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Results of the Greenland Bottom Trawl Survey for Northern Shrimp (*Pandalus borealis*) off West Greenland (NAFO Subarea 1 and Division 0A), 1988-2004

by

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Abstract

Stratified-random bottom trawl surveys have been carried out since 1988 in NAFO Subarea 1 and a small part of NAFO Division 0A as a contribution to the assessment of the stock of northern shrimp (*Pandalus borealis*) off West Greenland.

Survey estimates of total biomass of northern shrimp off West Greenland showed little variation over the initial ten-year period, but after a comparatively low estimate of about 200 000 tons in 1997 the biomass increased to approximately 655 000 tons in 2003 and remained at this level in 2004. During the period of increase the biomass changed mainly offshore in depths between 200 and 300 m and inshore in the Disko Bay/Vaigat area. Mean bottom temperature in the survey area increased in the mid-1990s and the relative warm period continued in 2004. Indices of both the size of the spawning stock and the fishable biomass are well above average. The length distribution in 2004 indicates that progression of males to the female group is secured for the next year, but the comparable low abundance of males below 15 mm carapace length recorded in 2003 and 2004 may suggest a decrease of the fishable biomass during the coming one or two years.

Introduction

Since 1988, the Greenland Institute of Natural Resources has conducted annual stratified-random trawl surveys off West Greenland between July and September to assess the *Pandalus borealis* stock biomass and to obtain information on the size composition of the stock as well as on the environmental conditions. This document presents the results of the 2004 survey, and compares them with previous results from the survey time series.

Material and Methods

Survey design and area coverage

The offshore survey area for northern shrimp covers the depth interval of 150-600 m in NAFO Subarea 1 and a small part in the east of NAFO Div. 0A. Since 1991 the survey has also included the inshore areas Disko Bay and Vaigat in NAFO Div. 1A.

The survey strata correspond to geographical areas, which are based on the distribution of the commercial fishery according to logbook information (Carlsson *et al*., 2000). The geographical areas are sub-stratified applying four depth zones: 150-200 m, 200-300 m, 300-400 m, and 400-600 m. Using information obtained from data loggings by the survey vessel recorded in the years since 2000 new depth contours were constructed for the offshore area as well as for the Disko Bay / Vaigat region and revised stratification schemes were introduced in 2004 (Wieland and Kanneworff, 2004). Major changes compared to the previous year affected region U, in which geographical borders were changed, and the former areas D1 to D9 (Disko Bay/Vaigat), which has been divided into two areas (I1 and I2) each sub-stratified by depth. In addition, the former two areas C1 and C3 in the Canadian EEZ (NAFO Subarea 0) were combined into one (C0). The new stratification scheme is illustrated in Figure 1. The total survey area increased from 124 994 km² in 1995-2002 to 132 868 km² in 2003 and to 136 812 km² in 2004.

From 1988 through 1999 trawl stations were allocated to strata in proportion to stratum area, but since 2000 allocation has been weighted towards strata with historically high densities of northern shrimp and where high variances are observed, in order to improve the precision of the biomass estimates. An exponential smoothing technique for the weighting was applied to give higher influence of the more recent observations to the weight factors (Kingsley, 2001a).

In 1999 a new method of choosing stations for the survey was introduced. This method combines the use of a minimum between-station-distance rule (a buffer zone) with a random allocation scheme (Kingsley *et al*., 2004).

From 1988 through 1998 stations have been selected at random by re-placing sampling sites for each year. To study the stability of the stock distribution and assess the performance of a fixed-station design relative to that of re-sampling (Kingsley, 2001a) about 50 % of the stations, which were randomly selected from the set of stations covered in the preceding year, were repeated as fixed stations in the following year in since 1999. The remaining stations were re-selected applying the above-mentioned buffer zone method and treating the fixed stations as already chosen. The introduction of fixing station positions from one year to the next has not explicitly been taken into account in the analysis, i.e. data from the fixed and the re-placed stations have been used without distinction and the analysis is therefore similar to those carried out in the years in which all stations were randomly selected.

As observed densities of northern shrimp in the region north of 69°30'N consistently have been low and because of severe difficulties in finding suitable bottom for trawling, a fixed-station sampling design in this area has been used since 1998. To cover all nine strata with a minimum of two stations in each, 20 possible trawl tracks were chosen. From these between 10 and 18 were realized annually in the years 1999 to 2002. In 2003 and 2004, after having obtained better bathymetric information, the same procedure for stratification and selection of stations as in the other offshore areas has been introduced.

In addition to the stations located in the survey strata designed primarily for the sampling of northern shrimp, trawling was conducted at depths <150 m in NAFO Div. 1A-1F. Furthermore, CTD casts were made along standard hydrographic transects in the offshore and the Disko Bay/Vaigat area. Both, the results of fish catches and the observations from the hydrographic transects will be reported as in the previous years elsewhere, i.e. at the NAFO Scientific Council meeting in June 2005.

Survey period

The trawl surveys have always been carried out at the same period of the year (July-September) with the ambition to minimize the effect of seasonal variation. In order to reduce the possible influence of light induced nocturnal vertical migrations of shrimp, trawling was carried out only between 0900 and 1900 UTC.

Similar to earlier years, the survey in 2004 was divided in different subsequent legs, 29.6.-11.7., 13.7.-22.7., 24.7.-12.8., and 14.8.-30.8.2004, respectively. During the first leg, a trawl calibration experiment was carried out in order to allow a future substitution of the survey trawl with a more efficient one, which is less sensitive to difficult bottom conditions, in the next year. The experiment followed the approach outlined by Lewy *et al.* (2004) and comprised about 90 tows. The actual survey trawl was set at 16 standard stations using the standard procedure, and these tows were included in the present analysis whereas the results of the calibration experiment will be presented elsewhere.

Tow duration

Tow duration at stations used for the estimation of northern shrimp biomass has been changed through the years from 60 min in the years 1988 to 1997, and then stepwise shortened to a mixture of 30 and 15 min tows randomly distributed in the strata in the proportion 2:1 in the years 2001 to 2003. These reductions were made in order to optimise the sampling schedule (Carlsson *et al*., 2000). In 2004, equal proportions of 30 and 15 minutes tows were applied in order to maintain a similar number of stations as in the previous years despite a shortage of time available for the routine sampling during the first leg of the survey.

Results reported by Kingsley *et al*. (2002) have so far indicated that 15 min tows do not give more variable results than 30 min tows and hence no weighting was applied to tows of different durations. On the other hand, analyses of survey data from 1999 and 2000 have shown that the effective swept area is somewhat larger than estimated corresponding to 2.78 min per trawling operation (Kingsley *et al*., 2002). This value, which is equal to 9% of a 30 min tow but corresponds to 18% of a 15 min tow, was estimated with a high variance (s.e.: 1.16 min) and could not be confirmed in a later study using a different methodological approach (Kingsley, 2001). It is assumed that difficulties in determining the precise time of beginning of the tow are the major cause for a considerable variability of this ‘end-error’. The start point of a tow is estimated by information from a trawl sonde ('trawl eye') encompassing the distance between the headline and the ground gear from the bottom. Because it takes some time for the trawl to 'land' completely on the bottom, the time of the beginning of a tow has been defined by the presence of a stable distance of the headline to the bottom. Judging when this occurs is difficult and to a certain degree subjective, in particular on rough bottom. Included in the end-effect is also fishing time on that part of the shrimp stock which is swimming above the bottom at the time of setting the trawl, which is very difficult to assess and is assumed to vary substantially with time of day, composition of the stock etc. Due to severe uncertainties concerning the magnitude of the end-effect no corrections have been included in the present analysis of the status of the stock.

