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Spatial and temporal patterns in recruitment of shrimp *Pandalus borealis* in the Barents Sea

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The shrimp spawn in autumn and the eggs are carried as out roe by the females until spring when the larvae hatch. Within a period of 2-3 months the shrimp larvae settle to the bottom. Today's assessment and forecast of the shrimp stock productivity and potential fishing yields is weak. This is partly due to poor knowledge on population dynamics from hatching and till the shrimp are caught in the fishery at the age of three or four years in the. Since 1995 juvenile shrimp has been caught by a net attached to the underbelly of the survey trawl during the annual cruise in the Barents Sea. The abundance of settled shrimp larvae varies in time and space. The recruitment to the fishery has been quite stable with the exception of the 1996 year-class that was observed as 1+ but has not been registered since. We study the annual settlement and survivor of juveniles until recruiting to the fishery. The spatial and temporal distribution as well as density of the four youngest year-classes are studied in relation to temperature, depth, shrimp stock abundance and presence of predating cod in the Barents Sea.

Key words: Pandalus borealis, recruitment,

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INTRODUCTION

The shrimp *(Pandalus borealis)* is a protandric hermaphrodite changing sex from male to female at an age of 4 to 7 years in the Northeast Atlantic (Nilssen and Hopkins 1991). The shrimp spawn in autumn and the eggs are carried as out roe by the females (ovigerous females) until spring when the larvae hatch. Within a period of 2-3 months the shrimp larvae pass through seven developmental stages where after they settle to the bottom (Shumway *et al.* 1985).

It is of major importance for the shrimp stock assessment to get information on the strengths of the recruiting year classes as early as possible. Today's assessment forecast of the shrimp stock productivity and potential fishing yields is weak, partly due to the lack of knowledge on the population dynamics from hatching and till the shrimp are caught in the fishery. According to Shumway *et al.* (1985) the year class strength of shrimp is probably largely established during the pelagic larval stage. It is assumed that the transport processes influence on the recruitment both directly as advectional losses of larvae and indirectly through temperature, food availability and predator-prey interactions (Apollino *et al.* 1986, Lysy and Dvinia 199 1, Clarke *et al.* 1991 and Ouellet *et al.* 1995). We will here identify relevant recruitment indices and relate these to environmental factors. Annual variation will be related to temperature, ice coverage, the North Atlantic Oscillation (NAO), number of ovigerous females the'previous year, cod consumption, number of cod in predating age group and number of capelin. Spatial variation will be related to depth temperature and presence of cod.

MATERIAL AND METHODS

Study area

The Barents Sea is a shelf sea with an average depth of 230 m. The circulation is dominated by the Atlantic Current flowing northwards along the western shelf break (Fig. 1). A branch enters the Barents Sea through the Bear Island Trench. South of this Atlantic inflow, the Norwegian Coastal Current continues along the Finmark and Kola coast. In the northern and eastern parts of the Barents Sea, Arctic water flows southwestwards near the surface. The Atlantic inflow continues towards northeast below this layer. The Barents Sea has bank areas with associated anticyclonic circulation. The Atlantic inflow to the Barents Sea shows considerable inter annual variability (Adlandsvik and Loeng, 1991).

The major water masses are Atlantic Water with salinity over 35, and the colder and fresher Arctic Water. These water masses meet in the Polar Front. In the western part, south of the Svalbard Bank, the front is sharp and its position is locked to the topography. Towards east the front becomes less distinct and there are large inter annual variations in the position. During winter the Arctic Water is covered with ice, while most of the Barents Sea is ice-free during summer (Loeng 1991).

Abiotic factors

Temperature

Temperature observations from the Barents Sea have been interpolated to a regular grid on a quarterly basis into a temperature atlas at the Institute of Marine Research (IMR)(Ottersen and Adlandsvik, pers. comm.). The atlas contains data from 1970 to 1997. From this atlas temperature values along a section at 30" E from 71" N to 77" N has been extracted from 1991-1996. The average temperature from 200 m to bottom is presented in Fig. 2, with time along the X-axis and latitude along the Y-axis. In the south there are high temperatures in 1992 and 1995, while there are cold conditions in the north particularly in 1996. The mean temperature for the third quarter (July-September) for 73-77" N 1992-1996 is presented in Fig. 3.

Since there are no updated temperature data available from the northern most parts of the Barents Sea where shrimp are most abundant we used the Russian temperature series from the Kola section (Bochkov 1982) when running the correlation analysis. This series consist of monthly values for the upper 200 m along the Kola meridian (33'30' E) from 70°30'N to 72°30' N (Fig. 3).

Ice index

The ice index is an integrated value for the ice coverage in the Barents Sea during winter (Fig. 4a). The index was introduced by Loeng (1979), a definition of the index is given in (Adlandsvik and Loeng, 1991) and updated values can be found in the annual environmental report published by IMR (Aure *et al.* 2000).

North Atlantic Oscillation (NAO)

The NAO Winter index (December – March) for 1990-2000 from NCAR (Hurrell 1995) is shown in Fig. 4b and is used in the correlation analysis.

Recruitment measures

Shrimp surveys have been conducted by Norway in the Barents Sea every spring since 198 1. However, effort has been put in identifying a good recruitment index only in the 90s. In addition to the Campelen 1800 sampling trawl sampling techniques for sampling the smallest shrimp have been evaluated. In the period 1992-1995 a bucket (10 1) of the catch was sorted for small shrimp and then length measured. In 1994 the shrimp sledge was used as it samples more small individuals than the trawl (Larsen *et al.* 1993). Nevertheless, this sampling takes time and doubles the time used at each station. In 1995 a fine meshed (8 mm) nylon bag with a 1 m^2 opening was attached to the lower trawl belly one m in front of the junction to the cod end (Nielsen and Larsen 1989, Aschan and Sunnanå 1997). Figure 5 shows the length frequency distribution of the three sampling methods as well as the length frequency distribution in the cod end of the trawl.

The belly bag samples both 1, 2 and 3 year old shrimp well, it is objective and does not require additional sampling time and is therefore chosen as the main sampling tool for small shrimp. Indices for 2, 3 and 4 year old shrimp were also produced from the cod end sample.

The samples were weighted to the shrimp catch at each station and the sub-area size in a swept area calculation. Number of shrimp in each 1 mm interval was produced for the cod end for the years 1992-2000 and for the belly bag for the years 1995-2000. As the Hopen area (E) (Fig. 1) has the highest abundance of shrimp in the Barents Sea and as it also seem to be the most important area for newly settled larvae the recruitment indices were created separately for this area and for the whole Barents Sea. The shrimp are divided into age groups by using the length at age key from the Hopen area (Aschan in press) Table 1. The index for each age group was then estimated by dividing the number of shrimp with the mean number of the age group of the years available.

Table 1. The age groups are defined according to length at age in the Northern Barents Sea, Hopen area (E) (Aschan in press). Recruitment indices are established on the basis of carapace length (CL). Number of shrimp consumed by cod in each age group of shrimp are defined according to total shrimp length (TL) using the same length at age key and knowing that TL= 4* CL.

