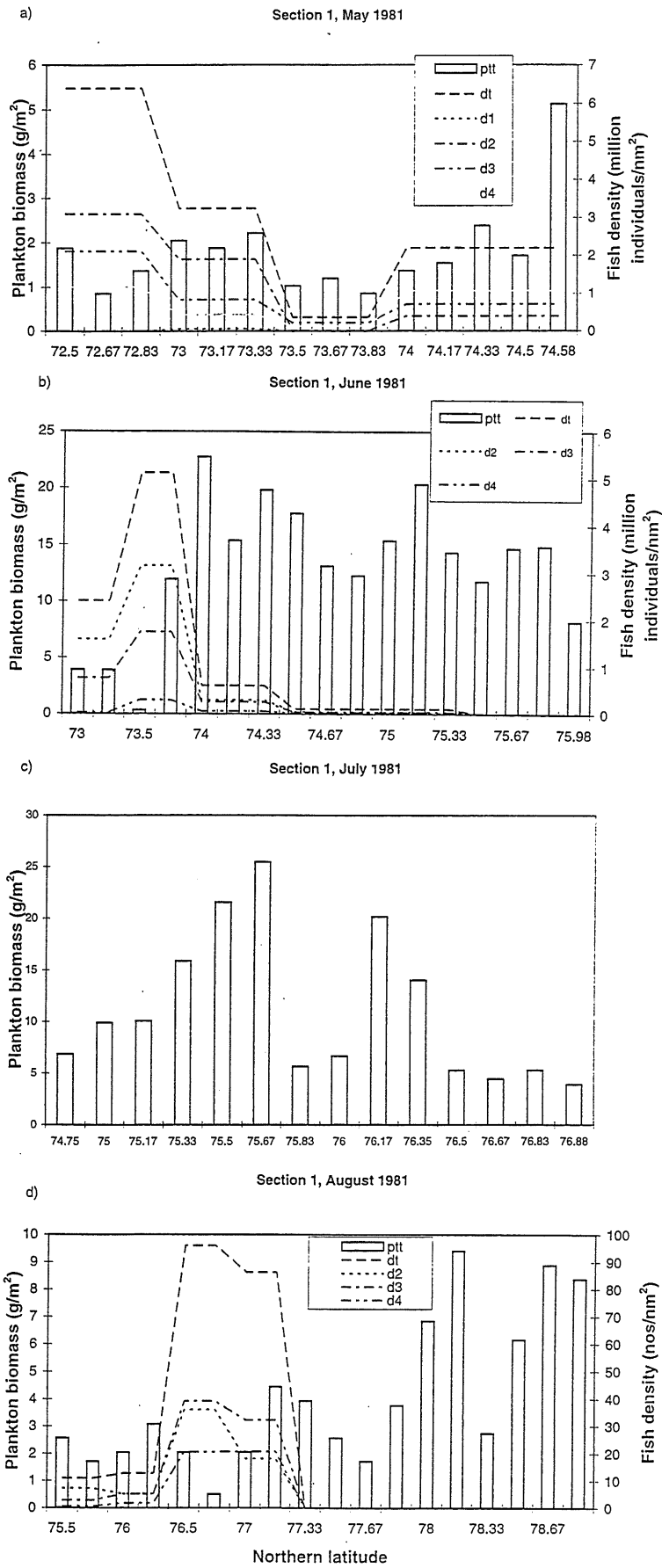
4

Figure 2. Plots of plankton biomass (bars) and density of capelin by age groups (lines)along Section I 1981. a) May, b) June, c) July, and d) August.

In 1982 section I was covered once, in June. The highest plankton concentrations were found from 74°00' to 74°20', just north of the main capelin distribution. In this case, there was no clear capelin front and low densities of capelin persisted northwards to 76°00'. There was a weak negative but not significant (r^2=0.07, p=0.31) relationship between capelin and plankton density. Also in 1983, this section was covered only in June. Low densities were detected both of plankton and capelin, and no relationship was evident. A capelin front was found at about 74°N. In 1984, section I was covered twice, in June and in August. During the last survey, total plankton biomass estimates are not available, only estimates for the 0-50 m depth stratum (see next section). During the June survey, low densities of both plankton and capelin were found. A capelin front was detected at about 75°40'. A negative, but not significant (r^2=0.15, p=0.17) relationship was found between total plankton density and capelin density.

Summing up, a negative relationship between total plankton biomass and capelin density along section I was evident in all but one case (1983). In most cases the relationship was rather weak and not significant at the 5% confidence level (Table 1).