Fishing practices

The survey was conducted with the research trawler *Paamiut* (722 GRT) using a 3000/20-mesh *Skjervøy* bottom trawl with a twin cod-end. Mesh size in the cod-end was reduced from 44 mm to 20 mm (stretched) in 1993, and the fine mesh cod-end has been used thereafter. Trawl geometry was measured with *Scanmar* acoustic sensors mounted on the trawl doors, and a *Furuno* trawl-eye on the headrope. From 1988 through 2003 the trawl doors were of the type *Greenland Perfect*, measuring 9.25 m² and weighing 2 420 kg. They were replaced in 2004 by *Injector International* 7.5 m² trawl doors with a weight of 2 800 kg. This was done to facilitate the change of the survey trawl in the coming year.

Swept area

The distance between the trawl doors was recorded 3 or 5 times during each haul for tow durations of 15 and 30 min, respectively. Mean wingspread for each tow was calculated from average door spread that and the geometry of the trawl:

$$WingSpread = \frac{TrawlLength * DoorSpread}{TrawlLength + BridleLength} + 0.7$$ with a trawl length of 55 m and a bridle length of 60.1 m.

Nominal swept area was calculated as the straight-line track length between start and end-positions (GPS) multiplied by the mean wingspread for the tow.

Estimates of biomass

For each tow, the catch was divided by the nominal swept area calculated from wingspread and track length to estimate the density. Mean stratum densities were multiplied by the stratum area to compute stratum biomass, and corresponding coefficients of variation (CV, in %) for each stratum were calculated from the swept area estimate of the biomass (B) and the standard deviation of the density times the stratum area (STD) according to:

$$CV = STD / B * 100.$$

Stratum biomasses and variances of these estimates were added to get regional and overall estimates. Overall error coefficients of variation (in %) were calculated as relative standard errors:

$$OECV = \sqrt{\sum \frac{STD^2_i}{n_i}} \; / \sum B_i * 100$$

where STD^2, n, and B denote variance , number of tows and biomass in stratum i, respectively. Standard deviations (STD) were calculated according to Cochran (1977) as B × 0.985 in cases in which only one tow per stratum has been available.

Biological samples

From each catch a sample of about 2 to 4 kg of shrimp was taken and sorted to species. All specimens of northern shrimp were grouped into males, primiparous and multiparous females based on their sexual characteristics as defined by Allen (1959) and McCrary (1971), and oblique carapace length (CL) was measured to the nearest 0.1 mm using slide callipers.

The number of northern shrimp in the samples was weighted by total catch and stratum area to obtain estimates of total number by sex and length group (0.5 mm intervals) for each stratum, for different inshore and offshore areas and the total survey area. These data were used to construct area-specific length frequencies and to calculate abundance indices for males and females as well as for small (<17 mm) males, which are expected to enter the fishery in the coming year.

An index of female biomass was computed from the proportion of females in weight converted from the overall length distribution and the estimate of total survey biomass. Fishable biomass was calculated from the total number of northern shrimp with a length equal to and greater than 17 mm CL converted to weight. In both cases length-weight relationships given in Carlsson and Kanneworff (2000) and Wieland (2002a) were used for the period prior to 2001 and the years 2001 and 2002, respectively. In 2003 and 2004 new length-weight data were collected from all parts of the survey area and female biomass and fishable biomass were calculated from these annual length-weight relationships.

Bottom temperature

Until 1994 bottom temperatures were measured in with a *Seabird* CTD and thereafter with a *Seamon* data storage sensor mounted on one of the trawl doors. The *Seamon* sensor recorded data in intervals of 30s with a resolution of 0.01°C, and average temperatures for the respective time period of the single trawl tracks were calculated after retrieval of the sensor. All measurements taken at depths >150 m were used to calculate a mean bottom temperature weighted for the areas of the survey strata between 150 and 600 m depth.

Results and Discussion

Effect of door types

Figure 2 compares door spread and vertical opening of the *Skjervøy* trawl with the *Greenland Perfect* doors in 2003 and the *Injector International* doors in 2004. Average door spread was about 2.3 m wider in 2004 than in 2003 and this difference, which is accounted for in the calculation of the swept area, was statistically significant (Mann-Whitney Rank Sum test, $p < 0.001$). The use of the two different door types had also a significant effect on the vertical net opening (Mann-Whitney Rank Sum test, $p < 0.05$), but its effect on the survey results can be regarded as negligible because the difference in the medians amounted only to 0.17 m.

Area coverage

As usual, a number of planned trawling sites had to be cancelled for various reasons. Because about half of the trawling sites are chosen at random some stations may have been placed in areas in which the conditions were not sufficiently known to judge if the sites should have been removed from the list of suitable locations. 200 stations were planned of which several were not be covered and for which no alternative positions could be found This was mainly due to a combination of unfavourable bottom conditions in the northern part of the survey area and time restrictions during the first three of the four cruise legs. In total 187 valid tows were available to describe the stock situation of northern shrimp in 2004.

Estimates of total biomass

For all strata biomass estimates have been calculated (Tables 1a-1d) on the basis of the nominal swept area. The biomass estimates (in t) for the five main regions and the entire survey area in 2004 were:

Region	Biomass estimate (t)	Number of stations	OECV (%)
North	127369	22	24,4
Canadian zone	3750	6	20.7
West (incl. South)	429779	139	23.3
Disko Bay / Vaigat	93863	20	12.4
Total	654761	187	16.1

The estimated biomass for the period 1988 to 1997 was fairly stable around a mean of 230 000 tons. After 1997, the biomass has increased significantly to record high estimates of 653 000 tons in 2003 and 655 000 tons in 2004 (Table 2, Fig. 3 upper panel). Survey indices of biomass per unit area, which accounts for the extension of the survey area in the past three years, indicate the same trend as the swept area estimates of total abundance (Fig. 3 lower panel).

After having optimised the sampling procedure, i.e. selection of sampling sites, reducing the tow duration and operating with a mixture of fixed and reallocated stations, the overall error coefficient of variation (OECV) of the biomass estimates has decreased during the past years (Table 3). The OECV for the total survey in 2004, however, was 16.1%, which is 1.5% above the average since all regions were included in the survey area in 1994.

If an end-error correction of 2.78 min as estimated by Kingsley *et al.* (2002) is applied to the biomass calculation for 2004, the total estimate is reduced by 12.8% to 570 848 tons. This value is about 7 000 tons below the corresponding estimate for 2003.

Geographical and depth distribution

The distribution of the northern shrimp density in 2004 was traditional with high densities in the deeps between the shallow banks along the coast (Fig. 4), especially in the Holsteinsborg Deep (≈66°30'N). High concentrations of northern shrimp were also found in the area north of Store Hellefiske Bank (≈68 to 69°N) and in the Julianehåb Bight (≈60°30’N) close to the coast. But in contrast to previous years, northern shrimp was almost absent in the Sukkertoppen Deep (≈64°30'N) as well as between Narsalik Bank (≈62°N) and Kap Desolation (≈60°30'N), the catches in the main part of Disko Bay were lower in 2004 than in the past three years.