Age year	Recruitment CL (mm)	Cod consumption TL (cm)
1	<9	<4.0
2	9<cl<12	4.0-4.9
3	12<cl<15	5.0-5.9
4	15<cl<18	6.0-6.9

The difference in annual catchability or availability of young shrimp was studied by presenting the mean of the recruitment indices by year.

Biotic factors

Spawning stock

The spawning stock index is presented as the number of reproducing females (egg carrying females and females with hatched eggs) by using data from the spring cruise in 1990-2000. Details on sampling, length measurements and sex determination are found in Aschan and Sunnanå (1997). The length (L50) at which 50% of the shrimp are reproducing females is estimated as described by Skúladóttir (1990, 1998), and shrimp larger than this size in the swept area analysis are considered to belong to the spawning stock. One spawning stock number (SSN) index is presented for the Barents Sea and one for the Hopen area (E) since this is the area with the highest shrimp density.

Cod consumption

The number of cod of age one to four are taken from the Arctic Fisheries Working Group report (Anon 2000). The mean weigh and number of shrimp by cm total length, and age group of cod was taken from the Norwegian-Russian stomach data base for the years 1993-99. We then multiplied the mean number of shrimp eaten by each age group of cod with the number of cod in the same age group. The database on cod consumption provides data on number of shrimp consumed annually in each length interval (1 cm total length). The total length is considered to be 25% of the carapace length and thereby a rough separation in age groups is possible (see Table 1).

Recruitment of other species.

The capelin stock was included in the correlation analysis since there may be a relationship between the shrimp and the capelin directly by capelin feeding on shrimp juveniles or indirectly by both being prey for the cod. The number of l-3 year old capelin stock was included in the correlation analysis. Number of 1,2 and 3 year old capelin was received from the environmental report published by IMR (Aune et *al. 2000).*

Numerical analysis

Regression analysis were run to identify the best recruitment index. Correlation analysis using a Spearmann correlation matrix (implemented in the Statistics module of SYSTAT, Wilkinson 1988) were run when analysing the relation between the recruitment index and abiotic and biotic parameters.

Maps presenting the density of spawning females and shrimp of age 1 ,2 and 3 were produced in SAS (1993) to study the spatial distribution of female and young shrimp.

RESULTS

Recruitment measures

The recruitment indices given as a relative index for each year class show quite good correlation between age groups (Fig. 6). If the recruitment indices created at different age would be comparable indices they should lie at the same level for each year class. The reduction in the index from 2-4 year old individuals in the beginning of the 90s may be explained by cod predation but the increase in the recruitment index for a year class from one year to the next year is probably also caused by change in catchability from one year to another. The catchability oscillates around 1 but especially in 92 and 93 it is high (Fig. 7). The catchability is high for the belly bag index especially age groups two and three. The recruitment indices are not corrected for annual change in catchability in the further analysis.

Since the correlation between the index for 2 year old shrimp in the belly bag is well correlated with the index of 2 year olds in the cod end (Barents Sea R^2=0.60 and Hopen R^2=0.56) we considered the 2 year index in 1996 from the cod end to be good for further analysis. For one year old shrimp we used the belly bag index.

Biotic factors

The average L50s for the main sub areas and for the Barents Sea as a whole are presented in Fig 8. The values for the Hopen area and for the Barents Sea were used when calculating the number of females reproducing annually (Fig. 9). The density of spawning females may vary by a factor of ten. Especially in the years 1993-98 the spawning stock has been small.

Large cod consume more shrimp than small cod and this consumption is dominated by 6-l 1 cm long shrimp older than 4 years (Fig. 10). However, in 1997 a lot of small shrimp of age 1 and 2 were consumed by the 95 year class of cod.

The number of cod in the young age groups present in the Barents Sea (Fig. 11) determines the total number of shrimp consumed (Fig. 12). The prey preference of cod seem to be size dependent as one year old cod prefers 1 year old shrimp.

Correlation analysis

The recruitment index based on 1 year old individuals show a negative correlation to temperature, the North Atlantic Oscillation and to the ice index (Table 2, Fig. 13). It seems as if the colder conditions the better is the recruitment. The index also react on high cod consumption and number of one year old cod. The recruitment index based on 2 year old individuals show a negative correlation to number of 2 year old cod but a positive correlation to temperature, the North Atlantic Oscillation and to the ice index. This relationship gets eaven more obvious when observing the index of 3 year old shrimp.

Table 2. Values from the Spear-man correlation matrix for 1 year shrimp recruitment index from belly bag (EB 1), 2 year index (EC2) and 3 year index (EC3) from the cod end for the Hopen area against spawning stock number (SSN), temperature the year of recruitment (TEMP), ice index, NAO, cod consumption of 1 or 2 year old shrimp (CON), number of cod of age 1 or 2 (COD) and the number of capelin.

	SSN	TEMP	ICE	NAO	CON1	COD1	CAPELIN
EB1	0.30	-0.80	-0.90	-0.60	-1.00	-0.90	1.00

	SSN	TEMP	ICE	NAO	CON2	COD2	CAPELIN
EC2	0.18	0.29	0.03	0.55	0.07	-0.50	0.39

	SSN	TEMP	ICE	NAO	CON3	COD3	CAPELIN
EC3	-0.07	0.21	0.50	0.21	0.10	-0.80	-0.79

Spatial distribution of recruits

The distributions of spawning females correspond with the distribution of settled juvenile shrimp. Annual variation is recorded when observing the time series of 1994-2000. The density of spawning females in 1996 is lower in the northern Hopen area than in other years (Fig 14.). The distribution of 1 year shrimp follow the distribution of females and the distribution seem to be stable from year to year with the highest densities in the Hopen area. However, the young shrimp (l-3 years) seem to be orientated towards shallower depths. Two and three year old shrimp occur in the same area as 1 year olds have been observed the previous years. The density of one year old shrimp vary with years but especially in 1997 there are no high densities observed as the 1996 year class is weak.

DISCUSSION

As earlier stated by e.g. Nilssen et al. (1994) the mean temperatures of the Kola section are useful indices of temperature trends but when they integrate temperatures over depth and over latitude they may provide misleading depictions of temperature conditions for commercial communities. Simultaneously the Kola section is located south of the areas with high shrimp density. In further analysis on the effect of temperature on recruitment indices, colder temperatures representative for the northern Barents Sea and the bottom layers should be used (Fig. 2 and 3). Thereby the effect of polar water penetrating from the North would be better detected.

The recruitment indices are influenced by variable natural mortality rates and catchability (Hannah 1993). The decrease in the index of 89-91 year class (Fig. 6) may be explained by high cod predation in 93-94 (Fig. 11 and 12). The catchablilty (Fig. 7) needs to be studied further by studying a longer time series and by including all age groups available in the sample.