3.1.2 Relationship between capelin density and zooplankton biomass in the upper 50m

For four of the surveys, in June and July 1981, and in June and August 1984, estimates of plankton biomass in the upper 50m are available. Table 2 summarises the results of linear regression analysis of capelin density versus plankton biomass for those coverages. Only one significant linear relationship was found (June, 1984), but in three of the four surveys a negative relationship between zooplankton biomass and capelin density was evident, significant at the 0.1 level.

Table 1: Linear regression analysis of various capelin variables versus total plankton biomass along section I

Time	Variable	N	Slope	r^2	p
1980, June	Density	12	-0.04	0.21	0.13
1980, July	Density	9	0.28	0.29	0.13
	Length	9	0.01	0.31	0.12
	Weight	9	0.03	0.31	0.12
	Condition factor	9	-0.00	0.31	0.12
1981, May	Density	14	-0.04	0.00	0.94
	Length	14	0.05	0.01	0.82
	Weight	14	0.26	0.02	0.60
	Condition factor	14	0.05	0.18	0.13
1981, June	Density	16	-0.19	0.47	0.01
	Length	12	0.03	0.33	0.04
	Weight	12	0.06	0.35	0.03
	Condition factor	12	0.00	0.09	0.32
1981, August	Density	16	-5.95	0.18	0.08
	Length	8	0.13	0.04	0.64
	Weight	8	0.45	0.03	0.70
	Condition factor	8	0.02	0.00	0.90

6

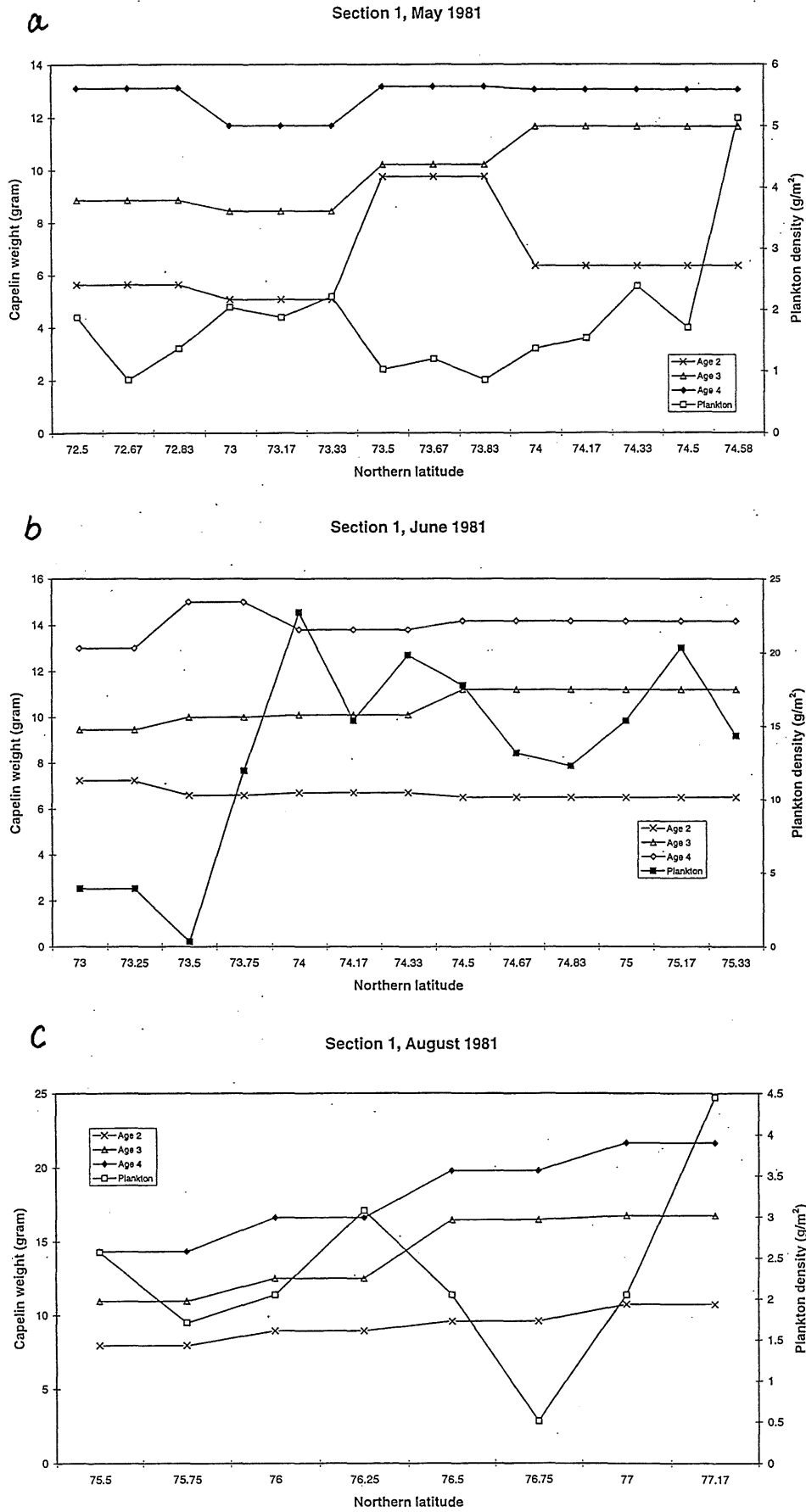**Table 1: Linear regression analysis of various capelin variables versus total plankton biomass along section I**