One exceptional large catch of more than 6.5 tons in a 15 min haul was recorded west of Sukkertoppen Bank (≈ 64°45'N) in area W5 between 200 and 300 m depth (Fig. 4). This resulted in a very high coefficient of variation (Table 1c), as all other catch in this stratum, which has an area of 3 648 km², were small (<0.5 ton including four zero catches). Worth noting is that the estimated biomass in this stratum (and the total survey biomass) would have been about 74 000 tons lower without that catch.

Figure 5 shows the variations in biomass distribution in various geographical areas and most strata have exhibited large changes throughout the years. The biomass in the Disko Bay/Vaigat area, in the southernmost offshore region and in the Canadian part of the survey area did not change much from 2002 to 2003, but an increase was found in the other areas along the coast, i.e. the regions W and U. In 2004, biomass continued to increase in region W while it was stable in region U, but decreased in the Canadian zone and the southernmost offshore region as well as in the Disko Bay/Vaigat area

The Disko Bay/Vaigat region has the longest history of commercial fishery for northern shrimp in Greenland as it developed in the early-1950s. When the trawl survey first included this area in 1991a biomass of around

50 000 tons was estimated, corresponding to 29% of the biomass for the total survey area at that time. The estimated biomass has increased steadily a low in 1993 to the record high estimates of near 120 000 tons in 2002 and 2003 (24% and 18%, respectively of the total survey biomass). It should be pointed out that in contrast to the increase in the offshore biomass by about 20% (excluding region U) between 2002 and 2003 the biomass in Disko Bay/Vaigat region levelled out. Estimated densities of northern shrimp in the Disko Bay/Vaigat region have always been very high compared to the offshore areas (Table 4) and ranged between 9.9 and 12.8 t/km² (or g/m²) in the three recent years, which is about three times the average offshore density during that period.

Relative distribution of the biomass in depth layers (Fig. 6) indicates that the bulk of the biomass was found between 300 and 400 m depth until 1994. This has gradually changed and most of the biomass (70% of the overall biomass) was observed in the 200-300 m in 2001. Subsequently the biomass increased in all depth intervals, but the 200-300 m depth layer still contributes the major part of the total biomass (66% in 2004).

Size distribution by area in 2004

Length distributions for the offshore areas U1-U3, C0 and W1-W9 indicate a relative high abundance of males between 18 and 22 mm CL (Fig. 7a, b). In most of these areas, smaller (15-18 mm CL) males were also abundant while large (>21 mm CL) males and females predominated in areas W4-W6 and W8. Males smaller than 15 mm CL were generally rare. Length frequencies for the inshore areas I1 and I2 differed from the offshore distributions showing a much more pronounced presence of males smaller than 13 mm CL (Fig. 7c).

Figure 8 shows the geographical distribution of mean size of all sexual groups pooled. Low mean size (<19 mm CL) of males was found in several survey regions, including the offshore area southwest of Disko Island (≈69°N, W1and W2), between the fishing banks and the coast between 62 and 63°N (W6) and in most of the Disko Bay/ Vaigat area (I1 and I2). The highest mean sizes (>23 mm CL) were observed in the deeper (>300 m) parts of areas W1 and C0, west of the Holsteinsborg Deep (W4), west and south of Sukkertoppen Bank (≈64°30'N, W5) and in the coastal part of the Julianehåb Bight (W8).

Annual size distributions

Overall length distributions for the offshore and the inshore area in 1988 to 2004 are compared in Fig. 9a-d. The offshore length frequency for 2004 shows no distinct modes of the males above 15 mm CL, which is likely due to an overlap of at least two age groups. Abundance of small (<15 mm CL) males appears to be slightly higher in 2004 than in 2003 but is low compared to e.g. 2001. The primiparous females show a mode at about 23.5 mm CL and modes at appr. 24 and 26 mm CL are discernable for multiparous females in the offshore areas in 2004 (Fig. 9d). The inshore length frequency for 2004 differed in some aspects from those recorded in the previous year, in particular concerning a pronounced peak for small males (12 mm CL) and a mode of the primiparous females at a smaller size (23 mm CL) whereas a mode for the multiparous females was found at 25 mm CL in all years since 2001.

Figure 10 shows overall length frequencies combined for the offshore and inshore area for 2001 to 2004. A progression of the 1999-year-class from about 13.5 mm CL in 2001, to 17.5 mm CL in 2002 and to 20 mm CL in 2003 is clearly visible, and parts of this year-class has probably passed into the female group in 2004. The subsequent year-classes were weaker and more difficult to trace in the length frequency distributions. However, the considerable increase in the level of abundance of the 1999-year-class at the progressing modes from 3×10^9 at age 2 in 2001 to about 7.5×10^9 at age 4 in 2003 is striking. A similar effect is visible for the 2000-year-class with its presumed modes at 9 mm CL in 2001 and 12.8 mm CL in 2002 and corresponding abundance levels of about 0.25×10^9 at age 1 and 1.5×10^9 at age 2. Several processes, which include mesh selection of the trawl especially for shrimp smaller 11 mm CL (Wieland, 2002b), escapement of juveniles below the footrope (Nilssen *et al.*, 1986) and immigration from nursery areas at depths shallower than intensively covered by the survey (Wieland and Carlsson, 2001) may be involved in this phenomena.

The high abundance of males between 17 and 22 mm CL in 2004 (Fig, 10) is promising in terms of progression to the female group in the next year, but there is no indication that another strong year-class will enter the fishable stock in the coming two years.

Length-weight relationship

Measurements of individual length and weight were pooled for all sexual groups and survey areas as a visual inspection of the data did not suggest a separate treatment (Fig. 11 upper panel), and the resulting length-weight relationship for 2004 differed not very much from those used in previous years (Fig. 11 lower panel):

1988-2000: $W = 0.000669 * L^{2.96}$

2001-2002: $W = 0.000483 * L^{3.0576}$

2003: $W = 0.000752 * L^{2.9177}$

2004: $W = 0.000765 * L^{2.9092}$ where W is weight in g and L is carapace length in mm.

The lower values of the exponent of the length weight relationship since 2002, however, may indicate a slight decrease in condition of northern shrimp in the most recent years and could have been an effect of the increase in stock density in large parts of the area. But this interpretation as well as the appropriateness of pooling the different sexual groups and survey areas awaits a more thorough statistical analysis.

Total abundance, spawning stock biomass, fishable biomass and recruitment to the fishery

Total numbers and proportions of male and female shrimp in the survey area (including both inshore and offshore areas) estimated from overall length distributions are given in Table 5. The total number of males and females together for 2004 is the third highest value on record and considerably exceeds the long-term mean. Corresponding estimates of biomass derived from a conversion of the length frequencies to weight are listed in Table 6. Total biomasses calculated in this way were about 2 to 5% lower than the direct estimates of the total survey biomasses (Table 2), except for 1989 (-6.2%), 1991 (-15.0%), 1992 (-5.7%), 2002 (-5.2%) and 2004 (-5.4%). The proportion of females is close to the long-term average, both in terms of abundance and in biomass.