Environmental fluctuations rather then changes in abundance of spawning females are the primary cause of shrimp stock fluctuations (Hancock 1973 and Garcia 1983). Therefore approaches including an environmental factor e.g. natural variability, temperature or sea level height have been suggested and three dimensional interpretations have been proposed (Garcia 1983, Hannah 1999). This is supported by our study where ambient factors, temperature, ice, NAO and biotic factors, cod consumption and spawning stock all effect the indices (Table 2).

One year old shrimp show a negative response to temperature, little ice and to the index of the North Atlantic Oscillation. Zooplankton data (80% Calanus) sampled by PINRO, Russia (S. Drobisheva and V. Nesterova) simultaneously with the temperature data along the Kola section show a negative correlation to temperature and the two parameters oscillate in the opposite direction (pers. comm. Kurt Tande, University of Tromsø, Norway). Our data indicate that the recruitment of the one year old shrimp has the same kind of response to abiotic factors as zooplankton, probably due to the need of good food conditions in the larval phase in May-July (Rasmussen et *al.* 2000). The one year olds are also well correlated with the number of capelin (Table 2). In a study conducted by Nilssen and Hopkins (1992) the capelin was considered "boreo-Arctic" as it was positively correlated with low temperature. The shrimp younger than one year seem to thrive in conditions also optimal for Calanus and Capelin.

The two year old shrimp show a positive response to abiotic factors and this response seem to be even better for 3 year olds (Table 2). This relationship is common when studying fish recruitment in the Barents Sea. Abundance estimates of O-group cod exhibit a close relationship with sea temperature variability at the Kola meridian section (Nilssen et *al.* 1994). A covariability in early growth and year class strength of cod, haddock and herring is explained by their common positive response to temperature (Ottersen and Loeng 2000).This study indicate that shrimp when passing the age of one show the same positive response to temperature as cod, haddock and herring.

The correlation between the recruitment index of two year olds (EC2) and the spawning stock number would have been higher if the outlier of 1993, with a very high spawning stock and a high cod consumption resulting in a low index, would have been excluded (Figure 13). The spawning stock size seem to have some effect on the number of one year olds but this correlation is not detectable in two and three year olds probably because the effect of cod predation and other factors governs the further development of the year classes. Therefore we suggest that the recruitment index measured as three year olds is used as input in future assessment models.

The low density of the 1996 year class shrimp in 1997 (Fig.6 an 14) may be explained by female shrimp having a southward distribution as a result of cold Arctic water dwelling inn from the north (Fig. 2). The number of spawning females was low in 1996 when comparing with earlier years (Fig. 9). Shrimp larvae are able to move along temperature gradients (Rasmussen et *al.* 2000). When the cold conditions continued throughout the spring and the summer the shrimp larvae were probably moving southwards and became thereby easy prey for the 1995 year class of cod (Fig. 10,11 and 12). The absence of the 1996 year class in the fishery as 4 year olds in year 2000 is thereby caused by several co-occurring factors, the low number and the distribution of the spawning females in 1996, temperature conditions and cod consumption.

The consumption of cod is a significant biotic factor influencing on the recruitment indices of all shrimp age groups. In further work when modelling the recruitment, the number of cod feeding on shrimp should be included in addition to abiotic factors (temperature, ice and NAO) as well as number of spawning females.

CONCLUSIONS

- The best index for one and two year olds is received from the belly bag that has been used since 1994. However, a longer time series is needed before an evaluation of the catchability and availability of shrimp juveniles can be done.
- The index of three year old shrimp from the cod end is a good measure and should be used as the recruitment index in future assessment work.
- The number of spawning females vary with a factor of ten between years. A low number of female shrimp does not alone cause low recruitment and a weak year class, as abiotic factors (temperature, ice and NAO) and cod consumption will influence on the young shrimp.
  The juvenile shrimp seem to thrive under conditions also optimal for Calanus and Capelin, but when passing the age of one they show the same positive response to temperature as cod, haddock and herring.
- When modelling the recruitment the number of cod feeding on shrimp should be included in addition to spawning stock number and abiotic factors such as temperature, ice and NAO.

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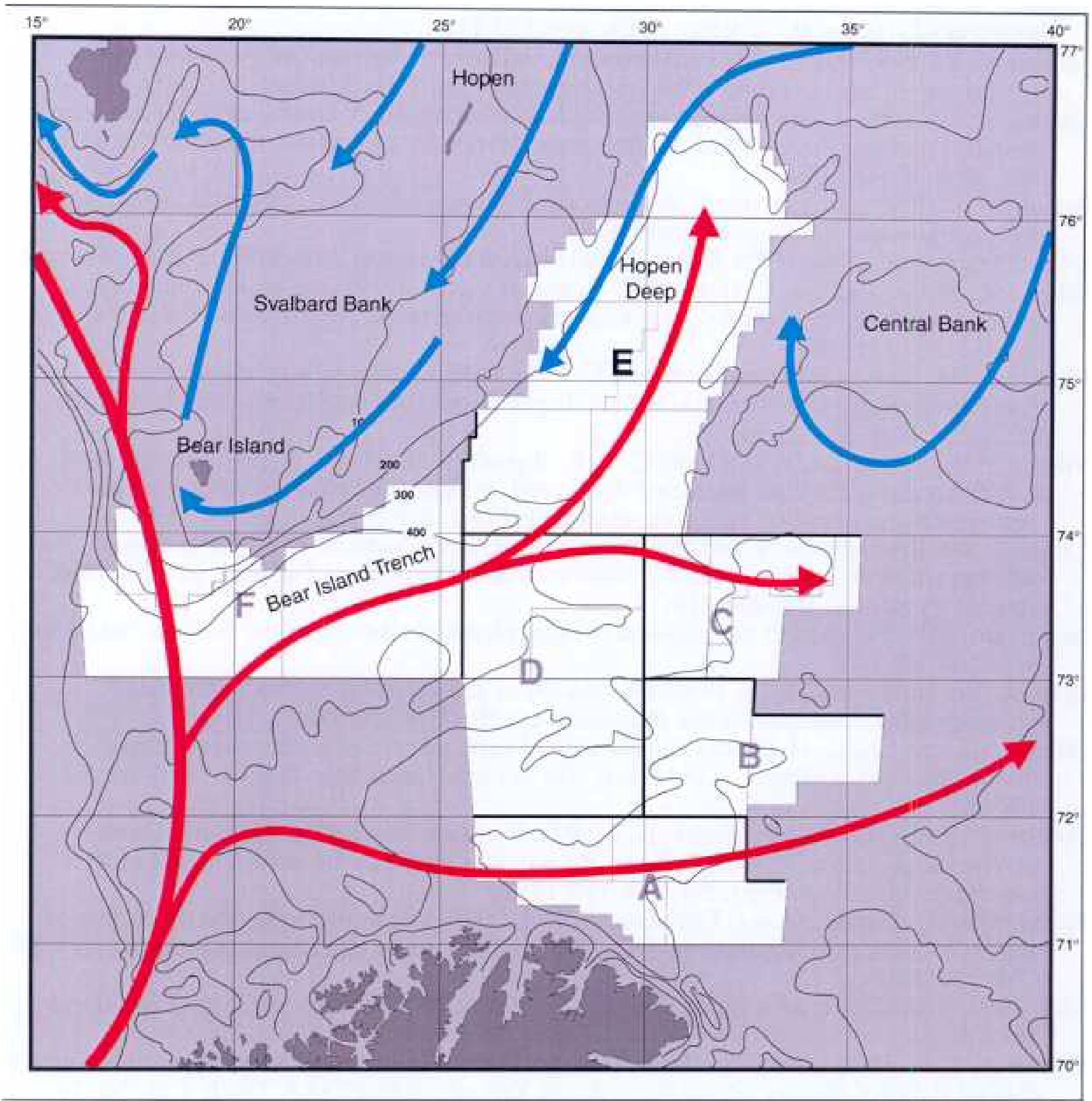

Fig. 1. A schematic description of the circulation of the Barents Sea. Arrows show the current of Atlantic water (red) and Arctic water (blue) (after Aure *et al. 2000*). Main survey areas are East Finnmark (A), Tiddly Bank (B), Thor Iversen Bank (C), Bear Island Trench (D), Hopen (E) and Bear Island (F).

