Status report on the Barents Sea Ecosystem, 2004-2005

Jan Erik Stiansen, Bjarte Bogstad, Paul Budgell, Padmini Dalpadado, Harald Gjøsæter, Kjellrun Hiis Hauge, Randi Ingvaldsen, Harald Loeng, Mette Mauritzen, Sigbjørn Mehl, Geir Ottersen, Morten Skogen and Erling Kåre Stenevik

PROSJEKTRAPPORT

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Sammendrag (norsk):
Denne rapporten er ment som en grov statusoversikt over økosystemet i Barentshavet i 2004, sett i ett historisk perspektiv. Hvis mulig er forventninger for 2005 også vurdert. Målet til denne rapporten er å gi relevant bakgrunnsinformasjon om økosystemelementer til ICES sine bestandsvurderings-arbeidsgrupper, som kan være av betydning for evalueringen av de kommersielle fiskebestandene i Barentshavet. Fokuset er derfor rettet mot viktige trofiske interaksjoner, og ikke mot hver fiskebestand spesielt.

Summary (English):
This report is intended as a rough overview of the status of the Barents Sea ecosystem in 2004, compared to a historical perspective. If possible the situation for 2005 is also treated. The aim of this report is to give background information for the ICES fishery assessment working groups on elements in the ecosystem, which may be of importance for the evaluation of the commercial fish stocks in the Barents Sea. Due to this focus the status of the fish stocks is not presented specifically, but instead important trophic relations are pointed out.

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By

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Contents

1. Summary

A close connection between environmental fluctuations and variation in recruitment, growth, distribution and migration of fish in the Barents and Norwegian Seas was suggested already by Helland-Hansen and Nansen (1909) and has been well documented during recent years (e.g. Gjøsæter and Loeng, 1987; Ottersen and Sundby, 1995; Tretyak *et al*., 1995; Loeng *et al.,* 1995; Ottersen and Loeng, 2000; Toresen and Østvedt, 2000).

This report is intended as a rough overview of the Barents Sea ecosystem. It gives the ecosystem status for 2004, compared to a historical perspective. If possible the situation for 2005 will also be treated, mostly based on subjective evaluation of knowledge. The aim of this report is to give background information for the ICES fishery assessment working groups on elements in the ecosystem, which may be of importance for the evaluation of the commercial fish stocks in the Barents Sea. Due to this focus the status of the fish stocks is not presented specifically, but instead important trophic relations are pointed out.

Much of the information in the presented report is based on an ecosystem status report from IMR (Anon 2005a), which is in Norwegian.

2. Key points

Climate
- In general 2004 was a very warm year, with values between 0.5 and 1.0 degree above the long term seasonal mean. Several of the single month observed values were the highest ever observed. The anomalies are higher in the south than in the north.
- The temperature in the southern Barents Sea is expected to be high also during 2005. Especially the first part of the year is expected to be warm. Later on the temperature anomalies are likely to become smaller, but still well above the long-term average.
- Ice cover in 2004 was low. In 2005 we expect the same ice conditions as in 2004.
- The inflow fluctuated around the long-term mean in the beginning of 2004, and below the long term mean in the spring/summer. Models show above long-term mean at the end of 2004.

Phyto- and zooplankton
- A phytoplankton model shows that the peak of the bloom may vary with about three weeks from year to year. In 2004 the model indicates that the bloom started relatively early.
- The zooplankton biomass in 2004 was high (compared to 2001 and 2003), most likely due to warm and saline water conditions.

Fish
- The last few years there has been an increase of blue whiting migrating into the Barents Sea. The abundance in 2004 was estimated to be 1.4 million tons, mainly age 1-4 fish.
- The consumption calculations show that the total consumption by cod in 2003 and 2004 was about 4.5 million tonnes, which is about average level.
- The individual growth of age 1 and 2 cod is below average, while it is average for older cod.
- There are strong year-classes of 2002 and 2004 herring present in the Barents Sea
- The distribution area of several species has increased.
- A particular feature in autumn 2004 was the wide distribution of 0-group saithe in the Barents Sea, which has only sporadically been observed earlier during the 0-group survey.
- The prognosis of the 0-group index of NEA cod shows a small decrease for 2005 and 2006 to medium low levels
- The prognosis of age 3 NEA cod shows a stable medium high recruitment in 2005, followed by a decrease to a medium low level in 2006
- The number of recruits (age 1) of Barents Sea capelin will be at a medium low level in 2005.
- The prognosis of age 3 Norwegian spring spawning herring shows a steady increase in recruitment for the period 2004 -2007, ending at a historic high level in 2007.

Mammals
- From 2003 to 2004 some changes in distribution of marine mammals were evident. In 2003 the fin, humpback and minke whales were mainly observed in the northern part of the sampling area, in association with capelin and polar cod. In 2004 these species were also observed in the southern part of the sampling area

3. Description of the Barents Sea

The Barents Sea is a shelf area, which borders to the Norwegian Sea in the west and the Arctic Ocean in the north and is part of the continental shelf area surrounding the Arctic Ocean. The extent of the Barents Sea is limited by the continental slope between Norway and Svalbard in the west, the top of the continental slope towards the Arctic Ocean in north, Novaja Zemlya in east and the coast of Norway and Russia in the south (see Fig. 3.1).

The Barents Sea covers an area of approx. 1.4 million km^2. The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths around 100-200 m. The three largest are the Central bank (Sentralbanken), the Great bank (Storbanken) and the Svalbard bank.
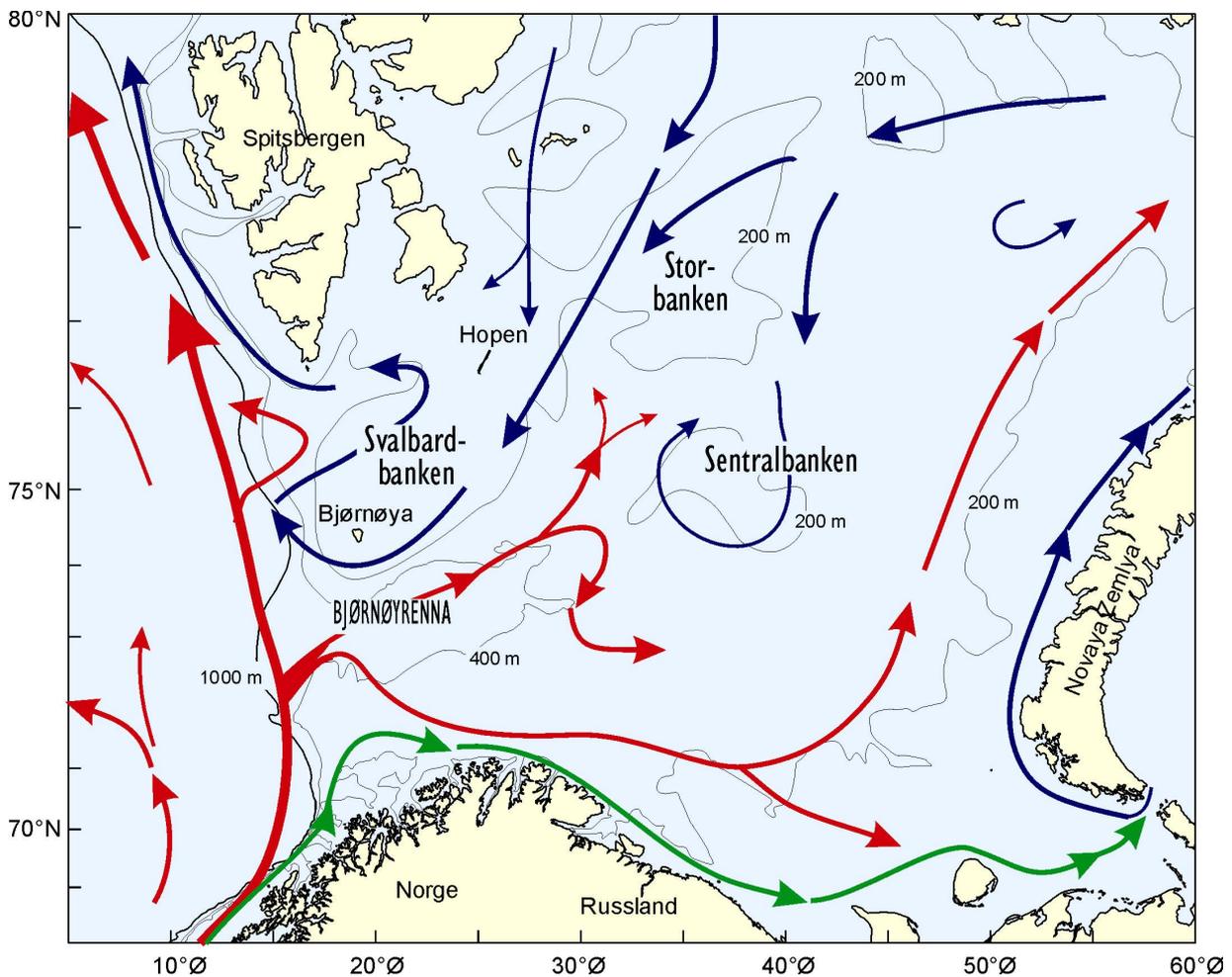

Figure 3.1. The main features of the circulation and bathymetry of the Barents Sea. Red arrows: Atlantic water. Blue arrows: Arctic water. Green arrows: Coastal water (from Anon, 2005a.).

4. Climate

4.1 General description of circulation pattern and water masses

The general circulation pattern is strongly influenced by topography. Warm Atlantic waters (from the Norwegian Atlantic Current) with a salinity of approx. 35 flows in through the Fugløya- Bear Island section. This current divides into two branches, one southern branch, which follows the coast eastwards against Novaja Zemlya and one northern branch, which flows into the Hopen Trench. The relative strength of these two branches depends on the local wind conditions in the Barents Sea. South of the Norwegian Atlantic Current and along the coastline flows the Norwegian Coastal Current. The Coastal Water is fresher than the Atlantic Water, and has a stronger seasonal temperature signal. In the northern part of the Barents Sea fresh and cold Arctic water flows from northeast to southwest. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, but in the eastern part the position of this front has large seasonal, as well as year- to-year, variations.

The Barents Sea is characterised by large year-to-year variations both in heat content and ice conditions. The most important cause of this is variation in amount and temperature of the Atlantic water that enters the Barents Sea.

4.2 Temperature and salinity

Processes of both external and local origin operating on different time scales govern the temperature in the Barents Sea. Important factors that influence the temperature regime are the advection of warm Atlantic water masses from the Norwegian Sea, the temperature of this water masses, local heat exchange with the atmosphere and the density difference in the ocean itself. The volume flux into the Barents Sea from the Norwegian Sea is influenced by the wind conditions in the western Barents Sea, which again is related to the Norwegian Sea wind field (Ingvaldsen et al., 2004). Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered when describing the variation in the temperature of the Barents Sea.

The variability in the physical conditions in the Barents Sea is monitored regularly in three sections (Fig. 4.1) as well as area coverage surveys in August/September and January/March and use of large hydrodynamical numerical models. The three sections are:

1) The Fugløya-Bear Island section (operated by IMR), situated at the entrance where the inflow of Atlantic water from the Norwegian Sea takes place, and representing the western part of the Barents Sea. Monitored regularly by hydrographical observations 6 times a year since 1977 (August observations from 1964), and by continuous current measurements since August 1997.

2) The Vardø-N section (operated by IMR), most representative for the Atlantic branch going into the Hopen Trench, i.e. the central part of the Barents Sea. Monitored regular by hydrographical observations 4 times a year since 1977 (August observations from 1953).

3) The Kola section (operated by PINRO), most representative for the Atlantic branch going eastwards parallel to the coastline, i.e. the southern part of the Barents Sea. Monitored regularly by hydrographical observations since 1900. The values are given quarterly for the period 1900-1921 and monthly for the period 1921-present. (In periods where observations were lacking the values are interpolated).

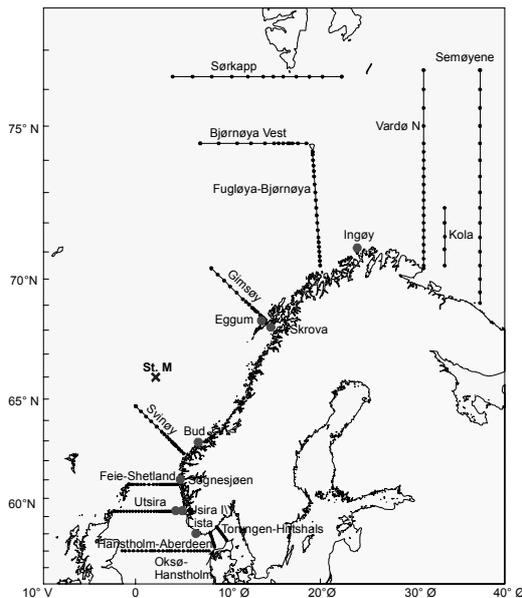(In addition the Semøyene section is monitored with irregular frequency.)

Figure 4.1. Standard sections and fixed oceanographic stations worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk.

Figure 4.2 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to October 2004. Temperatures in the Barents Sea were relatively high during most of the 1990s, and with a continuous warm period from 1989-1995. During 1996-1997, the temperature was just below the long-term average before it turned warm again at the end of the decade. Even if the whole decade was warm, it was only the third warmest decade in the 20th century (Ingvaldsen *et al.*, 2003). In the period 2000-2003 the temperature has stayed well above average, except for January 2003 when it was close to average.

Compared to the seasonal long-term mean the temperature in the beginning of 2004 in the Fugløya- Bear Island section was 0.4-0.5°C higher. In the spring and summer the temperature raised to 0.8-0.9°C above the long-term mean before it fell slightly in August/September to about 0.6 °C higher than the long-term mean. In October the temperature was 1.0°C above the long-term mean, and this is the first time the mean temperature passed 7°C in this area. In January 2005 the temperature was still very high, 1.12°C above the long-term mean. The temperature anomalies in October 2004 and January 2005, are the highest observed since the beginning of the time series in 1977. However, it cannot be ruled out that similar values were present during the warm periods of the 1930's and 1950's.

Table 4.1. Fugløya-Bjørnøya section semi-monthly temperature statistics. Temperature statistics (long-term seasonal mean, minimum, maximum and standard deviations) for the period 1977-2004, together with the values for 2002-2004 and the 2004 anomalies, are given for different calendar month for the 50-200 m depth interval.

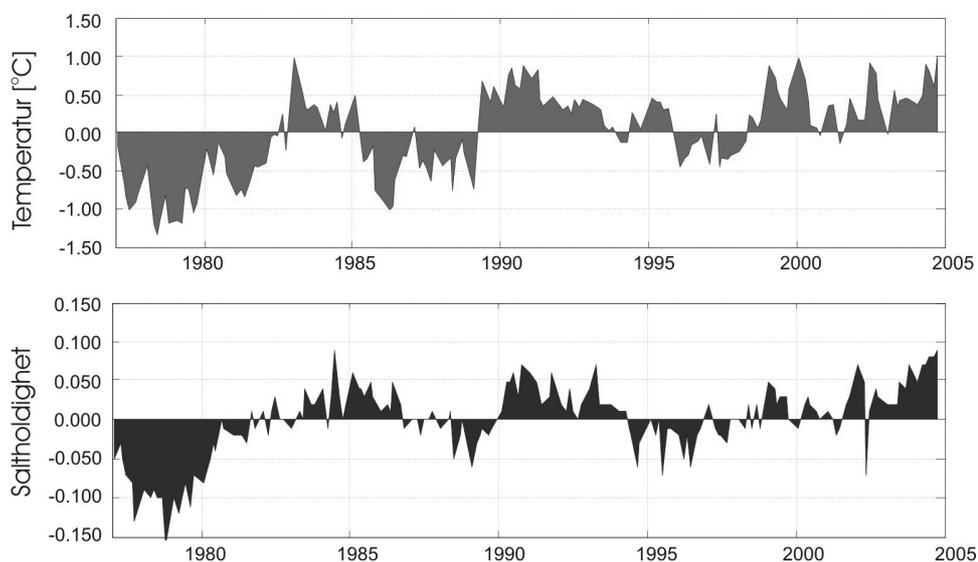|	Mean	Maximum	Minimum	Std Dev	2002	2003	2004	2004 anomaly
January	5.20	6.20	4.07	0.62	5.36	5.19	5.57	+ 0.36
March	4.83	5.65	3.63	0.55	4.98	5.37	5.33	+ 0.50
April/May	4.75	5.65	3.42	0.52	5.11	5.09	5.65	+ 0.90
June	5.15	6.06	4.05	0.45	6.06	5.57	5.95	+ 0.80
Aug/Sep	5.77	6.54	4.73	0.41	6.54	6.23	6.36	+ 0.59
October	6.03	7.03	4.85	0.48	6.47	6.47	7.03	+ 1.00

Figure 4.2. Temperature anomalies (upper panel) and salinity anomalies (lower panel) between 50 and 200 m depth for the period 1977-2004 in the section Fugløya – Bear Island.