Spawning stock biomass (SSB) indices estimated from the proportions of females in the stock based on weight, i.e. derived from the conversion of the overall female length distributions to weight (Table 5), and the direct estimates of survey biomasses (Table 2) are given in Table 7. The SSB index for the 2004 survey for the offshore and the inshore areas combined is by far the highest on record amounting to more than two times the long-term average. It has, however, recently been questioned whether this index is an adequate measure for the reproductive potential of the stock as the change in the temperature regime and high stock density in major parts of the survey area might have affected fecundity and pre-recruit survival (Wieland, 2004a).

Table 8 shows the fishable biomass calculated from the number of individuals equal to and above 17 mm CL. This size limit is assumed to correspond roughly to the L_{50} value of a commercial shrimp trawl with a mesh size of 44 mm in the cod-end. The fishable biomass increased in 2003 to record high values in both, the offshore and the inshore area. In 2004, the fishable biomass index for the entire survey was about 581 000 tons, which is at the same level as in 2003 and is far above the long-term average. This is mainly a result of the progression of the exceptional strong 1999-year-class and the 2000-year-class beyond 17 mm CL (Fig. 10).

Abundance index of small (<17 mm CL) males calculated for all years since 1993, i.e. the year in which the mesh size of the cod-end liner were reduced from 44 to 20 mm, are given in Table 9. The 2004 value for the offshore area is about 20% below the index for 2003 whereas only a minor decrease was recorded for the inshore area. For both, the offshore and the inshore areas combined, the abundance of small males is still above average indicating that recruitment to the fishery is secured for the next year. However, low abundance of males at sizes below 15 mm CL as well as a more detailed analysis on abundance indices of juveniles and males by age are given in Wieland (2004b) and suggest that stock size will decrease in the coming one or two years.

The contribution of the inshore component (Disko Bay and Vaigat) of the stock to the overall spawning stock biomass, fishable biomass and recruitment to the fishery varied through the years (Tables 7-9) and is actually 15% in terms of spawning stock biomass, 13% in terms of fishable biomass and 35% in terms of recruitment to the fishery. Except for recruitment, these values are below average, which may indicate a decrease in the fishery potential of the Disko Bay/Vaigat region relative to the offshore area.

Bottom temperature

Bottom temperatures ranged from 0.9°C in the shallow (<200 m) parts of the Disko Bay to about 6°C in the southern offshore areas (Fig. 12). Values above 4 °C were found in large parts of offshore area south of 63°45'N whereas bottom temperatures between 2 and 3°C prevailed in the remaining parts of the survey area. The overall area weighted mean bottom temperature amounted to 2.84°C, which is close the average observed since 1997 (Fig. 13 upper panel) and indicates that the recent relative warm period has continued. It is further noteworthy that the change from a cold to a warm period has affected all different depth layers in a similar way (Fig. 13 lower panel).

Conclusions

Estimates of northern shrimp (*Pandalus borealis*) biomass derived from stratified random surveys performed West Greenland waters since 1988 showed little variation until 1997 with annual estimates of the standing stock of between 20 000 and 25 000 tons. Since 1997 a pronounced increase in survey biomass has been observed with record high values of about 651 000 and 65 500 tons in 2003 and 2004, respectively. Large variations from year to year both geographically and over depth zones were observed suggesting that the stock is highly migratory. The survey design has been evaluated and adjusted in the later years in order to reduce sampling variation. Indices of spawning stock and fishable biomass for 2004 are well above long-term average. The length distribution observed in 2004 indicates that progression of males to the female group is secured for the next year, but low abundance of small males suggests a decrease in stock size during the coming one or two years.

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Table 1a. Estimated trawlable biomass (tons) and sampling statistics for strata in region U, 2004.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
U1-1	150-200	3325	48.9	1	-	-
U1-2	200-300	4517	3917.2	2	5005.9	127.8
U1-3	300-400	4671	19867.6	2	21267.1	107.0
U1-4	400-600	5379	9146.9	2	10156.5	111.0
U2-2	200-300	7168	25413.7	2	21548.8	84.8
U2-3	300-400	8919	23692.6	3	5753.3	24.3
U2-4	400-600	8290	4811.7	2	3861.7	80.3
U3-1	150-200	2215	90.0	1	-	-
U3-2	200-300	2317	25261.9	2	28968.7	114.7
U3-3	300-400	1304	10957.0	3	3835.5	35.0
U3-4	400-600	2415	4161.5	2	772.0	18.6
Total		50520	127369.0	22		

Table 1b. Estimated trawlable biomass (tons) and sampling statistics for strata in region C, 2004.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
C0-2	200-300	897	1940.6	2	1048.8	54.0
C0-3	300-400	2126	1553.8	2	139.8	9.0
C0-4	400-600	1213	255.5	2	283.0	110.7
Total		4236	3749.9	6		

Table 1c. Estimated trawlable biomass (tons) and sampling statistics for strata in region W, 2004.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
W1-1	150-200	2968	25.9	1	-	-
W1-2	200-300	6035	27651.7	6	33603.3	121.5
W1-3	300-400	7515	44699.9	9	32093.4	71.8
W1-4	400-600	877	23.6	1	-	-
W2-1	150-200	1699	45.5	1	-	-
W2-2	200-300	2616	75950.5	4	106426.5	140.1
W2-3	300-400	1768	25329.1	4	20629.6	81.4
W2-4	400-600	965	1636.8	2	1118.0	68.3
W3-1	150-200	2160	558.8	2	757.2	135.5
W3-2	200-300	4698	57645.1	16	75966.4	131.8
W3-3	300-400	2119	3626.6	2	5083.1	140.2
W3-4	400-600	2921	3960.3	2	1055.4	26.6
W4-1	150-200	4255	9.3	1	-	-
W4-2	200-300	1695	26029.6	6	30107.1	115.7
W4-3	300-400	777	19.3	5	26.2	135.4
W4-4	400-600	1873	18836.7	2	26592.1	141.2
W5-1	150-200	3001	11070.9	5	22162.3	200.2
W5-2	200-300	3648	79798.0	14	276624.1	346.7
W5-3	300-400	1950	111.8	2	144.9	129.6
W5-4	400-600	3021	183.4	2	257.9	140.6
W6-1	150-200	1206	6.6	2	7.4	112.1
W6-2	200-300	2006	17055.5	6	23649.8	138.7
W6-3	300-400	1585	11082.0	2	11407.1	102.9
W6-4	400-600	1234	5124.3	2	7246.9	141.4
W7-1	150-200	2442	0.7	2	0.2	29.1
W7-2	200-300	891	18.5	10	56.9	306.8
W7-3	300-400	265	0.3	2	0.1	28.1
W7-4	400-600	317	0.0	2	0.0	141.4
W8-1	150-200	349	7.4	3	11.7	159.0
W8-2	200-300	534	413.1	2	540.8	130.9
W8-3	300-400	470	5693.4	6	11364.3	199.6
W8-4	400-600	745	13159.7	3	22249.7	169.1
W9-1	150-200	1886	1.0	2	1.4	141.4
W9-2	200-300	806	0.0	3	0.0	-
W9-3	300-400	568	1.7	2	1.6	96.8
W9-4	400-600	457	1.8	3	1.9	106.2
Total		72321	429778.8	139		

Table 1d. Estimated trawlable biomass (tons) and sampling statistics for strata in region I, 2004.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
I1-1	150-200	346	4958.9	1	-	-
I1-2	200-300	1853	27462.0	2	3165.2	11.5
I1-3	300-400	2470	18984.9	3	7369.1	38.8
I1-4	400-600	1557	11105.9	2	9003.3	81.1
I2-1	150-200	394	5588.3	2	7232.5	129.4
I2-2	200-300	769	15300.7	5	7431.2	48.6
I2-3	300-400	1025	7840.3	3	7794.2	99.4
I2-4	400-600	1321	2621.6	2	1672.7	63.8
Total		9735	93862.6	20		

Table 2. Biomass estimates (in ‘000 tons) for combined strata and standard errors for the entire survey area 1988-2004.