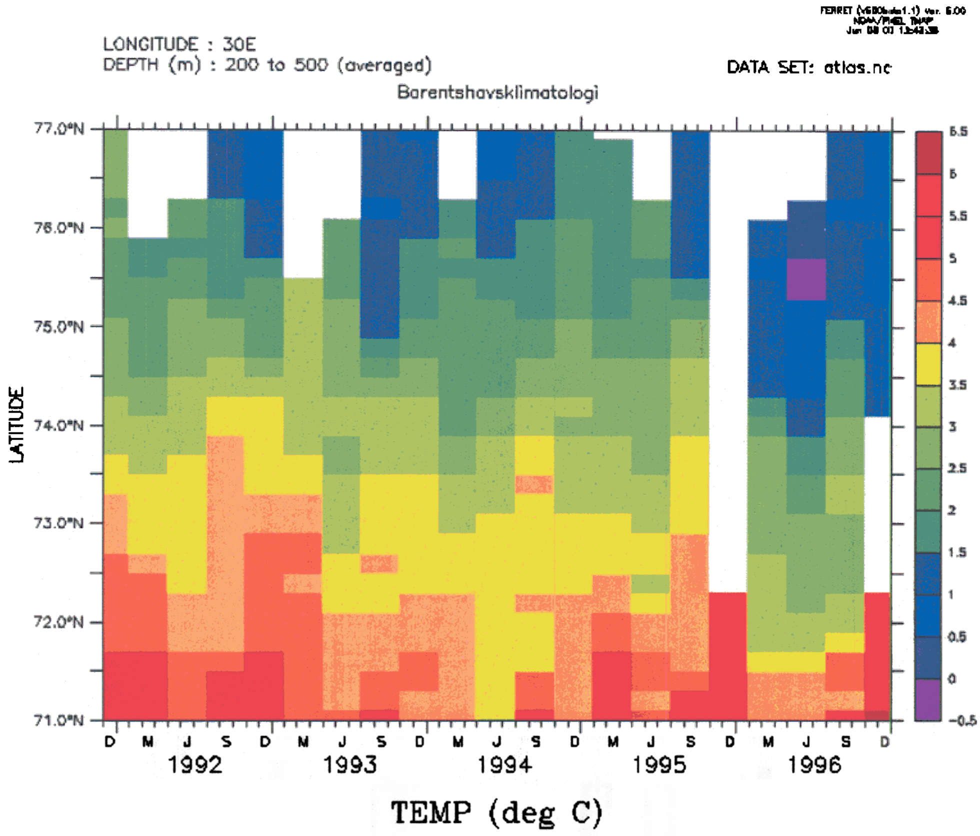

Figure 2. Quarterly values from 1992 to 1996 of sea temperature along a section at 30°E from 71°N to 77°N. The temperature is averaged from 200 m depth to the bottom. White fields indicate missing data.

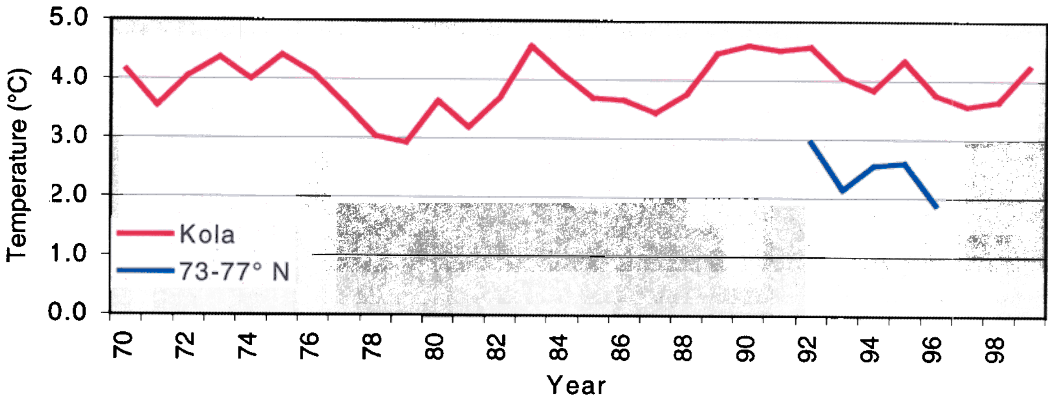

Figure 3. Annual mean of the temperature in the Kola section (1970-99) with the mean temperature from 73-77°N at 30° E, <200m, in the third quarter in 1992-1996.

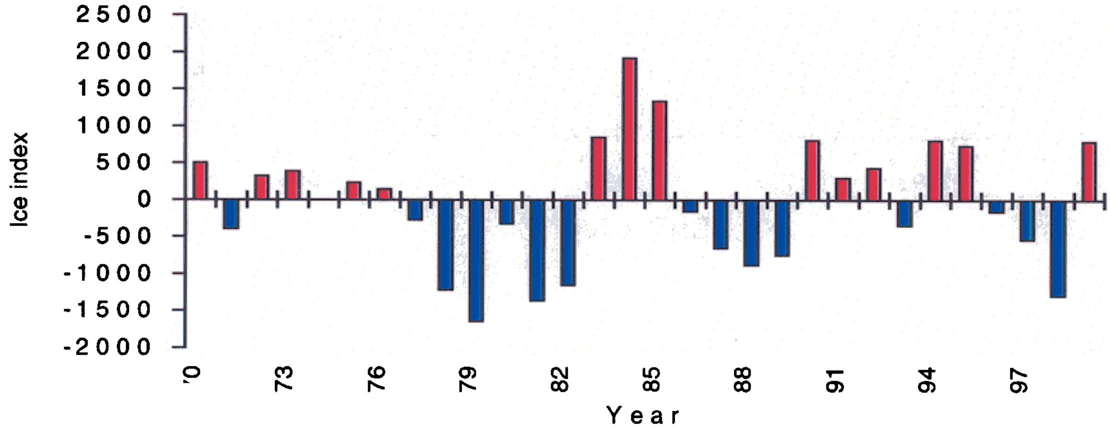

Figure 4a. Ice index (1970-99). Positive values indicate little ice. From (Aune *et al.* 2000).