In the Vardø-N section the temperature in January 2004 was about 0.3 °C above the long-term seasonal mean. In June and August/September the temperature increased to 0.6°C above the long- term mean. In January 2005 the temperature was 1.2°C above the long-term mean. However, the three most northern stations were not sampled on this survey, which means that this temperature estimate is too high compared to earlier years. The high temperature still indicated that the beginning of 2005 is warm in the central part of the Barents Sea.

Table 4.2. Vardø-North section temperature statistics. Temperature statistics (long-term seasonal mean, minimum, maximum and standard deviations) for the period 1977-2004, together with the values for 2002-2004 and the 2004 anomalies, are given for different calendar month for the 50-200 m depth interval.

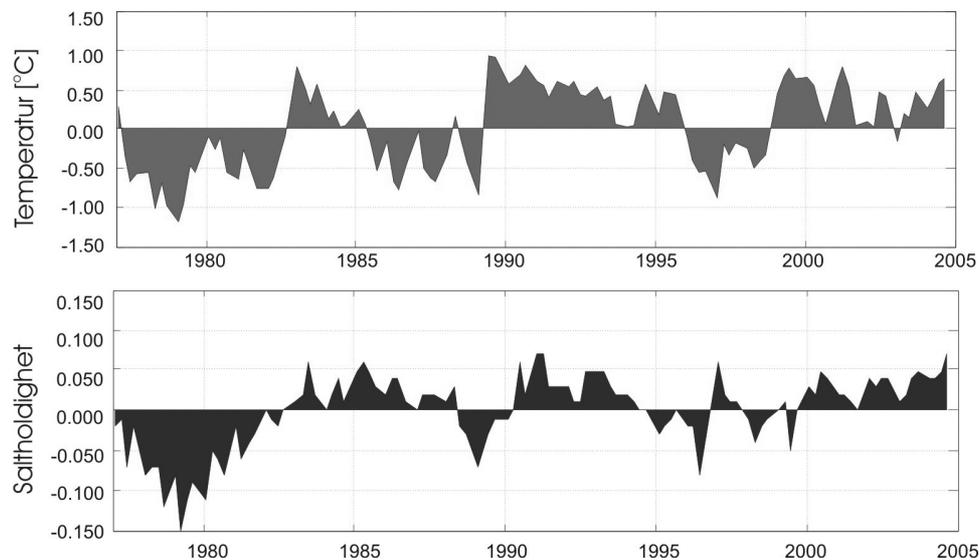|	Mean	Maximum	Minimum	Std Dev	2002	2003	2004	2004 anomaly
January	3.49	4.28	2.32	0.54	3.57	3.33	3.76	+ 0.27
March	3.02	3.81	2	0.49	3.03	3.21		
June	3.40	4.17	2.63	0.46	3.87	3.54	3.98	+ 0.58
Aug/Sep	4.19	5.10	3.2	0.51	4.61	4.66	4.82	+ 0.63

Figure 4.3. Temperature anomalies (upper panel) and salinity anomalies (lower panel) between 50 and 200 m depth for the period 1977-2004 in the section Vardø-N.

The monthly sea temperature series from the Russian Kola meridian transect (33°30' E, 70°30'N to 72°30'N) begins in 1921 (quarterly values back to 1900). The values were calculated by averaging along the transect and from 0 to 200 m water depth vertically (Bochkov, 1982). The Kola section is strategically placed to monitor the variability in the temperature of the eastern part of the Barents Sea dominated by inflowing Atlantic water masses. Values for 2002-2004 and statistics for the period 1921-1999 are shown in Table 3. The 2004 data are published in Anon. (2005b), and the January and February data for 2005 were kindly provided by PINRO.

The temperature in the Kola section was between 0.6 and 1.0°C above the long-term seasonal mean (1921-1999) in 2004. In January-April the positive temperature anomaly was 0.6-0.7°C, increasing to 0.9-1.0°C in the period May-October, before falling slightly to 0.8°C in November-December compared to the long-term seasonal mean. The temperature in August was the highest observed for this month (5.73°C which is 1.06°C above the long-term mean). In 2005 the temperature for January and February stayed high with anomalies of 1.0 and 1.1°C above the long-term mean.

Table 4.3. Kola section monthly temperature statistics. Temperature statistics (long-term seasonal mean, minimum, maximum and standard deviations) for the period 1921-1999, together with the values for 2002-2004 and the 2004 anomalies, are given for each calendar month for the 0-200 m depth interval. Data are kindly provided by PINRO.

| Month	Mean	Minimum	Maximum	Std Dev	2002	2003	2004	2004 anomaly
JANUARY	3.88	2.70	5.00	0.47	3.8	3.7	4.47	+ 0.59
FEBRUARY	3.44	1.80	4.70	0.51	3.6	3.3	4.10	+ 0.66
MARCH	3.12	2.00	4.20	0.48	3.4	3.3	3.70	+ 0.58
APRIL	2.94	1.50	3.90	0.51	3.3	3.3	3.59	+ 0.65
MAY	3.09	1.70	4.10	0.52	3.6	3.8	3.97	+ 0.88
JUNE	3.56	2.30	4.50	0.51	4.2	4.5	4.49	+ 0.93
JULY	4.18	3.00	5.20	0.52	4.9	4.8	5.17	+ 0.99
AUGUST	4.67	3.50	5.60	0.52	5.5	4.9	5.73	+ 1.06
SEPTEMBER	4.91	3.80	5.90	0.48	5.7	5.3	5.90	+ 0.99
OCTOBER	4.91	3.40	6.00	0.51	5.3	5.2	5.89	+ 0.98
NOVEMBER	4.69	3.50	5.80	0.48	5.0	4.8	5.44	+ 0.75
DECEMBER	4.32	3.50	5.50	0.43	4.5	4.2	5.07	+ 0.75
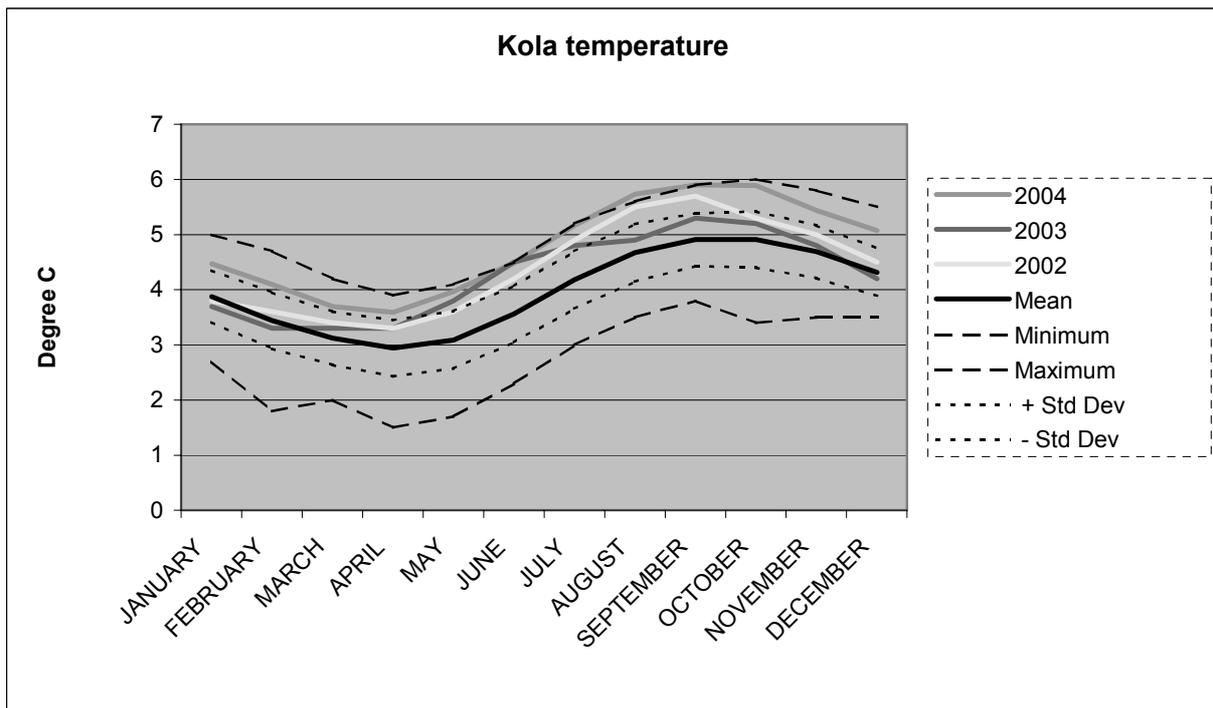
Figure 4.4. Kola section monthly temperatur. The figure shows temperature statistics (long-term seasonal mean, minimum, maximum and standard deviations) for the period 1921-1999, together with the values for 2002-2004, given for each calendar month for the 0-200 m depth interval. Data are kindly provided by PINRO.

Figure 4.5 show the observed horizontal temperature field at 100 m depth in August/September 2004, and Figures 4.6 and 4.7 the modeled sea surface temperature (SST) with anomalies in

August and September 2004. Both the model and the observations show the general high temperature, especially in the southern Barents Sea.

In general, the temperature conditions in the Barents Sea were very high in 2004, and this also transfers into the beginning of 2005. Overall the temperature in all the three sections followed the similar development in 2004. However, compared to the Fugløya-Bear Island section, the temperature anomalies in the Vardø-N section were about 0.1-0.2^oC lower, while the temperature anomalies in the Kola section were about 0.2^oC higher. This indicates that most of the warm water entering the Barents Sea in the west in 2004 has been channelled into the Atlantic branch going parallel to the coast compared to the branch going into the Hopen Trench, i.e. the southern Barents Sea has experienced most heating.

The salinity in the Fugløya- Bear Island section generally fluctuates in phase with the variation of the temperature (Fig. 4.2). This is also the situation in the rest of the Barents Sea, which is influenced by the Atlantic waters. Since the summer of 2003 there has in general been increase in the salinity in the southwestern Barents Sea.
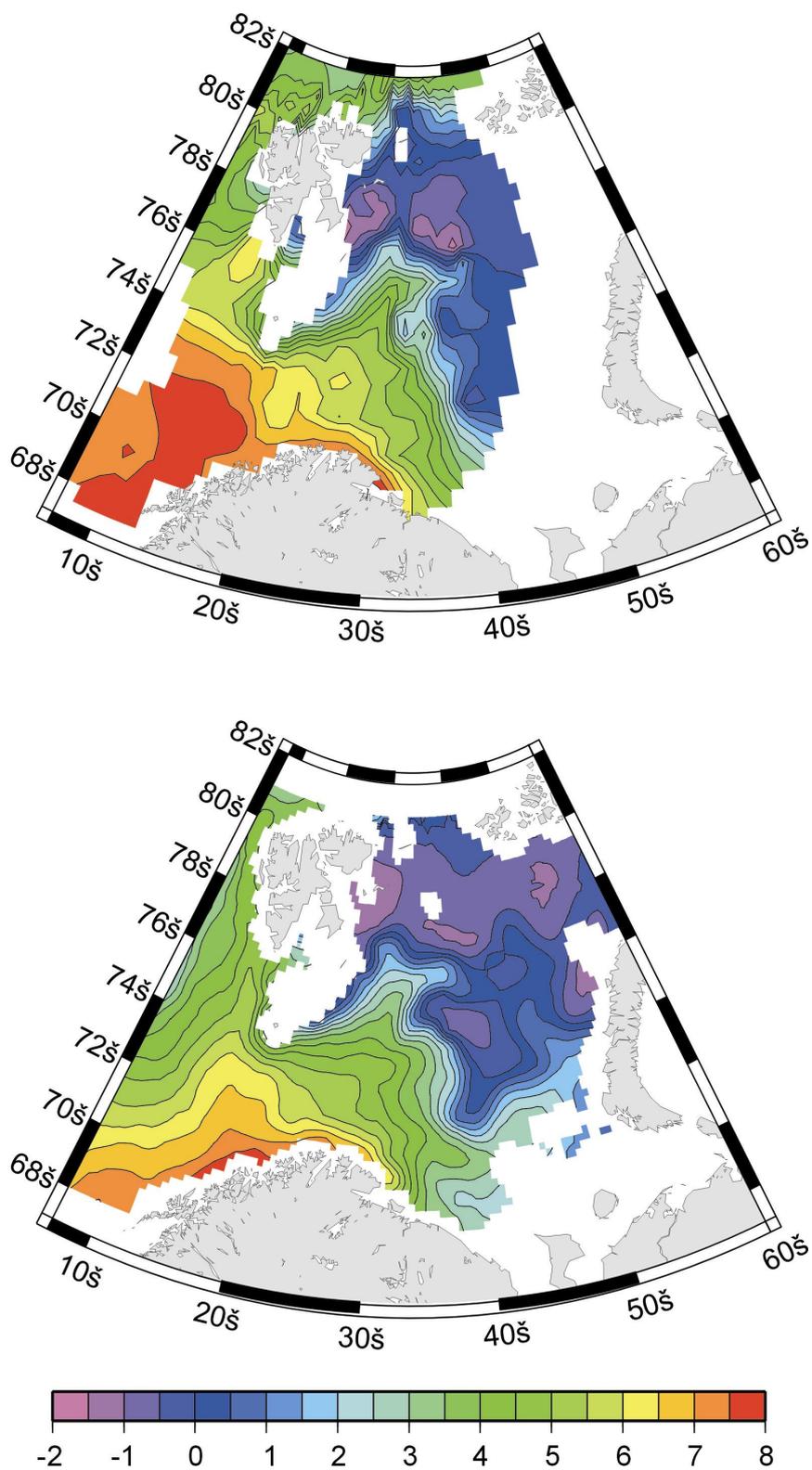
Figure 4.5. Distribution of mean temperature at 100 m depth during August–September. Upper panel: 2004. Lower panel: mean temperature.