Year	N1-N9	U1-U3 [1]	C1+C3	C0 [1]	W1-W2	W3-W4	W5-W7 [2]	S1+S2	W8-W9 [1]	D1-D9 [3]	I1-I2 [1]	Total	SE [4]
1988	21.7		9.6		58.6	74.4	19.0	-		46.5		229.8	24.7
1989	11.3		3.9		48.2	79.6	38.6	-		46.5		228.0	32.3
1990	11.1		11.1		82.1	54.2	23.3	-		46.5		228.3	32.6
1991	5.8		4.8		30.9	52.4	28.1	-		50.6		172.6	22.8
1992	20.6		24.1		52.0	35.0	46.1	-		47.4		225.1	29.2
1993	8.0		3.4		103.1	41.3	67.5	-		33.6		256.8	30.0
1994	8.0		6.8		107.7	49.7	37.7	20.7		40.0		270.6	53.0
1995	8.2		4.4		43.7	58.6	53.0	1.7		47.3		217.1	29.1
1996	10.0		1.7		53.8	34.9	90.5	3.7		54.3		248.9	39.9
1997	7.2		0.2		40.1	15.1	66.5	24.9		52.3		206.2	30.9
1998	8.3		0.4		42.2	107.1	50.9	22.3		61.9		293.3	55.6
1999	14.4		11.9		54.2	26.1	55.9	63.7		61.2		287.4	40.6
2000	9.6		11.7		68.0	72.7	79.6	24.5		83.5		349.5	37.8
2001	39.0		4.2		83.1	52.7	67.7	19.7		82.7		349.2	43.1
2002	21.8 [5]		6.0		128.4	70.5	109.1	37.6		119.4		492.7	65.9
2003		122.6	6.3		157.3	100.1	110.1		40.4	116.4		653.3	74.3
2004		127.4		3.7	175.4	110.7	124.5		19.3		93.9	654.8	105.6

[1]: New stratification introduced in 2003 (regions N and S) and in 2004 (regions U, C and D)

[2]: Areas W6 and W7 were sampled from 1990 and 1993, respectively

[3]: D1-D9 1988-90 not sampled, but set to mean of 1991-1997.

[4]: Standard error calculated excluding D1-D9 in 1988-1990

[5]: Probably underestimated due to poor coverage of the northern part of the area

Table 3. Overall error coefficients of variation (%) for the biomass estimates of the five main regions and the entire survey together with the corresponding number of hauls 1988-2004.

Year	N/U	C	W	S	D/I	Total suvey	Number of hauls
1988	30.4	37.0	15.5	-	-	13.5	139
1989	22.6	44.0	19.3	-	-	17.8	137
1990	42.5	43.8	19.9	-	-	17.9	116
1991	40.2	25.5	17.3	-	23.3	13.2	197
1992	17.2	68.4	17.0	-	15.6	13.0	173
1993	50.9	53.4	13.6	-	20.4	11.7	148
1994	47.7	18.9	24.4	99.2	25.9	19.6	157
1995	32.7	44.6	17.9	73.9	16.9	13.4	165
1996	51.5	90.8	21.8	95.1	10.3	16.0	149
1997	36.9	59.1	24.3	15.9	14.1	15.0	167
1998	41.0	40.7	26.3	59.2	18.3	18.9	211
1999	54.1	79.7	13.7	51.5	13.8	14.1	230
2000	36.8	6.9	15.1	56.0	13.3	10.8	202
2001	26.2	45.9	18.6	48.6	18.2	12.3	224
2002	100.6	46.0	15.9	45.0	28.7	13.4	218
2003	27.2	44.5	16.2	51.2	17.2	11.4	172
2004	24.4	20.7	24.2	70.9	12.4	16.1	187

Table 4. Estimated mean densities (t/km²) for combined strata in 1988-2004.

Year	N1-N9/U1-U3	C1+C3/C0	W1-W2	W3-W4	W5-W7	S1-S2/W8-W9	D1-D9/I1-I2
1988	0.52	2.79	2.49	3.43	1.89	-	-
1989	0.25	1.12	2.66	3.67	3.84	-	-
1990	0.25	3.23	3.48	2.50	1.57	-	-
1991	0.14	1.39	1.31	2.42	1.90	-	5.40
1992	0.50	6.99	2.21	1.61	3.11	-	5.06
1993	0.19	0.98	3.89	1.88	3.60	-	3.59
1994	0.21	1.98	4.07	2.27	2.01	3.98	4.27
1995	0.21	1.28	1.65	2.67	2.83	0.26	5.05
1996	0.26	0.49	2.03	1.59	4.83	0.57	5.80
1997	0.19	0.07	1.51	0.69	3.55	3.81	5.58
1998	0.21	0.13	1.60	4.89	2.72	3.43	6.61
1999	0.37	3.46	2.05	1.19	2.98	9.77	6.53
2000	0.25	3.39	2.57	3.32	4.25	3.76	8.92
2001	1.01	1.22	3.14	2.40	3.62	3.03	8.84
2002	0.56	1.74	4.85	3.21	5.82	5.77	12.75
2003	2.49	1.48	6.47	4.79	5.87	6.69	12.42
2004	2.52	0.89	7.17	5.40	5.77	3.32	9.64

Table 5. Abundance estimates (billions) for males and females from overall length distributions for the total survey area 1988-2004 (mean values for Disko Bay/Vaigat area 1991-1997 used in 1988-1990).

Year	Males	Females	Total	Males %	Females %
1988	24.3	9.9	34.2	71.1	28.9
1989	35.0	7.6	42.6	82.2	17.8
1990	28.5	10.0	38.5	74.0	26.0
1991	17.4	6.2	23.6	73.7	26.3
1992	29.7	7.3	37.0	80.3	19.7
1993	35.5	9.7	45.2	78.5	21.5
1994	33.9	10.9	44.8	75.7	24.3
1995	29.2	7.9	37.1	78.7	21.3
1996	41.4	8.1	49.5	83.6	16.4
1997	29.5	7.6	37.1	79.5	20.5
1998	42.9	11.5	54.4	78.9	21.1
1999	44.8	11.3	56.1	79.9	20.1
2000	66.7	12.7	79.4	84.0	16.0
2001	61.1	13.7	74.8	81.7	18.3
2002	90.6	16.7	107.2	84.5	15.5
2003	103.2	27.9	131.1	78.7	21.3
2004	77.2	27.2	104.4	73.9	26.1
Average	46.5	12.1	58.6	78.8	21.2

Table 6. Biomass estimates for males and females ('000 tons) in the total survey area based on length-weight relationships applied to overall length-frequency distributions 1988-2004 (mean values for Disko Bay/Vaigat area 1991-1997 used in 1988-1990).