Time	Variable	N	Slope	r^2	p
1982, June	Density	17	-0.09	0.07	0.32
	Length	17	0.01	0.00	0.90
	Weight	17	-0.01	0.00	0.95
	Condition factor	17	-0.01	0.07	0.32
1983, June	Density	20	-0.03	0.00	0.96
	Length	17	0.10	0.02	0.54
	Weight	17	0.10	0.02	0.54
	Condition factor	17	-0.01	0.03	0.52
1984, June	Density	12	-2.19	0.15	0.17

Table 2: Linear regression analysis of various capelin variables versus plankton biomass in the upper 50m along section I

Time	Variable	N	Slope	r^2	p
1981, May	Density	13	3.41	0.05	0.44
	Length	13	1.05	0.03	0.55
	Weight	13	3.81	0.09	0.29
	Condition factor	13	0.60	0.56	0.00
1981, June	Density	15	-0.25	0.18	0.10
	Length	12	0.05	0.26	0.07
	Weight	12	0.12	0.32	0.04
	Condition factor	12	0.01	0.20	0.12
1984, June	Density	30	-3.09	0.16	0.02
1984, August	Density	8	-0.23	0.38	0.08
	Length	8	-0.01	0.00	0.98

3.1.3 Relationship between plankton density and weight, length and condition factor of capelin

During most of the coverages of section I, length and weight of capelin were measured and condition factor calculated in samples taken along the section. Results of linear regression analyses between these capelin variables and total plankton density and plankton density in the upper 50 meters are shown in Tables 1 and 2, respectively, and between these variables and northern latitude in Table 3. Figure 3a, b, and c show the mean weight of capelin along section I compared to plankton density in May, June and August 1981 respectively. Mean weight of the capelin was generally increasing towards the north, most notable in August. The increase in weight was partly an effect of the oldest capelin being in front of the northwards migration, but as seen from Fig. 3, weight also increased within age groups, showing that the largest individuals within each age group were found farthest north on the section

Figure 3. Plots of plankton biomass and individual mean weight by age group of capelin along section I 1981. a) May, b) June, c) August.

8

Table 3: Linear regression analysis of length, weight and condition factor of capelin versus northern latitude along section I

Time	Variable	N	Slope	r^2	p
1980, July	Length	9	0.71	0.58	0.02
	Weight	9	1.74	0.58	0.02
	Condition factor	9	-0.02	0.58	0.02
1981, May	Length	14	0.88	0.56	0.00
	Weight	14	1.99	0.64	0.00
	Condition factor	14	0.06	0.14	0.18
1981, June	Length	13	0.40	0.81	0.00
	Weight	13	0.86	0.85	0.00
	Condition factor	13	0.03	0.17	0.16
1981, August	Length	8	1.18	0.97	0.00
	Weight	8	4.64	0.94	0.00
	Condition factor	8	0.52	0.84	0.00
1982, June	Length	17	0.76	0.86	0.00
	Weight	17	1.27	0.83	0.00
	Condition factor	17	-0.08	0.75	0.00
1983, June	Length	62	-0.44	0.67	0.00
	Weight	62	-0.46	0.68	0.00
	Condition factor	62	0.04	0.60	0.00

Except for June 1983, there was a significant increase in both length and weight of capelin towards the north along section I (Table 3). In June 1983, both length and weight were decreasing towards the north. The condition factor showed no clear trend in variation with latitude. It showed a significant increase in two cases and a significant decrease in two cases, but in four out of six cases it was increasing towards the north. Only in 1981 do we have data from the main feeding season, August, and in this case the condition factor shows a clear and highly significant increase with northern latitude.