Figure 4.6. Modeled monthly mean SST (upper left panel) and ice concentration (upper right panel) images and corresponding anomalies (lower panels) from August 2004. Note that the axis is in grid numbers. Each grid is 20x20 km.
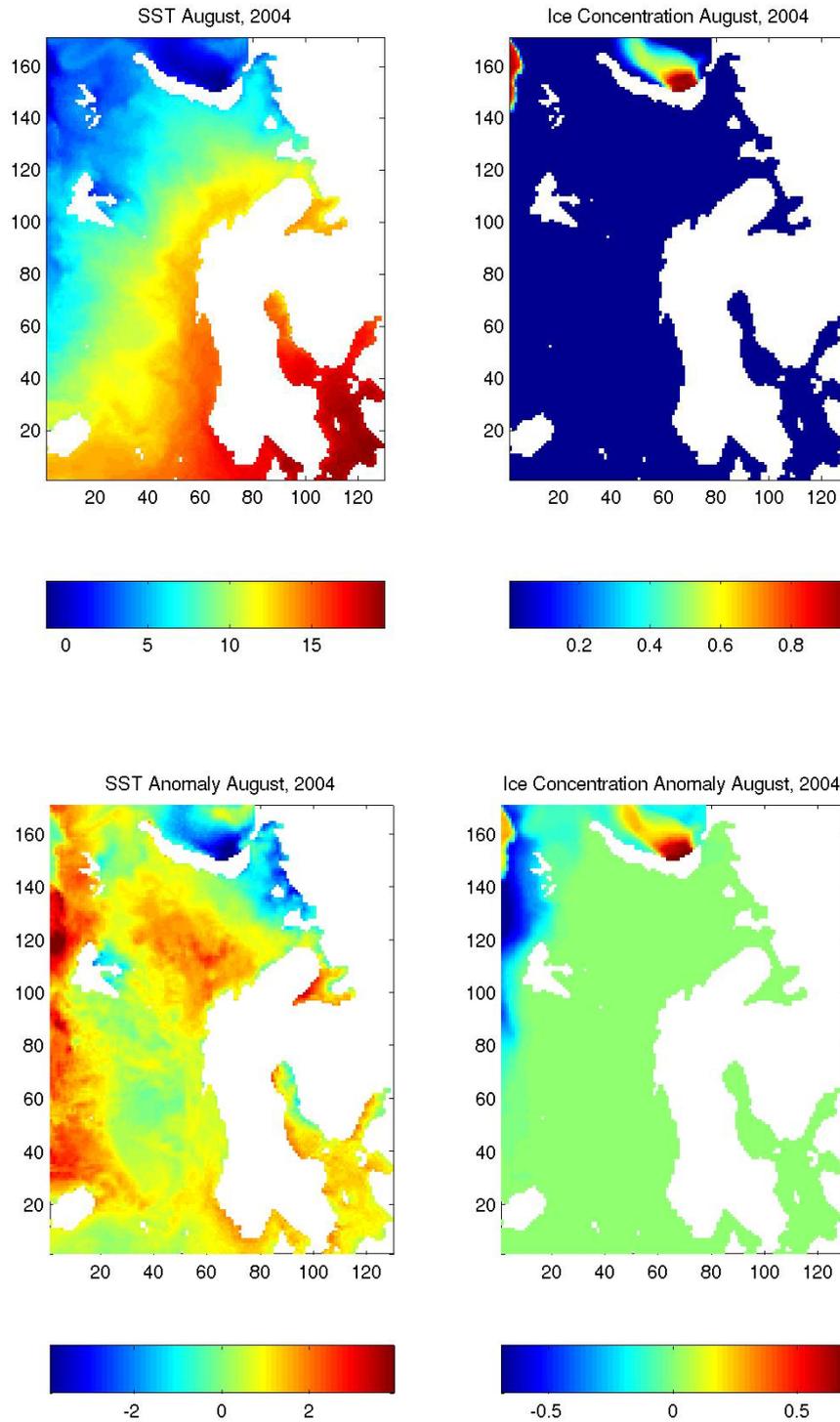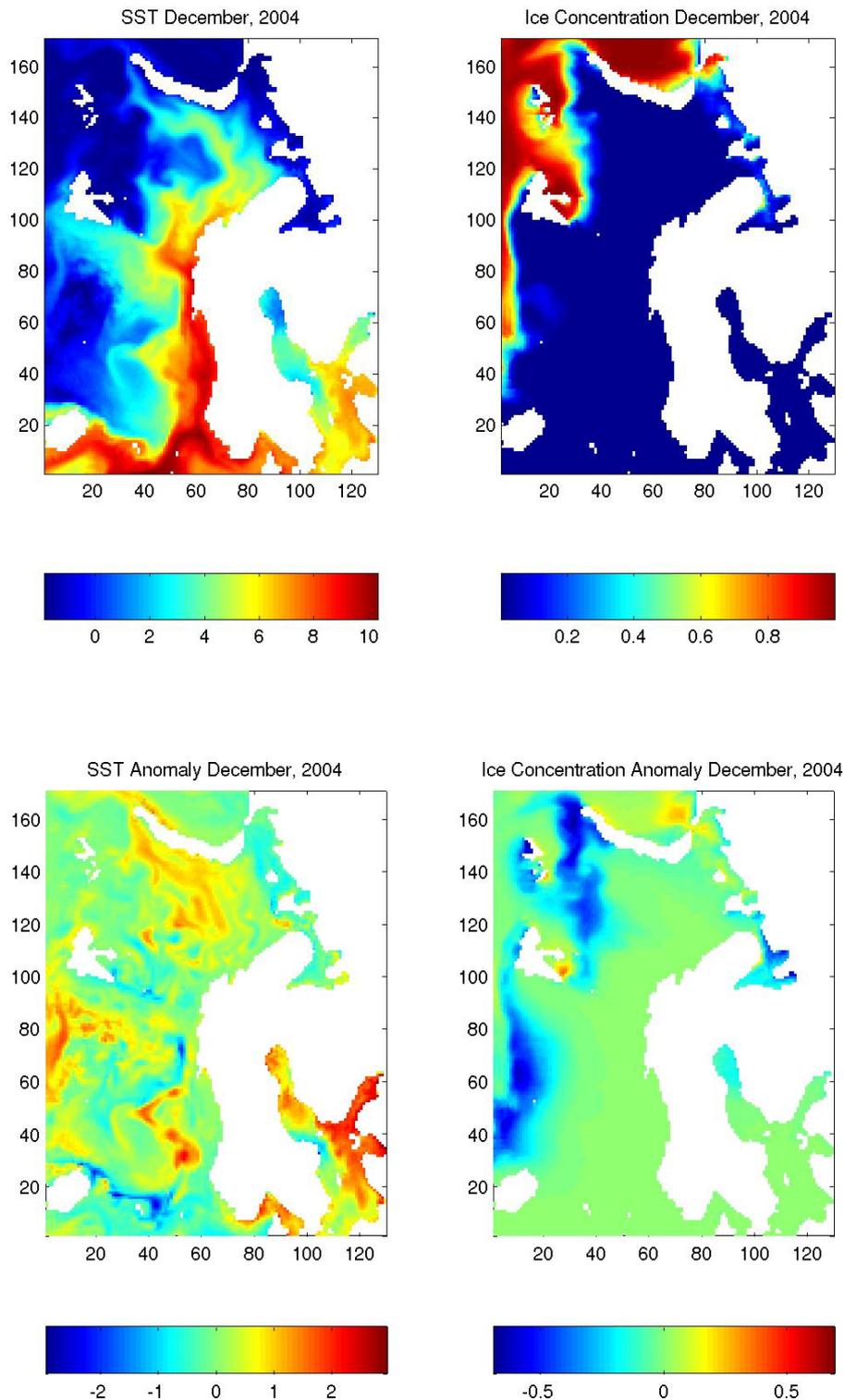
Figure 4.7. Modeled monthly mean SST (upper left panel) and ice concentration (upper right panel) images and corresponding anomalies (lower panels) from December 2004. Note that the axis is in grid numbers. Each grid is 20x20 km.

4.3 Ice conditions

Figure 4.8 shows the ice index for the Barents Sea. The variability in the ice coverage is closely linked to the temperature of the inflowing Atlantic water. The ice has a relatively short response time on temperature change (about one year), but usually the sea ice distribution in the eastern Barents Sea respond a bit later than in the western part.

2003 had a negative ice index, which means more ice than average. This was very surprising since the sea temperature was high. There were two reasons for this. Firstly the ice melt did not really start before mid June, which is about one month later that usual. Secondly, the ice melt during summer was extremely low, most likely due to atmospheric forcing.

In 2004 the ice coverage in the Barents Sea was low, with a strong decease in ice from 2003. In the same period, the temperatures increased while the amount of inflowing water decreased (see section 4.4). This indicates that the ice cover is more dependant on the temperature of the incoming water that of the amount.

Figures 4.6 and 4.7 shows modelled ice cover with anomalies in August and December 2004, respectively. They show that the low ice conditions are present both in summer and in winter. The model has a resolution of 20 km, and covers the North Atlantic and Arctic.

In 2005 we expect similar ice conditions as in 2004, due to the expected high temperature in 2005.
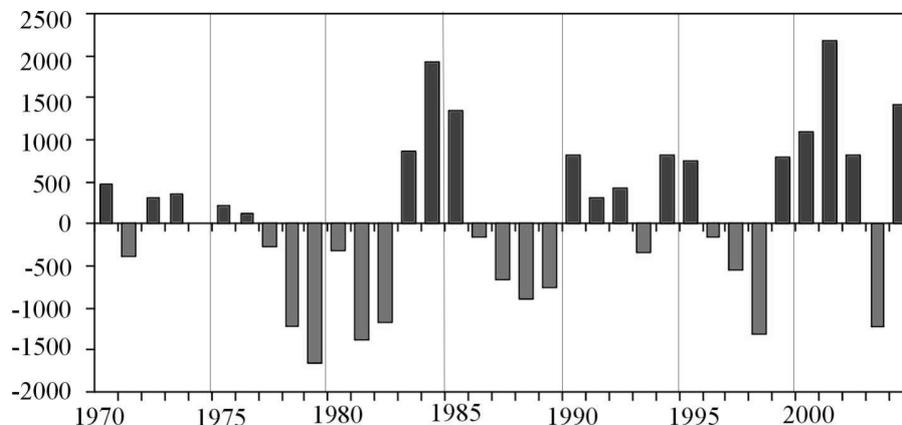

Figure 4.8. Ice index for the period 1970-2004. Positive values means less ice than average, while negative values show more severe ice conditions.

4.4 Currents and volume transports

The observed current in the section Fugløya- Bear Island is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen *et al.,* 2002 and 2004). The inflow of Atlantic water may take place in one wide core or split in several cores. Between the cores there is a weaker inflow or a return flow. In the northern parts of the section there is outflow from the Barents Sea. The outflow area may at times be much wider than earlier

believed, stretching all the way south to 72°N. This phenomenon is not only a short time feature; it might be present for a whole month. These patterns are most likely caused by horizontal pressure gradients caused by a change in sea-level between the Barents Sea and the Arctic or the Norwegian Sea by accumulation of water and/or by an atmospheric low or high.

There seems to be seasonality in the structure of the current. During winter the frequent passing of atmospheric lows, probably in combination with the weaker stratification, intensify the currents producing a structure with strong lateral velocity-gradients and a distinct, surface-intensified, relatively high-velocity, core of inflow. During the summer, when the winds are weaker and the stratification stronger, the inflowing area is wider, and the horizontal shear and the velocities are lower. In the summer season there is inflow in the upper 200 m in the deepest part of the Bear Island Trough.

The time series of volume and heat transports reveal fluxes with strong variability on time scales ranging from one to several months (Fig. 4.9). The monthly mean volume flux is fluctuating between about 5.5 Sv into and 6 Sv out of the Barents Sea, and with a standard deviation of 2 Sv. The strongest fluctuations, especially in the inflow, occur in late winter and early spring, with both maximum and minimum in this period. The recirculation seems to be more stable at a value of something near 1 Sv, but with interruptions of high outflow episodes. High outflows occurred in April both in 1998 and 1999 and in 2000 there were two periods with strong outflow, one in January and a second one in June. In the first half of 2003 the inflow was high, but the intensity of the flow was reduced during spring and summer.

The time series of volume transports shows a relatively high inflow during 1997 and 1998, before the transport decreased and reached a minimum in end of 2000. Then there was a strong increase in the transport until beginning of 2003. During 2003 there were a continuous decrease in the inflow throughout the whole year, and around New Year (2003-2004) the inflow was at the lowest observed for wintertime. In the first half of 2004 the inflow slightly increased again, but was still at a low level.

The wind driven modelled inflow (Fig. 4.10) show that the inflow the first four months of 2004 shifted between values above to below the long-term mean (1955-2004). This is roughly in accordance with observations, though the range in the model is lager than found in the observations. The reason for this is most likely that the model mirrors the wind driven part of the circulation, while observations includes all processes. The modelled inflow in the summer 2004 is slightly less than average, which is in accordance with observations. The model and observations also agree fairly well for April and May, which are the period where zooplankton and fish larvae usually are advected into the Barents Sea from the Norwegian Sea. Observations from the autumn/winter 2004 are not yet available, but the model shows an increased inflow in November and December. This is a consequence of weather conditions with many strong low pressures in the area.

Earlier it has been believed that the temperature and the volume transport varied in a similar manner; that is that high temperature was linked to high volume transport and lower temperature was linked to reduced inflow of Atlantic water. However, Figure 4.9 shows that there seems to be no correlation between the fluxes and the temperature of the inflowing water. In fact, in periods the temperature increase while the volume flux decreases, and high positive anomalies observed

in 2004 are not due to an increased inflow, as we did believe earlier. This shows that in the Fugløya-Bear Island section the temperature is independent of the volume flux into the Barents Sea. The reason is simply that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner.
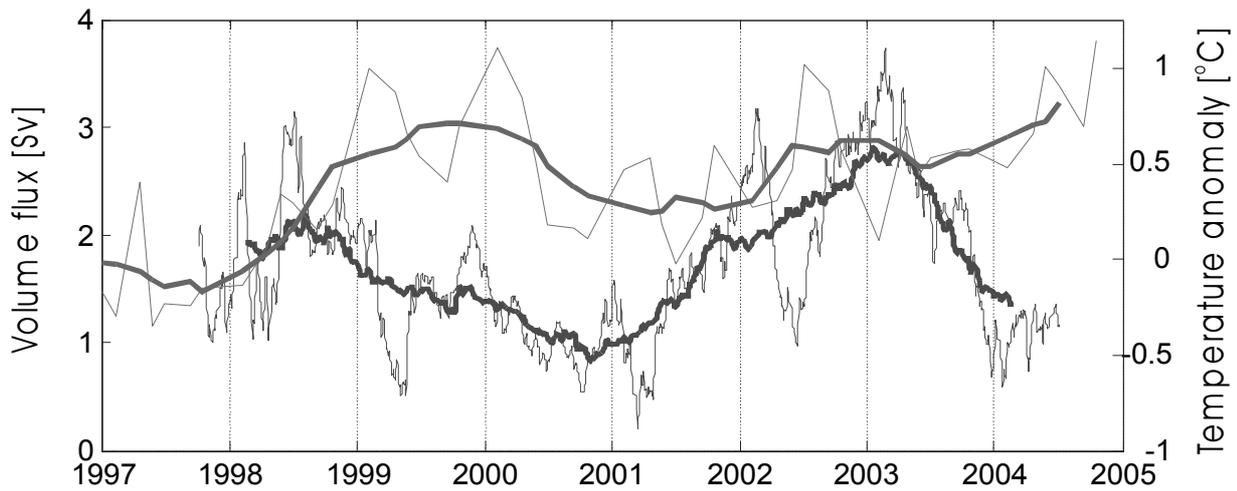

Figure 4.9. The blue lines show Atlantic Water volume flux through the section Norway-Bear Island. Time series are 3 and 12 months running means. The red lines show temperature anomalies the section Fugløya – Bear Island section. Time series are actual values and 12 months running means.
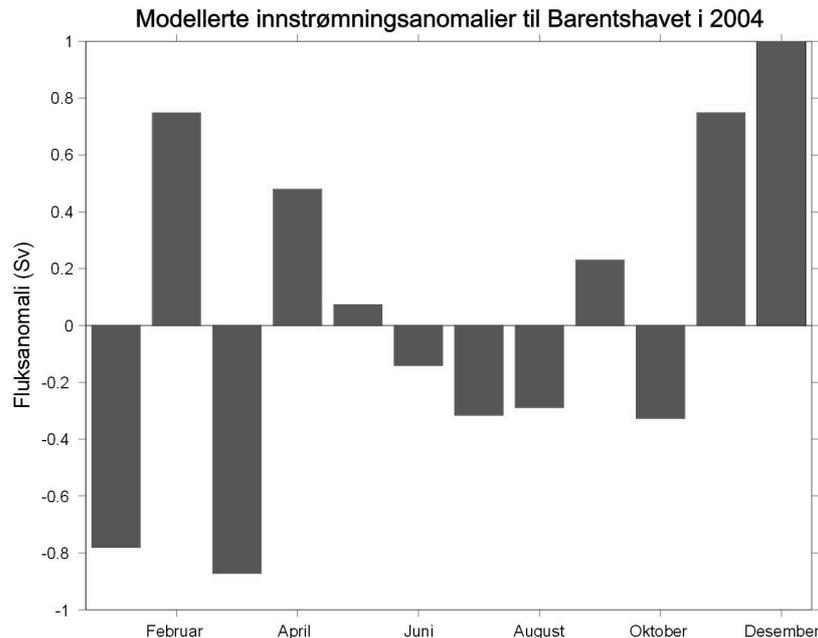
Figure 4.10. Modelled flux anomalies in 2004 through the section between Norway and Bear Island (Anon, 2005a). The anomalies are deviations from the long-term mean period 1955-2004.