Year	Males	Females	Total	Males %	Females %
1988	120.5	102.9	223.4	53.9	46.1
1989	140.8	74.0	214.8	65.5	34.5
1990	124.3	97.9	222.2	55.9	44.1
1991	89.9	60.1	150.0	59.9	40.1
1992	141.3	71.7	213.0	66.3	33.7
1993	150.3	97.9	248.2	60.6	39.4
1994	153.5	109.6	263.1	58.3	41.7
1995	129.0	81.1	210.1	61.4	38.6
1996	155.5	83.6	239.1	65.0	35.0
1997	121.2	76.2	197.4	61.4	38.6
1998	174.9	107.2	282.1	62.0	38.0
1999	169.6	108.4	278.0	61.0	39.0
2000	221.2	116.8	338.0	65.4	34.6
2001	208.2	127.6	335.8	62.0	38.0
2002	305.3	144.6	449.9	67.9	32.1
2003	397.6	237.2	634.8	62.6	37.4
2004	371.0	250.0	621.0	59.7	40.3
Average	186.7	114.5	301.2	61.7	38.3

Table 7. Estimates of female biomass ('000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2004 (mean values for Disko Bay/Vaigat area 1991-1997 used in 1988-1990).

Year	Offshore	Disko	Total
1988	88.1	18.8	106.9
1989	59.7	18.8	78.5
1990	83.0	18.8	101.8
1991	48.2	20.9	69.1
1992	59.7	16.1	75.8
1993	85.6	15.7	101.3
1994	97.2	15.5	112.7
1995	62.5	21.3	83.8
1996	61.8	25.2	87.0
1997	62.9	16.8	79.7
1998	88.6	22.8	111.4
1999	93.2	18.8	112.0
2000	88.5	32.3	120.8
2001	101.1	31.6	132.7
2002	122.5	29.7	152.2
2003	200.0	44.1	244.1
2004	232.0	31.5	263.6
Average	96.2	23.4	119.6

Table 8. Estimates of fishable biomass (≥17 mm CL, '000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2004 (mean values for Disko Bay/Vaigat area 1991-1997 used in 1988-1990).

Year	Offshore	Disko	Total
1988	174.8	42.1	216.9
1989	157.5	42.1	199.6
1990	171.8	42.1	213.9
1991	100.3	46.0	146.3
1992	158.6	43.4	202.0
1993	201.3	31.4	232.7
1994	213.2	36.3	249.5
1995	156.8	44.4	201.2
1996	163.8	48.2	212.0
1997	140.7	44.7	185.4
1998	209.3	53.7	263.0
1999	204.6	47.0	251.6
2000	236.2	64.9	301.0
2001	234.6	69.7	304.3
2002	316.7	76.6	393.3
2003	483.3	98.7	582.0
2004	508.3	73.0	581.3
Average	225.4	53.2	278.6

Table 9. Abundance estimates for juveniles and males <17 mm CL (billions) in the offshore, the Disko Bay/Vaigat and total survey area 1988-2004 (years before 1993 not considered due to inappropriate large mesh size in the trawl's cod-end).

Year	Offshore	Disko	Total
1993	8.21	0.65	8.86
1994	6.15	1.07	7.22
1995	5.10	0.43	5.53
1996	14.06	2.06	16.12
1997	4.74	3.18	7.92
1998	7.00	3.59	10.59
1999	8.38	7.21	15.59
2000	15.13	12.19	27.32
2001	15.05	7.59	22.64
2002	19.93	12.85	32.78
2003	19.44	8.02	27.46
2004	14.31	7.70	22.02
Average	11.46	5.55	17.00

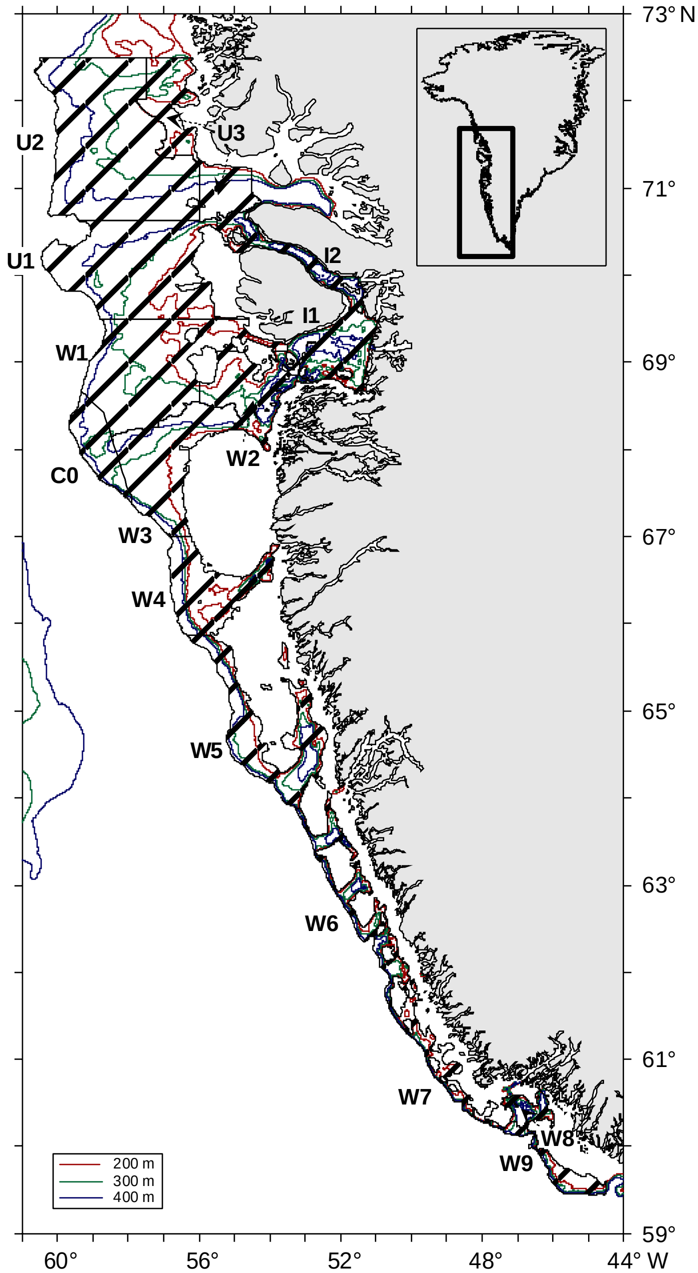

Fig. 1. Revised depth contours and survey stratification in 150-600 m depth applied in 2004.