From table 1 and 2 it can be seen that both length and weight of capelin during most coverages of section I show a positive but in most cases not significant relationship with plankton density.

3.2 Area coverage of the Barents Sea

During the period 1987 to 1994, extensive plankton sampling were done at an acoustic survey for capelin each autumn (September to early October). Both Juday net hauls and MOCNESS hauls were used to sample plankton. Because these gears have different characteristics, the data from the two gears have been treated separately.

Various datasets were developed for different purposes. To compare average growth of capelin within a year with average plankton density, mean individual weight in each age group of capelin in September one year was subtracted from the corresponding value of the same year class

in September the next year. These values were compared to arithmetic mean values of plankton density from all plankton stations taken during the September survey. A size dependent spawning mortality will to a large degree affect the size of observed four years old capelin. Therefore, only mean weight increment from age zero to age one, from age one to age two, and from age two to age three were calculated. When comparing mean plankton density with mean values of length, weight, and condition factor of capelin, the capelin variables were taken from the ICES Report of the Atlanto-Scandian Herring and Capelin Working Group (Anon, 1994). Those data are weighted averages, representative for the whole capelin stock.

To compare plankton density and capelin variables on a geographical scale, plankton data from each plankton station was compared to mean values of the capelin variables within a 2 by 1 degree rectangle where the plankton station was taken. In cases where plankton stations were taken outside the capelin distribution area, the capelin biomass was set to zero, and all other capelin variables denoted to "missing value".

3.2.1 Comparison between annual capelin growth and plankton biomass

To the extent that the observed plankton density in September is representative for the amount of available food for capelin during the growth season, we expect a positive relationship between observed plankton density and capelin growth. This was tested by linear correlation analysis. The densities of the three plankton size fractions plus their sum in the upper 100 m depth stratum and in the total water column were compared with the annual weight increments of capelin of age one, two and three years (Tables 4 and 5).

Table 4: Correlation matrix between mean plankton density (g/m^2) from MOCNESS hauls and mean capelin weight increase during one growth season (g). Correlations significant at the 5% level are marked with an asterisk

Plankton density		Capelin growth increment		
Depth stratum	Size fraction	Age 1	Age 2	Age 3
100 m - surface	> 2000 μm	0.37	0.12	0.21
100 m - surface	1000 - 2000 μm	0.36	0.09	0.15
100 m - surface	180 - 1000 μm	0.67	0.00	0.17
100 m - surface	Total	0.69	0.01	0.14
Total water column	> 2000 μm	0.50	0.63	0.92[*]
Total water column	1000 - 2000 μm	-0.04	0.33	0.09
Total water column	180 - 1000 μm	0.64	0.10	0.32
Total water column	Total	0.63	0.25	0.45

10

Table 5: Correlation matrix between mean plankton density (g/m^2) from Juday net hauls and mean capelin weight increase during one growth season (g). Correlations significant at the 5% level are marked with an asterisk

Plankton density		Capelin growth increment		
Depth stratum	Size fraction	Age 1	Age 2	Age 3
100 m - surface	> 2000 μm	0.24	-0.15	0.30
100 m - surface	1000 - 2000 μm	-0.31	0.87*	0.41
100 m - surface	180 - 1000 μm	0.51	0.63	0.76
100 m - surface	Total	0.23	0.77	0.71
Total water column	> 2000 μm	0.19	0.30	0.51
Total water column	1000 - 2000 μm	-0.19	0.88*	0.05
Total water column	180 - 1000 μm	0.56	0.16	0.12
Total water column	Total	0.41	0.45	0.22