4.5 Predicting Barents Sea temperature

Prediction of forthcoming environmental conditions, or at least some knowledge on the predictability, is most valuable for projecting the survival of fish through the early life stages, as well as weight and maturity at age. The natural first environmental parameter to try to forecast is sea temperature. The rates of a number of growth-related processes are controlled by temperature (Michalsen *et al*., 1998). In addition, temperature affects almost all species in the ecosystem, making it an important indicator of changes in fish population dynamics (Daan *et al*., 1994). Furthermore, the "long memory" of the ocean, as compared to the atmosphere, makes it, at least a priori, feasible to realistically predict ocean temperature much further ahead than the typical weather forecast.

It should be stressed that long-term predictions are fundamentally different from the global change scenarios for 50 or even 100 years ahead. When modelling such scenarios a specific change in some important driving factor(s) is assumed (for instance a doubling of atmospheric CO_2 within a certain time span). The output is that of a new mean level, not the situation for any specific year. Since the natural variation around the new mean may be high, this kind of model is not suited for determining if say 2050 will be a warm year or not.

Prediction of Barents Sea temperature is complicated by the variation being governed by processes of both external and local origin operating on different time scales. The volume flux of Atlantic water masses flowing in from the Norwegian Sea is an important factor. It is influenced by the wind conditions in the western Barents Sea, which again is related to the Norwegian Sea

wind field (Ingvaldsen et al., 2004). Also the temperature of these water masses as well as local heat exchange with the atmosphere, possibly linked to atmospheric teleconnections, is important in determining the temperature of the Barents Sea (Ådlandsvik and Loeng, 1991; Loeng *et al.*, 1992). Furthermore, also density differences in the ocean itself are of importance. Thus, both slowly moving advective propagation and rapid barotropic responses due to large-scale changes in air pressure must be considered.

Advection may be considered a natural starting point for predicting Barents Sea temperatures and the literature suggests different time lags according to the distance to the upstream location. (Helland-Hansen and Nansen, 1909) suggested that a temperature signal takes 1 year from Fugløya-Bjørnøya to Kola, 2 years from Sognesjøen to Kola, while Sutton and Allen (1997) suggest that a SST signal takes 12-14 years from Cape Hatteras to NW Scotland. However, Ottersen *et al.*, (2000) didn't find much foundation for prediction based upon advection alone. Recently, Orvik and Skagseth (2003) studied the relation between the North Atlantic wind stress field and inflow to the Norwegian Sea. They found a maximum correlation of 0.88 between the volume transport of the Norwegian Atlantic Slope Current (NwASC) and the Zonally integrated North Atlantic Wind Stress Curl (NAWSC) at 55°N 15 months earlier. However, the calculations are based on data for the short period 1995-2003 and the correlative relation was not tested beyond the period it was derived for.

The major changes in Barents Sea climate take place during the winter months. The variability in the amount of heat flowing in with Atlantic water masses from the south is particularly high during this season. Furthermore, variability in low-pressure passages and cloud cover has an extra strong influence on the winter atmosphere-ocean heat exchange. The difference in temperature between ocean and atmosphere is highest, but highly variable, at this time of year. The air temperature may at times be 30 degrees lower than the SST. Thus, also with regards to the degree of loss of energy to the atmosphere, this season is decisive.

Table 4.4. Linear regression models for monthly 0-200m temperature values in the Kola section based on corresponding temperatures from six months earlier. The equations are derived from data from January 1921 to February 1997. All coefficients of determination (R^2) are significant at the 5% level. Monthly temperatures for 2005 predicted by means of the corresponding model.

Predicted from month (x)	Prediction for month (y)	Equation	R^2	Prediction 2005	Mean 1921-1999
July	January	y=1.77 + 0.50x	0.31		3.88
August	February	y=1.05 + 0.51x	0.27		3.44
September	March	y=0.95 + 0.44x	0.21		3.12
October	April	y=0.53 + 0.49x	0.25	3.42	2.94
November	May	y=0.74 + 0.50x	0.22	3.46	3.09
December	June	y=0.98 + 0.60x	0.25	4.02	3.56
January	July	y=1.60 + 0.67x	0.36	4.86	4.18
February	August	y=2.37 + 0.67x	0.41	5.41	4.67
March	September	y=2.67 + 0.72x	0.49		4.91
April	October	y=2.71 + 0.75x	0.55		4.91
May	November	y=2.91 + 0.57x	0.38		4.69
June	December	y=2.71 + 0.45x	0.29		4.32

This seasonal difference is reflected in the merit of simple six months forecasts of sea temperature based on linear regression models. Data from the Kola section temperature time series (Bochkov, 1982), the longest below-surface sea temperature series in the region, is used. The 2004 data are published in Anon. (2005b), and the January and February data for 2005 were kindly provided by PINRO. Table 4.4 (after Ottersen *et al.*, 2000) shows that the predictive value for a specific month based on values from six months earlier vary considerably throughout the year. The tendency found was that of persistence across the spring and summer months being higher than for other seasons, allowing for reasonably reliable forecasts from spring until autumn.

Since reliable objective long-term forecasts still are unavailable, our predictions depend on subjective expertise. Based upon the record high temperatures in the western Barents Sea and high temperatures in the Norwegian Sea during late 2004, it is expected that the temperatures in the southern Barents Sea will be high also during 2005. Especially the first part of the year is expected to be warm, partly as an effect of the strong low-pressure activity in November-January leading to large inflow to the south western Barents Sea. Later on the temperature anomalies are likely to become smaller, but still well above the long-term average.

5. Phytoplankton

The Barents Sea is a spring bloom system and during winter the primary production is low and the chlorophyll concentrations are close to zero. The timing of the phytoplankton bloom is variable throughout the Barents Sea. Primary production in this area is mainly limited by light during winter. At this time the water is mixed and nutrients are transported to the surface. In early spring, the water is still mixed and even though there are nutrients and light enough for production, the main bloom does not appear until the water becomes stratified. The stratification of the water masses in the different parts of the Barents Sea may occur in different ways. Along the marginal ice zone, the increased sun radiation during spring leads to melting of the sea ice and thereby to a thin upper layer of relatively fresh melt water. As the ice melting continues and the ice retracts northwards, the upper layer gets heated and this increases the stratification and gives the necessary conditions for the spring bloom to start in this area. In the Atlantic water masses the stratification is a consequence of solar heating of the surface waters. In the southern part close to the Norwegian coast, the bloom may start following increased vertical stability caused by lateral spreading of coastal water from the Norwegian Coastal Current (Rey, 1981). The timing and development of the spring bloom in the Barents Sea show high interannual variability, particularly in regions where there are interannual variability in sea ice cover which when it melts may cause stratification to appear earlier than if no ice were present (Olsen et al., 2003).

The dominating algal group in the Barents Sea is diatoms like in many other areas (Rey, 1993). Particularly, the first spring bloom is dominated by diatoms and the most abundant species is *Chaetoceros socialis*. During the first spring bloom there can be very high concentrations of diatoms (up to several million cells per litre). The diatoms require silicate and when this is consumed other algal groups such as flagellates take over. The most important flagellate species in the Barents Sea is *Phaeocyctis pouchetii*.

The bloom situation in the Barents Sea is covered on a regular basis both during the survey coverage in August-October and on the standard sections Fugløya-Bjørnøya and Vardø-Nord. During these surveys the chlorophyll concentration is measured as fluorescence in water samples taken from standard depths down to 100 m depth. This gives an indication on the primary production in the area. In addition to observations, the primary production is simulated using numerical models. Figure 5.1 shows the measured chlorophyll values at the Fugløya-Bjørnøya section in March, April, June and August 2004. In March no production was measured and there were still winter values of chlorophyll. In April the spring bloom had started and the values of chlorophyll were particularly high in the upper parts of the coastal water close to the Norwegian coast, but also extending into Atlantic water. In June, the chlorophyll layer was mainly found in the upper 30-40 m along the entire section but also at that time with a maximum close to the Norwegian coast. In August the lower values of chlorophyll near the surface indicated that the phytoplankton had started to sink.
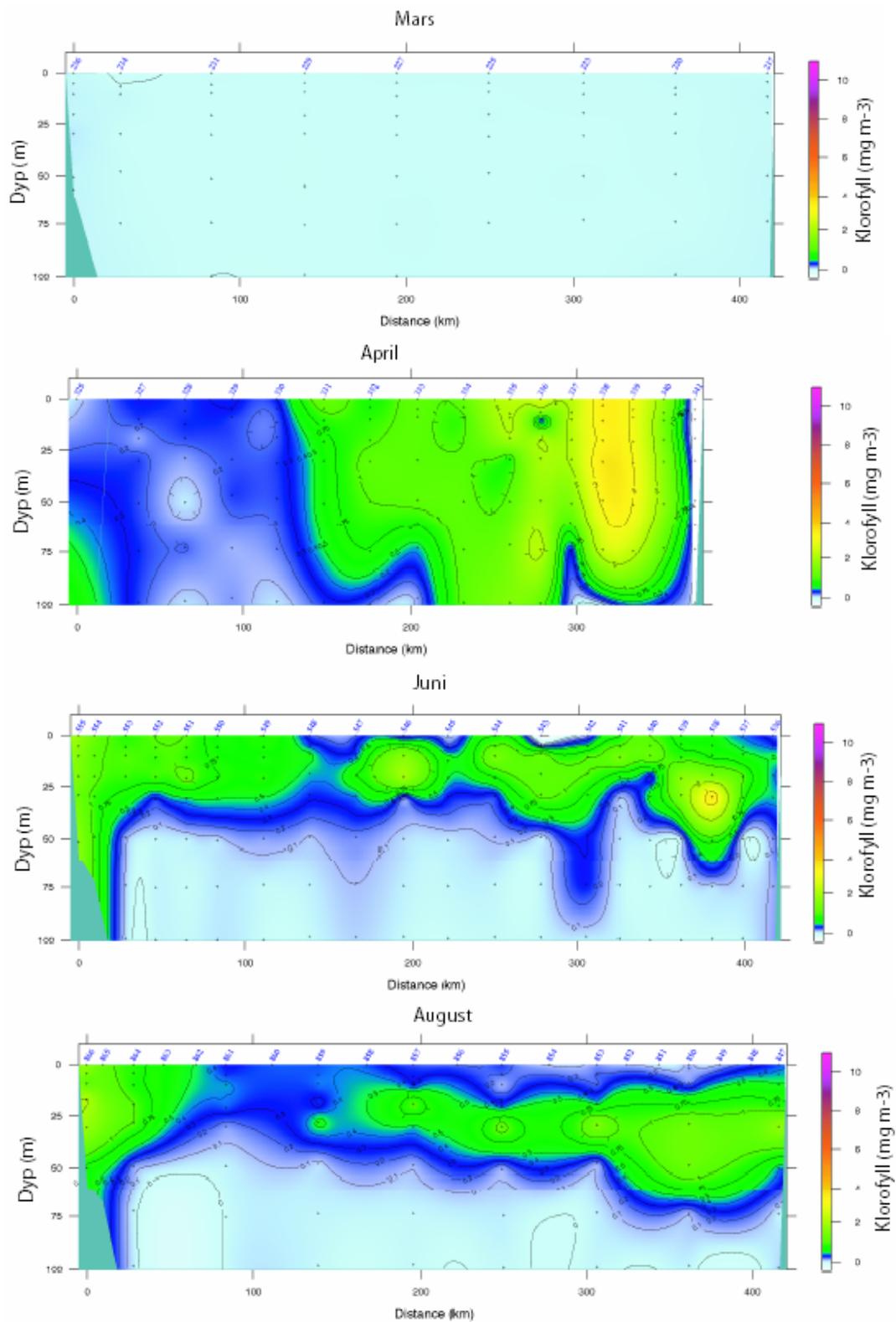
Figure 5.1. Measured chlorophyll in the upper 100 m on the transect Fugløya – Bjørnøya in March, April, June and August. North is to the left.

Simulations of the primary production in the Barents Sea using the NORWECOM (NORWegian ECOlogical Model system) numerical model showed that there was considerable interannual variation in timing of the spring bloom at the Fugløya-Bjørnøya section during the years 1992 to 2004 (Figure 5.3). Even though we suspect the model to produce the bloom somewhat too early in the year, we expect the trends to be correct. The model results showed that the peak of the bloom may vary with about three weeks from year to year and in 2004 the results indicates that the bloom was relatively early. Figure 5.2 shows the timing of the bloom throughout the Barents Sea in 2004. It shows that the bloom was earliest close to the coast at the western entrance of the Barents Sea. Also close to some of the bank areas, the bloom started early. Particularly in the eastern part close to Goose Bank and North Kanin Bank but also at the Central Bank and the Svalbard Bank. Some of these banks are very shallow and water masses may be trapped there. The bank may therefore act as a barrier to downward transport of plankton cells in the same way as a stratification of the water masses. This may explain the early bloom in the bank areas.
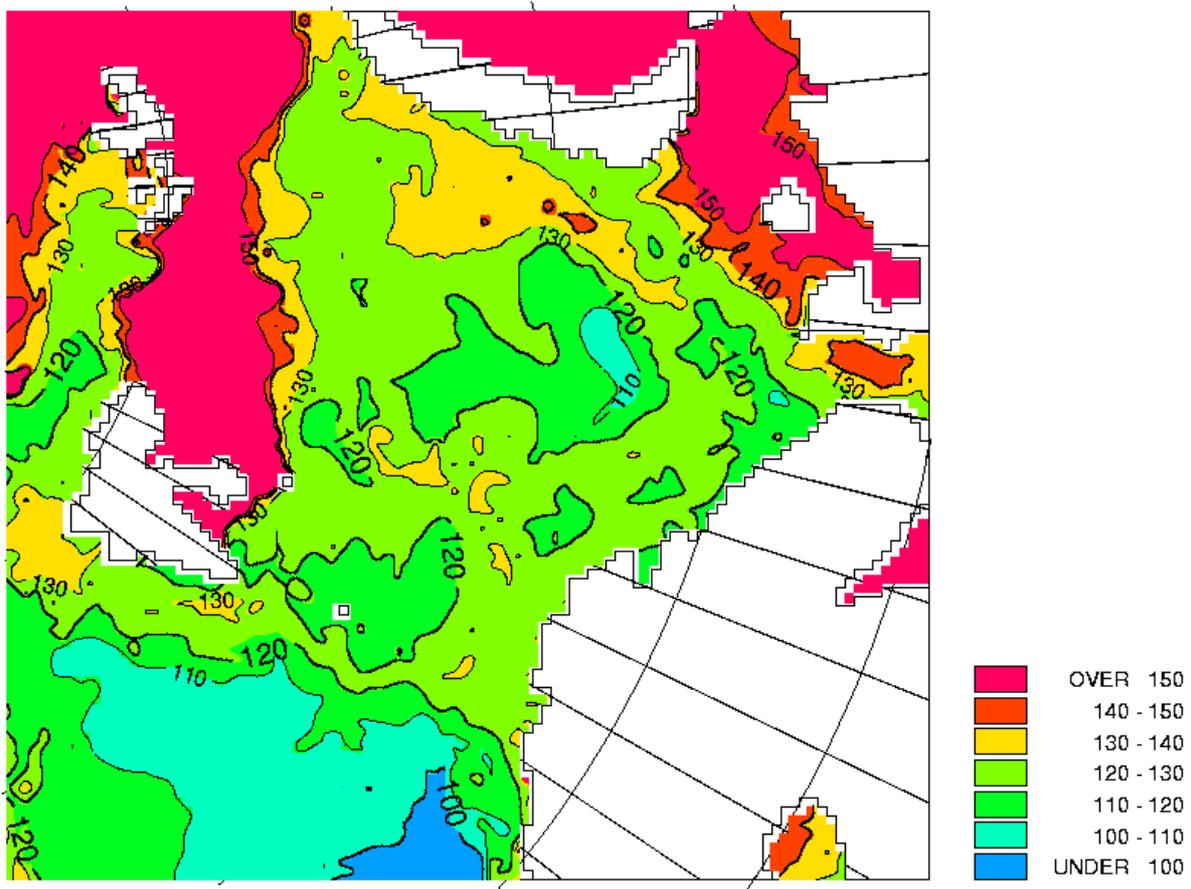
Peak (daynr) diatom spring bloom, 2004