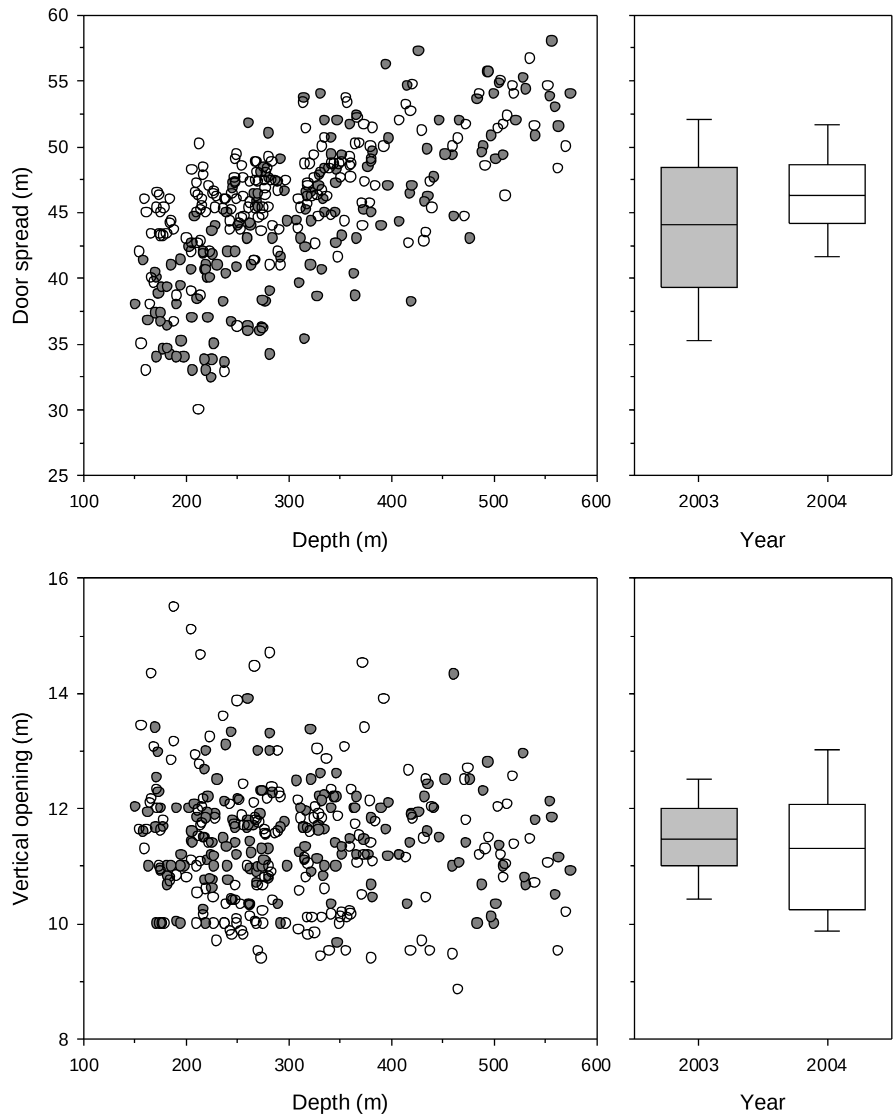

Fig. 2. Comparison of door spread and vertical net opening of the 3000/20-mesh *Skjervøy* bottom trawl using *Greenland Perfect* doors in 2003 and *Injector International* doors in 2004.

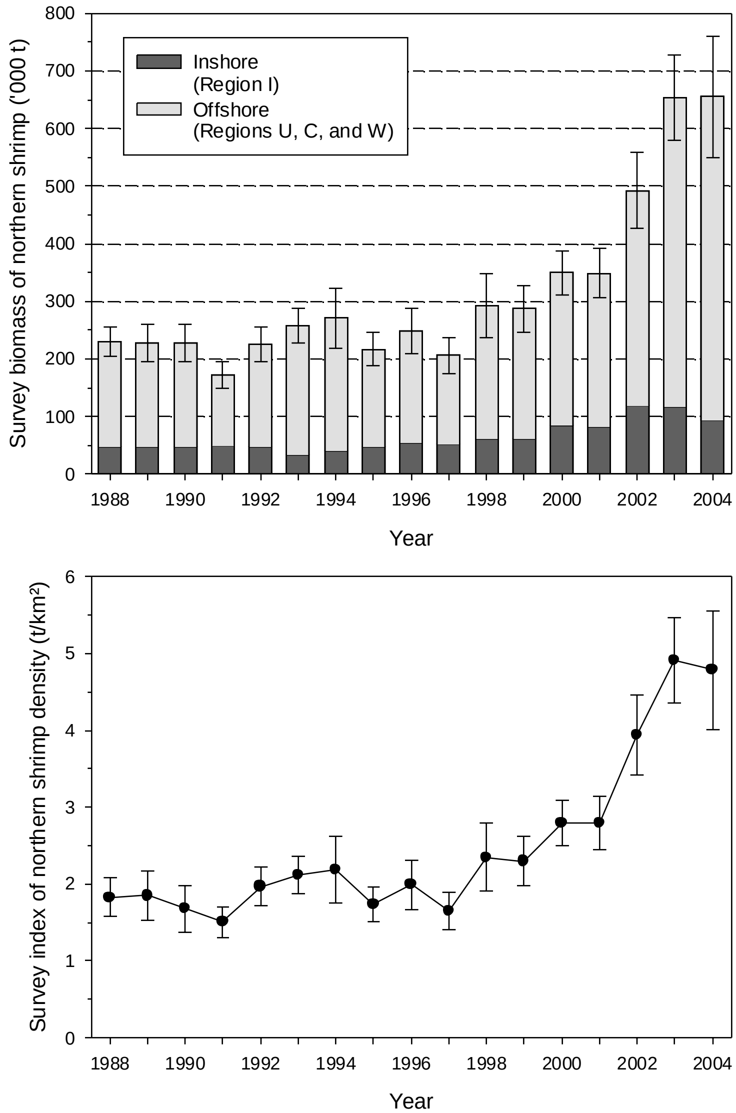

Fig. 3. Estimated total survey biomass and survey index for average density of northern shrimp with standard errors 1988-2004 (Average biomass estimate for inshore areas 1991-1997 are used for 1988-1990 to facilitate between-year comparisons, see table 2).