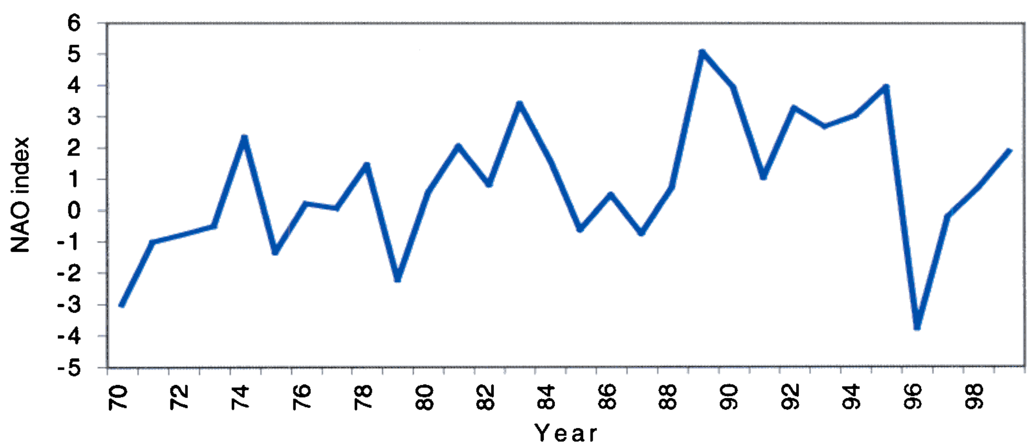

Figure 4b. Index for the North Atlantic oscillation (Hurrell 1995) in (1970-99).

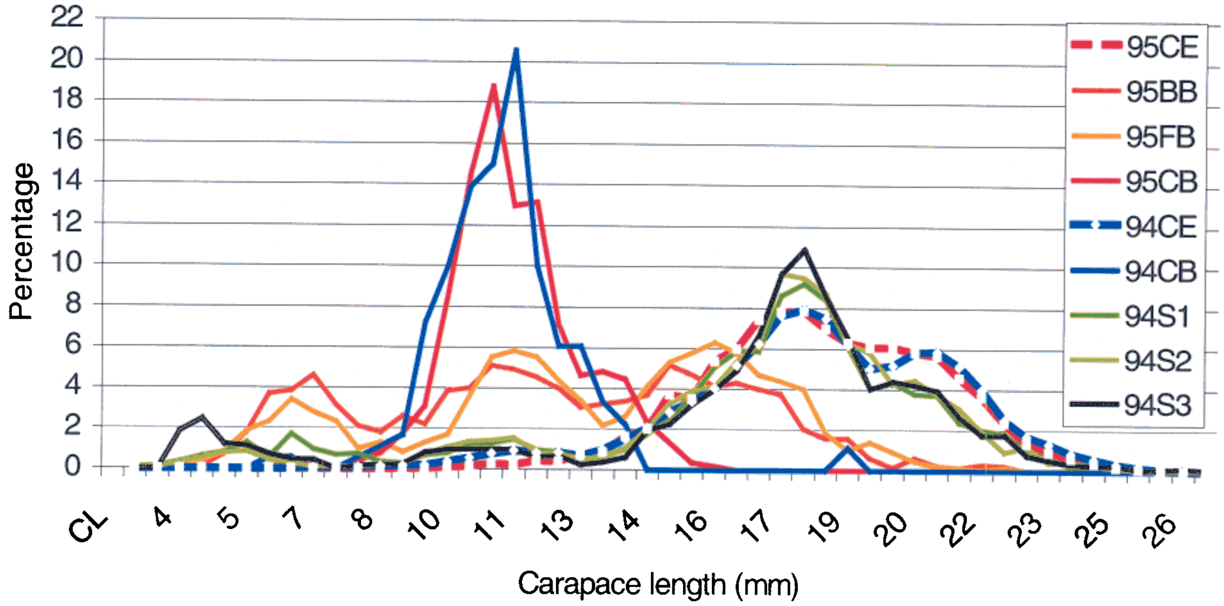

Figure 5. The length frequency distribution (0.5 mm) of shrimp in the cod end (CE), in the belly bag 1m from junction to cod end (BB), 5 m from the junction (FB), small individuals picked out of a bucket (CB) and samples caught by the shrimp sledge (S1,S2 and S3). The figures accumulate all samples taken during the shrimp cruise in the Barents Sea in 1994 and 1995.

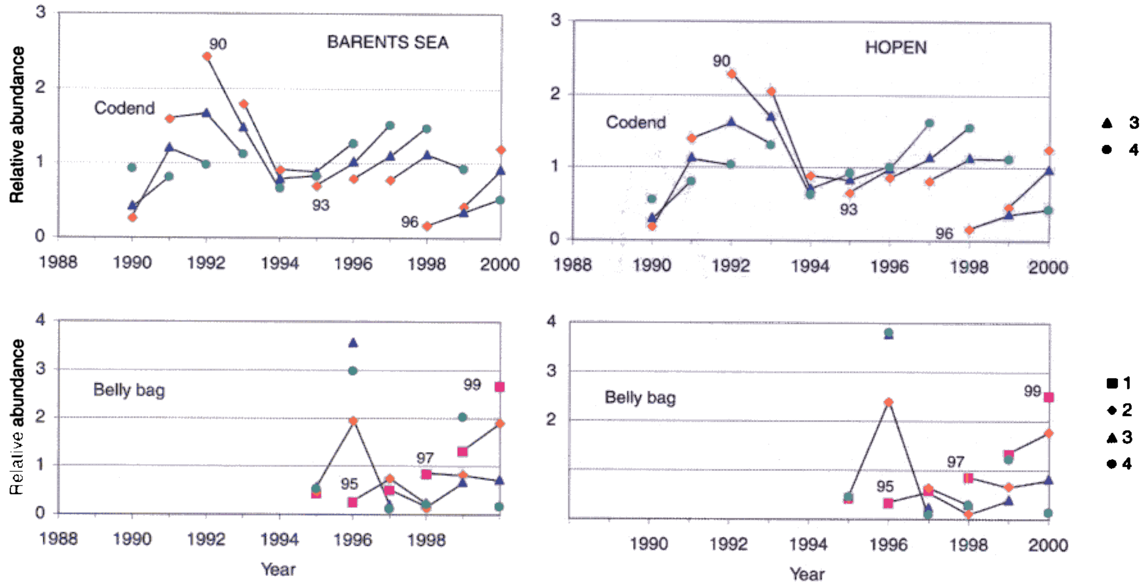

Figure 6. Recruitment indices for each age class as 2,3 and 4 year old shrimp sampled in the cod end. Recruitment indices for each age class as 1,2,3 and 4 year old shrimp sampled in the belly bag. The indices for the whole Barents Sea area are presented to the left while indices for the Hopen area are presented to the right.