Figure 5.2. Modeled day number of peak diatom spring bloom in 2004 using the NORWECOM (NORWegian ECOlogical Model system) *numerical model.*
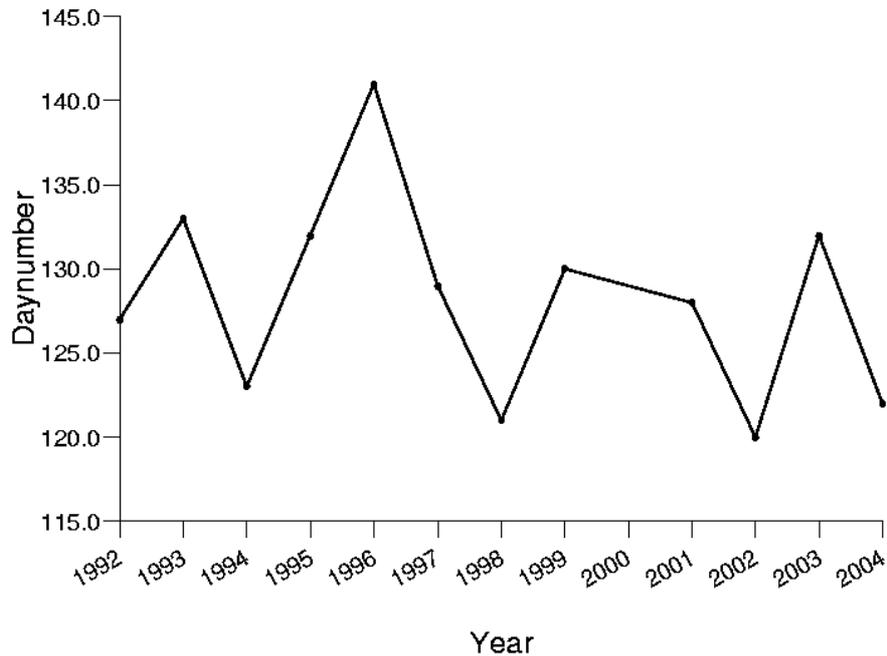
Figure 5.3. Modeled day number of peak diatom spring bloom at the Fugløya-Bjørnøya section during the period 1992 to 2004 using the NORWECOM (NORWegian ECOlogical Model system) *numerical model.*

6. Zooplankton

6.1 Status of the Zooplankton

In the Barents Sea, the Institute of Marine Research started regular sampling (August-September) of zooplankton in 1986, but had already since 1979 conducted several cruises with plankton investigations at different times of the year. Since 2003 PINRO and IMR have had joint cruises for monitoring zooplankton in the Barents Sea in autumn. The Russian vessels covered mostly the eastern part whereas the Norwegian cruises were in the central and western parts of the Barents Sea. In addition, the standard sections Fugløya-Bjørnøya and Vardø-N (since 1991) are covered on average 6 and 4 times a year, respectively. These investigations have provided important information on zooplankton e.g. annual and regional variations in abundance, biomass and species composition.

Plankton samples are obtained by using WP2 and MOCNESS (Multiple Opening and Closing Net and Environmental Sensing System) plankton nets with 180 μm mesh size. The sampling depths in the Barents Sea for the WP2 are from bottom to 0 m and 100 to 0m. At most stations the MOCNESS nets are towed in oblique hauls from 300-200, 200-150, 150-100, 100-50, 50-25, and 25-0m. The number of nets varies from about 3 to 8 according to the bottom depth. The zooplankton samples are usually separated into two halves. One half preserved in 4% formaldehyde is used for species identification. The second half is size fractionated on 180 μm, 1000 μm and 2000 μm sieves for dry weight measurements.

The zooplankton biomass based on combined data from WP2 and MOCNESS gave an average dry weight of 7.8 g m^{-2}. The biomass in 2004 was higher compared to 2001 (5.9 g m^{-2}) and 2003 (6.5 g m^{-2}). Possible reasons for large variations are the differences in advective transport, temperature conditions and predation pressure. 2004 was one of the warmest years recorded and with very high salinity values. The high temperatures may have lead to increasing growth rates of zooplankton. In addition, increased advection may also have lead to high zooplankton abundance in the Barents Sea. Another explanation for the high biomass observed in 2004 could be the low predation pressure from capelin. The capelin stock size has declined from about 3.5 million tonnes in 2001 to a very low level (ca 0.5 million tonnes) in 2004. Horizontal distribution of zooplankton for 2001 and 2004 in August/September are shown in Figure 6.1.

Based on the biomass information we have from 2004, the zooplankton production in 2005 is expected to be comparatively higher, providing good feeding conditions for capelin, herring and other juvenile fish.
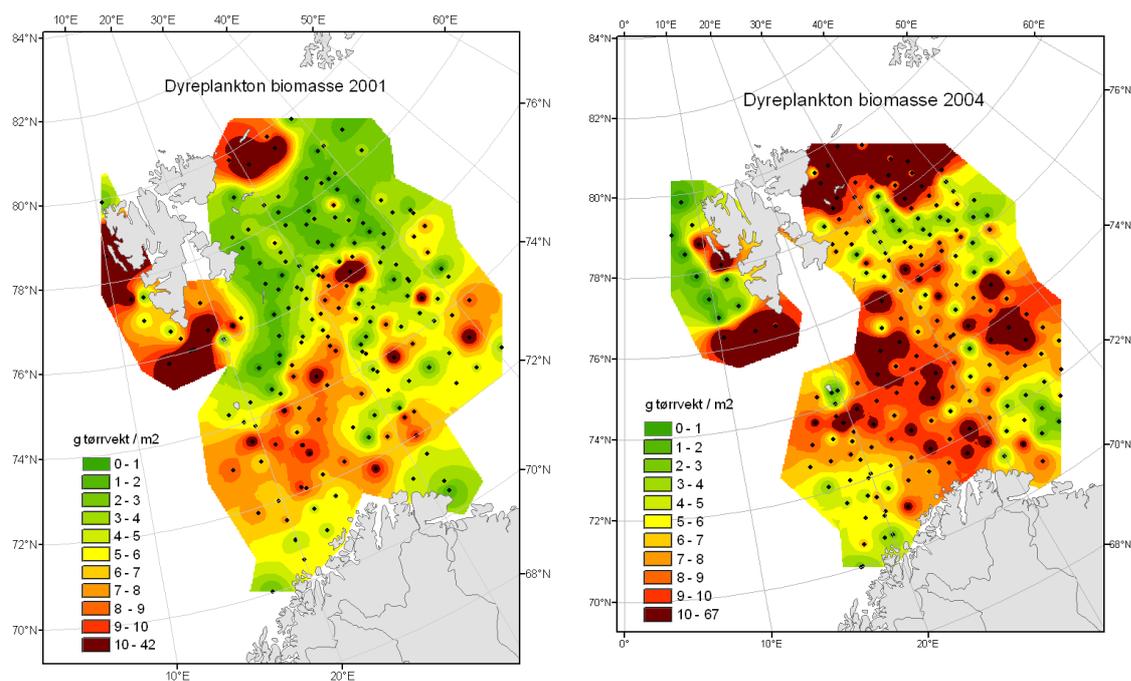

Figure 6.1. Horizontal distribution of zooplankton (g dry weight m^{-2} from bottom - 0 m) in August/September based on WP2 and MOCNESS for 2001 (left panel) and 2004 (right panel).

6.2 Zooplankton and capelin interactions

In the Barents Sea ecosystem, capelin plays a very important role, on one hand as a major predator and on the other hand as a major prey. Capelin is the main predator on zooplankton, feeding mainly on copepods, krill and amphipods. The investigations in the Barents Sea have demonstrated a several fold variation in zooplankton biomass among years in the period 1979-2004 (Fig. 6.2). The observations of low zooplankton abundance when the capelin stock is large is not surprising as capelin is the most important predator on zooplankton in the Barents Sea ecosystem and probably exploits most of the secondary production, during its feeding season (Fig. 6.2). During periods when the capelin stock was at very low levels, the predation pressure on zooplankton was at a minimum, thus causing an increase in the zooplankton biomass. These observations seem to indicate strong interactions between capelin and zooplankton in the Barents Sea.
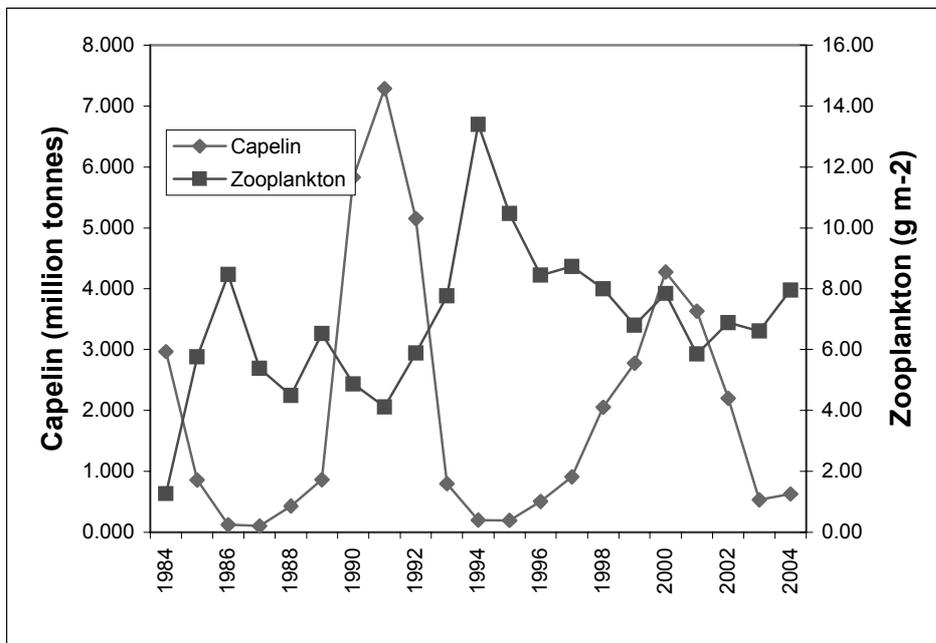

Figure 6.2. Annual fluctuations in zooplankton biomass and size of capelin stock in the Barents Sea.

In general, the plankton biomass is higher in the Atlantic waters and constitutes mostly of copepods and krill. Based on salinity and temperature values at different depths and classifications of water masses given by Loeng (1991), we have classified the zooplankton biomass in to different water masses (Table 6.1). The biomass in the Atlantic and Polar Front region was close to 8,0 g m^{-2}. In 2004, we observed high biomass in the Arctic waters (9.3 g m^{-2}). The high values are reflected by few MOCNESS stations with high amphipod (*Themisto libellula*) biomass.

Table 6.1. Zooplankton biomass in different water masses in 2004.

Watermass	No. of stations	Mean dry weight ($g\ m^{-2}$)	Standard deviation
Arctic water	30	9.3	11.6
Polar Front water	54	7.8	6.2
Atlantic water	85	7.8	3.0
Coastal - Atl. water	11	4.2	3.1

6.3 Zooplankton, capelin and cod interactions

Cod (*Gadus morhua*) is a major predator on the Barents Sea ecosystem. Growth of young Northeast Arctic cod in the Barents Sea has shown strong fluctuations. The mean length of age 3 cod in the Norwegian winter bottom trawl survey has varied between 28 and 42 cm during the period 1984-2005 (ICES, 2005). Correspondingly, the mean weight at age 3 in this survey has varied between 200 and 800 g. Thus, in order to give predictions of cod stock biomass, it is important to predict size at age and not only abundance at age.

Individual growth in fish depends on density dependent factors such as availability of prey. However growth is also dependent on a series of processes (feeding, metabolism, excretion etc.), which are controlled by temperature (Ottersen et al. 2002; Michalsen et al. 1998).

Diet investigations were carried out on 0, 1 and 2 year old Northeast Arctic cod sampled in the Barents Sea during 1984-2002 (Dalpadado and Bogstad, 2004). The purpose of this paper was twofold. First, to investigate variations in the diet of age 0-2 Northeast Arctic cod in the Barents Sea related to prey abundance. Second, to study how variability in growth of these age groups of cod is related to stomach content and food abundance.

Stomach content analyses showed that the 0 and 1 group cod fed mainly on crustaceans with krill and amphipods comprising up to 70% of their diet (Fig 6.3 and 6.4). Krill (*Thysanoessa* spp. and *M. norvegica*) and amphipods (*Themisto* spp.) were mainly found in cod stomachs sampled in the central and close to the Polar Front region in the Barents Sea where these prey organisms are reported to be abundant in summer.

A shift in the main diet from crustaceans to fish was observed from age 1 to age 2. The diet of 2-year-old cod mainly comprised capelin (*Mallotus villosus*) and other fish, and to a lesser degree, krill and amphipods (Fig 6.5). Shrimp (mainly *Pandalus spp.*) was also an important prey in both age 1 and 2 cod. A statistically significant positive relationship was obtained between capelin stock size and the amount of capelin in the diet of 2-year-old cod. Results from this study also show that the larger age 2 cod preyed more on capelin in winter and that larger cod (> 22 cm) prefer larger capelin (> 12 cm). During summer capelin migrates to Arctic waters to the north of the Polar Front to feed. Thus, to a large extent, the main

distribution area of cod and capelin do not overlap, during summer. This is possibly the reason why we observed the age 2 cod to feed little on capelin during the summer-autumn period. In warm years e.g. 1992, the distribution of capelin is extended to eastern areas. Age 2 cod feed heavily on capelin during winter, in the eastern Barents Sea. Our results show that in years with low capelin abundance, the cod switched to other prey organisms such as shrimps, krill and amphipods. Similarly, the Icelandic cod also switched to other prey when capelin abundance was low (Magnússon and Pálsson 1989).

A positive significant relationship was also obtained between Total Fullness Index (TFI) and the amount of capelin in the diet and between TFI and the growth of 2-year-old cod indicating that the growth of age 2 cod is to a large extent dependent on the amount of capelin consumed.

Results have not been updated for 2003-2004.

Age 0 cod

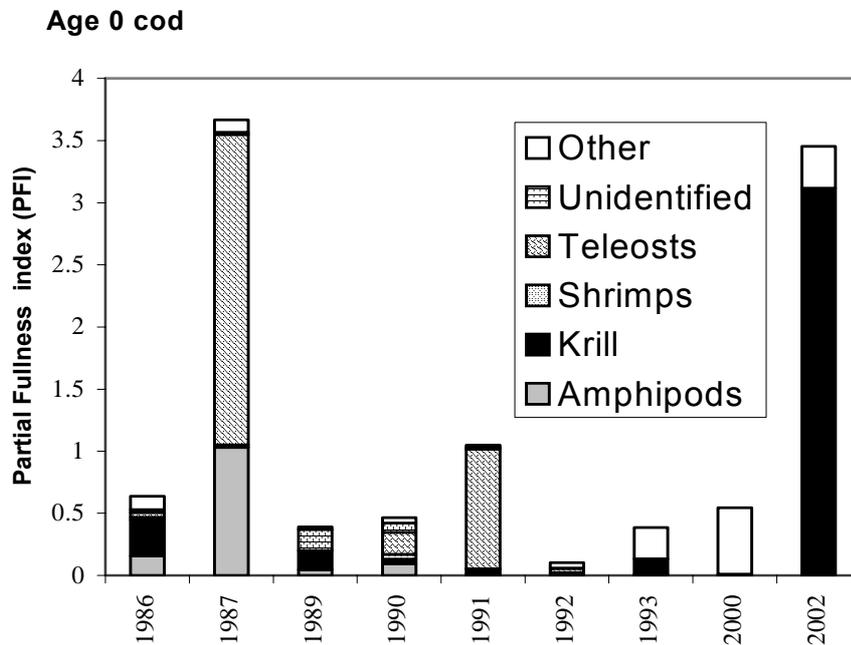*Figure 6.3. Annual variation in Partial Fullness Index (PFI) for age 0 cod from 1986-2002. Only years with more than 20 stomach samples are shown.*