In the analysis based on MOCNESS data (Table 4), all but one correlation coefficient were positive, but only one was significant at the 5% level. Plankton density in the upper water column showed low to moderate correlation with growth of one year old capelin, the highest correlation being for the smallest size fraction of plankton. The growth of older capelin was uncorrelated with the amount of plankton in the upper 100 m. In the total water column, the density of the largest size fraction of plankton was highly correlated with the growth of the largest capelin (Fig. 4),
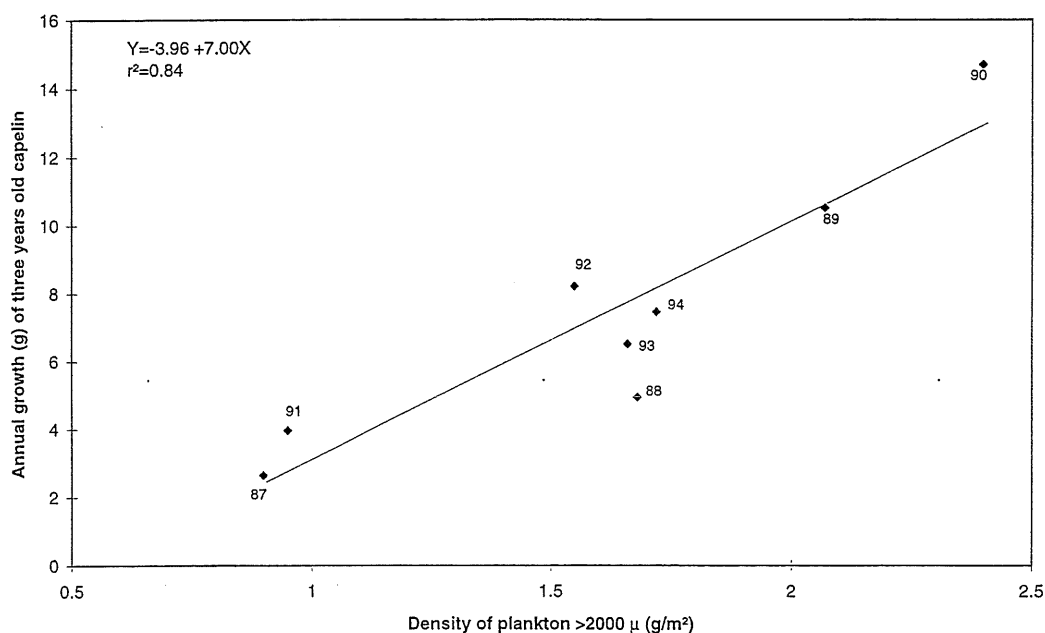
Figure 4. The relationship between density of plankton in the largest size fraction and the annual growth of three years old capelin. The linear regression line is shown on the figure, and each observation is labelled with year.

while the smallest size fraction show a high correlation with the growth of the youngest capelin, although not significant at the 5% level. The Juday net data showed some of the same trends but with larger variation (Table 5). In contrast with the analysis of the MOCNESS data, the growth of the two years old capelin showed the highest correlation with plankton density, the correlation coefficients being significant for the plankton size fraction 1000-2000 μm.

3.2.2 Comparison between capelin length, weight and condition factor and plankton biomass

If the measured concentrations of plankton in September reflects the available food for capelin, one should expect a correlation between the plankton density and the length, weight and condition factor of the capelin. This was tested on a between-years basis in a correlation analysis. No significant correlations were found in this analysis based on MOCNESS data (Table 6). A trend resembling that found for capelin growth was found in that the correlation coefficients for length, weight and condition factor of age one capelin were generally higher for the smallest size fraction of plankton while the highest correlation coefficients were found for the largest size fraction for older capelin. The analysis based on Juday net haul data (Table 7) again differed somewhat from that based on MOCNESS data. Significant positive correlations were found for length and weight of two years old capelin and density of plankton in the two smallest size fractions and the total plankton density. Also the middle size fraction of plankton showed a significant positive correlation with the condition factor of two years old capelin, while the density of the largest size fraction was uncorrelated with the capelin variables.

Table 6: Correlation matrix between mean plankton density in the upper 100 m (g/m^2) from MOCNESS samples and mean capelin length, weight and condition factor

Capelin variable		Plankton density in upper 100m			
		> 2000 μm	1000-2000 μm	180-1000 μm	Sum
Age 1	mean length	0.18	0.39	0.42	0.41
	mean weight	0.12	0.52	0.56	0.55
	condition factor	0.25	0.44	0.60	0.62
Age 2	mean length	0.23	0.23	0.21	0.20
	mean weight	0.25	0.14	0.11	0.12
	condition factor	0.28	0.09	0.04	0.06
Age 3	mean length	0.33	0.02	-0.02	-0.07
	mean weight	0.35	-0.02	-0.07	-0.11
	condition factor	0.47	-0.12	-0.06	-0.09

Table 7: Correlation matrix between mean plankton density in upper 100 m (g/m^2) from Juday net hauls and mean capelin length, weight and condition factor. Correlations significant at the 5% level are marked with an asterisk