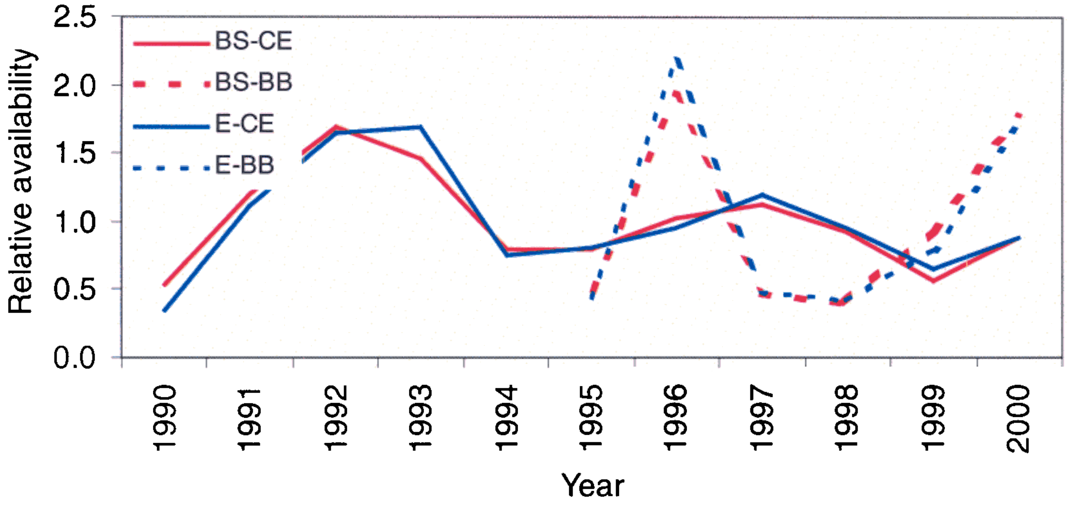

Figure 7. The relative annual catchability of 2- 4 year shrimp in the cod end (CE) and 1-3 year old shrimp in the belly bag (BB) for the Barents Sea (BS) and the Hopen area (E).

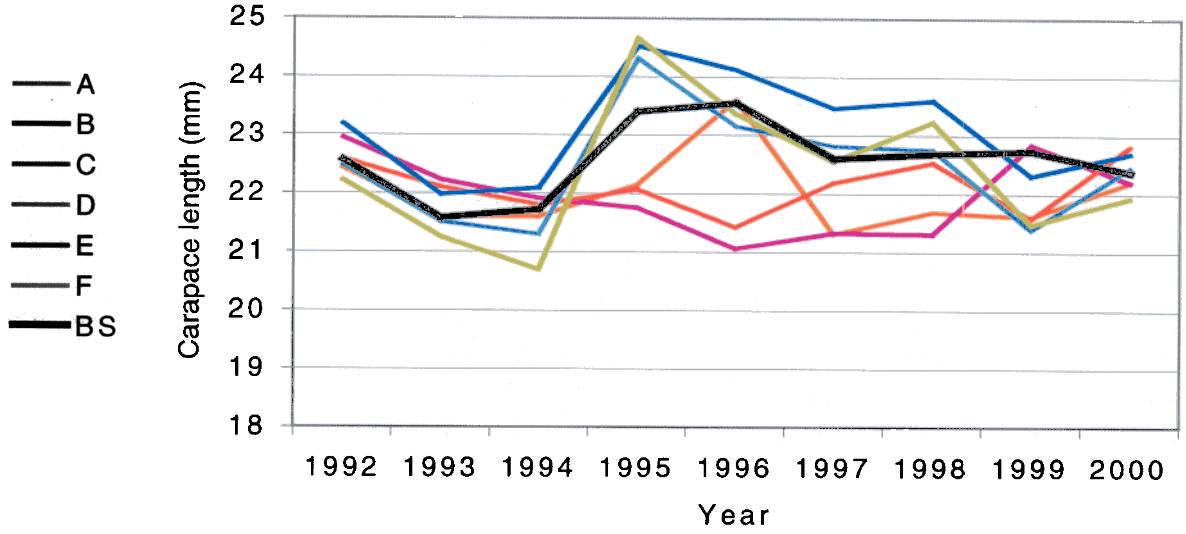

Figure 8. Length at which 50% of the shrimp are reproducing females by year in East Finnmark (A), Tiddly Bank (B), Thor Iversen Bank (C), Bear Island Trench (D), Hopen (**E**), Bear Island (F) and the Barents Sea (**BS**).

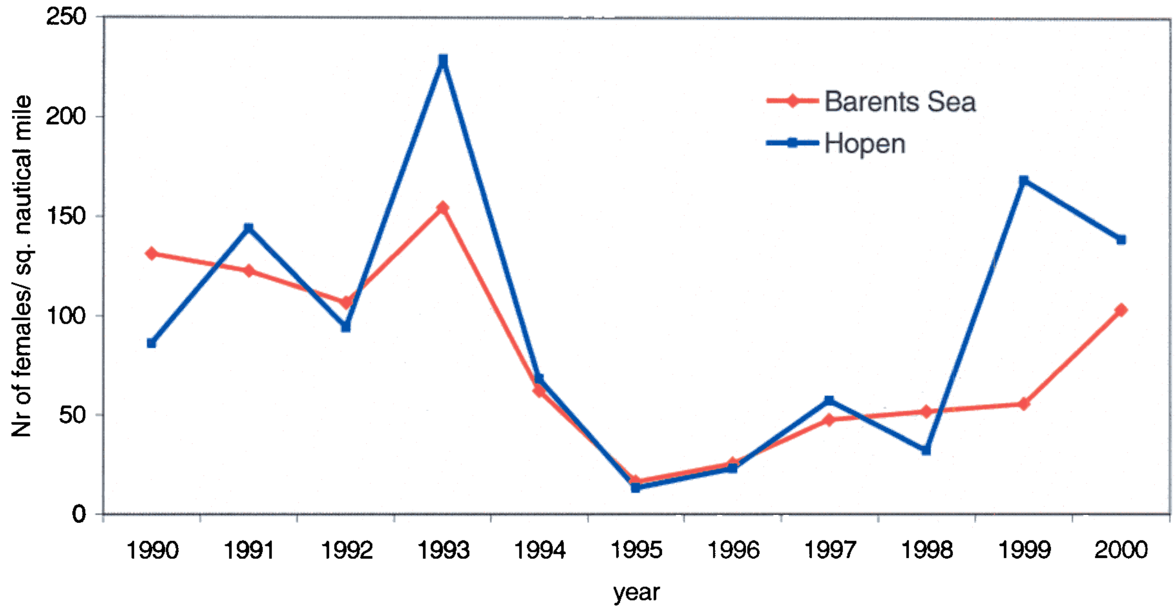

Figure 9. Number of reproducing female shrimp per square nautical mile in the Barents Sea and in the Hopen area.