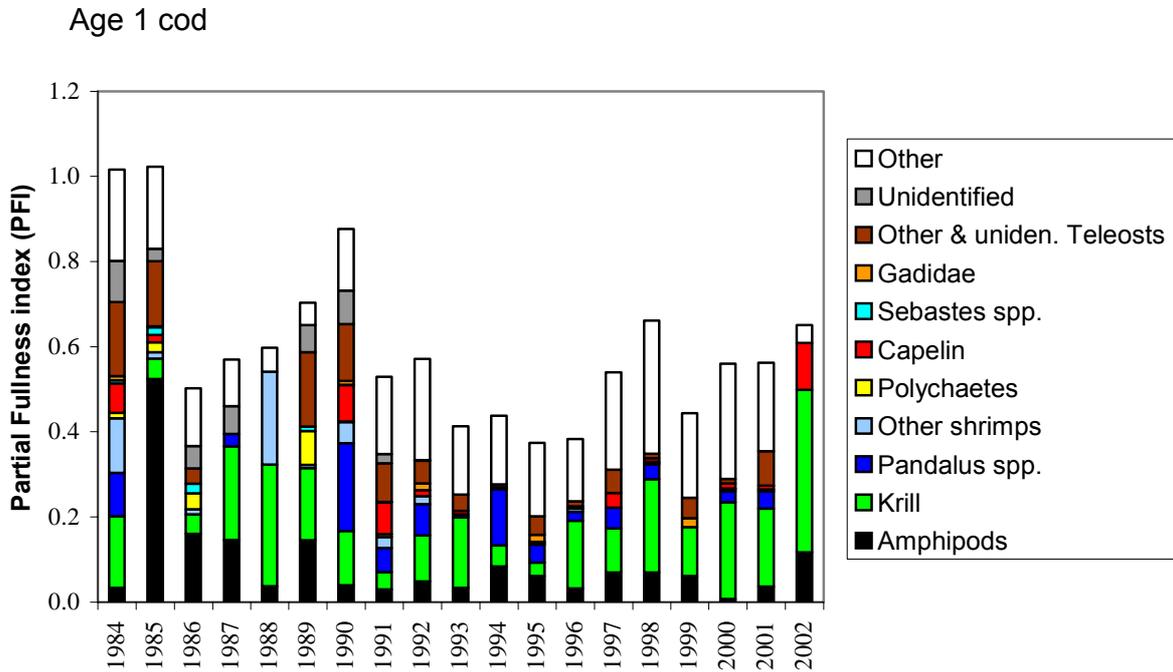## Age 1 cod

Figure 6.4. Annual variation in Partial Fullness Index (PFI) for age 1 cod from 1984-2002.
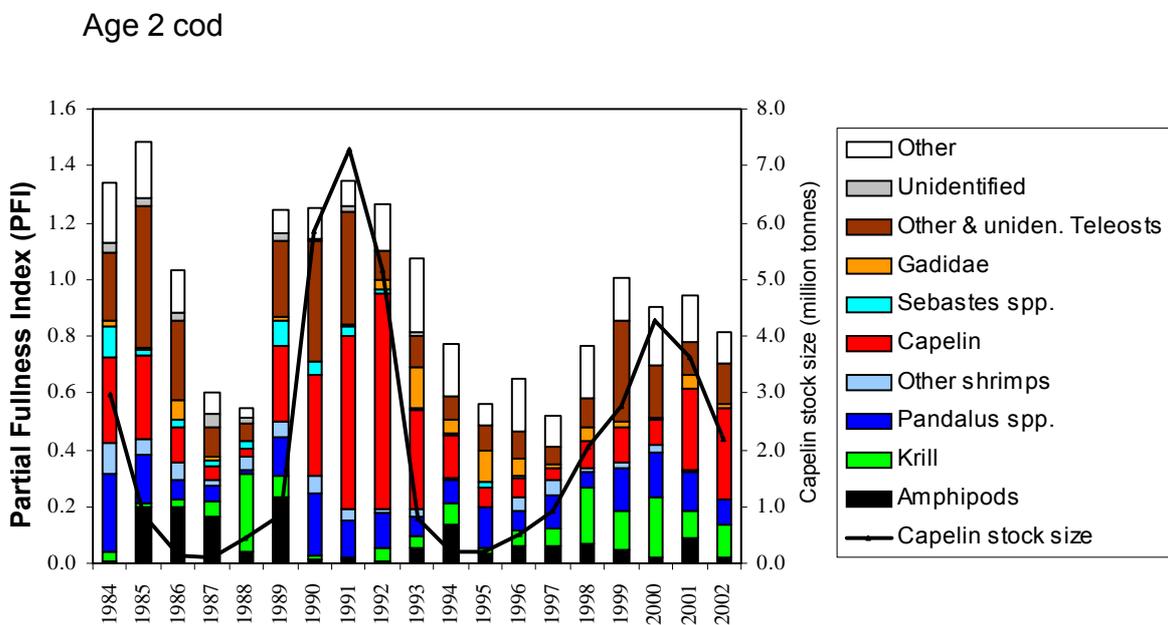
Age 2 cod

Figure 6.5. Annual variation in Partial Fullness Index (PFI) for age 2 cod from 1984-2002.

7. Fish

7.1 Fish community and multispecies interactions

The Barents Sea is a highly productive area, which may provide food for large pelagic fish stocks that may serve as food for other species in the food web, including man. It is a relatively simple ecosystem with few fish species of potentially high abundance. These are Northeast Arctic cod, haddock, Barents Sea capelin, Polar cod and immature Norwegian Spring-Spawning herring. The last few years there has in addition been an increase of blue whiting migrating into the Barents Sea. The abundance in 2004 was estimated to be 1.4 million tons (IMR, 2004). The composition and distribution of species in the Barents Sea depend considerably on the position of the polar front. Variation in the recruitment of some species, including cod and herring, has been associated with changes in the influx of Atlantic waters into the Barents Sea.

Cod, capelin and herring are key species in this system. Cod prey on capelin, herring and cod, while herring prey on capelin larvae. Cod is the most important predator fish species in the Barents Sea, and feeds on a large range of prey, including the larger zooplankton species, most of the available fish species and shrimp (ICES, 2005). The diet of cod is a good indicator of the state of the Barents Sea ecosystem. Fig. 7.1 shows the diet of cod in the period 1984-2004, calculated from data on stomach content, gastric evacuation rate and number of cod by age. The data for cod stomach content are taken from the Joint IMR-PINRO stomach content database. The model for gastric evacuation rate for cod is based on experiments conducted at Norges Fiskerihøgskole in Tromsø. The consumption calculations show that the total consumption by cod in 2003 and 2004 was about 4.5 million tonnes. The consumption per cod for the various age groups was also approximately the same in both years. Capelin was also in 2004 the most important prey item for cod, followed by amphipods, polar cod, krill, shrimp, blue whiting, herring, haddock and cod. The proportion of capelin in the diet of cod decreased from 2002 to 2004, but not as much as the decrease in the abundance estimate of capelin should indicate. This phenomenon was, however also observed during the previous capelin collapse. Cod cannibalism is now at a low level. The individual growth of age 1 and 2 cod is below average, while it is average for older cod. The cod migrates out of the Barents Sea and spawns in the Lofoten area in March. The average age at first maturation has been declining the last decades (ICES, 2005).

Capelin is a key species because it feeds on the zooplankton production near the ice edge and is usually the most important prey species in the Barents Sea, serving as a major transporter of biomass from the northern Barents Sea to the south (von Quillfeldt and Dommasnes, in prep.). During summer they migrate northwards as the ice retreats, and thus have continuous access to new zooplankton production in the productive zone recently uncovered by the ice. They often end up at 78-80°N by September-October, and then they start a southward migration to spawn on the northern coasts of Norway and Russia. Cod prefer capelin as a prey, and feed on them heavily as the capelin spawning migration brings them into the southern and central Barents Sea. Capelin also is important prey for several species of marine mammals and birds.

Fluctuations of the capelin stock have a strong effect on growth, maturation and fecundity of cod, as well as on cod recruitment because of cannibalism. The juveniles of the Norwegian spring-spawning herring stock are distributed in the southern parts of the Barents Sea. They stay in this area for about three years before they migrate west and southwards along the Norwegian coast

and mix with the adult part of the stock. The presence of young herring in the area has a profound effect on the recruitment of capelin, and it has been shown that when rich year classes of herring enter the Barents Sea, the recruitment to the capelin stock is poor and in the following years the capelin stock collapses. This happened after the rich 1983 and 1992 year classes of herring entered the Barents Sea. Also when medium sized year classes of herring are spread into the area there is a clear sign of reduction in recruitment to the capelin stock, as is currently the case. In this way, the herring impact both the capelin stock (directly) and the cod stock (indirectly).

Which consequences will the collapse of the capelin stock in 2003-2004 imply for the Barents Sea ecosystem? The collapses of the capelin stock in the 1980s and 1990s had major consequences for the predators preying on capelin, in particular cod and harp seal. In particular, during the collapse in the 1980s, length growth decreased and age at maturity increased, and the condition factor also decreased. The cod switched to less nutritious food (krill and amphipods), and predation on young cod (cannibalism) increased. The harp seal searched for food to the south and west of its usual habitat, and in 1987-1988 at least 77 000 harp seals drowned in gillnets along the Norwegian coast. Seabirds feeding on capelin had very low breeding success, and the mortality of adult seabirds also increased. During the second collapse in 1993-1995 the effect on growth and maturation was much smaller, although the cod stock was higher during this period than in 1986-1988. The cod also switched to other fish prey, including young cod, but also seemed to have more capelin available. During this period there was no seal invasion on the Norwegian coast, and the seabirds also did fairly well.

Herring is the only other prey item with similar abundance and energy content as capelin. If herring is an important food item and may replace capelin in the period where the capelin stock is low, may this be an explanation of the differences between the first and second capelin collapse. During the first capelin collapse, herring disappeared from the Barents Sea during the first year of the collapse, as the herring in the Barents Sea consisted almost exclusively of the 1983-year class. During the second collapse, several strong herring year classes, in particular the 1991 and 1992 year classes, were present, and thus there was herring in the Barents Sea also in parts of the period when the capelin stock was depleted.

Although the amount of herring in cod stomachs increased during the two previous capelin collapses, it cannot be said that herring wholly or partially replaced capelin as food for cod. Data from the joint IMR-PINRO stomach content data base, together with Russian qualitative stomach content data (Ponomarenko & Yaragina, 1979), show that the proportion of cod stomachs containing herring was much higher in many years during the 1950s and 1960s than during the capelin collapses in the 1980s and 1990s. The reason for this difference is not known. Possible explanations could be: more young herring in the Barents Sea in the 1950s and 1960s; higher overlap between cod and herring, or that a larger proportion of the cod stock in the 1950s and 1960s was large cod, which is more capable of feeding on herring. The herring abundance in the Barents Sea will probably be high for a longer period of time, from 2002 up to at least 2007, since the 2002-year class of herring is very strong, as is probably also the 2004-year class. We will thus probably get a situation, which is fairly similar to that in the mid-1990s. The period with high abundance of herring will, however, be at least one year longer this time, and this may cause the period of low recruitment of capelin to become longer than the life cycle of capelin (4 years). This may hamper capelin recovery.

Recruitment seems to be strong for most fish species, so that, in addition to young herring, also haddock, blue whiting, polar cod and cod are abundant in the Barents Sea. It is thus likely that cod and other predators, except capelin specialists like guillemot, will have alternative fish prey available, as in the mid-1990s. It is thus most likely that the consequences of this capelin collapse will be modest and fairly similar to those in the mid-1990s. Another interesting phenomenon is that the collapse of the capelin stock is less abrupt this time than in the two previous collapses, because the recruitment failure has not been so drastic. We also note that recruitment of 0-group capelin has been around or above average in 2002-2004, while the survival from 0-group to age 1 seems to be poor. Whether this is due to predation by herring on 0-group capelin after the survey on 0-group capelin in August-September, is unknown.

Haddock is also a common species, and migrates partly out of the Barents Sea. It is a predator on smaller organisms including bottom fauna. The stock has large natural variations in stock size. Saithe is common in coastal water. The smaller individuals feed on zooplankton, but larger saithe is known to be a predator on fish. In warm years there may be considerable quantities of blue whiting coming in with the Atlantic water in the southern Barents Sea. The blue whiting is a plankton feeder. Polar cod is a cold-water species found particularly in the eastern Barents Sea and in the north. It seems to be an important forage fish for several marine mammals, but to some extent also for cod. There is little fishing on this stock. Deep-sea redfish and golden redfish used to be important elements in the fish fauna in the Barents Sea, but presently the stocks are severely reduced. Young redfish are plankton eaters, but larger individuals take larger prey, including fish. Fishing on these two species is severely restricted in order to rebuild the stock. Greenland halibut is a large and voracious fish predator with the continental slope between the Barents Sea and the Norwegian Sea as its most important area, but it is also found in much of the Barents Sea.
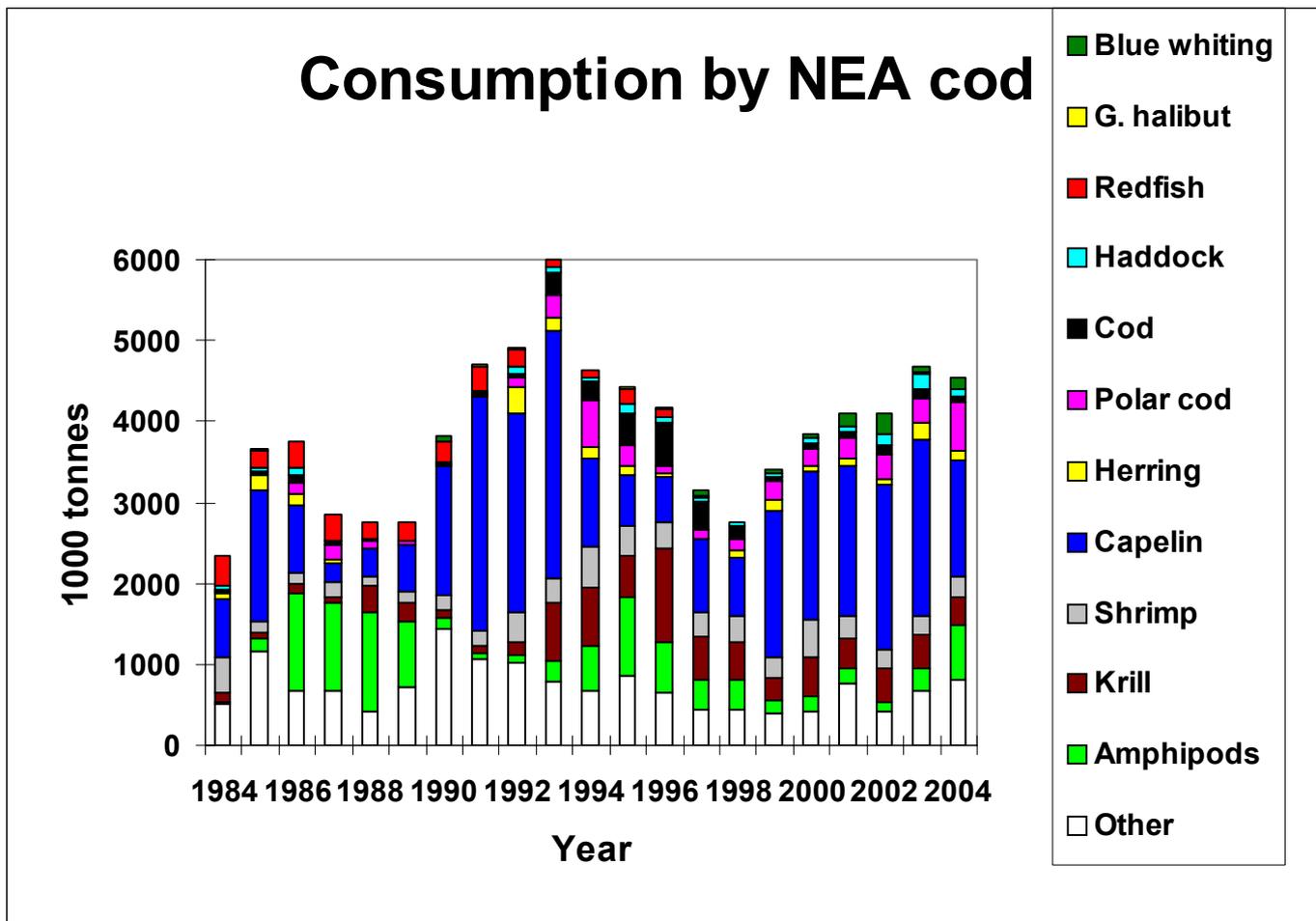
Consumption by NEA cod

Legend:
- Blue whiting
- G. halibut
- Redfish
- Haddock
- Cod
- Polar cod
- Herring
- Capelin
- Shrimp
- Krill
- Amphipods
- Other

Y-axis: 1000 tonnes (0, 1000, 2000, 3000, 4000, 5000, 6000)

X-axis: Year (1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004)

Figure 7.1. Consumption by Northeast Arctic cod in the period 1984-2004.