Capelin variable		Plankton density in upper 100m			
		> 2000 μm	1000-2000 μm	180-1000 μm	Sum
Age 1	mean length	-0.33	0.38	0.61	0.49
	mean weight	-0.31	0.36	0.67	0.53
	condition factor	-0.28	0.09	0.56	0.35
Age 2	mean length	0.13	0.87*	0.81*	0.92*
	mean weight	-0.03	0.92*	0.72	0.85*
	condition factor	-0.24	0.91*	0.56	0.71
Age 3	mean length	0.05	0.75	0.58	0.69
	mean weight	0.05	0.76	0.56	0.68
	condition factor	0.06	0.63	0.51	0.59

3.2.3 Comparison between length, weight, and condition factor of capelin and plankton density based on geographically distributed data

Since parallel observations of plankton density and the capelin variables exist for each year, this relationship can also be studied based on individual station data. Linear correlation analyses were run separately for the MOCNESS data (Table 8) and the Juday net data (Table 9) on the pooled data from all years. The analysis based on MOCNESS data shows no significant correlation coefficients. The plankton data from Juday net hauls generally showed higher correlation with the capelin variables, except for the three years old capelin and the largest size fraction of plankton (Table 9).

Similar analyses were also run for each year separately, and pairs of variables were plotted and included in regression analyses. Generally, it was difficult to interpret and extract clear patterns from the analyses and the scattergrams. The relationship between the density of the smallest size fraction of plankton and the condition factor of one year old capelin, which were highly correlated when studying the pooled data from all years (Juday net data), was positive in three of the years and uncorrelated in the other years. Similar results were obtained for the relationship between the other capelin parameters and the density of the various size fractions of plankton.

Table 8: Correlation matrix between plankton density in the upper 100 m (g/m²) from MOCNESS hauls and mean capelin length, weight and condition factor

Capelin variable		Plankton density in upper 100m			
		> 2000 μm	1000-2000 μm	180-1000 μm	Sum
Age 1 (N=34)	mean length	-0.00	0.16	0.26	0.24
	mean weight	0.02	0.16	0.33	0.30
	condition factor	0.07	0.05	0.22	0.20
Age 2 (N=45)	mean length	-0.24	-0.05	0.11	-0.04
	mean weight	-0.22	-0.06	0.11	-0.03
	condition factor	-0.10	-0.04	0.14	0.04
Age 3 (N=35)	mean length	-0.17	-0.08	0.00	-0.09
	mean weight	-0.13	-0.12	-0.03	-0.11
	condition factor	0.03	-0.14	-0.03	-0.05

Table 9: Correlation matrix between plankton density in the upper 100 m (g/m²) from Juday net hauls and mean capelin length, weight and condition factor. Correlations significant at the 5% level are marked with an asterisk

Capelin variable		Plankton density in upper 100m			
		> 2000 μm	1000-2000 μm	180-1000 μm	Sum
Age 1 (N=58-84)	mean length	-0.23	0.14	0.27*	0.19
	mean weight	-0.24	0.16	0.35*	0.27*
	condition factor	-0.29*	0.11	0.31*	0.21
Age 2 (N=82-108)	mean length	-0.15	-0.00	0.20	0.12
	mean weight	-0.14	0.03	0.18	0.12
	condition factor	-0.09	0.08	0.16	0.12
Age 3 (N=64-87)	mean length	0.01	0.14	0.02	0.04
	mean weight	0.02	0.15	0.00	-.03
	condition factor	0.07	0.19	0.02	0.08