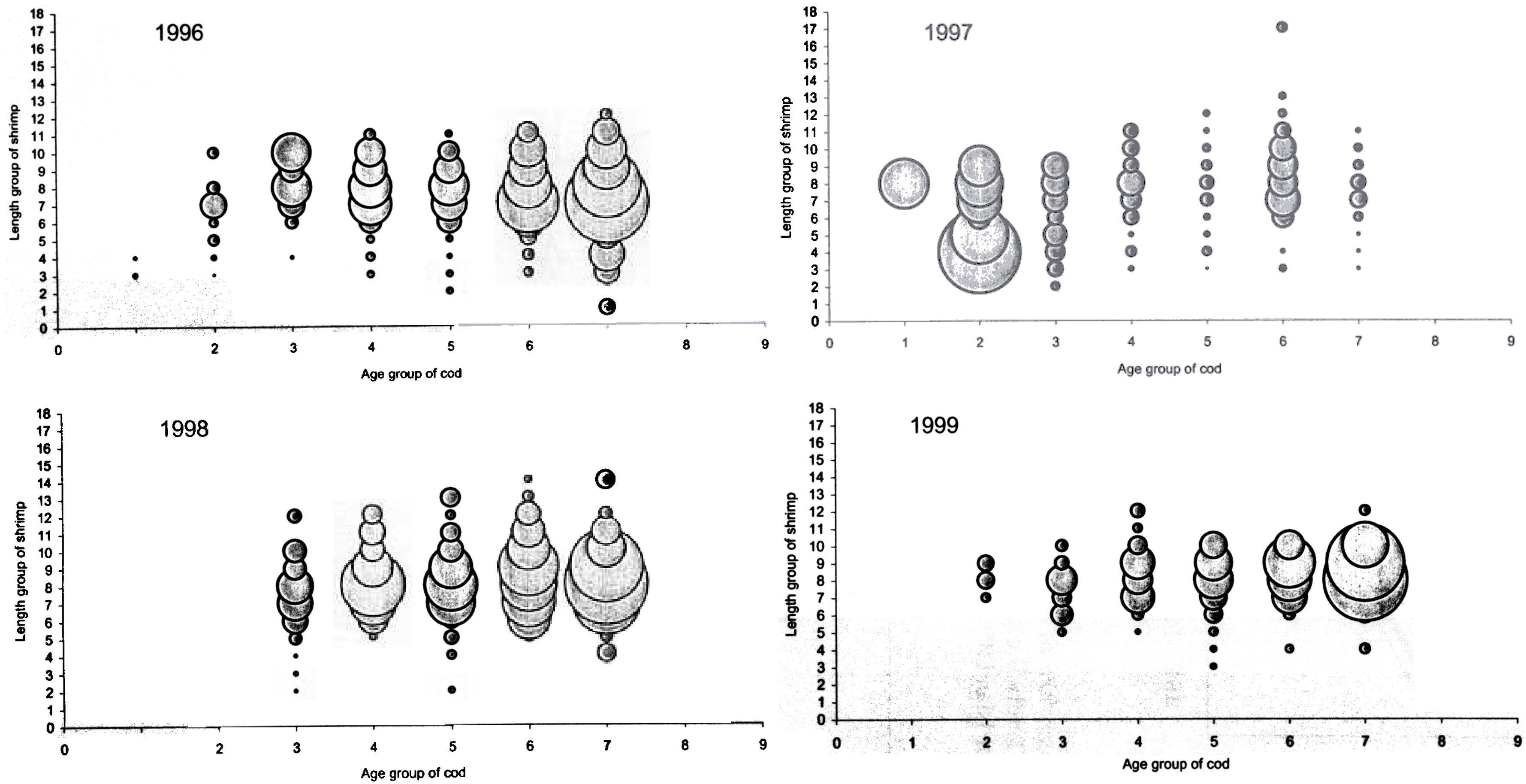

Figure 10. Mean weight of shrimp by length group (total length cm) in cod by age group for the years 1996-99.

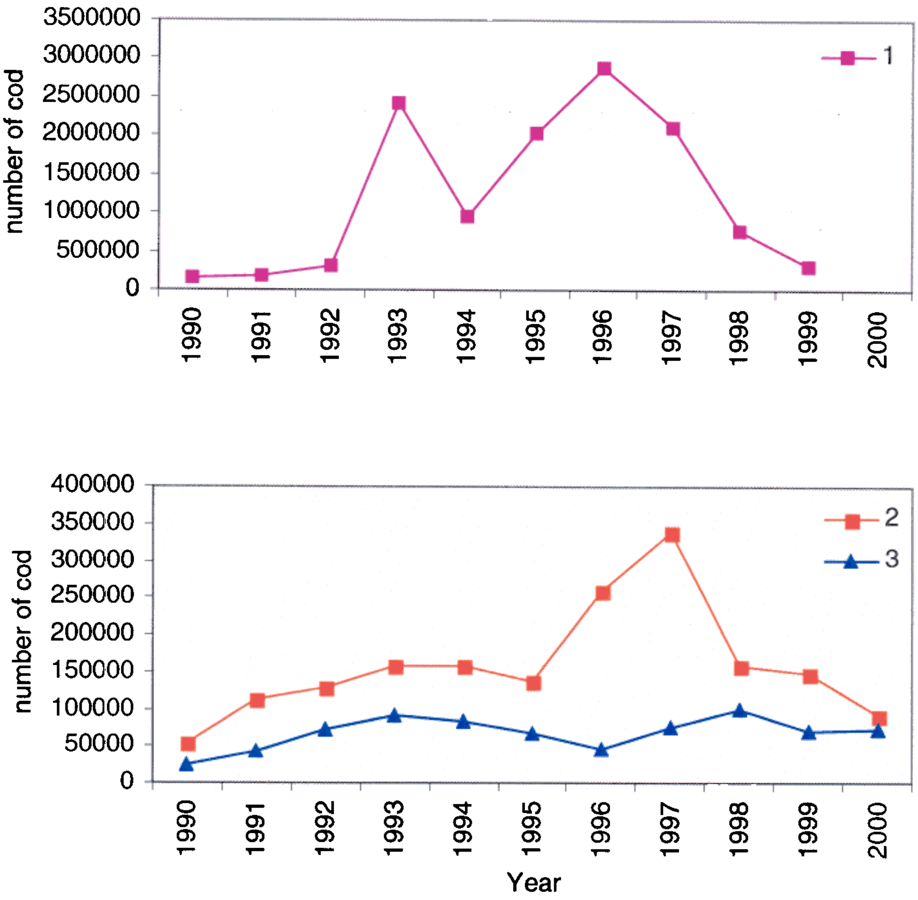

Figure 11. Number of cod of age group 1, 2 and 3. (ICES 2000).