7.2 Special conditions

The temperature in the Barents Sea has been above normal in recent years, and is currently close to an all-time high for the period where observations are available (Section 3). Although the changes are not very large, they may still cause changes in the ecosystem. The temperature conditions in the Barents Sea are, for some of the species found there, probably close to the limit of what they can adapt to. Then even a minor temperature change may lead to an increase of the distribution area. Temperature itself is not the only relevant factor in this context. An increase in temperature may either be due to an increased inflow of Atlantic water, or to a higher temperature of the water flowing into the Barents Sea. Increased inflow will lead to increased abundance of nutrients and planktonic organisms, and this may lead to changes in living conditions for the fish species in the Barents Sea and enhance growth and survival. Increased temperature in inflowing water, which was apparently the case in 2004, will mainly lead to a change in the distribution area.

The increased abundance of blue whiting in the Barents Sea in recent years may be due to increased temperature. Blue whiting has been observed in the western and southern Barents Sea

for many years, but never in such quantities as now, and never as far east and north in this area as in 2004. In autumn 2004, the acoustic abundance of blue whiting was estimated to 1.4 million tonnes, mainly age 1-4 fish.

How could this affect the rest of the ecosystem? It is reasonable to look for the answer both in the feeding habits of blue whiting, and in the knowledge about which predators feed on blue whiting. Some blue whiting stomachs have been sampled by IMR, but they have not yet been analysed. PINRO studies (Dolgov et al., WD11, AFWG 2002) show that blue whiting will not have a significant impact on the recruitment of cod and other commercial fishes (haddock and redfishes). Increased competition between blue whiting and juvenile commercial fishes grazing on zooplankton is possible.

Concerning blue whiting as prey, we mainly know about the diet of cod. In this time series we can see that blue whiting appears at the end of the period (2001-2004). We may conclude that a 'new' prey species has become available for cod, and then mainly for larger individuals (ages 5 and older). Since blue whiting is a rather fat and nutritious fish, it may influence cod growth positively, at least in periods with low capelin abundance?

The distribution area of several species has increased, saithe being an example. A particular feature in autumn 2004 was the wide distribution of 0-group saithe in the Barents Sea. This species has only sporadically been observed during the 0-group survey, which has been carried out annually since 1965. In 2004, 0-group saithe was found to be distributed continuously all the way eastwards to Novaya Zemlya, and the densest concentrations were found in the Russian EEZ (Figure 7.2). Whether this was a special phenomenon for a particular year class remains to be seen.
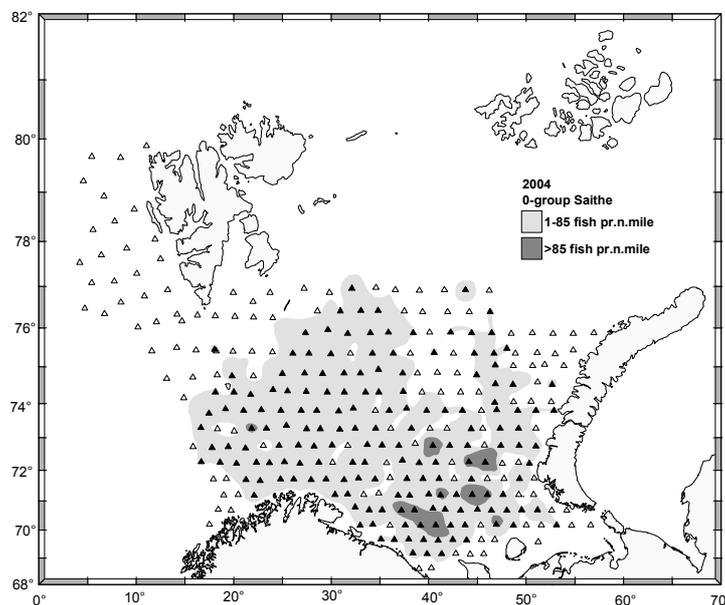

Figure 7.2. Distribution of 0-group saithe in the Barents Sea during August–September 2004.

7.3 Predicting fish recruitment

Predictions of the recruitment in fish stocks are essential for future harvesting. Traditionally prediction methods have not included effects of climate variability. In the following some results of multiple linear regression models are presented, where couplings between climate variables and fish stock variables have been used to model the recruitment of North East Arctic cod, Barents Sea capelin and the Norwegian spring spawning herring. The models are novel, and are still under evaluation in search for better fit (Stiansen *et al.,* 2002, Stiansen *et al.*, 2003a, Stiansen, 2003). However, the fit of the model are encouraging, and the models might at present prove useful as background information in stock assessment. In the 2003 capelin assessment the presented capelin model was incorporated into the 1.5-year projection.

Four models are presented.
- For the 0-group log index of North East Arctic cod, with two year prognoses
- For the number of recruits (3 year olds) of North East Arctic cod, with two year prognoses
- For the number of recruits (1 year olds) of Barents Sea capelin, with one year prognoses
- For the number of recruits (3 year olds) of Norwegian spring spawning herring with three year prognoses

0-group index of North East Arctic cod

A model of the log 0-group index (modified from Stiansen *et al.*, 2003b) based on the NAO index (North Atlantic Oscillation index) 2 years earlier explains ~50 % of the variation in the 0-group index in the period 1978-2004 (Fig. 7.3). For an autorative overview of the NAO and it's ecological effects see Hurrell *et al.* (2003).

The correlation between the 0-group log index and the NAO winter index 2 years earlier is high (0.82 for the period 1978-2004). This might be explained through food availability. Melle and Holst (2001) have found a high correlation between NAO and the zooplankton biomass in the Norwegian Sea the following year. This might imply that another year later food supply is still good for cod larvae on their drift along the Norwegian coast. The good recruitment of copepods may also use one year to advect into the Barents Sea, giving a two-year time lag. The condition of the spawning stock in the preceding year may also be an important factor.

The model is:

$$0group_t = 0.31 \times NAO_{t-2} + 0.92$$

where *0-group* is the log 0-group index and *NAO* the Lisboa-Iceland winter index. The subscripts denote the time lag in years.

The prognoses of the 0-group index show a small decrease for 2005 and 2006 to medium low levels (0.98 and 0.90 for 2005 and 2006, respectively, see also Tab. 7.1).
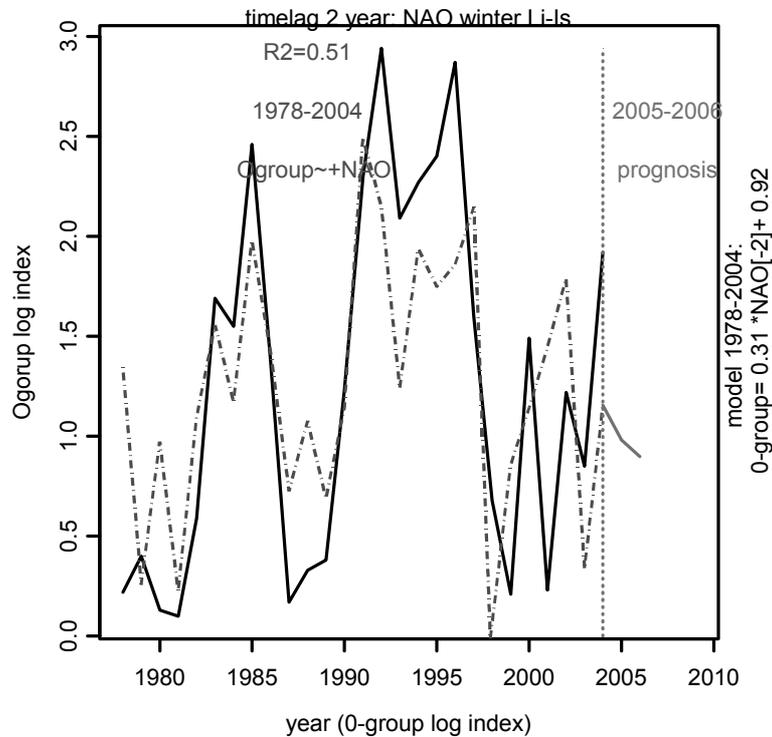
Figure 7.3. The figure shows the 0-group log index of North East Arctic cod (black) and the model fit (red), together with prognoses for 2004-2005 (green).

Recruits of North East Arctic cod

A model of the number of three year old recruits in 10^3 of North East Arctic cod (Stiansen *et al.*, 2003a) based on the Kola temperature, the number of 1 year old cods and the capelin maturing biomass explains ~77 % of the variation in the recruitment (fig. 7.4).

The model is:

$$\mathrm{Re}\,c3_t = 2.1 \times 10^8 \times Temp_{t-3} + 0.074 \times \mathrm{Re}\,c1_{t-2} + 8.1 \times 10^7 \times \log(Cap_{t-2}) - 1.5 \times 10^9$$

where *Rec3* is the number of 3 year olds from the AFWG assessment 2003 with cannibalism (ICES, 2004a), *Temp* the yearly average temperature between 0 and 200m in the Kola section three years earlier, *Rec1* is the age 1 index of NEA cod from the Norwegian bottom trawl survey in January/February 2 years earlier and *Cap* is the maturing biomass (tonnes) of capelin from survey estimate (October 1) of individuals larger than 14 cm 2 years earlier. The subscripts denote the time lag in years. Further details of the model can be found in Stiansen *et al*. (2003a).

The prognosis shows a stable medium high recruitment in 2005, followed by a decrease to a medium low level in 2006 (se also Tab. 7.1).

If the calculations of the model is performed after the winter survey, which gives the bottom trawl term, and the AFWG assessment meeting it is possible to extend the model by one year by using a prognosis estimate of the capelin maturing biomass (which for October 1 2005 is 272 000 tonnes). The result of this procedure is show in Table 7.1.

Exchanging the age1 term with age 2 or age3 from the same bottom trawl survey time series can make alternative models, which gives a one-year and 0-year prognosis, respectively. The results of these models are summarized in Table 7.1.

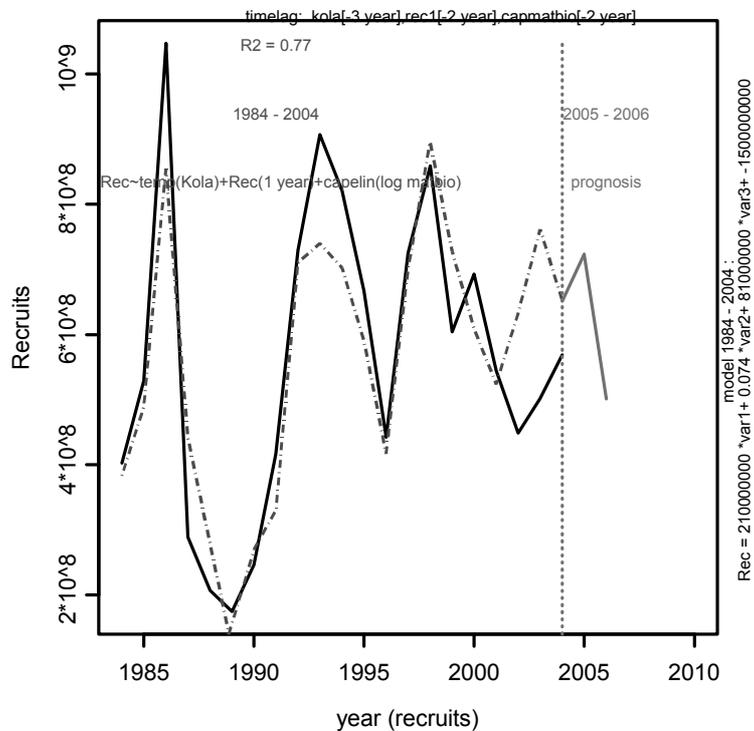North East Artic cod, 3 year old,vpa2004,can,1984-2004

Figure 7.4. The figure shows the number of recruits (three year olds) of North East Arctic cod (black) and the model fit (red), together with prognoses for 2005-2006 (green).

Recruits of Barents Sea capelin

A model of the one year old recruits of Barents Sea capelin (Stiansen, 2003) based on the surface (skin) temperature in the Barents Sea, the 0-group index and the maturing biomass explains ~ 66 % of the variation in the recruitment (Fig. 7.5). The model has been calculated for the years 1982-2004 (1981-2003 for the dependent variables), with prognoses for 2005.
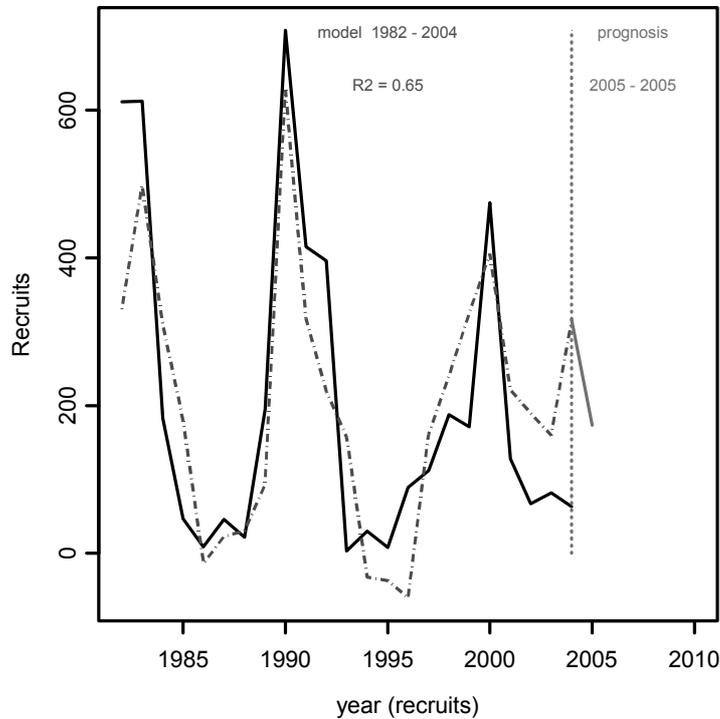
BS capelin

Figure 7.5. The figure shows the number of recruits (1 year olds) of Barents Sea Capelin (black) and the model fit (red), together with prognoses for 2005 (green).

The model is:

$$\mathrm{Re}\,c_t = -37 \times skin_{t-1} + 0.41 \times 0group_{t-1} + 0.11 \times matbio_{t-1} - 69$$

where *Rec* is the numbers of recruits in 10^9 (data is survey estimates back-calculated to 1 August), *skin* the skin temperature from the NCEP reanalysed database average from January to March and over the area between 30-45°E and 71-75°N one year earlier, 0-group the capelin 0-group index one year earlier and *matbio* the capelin maturing biomass (survey estimates October 1 of fish above 14 cm length) one year earlier. The subscripts denote the time lag in years.

The Model have R^2=0.66 and P-value < 0.01, with all individual P-values <0.06. The one-year time lag of the dependent variables gives opportunity of a prognosis one year ahead. Further details can be found in Stiansen (2003). Capelin data is taken from Anon. (2004).

The prognoses show a medium recruitment for 2005, with a value of $173*10^9$ individuals.