Time series of plankton density (Juday net data) averaged over subareas of the Barents Sea reveal some consistent and gradual changes over the last 15 years (Figure 5). The plankton biomass in the central Barents Sea showed a marked minimum in 1983-1984. This minimum has been interpreted to reflect a major inflow of water from the adjoining Norwegian Sea during winter at the transition from a cold to a warm period in 1982/83. THis water contained little *Calanus finmarchicus* which reside deep in the Norwegian Sea during winter (Skjoldal and Rey 1989, Blindheim and Skjoldal 1993). This minimum in zooplankton contributed to low growth of capelin at the time when the capelin stock was decreasing (Skjoldal et al. 1992). In the following years (1986-89) when the capelin stock was low, there was a marked increase in the abundance of krill
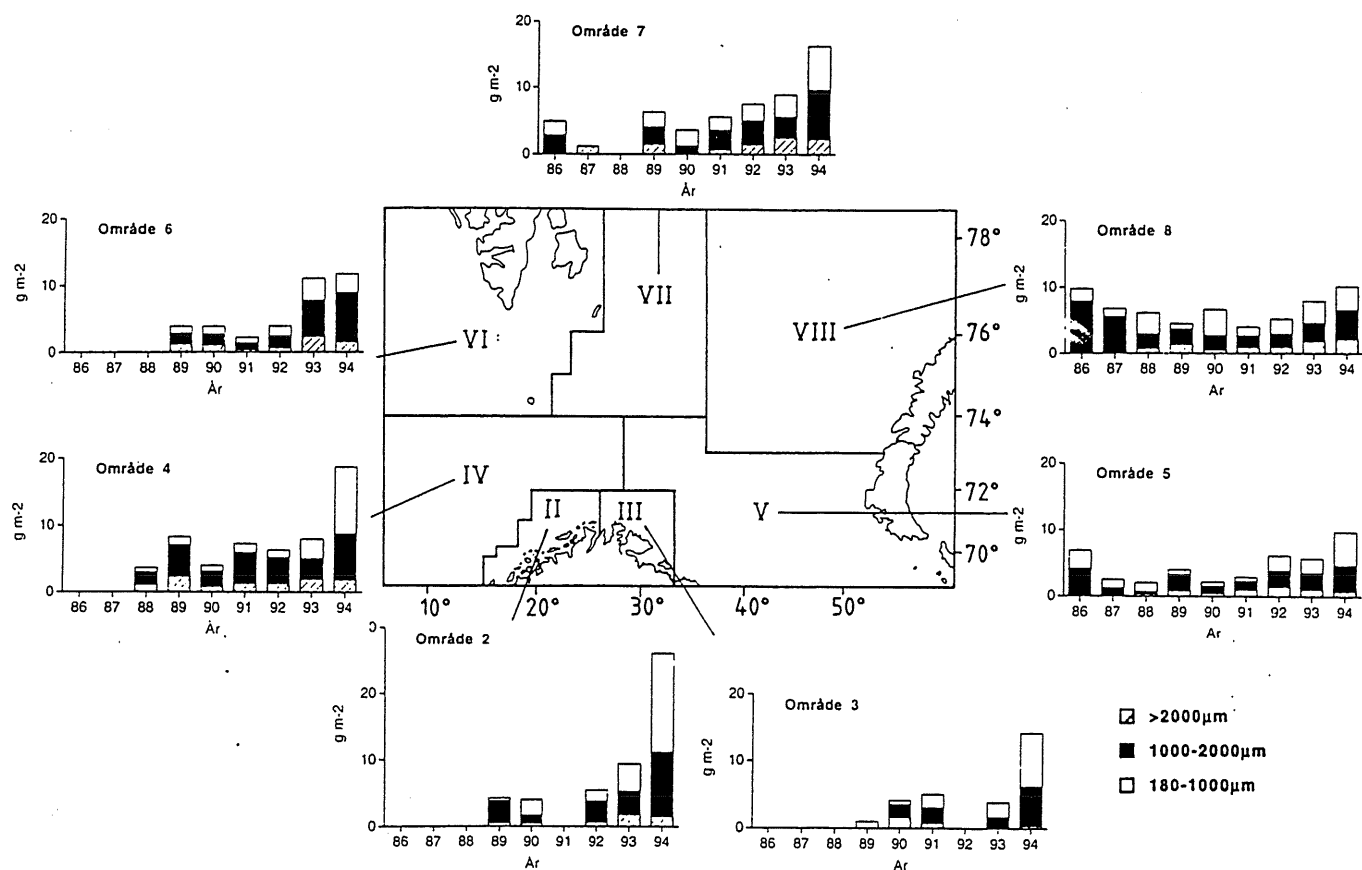
Mean values of size-fractioned biomass of plankton in seven subareas "område" of the Barents Sea.

and amphipods (Dalpadado et al. 1994, Dalpadado and Skjoldal, unpublished results). The high abundance of these large prey organisms contributed to recovery of the capelin stock (Skjoldal et al. 1992)

4.0 Discussion

The observations along section I in summer lend in most cases support to the theory presented by Hassel et al. (1991) that the capelin is "eating its way" through the plankton fields as it moves northwards during summer, leaving areas of low plankton density behind. A negative relationship between density of plankton and capelin was more easily seen when plankton density in the upper 50m was considered. This is to be expected, since capelin as a visual feeder, will feed more intensively in the lighted upper water layer. The grazing effect of a moving capelin front, although apparent from most graphical presentations (Fig. 2), is not generally apparent as a negative relationship between density of capelin and density of zooplankton when data along the whole section is considered (Tables 1, 2). The reason is that although plankton density is high where capelin density is low or zero in front of the capelin front, and low in the capelin front, both plankton density and capelin density is generally low behind the capelin front. Also horizontal dispersion will tend to erase the spatial structures of low plankton densities with time after a grazing impact.