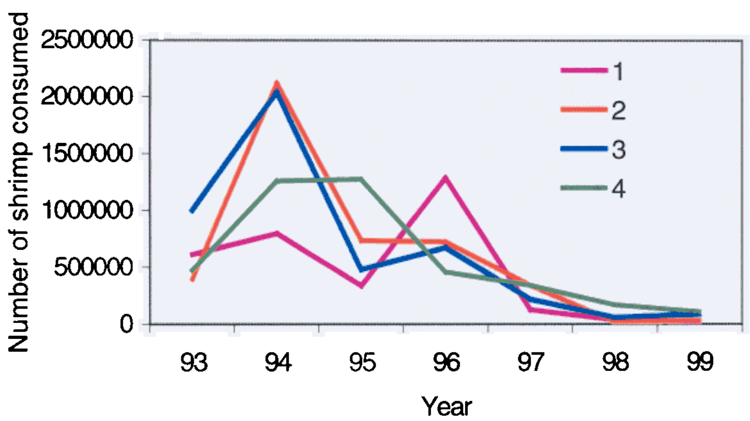

Figure 12. Number of 1- 4 year old shrimp consumed by cod.

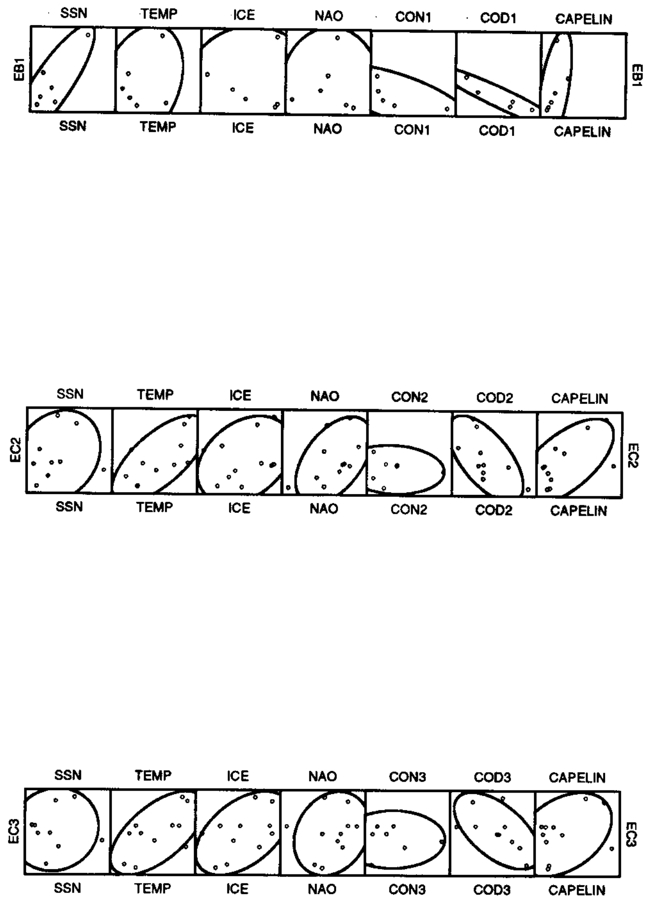

Figure 13. Plots illustrating the relationship between recruitment indices (one year olds in belly bag EB1, two year olds EC2 and three year olds EC3 in cod end) against abiotic factors (spawning stock number (SSN), temperature, ice and the North Atlantic Oscillation (NAO)),and number of shrimp in age group consumed by cod (CON), number of cod in age group (COD) and number of capelin.

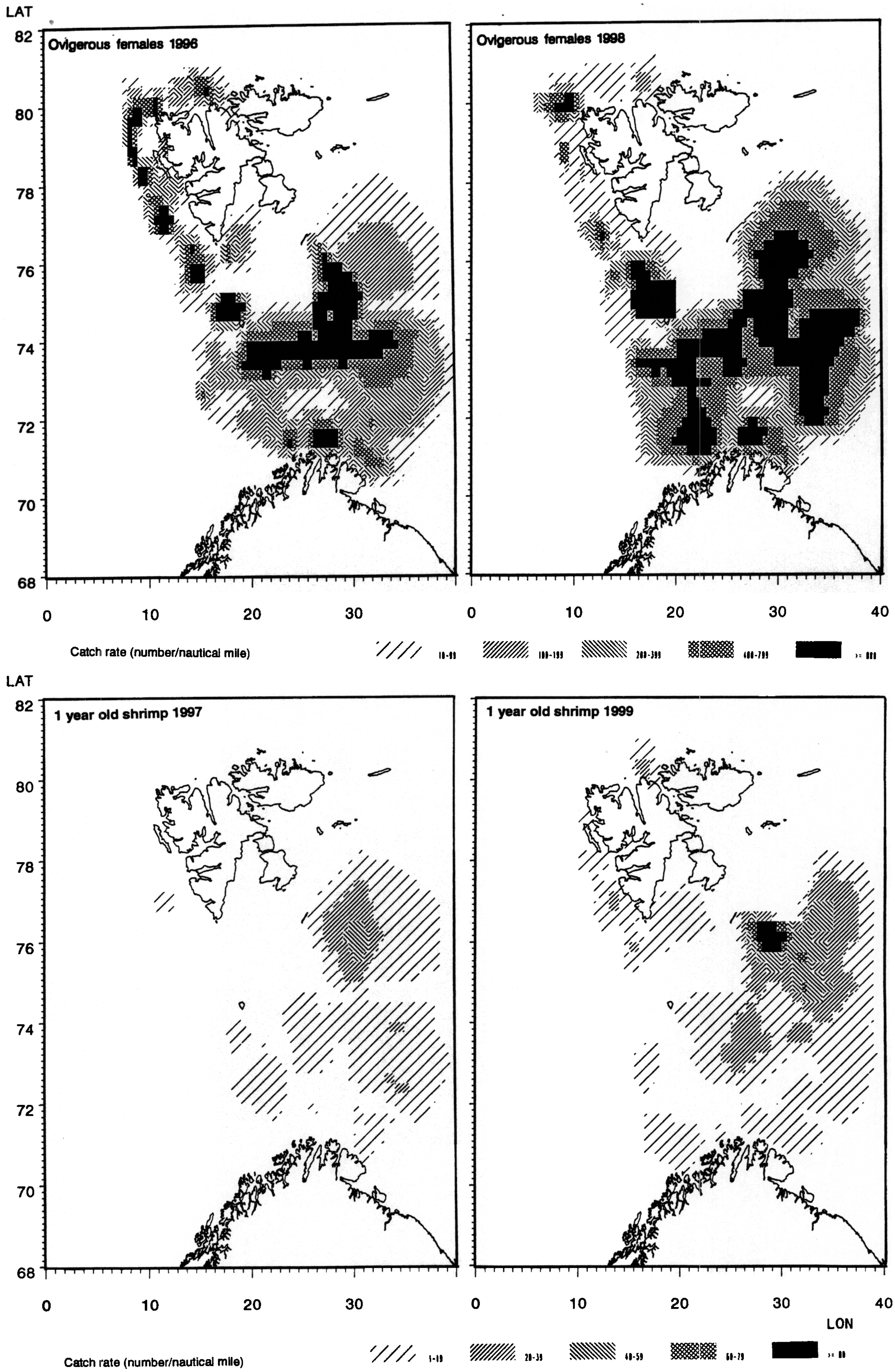

Figure 14. Density of spawning females in 1996 and 1998 and 1 year old shrimp registered the next year (1997 and 1999)