Norwegian spring spawning herring

A model for the number of three year old recruits of Norwegian spring spawning herring using the herring 0-group log index and the NCEP skin temperature describes ~80 % of the variation in the recruitment (Figure 7.6).
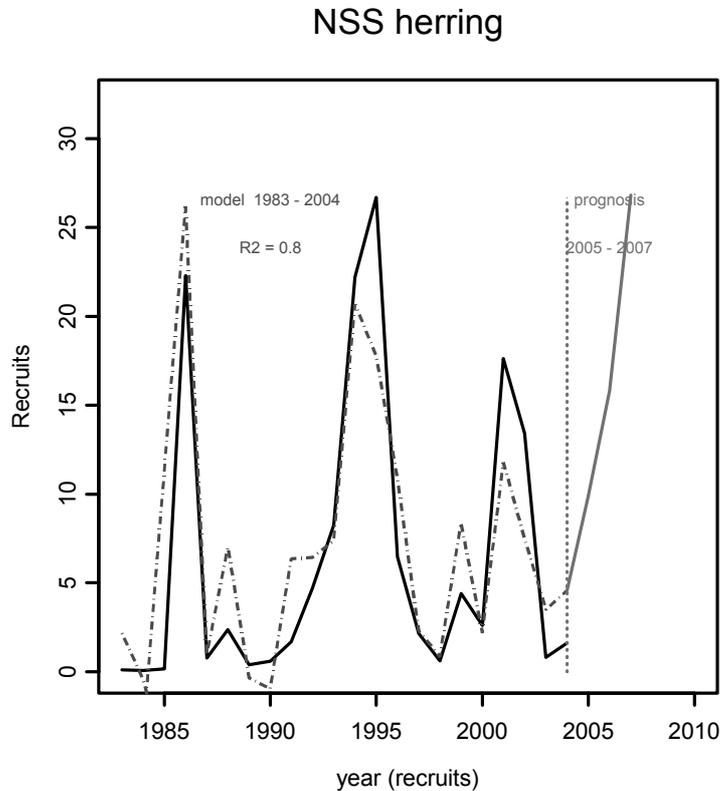

Figure 7.6. The figure shows the number of recruits (3 year olds) of Norwegian spring spawning herring (black) and the model fit (red), together with prognoses for 2005-2007 (green).

The model is:

$$\mathrm{Re}\,c_t = 8.3 \times skin_{t-3} + 16 \times 0group_{t-3} - 44$$

where *Rec* is the number (in 10^9) of 3 year old recruits of Norwegian spring spawning herring from the WGNPBW 2003 SEASTAR assessment (ICES, 2004b), *skin* the NCEP skin (sea surface) temperature in degree C in the Norwegian Sea (64 -70°N, 6°W – 8°E) averaged from January to March 3 years earlier and *0group* the 0-group log index of herring larvae from the survey in the autumn 3 years earlier. The subscripts denote the time lag in years. Further details can be found in Stiansen *et al.* (2002).

The dominant variable in the model is the 0-group index, which has a correlation coefficient of 0.84 with the Recruitment (3 years later). When the model was tested on the 0-group index alone

it gave an R^2 of 0.71. Still the model explained 9 % more of the variability when adding the skin temperature.

The prognosis shows a steady increase in recruitment for the period 2004 -2007, ending at a historic high level in 2007 (Tab. 7.1).

Table 7.1. Overview of the different models, with prognoses estimates of the variable in question. The given month indicate when the prognoses can be extended for another year.

Species	Variable	Prognoses year	Prognoses available	Prognosis 2005	Prognosis 2006	Prognosis 2007
North East Arctic cod	0-group, log (0 year olds)	2	November	0.98	0.90	X
North East Arctic cod	Recruits (3 year olds)	2	February	$723*10^6$	$501*10^6$	$644*10^{6\ \S}$
North East Arctic cod *	Recruits (3 year olds)	1	February	$461*10^6$	$495*10^{6\ \S}$	X
North East Arctic cod **	Recruits (3 year olds)	0	February	$627*10^{6\ \S}$	X	
Barents Sea capelin	Recruits (1 year olds)	1	November	$173*10^9$	X	X
Norwegian spring spawning herring	Recruits (3 year olds)	3	November	$9.9*10^9$	$15.8*10^9$	$26.8*10^9$

* Same model as above, but with age2 instead of age 1 in the bottom trawl term
** Same model as above, but with age3 instead of age 1 in the bottom trawl term
§ Based on prognosis estimate of capelin maturing biomass for October 1 2005 of 272 000 tonnes

8. Marine mammals

About 24 species of marine mammals regularly occur in the Barents Sea, comprising 7 pinnipeds, 12 large cetaceans and 5 small cetaceans (porpoises and dolphins). Some of these species have temperate mating and calving areas and feeding areas in the Barents Sea (e.g. minke whale *Balaenoptera acutorostrata*), others reside in the Barents Sea all year round (e.g. white-beaked dolphin *Lagenorhynchus albirostris* and harbour porpoise *Phocoena phocoena*). Some marine mammals are rare, either because this is natural (like beluga whale *Delphinapterus leucas*) or because of historic exploitation (like bowhead whale *Balaena mysticetus* and blue whale *Balaenoptera musculus*). Other marine mammals are abundant, and the currently available abundance estimates of the most abundant cetaceans in the north-east Atlantic (comprising the North, Norwegian, Greenland and Barents Seas) are: minke whales 107,205 (99% CI 83,000 - 138,400); fin whales *B. physalus* 5,400 (95% CI 3,600 – 8,100); humpback whales *Megaptera novaeangliae* 1,200 (95% CI 700 – 2,000) sperm whales *Physeter catodon* 4,300 (95% CI 2,900 – 6,400) (Skaug *et al.* 2002, Øien 2003, Skaug *et al.* 2004). *Lagenorhyncus* dolphins are the most numerous smaller cetacean, with an abundance of 130,000 individuals (Øien 1996), while harp seals are the most numerous seal in the Barents Sea with approximately 2.2 million seals.

Marine mammals are significant ecosystem components. Food consumption by cetaceans in the world's oceans has been estimated to 280-500 million tonnes of total biomass (both vertebrates and invertebrates), which is between 3 to 6 times the total catch by commercial marine fisheries. In the Barents Sea, marine mammals may eat 1.5 times the amount of fish caught by the fisheries. Minke whales and harp seals may consume 1.8 million and 3-5 million tonnes of of prey per year, respectively (e.g., crustaceans, capelin, herring, polar cod and gadoid fish; Folkow et al. 2000, Nilssen et al. 2000). Functional relationships between marine mammals and their prey seem closely related to fluctuations in the marine systems. Both minke whales and harp seals are suggested to switch between krill, capelin and herring depending on the availability of the different prey species (Lindstrøm et al. 1988; Haug *et al.* 1995, Nilssen et al. 2000).

Abundance and distribution of some marine mammals species in the Barents Sea are regularly monitored. Sighting surveys of pelagic cetaceans provide abundance estimates every 6 years, while harp and hooded seal abundances in the Greenland Sea is monitored every 5 years. With the exception of polar bears (3000 individuals, Norwegian Polar Institute 2005), no abundance estimates are available for the ice-associated marine mammals. Hence, there is little information available to evaluate year-to-year variation in abundance of marine mammals in the Barents Sea in relation to annual fluctuations in the Barents Sea ecosystem. Nevertheless, being long-lived animals with long generation times, annual fluctuations in the system are more likely to be reflected in the distribution of the marine mammals rather than the abundance.

To investigate marine mammal - prey interactions, and hence the role of marine mammals in the Barents Sea ecosystem, stomach content of minke whales and harp seals have been sampled and analysed for several years (Haug *et al.* 1995, Nilssen *et al.* 2000). A sampling programme on harp seal diet is still ongoing at IMR. Furthermore, in July from 2000 to 2002, marine mammal observers took part in annual IMR cruises along the Barents Sea shelf edge where also the distribution of 0-group fish, zooplankton, capelin and herring were recorded (Fig. 8.1). As predators tend to aggregate where their prey is abundant (e.g. Fauchald *et al.* 2002), we expect to identify marine mammal – prey interactions as positive spatial
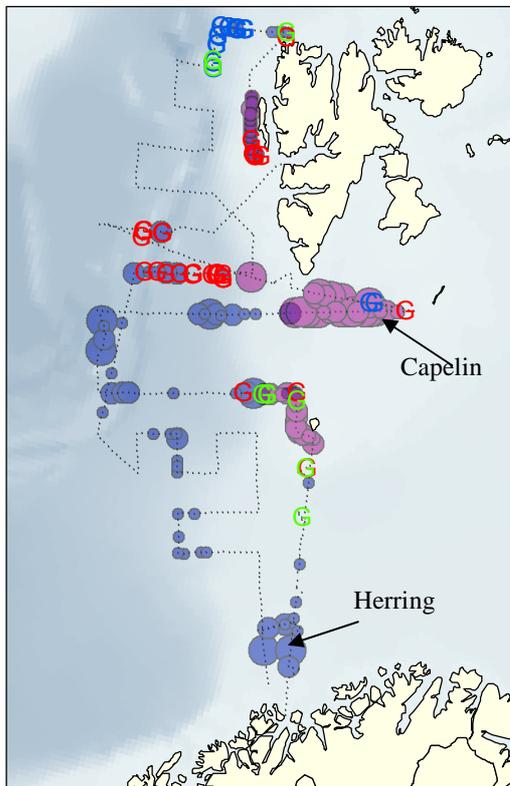
Figure 8.1. Distribution of minke whales, fin whales and Lagenorhynchus dolphins relative to capelin and herring distributions as observed in August 2001.

associations between marine mammals and their preferred prey. Along the shelf edge, minke and fin whales and *Lagenorhynchus* dolphins were significantly associated with capelin, and in addition minke whales were associated with herring and fin whales were associated with zooplankton (Mauritzen *et al*. in press). However, preliminary analyses suggest that prey selection of these species are habitat specific. For instance, while minke whales are associated with capelin in warmer Atlantic water masses, fin whales are associated with capelin along the polar front and *Lagenorhynchus* dolphins in colder waters mainly on the shelf (Mauritzen *et al*. unpublished results). Hence, habitat-specific prey selection may relieve interspecific competition for the most dominating and important prey species in the Barents Sea.

In 2003 and 2004 marine mammal observers were on board Johan Hjort during the August-October ecosystem cruises, covering the western Barents Sea during August- September (Fig. 8.2). Also during the ecosystem cruises distributions of important prey species are sampled simultaneously, so we will now start to investigate spatial associations between marine mammals and potential prey species in the central Barents Sea. From 2003 to 2004 some changes in distribution of marine mammals were evident. In 2003 the fin, humpback and minke whales were mainly observed in the northern part of the sampling area, in association with capelin and polar cod. In 2004 these species were also observed in the southern part of the sampling area, thus overlapping with capelin and polar cod in the north and herring and blue whiting in the south. Both herring and capelin were more abundant in 2003 than in 2004, while polar cod was more abundant in 2004 than in 2003. Hence, there are no obvious reasons for the southward displacement of the baleen whales. However, at present time the spatial associations between the marine mammal species and potential prey species have not yet been properly quantified and assessed. Also, effects of varying observer effort and weather conditions needs to be taken into account before any conclusions can be drawn as some baleen whale species are difficult to observe under windy conditions, and weather conditions may thus severely influence the observed distributions.
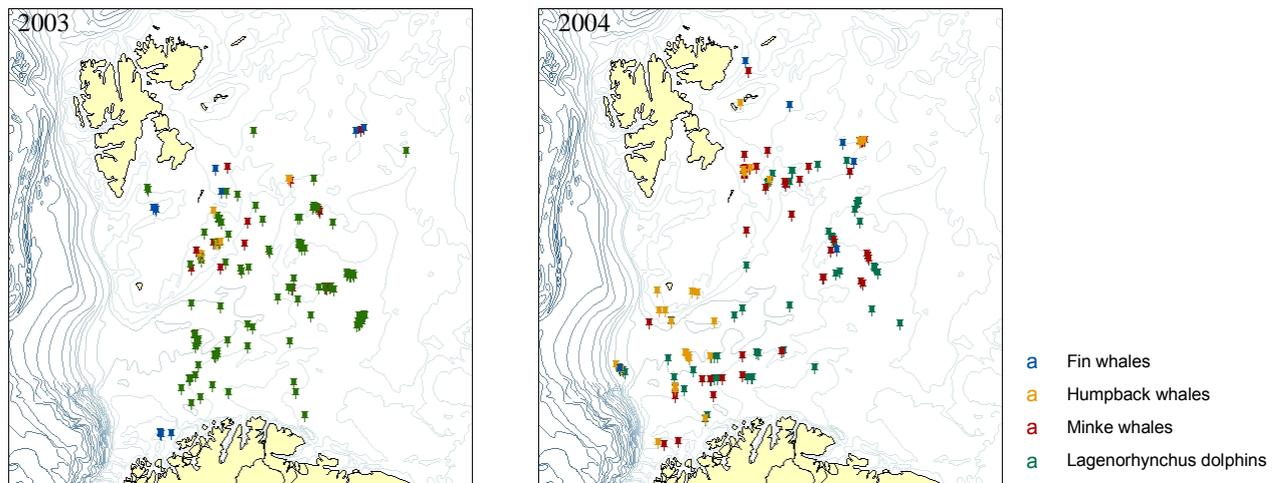
41

Figure 8.2. Distributions of fin, humpback and minke whales and Lagenorhynchus dolphins as observed during the ecosystem cruises in the Barents Sea in 2003 and 2004.

9. Bottom habitat and bottom fauna

Most of the area in the Barents Sea is covered by fine-grained sediment with coarser sediment prevailing on the relatively shallow shelf banks (<100m) or in the sub littoral zone around islands (Jørgensen and Hop, in prep.). Stones and boulders are only locally abundant. The most south-westerly parts of the Barents Sea are influenced by Atlantic fauna with the diverse warm-water fauna decreasing and cold-water species increasing to the east and north. In general, the fauna biomass, including the benthic, increases near the polar front and in the shallow regions and edges of the banks. A generally reduced biomass towards the west is likely due to reduced mixing of water and consequently a shortage of food. The richest infauna is found on the sandy silts and silty-sand floors. Low biomass occur at areas with impeded upwelling, in areas of low primary production (and reduced vertical flux), and areas of less suitable substrata with heavy sedimentation (e.g. inner parts of glacial fjords).

In the open parts of the Barents Sea, polychaets (bristle worms) are predominant at great depths and on soft sediment. Bivalves dominate lesser depths and harder bottoms. The main mass of echinoderms is found in western and central parts of the Sea, whereas the mass developments of bivalves are found in the southeastern parts of the Sea. The deeper western part of the Sea is rich in echinoderms and particularly poor in polychaets. The bivalves are considerably reduced with depth, whereas the echinoderms increase in numbers and the polychaets remain essentially unchanged.

Red king crab (*Paralithodes camtschatica*) was introduced to the Barents Sea, the Murmansk fiord, in the 1960s (Jørgensen and Hop, in prep.). The stock is growing and expanding eastwards but more dominantly along the Norwegian coast westwards. Adult red king crabs are opportunistic omnivores. Epibenthic species such as the commercial Iceland scallop *Chlamys islandica* beds might be particularly exposed to risk of local extinction. Decapods are known predators of benthic bivalves, including scallops. Both the red king crab and the scallop have a sub-Arctic distribution. The Iceland scallop has a life span of 30 years, and matures after 3-6 years.

Northern shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES, 2005). Consumption by cod significantly influences shrimp population dynamics. The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings. Shrimp is most abundant in central parts of the Barents Sea and close to Svalbard, mostly on 200 – 350 meter depths (Aschan, 2000). It is common close to the sea floor, preferably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts.

10. Impact of fishing activity on ecosystem

The most widespread gear used in the Barents Sea for demersal fish species is otter trawl. In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. However, its qualitative effects have been studied to some degree. The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. In sandy bottoms of high seas fishing grounds trawling disturbances have not produced large changes in the benthic assemblages, as these habitats may be resistant to trawling due to natural disturbances and large natural variability. Studies on impacts of shrimp trawling on clayey-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats (Løkkeborg, in press). The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti et al., *in press*.) Trawling seems to affect the benthic assemblage mainly through resuspension of surface sediment and through relocation of shallow burrowing infaunal species to the surface of the seafloor.

The harbour porpoise is common in the Barents Sea region south of the polar front. The species is most abundant in coastal waters. The harbour porpoise is subject to severe bycatches in gill net fisheries (Bjørge and Kovacs, in prep). In 2004 Norway initiated a monitoring program on bycatches of marine mammals in fisheries.
Several bird scaring devices has been tested for long-lining, and a simple one, the bird-scaring line (Løkkeborg 2003), not only reduces significantly bird bycatch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen, and where bird bycatch is a problem, the bird scaring line is used without any forced regulation.
Estimates on unreported catches on cod in 2002 - 2004 indicate that this is a considerable problem. Unreported catches are estimated at 90 000, 115 000 and 90 000 tonnes, respectively, each of these years, i.e. about 20% in addition to official catches (ICES, 2005).
Discarding of cod and haddock is thought to be significant in periods although discarding is illegal in Norway and Russia. Data on discarding is scarce.

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