An increase in weight and length of capelin towards the north is probably an effect of larger fish swimming faster, and large fish will consequently be in front during migration. In a situation where the food resources are significantly depleted as the capelin front moves northwards, one should expect that the larger fish have better conditions for growth during the period of migration. There was no strong evidence for this effect in the data. However, the condition factor increased with increasing latitude on most occasions.

The simple hypothesis that the amount of plankton measured in the upper water layer during September is correlated with the capelin growth in the current growth season is partly supported by the data. Based on the MOCNESS data, the correlation coefficients between the various plankton density measurements and the capelin growth data varies from 0.1 to 0.9. The growth of the three-year-olds show a significant positive correlation with the density of the largest fraction of plankton in the total water column. This lends support to the hypothesis. The highest correlation being evident for the larger size fractions of plankton is expected, since the larger plankton contains the most important food items for large capelin (Hassel et al. 1991). The growth of the two-year-olds also showed relatively high correlation with the amount of large plankton organisms, although the correlation coefficients were not significant at the 5% level. The growth of the one year old capelin on the other hand, showed rather low correlation with the density of large plankton in the upper layer, but a relatively high correlation with the density of small plankton organisms. This is consistent with observations that small capelin feed primarily on the smaller plankton forms.

The analysis based on Juday net hauls gave a slightly different picture. The growth of all age groups of capelin showed low to moderate correlation with the density of the largest size fraction of plankton. The largest size fraction is, however, expected to be underrepresented in this sampling gear, and this may explain the lack of significant correlations. The growth of age two capelin was significantly positively correlated with the density of 1-2 mm plankton, which again supports the hypothesis cited above. The observation that the one year old capelin seems to be most dependent on the smallest plankton organisms sampled is repeated in this data set.

The hypothesis that mean length, weight and condition factor of capelin are positively correlated with mean plankton density in the upper 100 m as measured in September must be rejected, although some few correlations in the matrix based on Juday net hauls (Table 7) are significant. Positive correlation coefficients existed between these parameters and the density of large plankton forms for age two and age three (MOCNESS data) and age two (Juday net data) capelin, and the density of small plankton forms for age one (MOCNESS data) and all age groups (Juday net data) capelin. However, the correlation coefficients were generally low and not significant at the 5% level. The only exceptions were the length and weight of two and three years old capelin in the Juday net haul data, which were highly significantly correlated with the density of the middle size fraction of plankton. Again, unrepresentative sampling of the largest size fraction of plankton in the Juday net hauls may have affected the analysis.

The most striking feature of the geographically distributed data on plankton density and capelin parameters are weak relationships and much scatter around trend lines. Even in cases where significant linear relationships were found, e.g. between length, weight and condition factor of age 1 and age two capelin and the density of the smallest size fraction of plankton from the Juday

16

net data (Table 9), the correlation coefficients are rather low, and linear regression of capelin parameters on plankton density only explains a small fraction of the total variation.

Many factors may add to the variation and low correlation in the data. First, sampling variability and patchiness of the plankton make the plankton density estimates in a single point uncertain. Second, the capelin data, which are mean values for rather large areas (6-10 000 km^2) may not be easily compared to the plankton station, being a point estimate. Third, the capelin and plankton represents highly dynamic systems. There is a continuous growth and production of plankton and the plankton is transported with the currents, while the capelin moves around in the area and grazes on the plankton, thereby affecting both the standing stock and the future production of plankton.

Despite the often low correlation between capelin variables and plankton densities in the distributed data, the aggregated and averaged data show some clear and strong relationships between capelin and zooplankton. The large interannual variation in capelin growth rate is important for the population dynamics and management of the capelin stock as well as other fish stocks in the Barents Sea (Gjøsæter, 1986). This variation in annual capelin growth rate can to a large extent be linked to variations in zooplankton stocks in the Barents Sea. It is therefore our aim to incorporate information on zooplankton abundance from a monitoring program in the basis for capelin management.

Further analyses of these data will be made along the following lines: Can multivariate analyses, where the geographical position of the samples are included as variables, together with physical parameters, explain more of the variation in the data? Can further analyses of average plankton density in subareas and capelin growth in the same subareas give clues to explain more of the capelin growth variation?

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