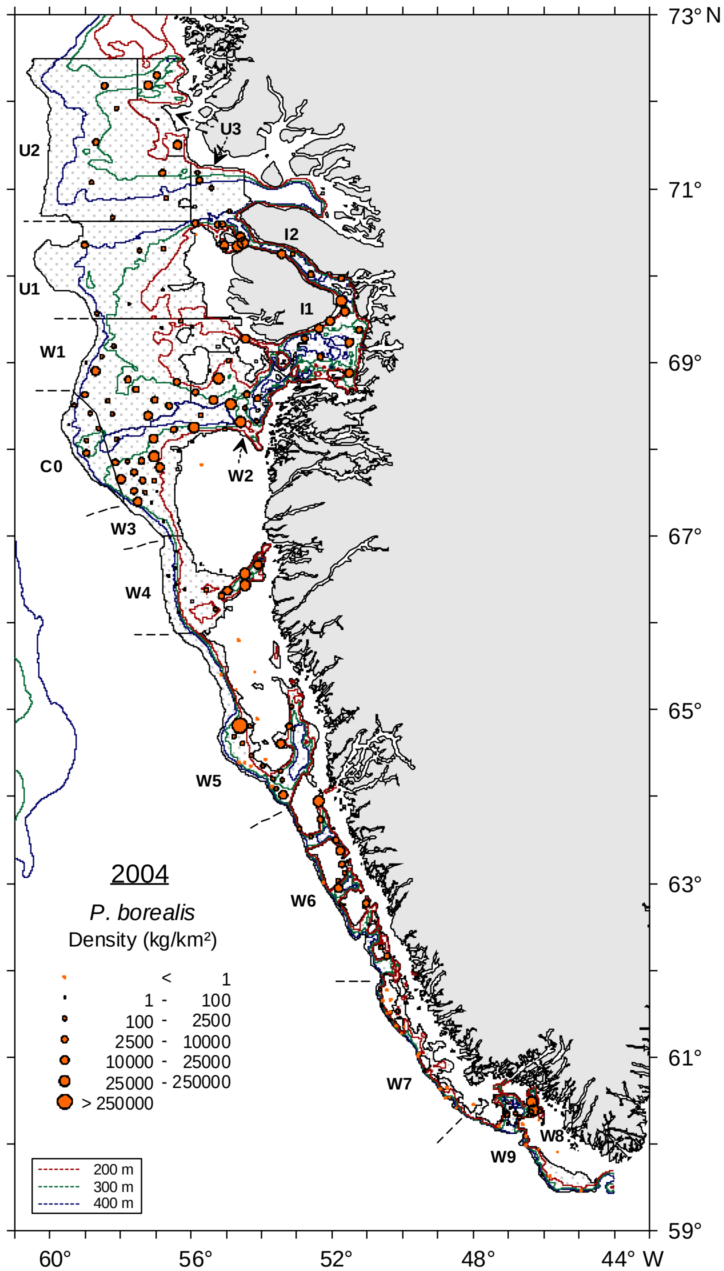

Fig. 4. Geographical distribution of northern shrimp density in 2004.

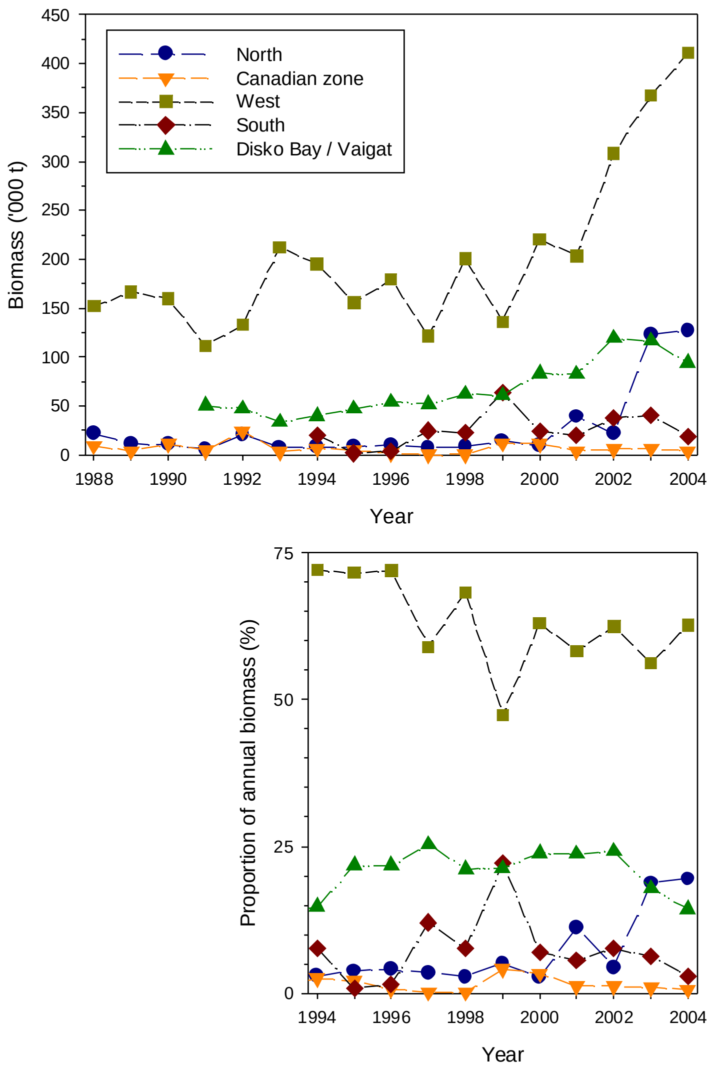

Fig. 5. Biomass in the five main survey region 1988-2004 and contribution of these regions to the total biomass 1994-2004.

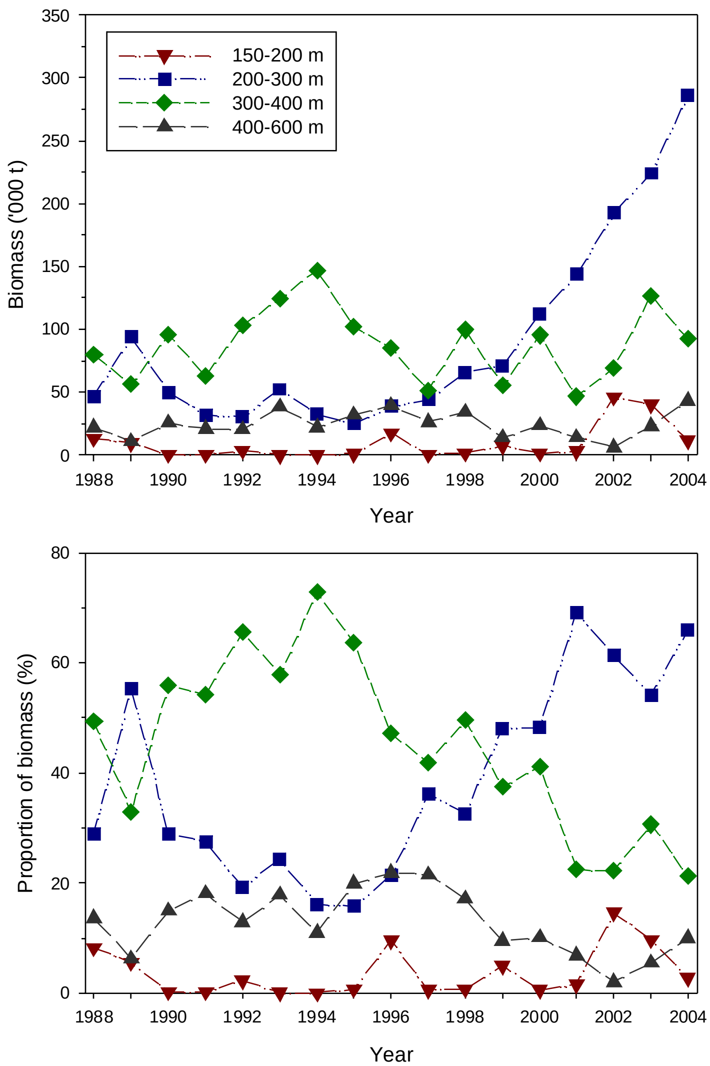

Fig. 6. Biomass distribution in the four depth strata in areas C and W1-W7 1988-2004.

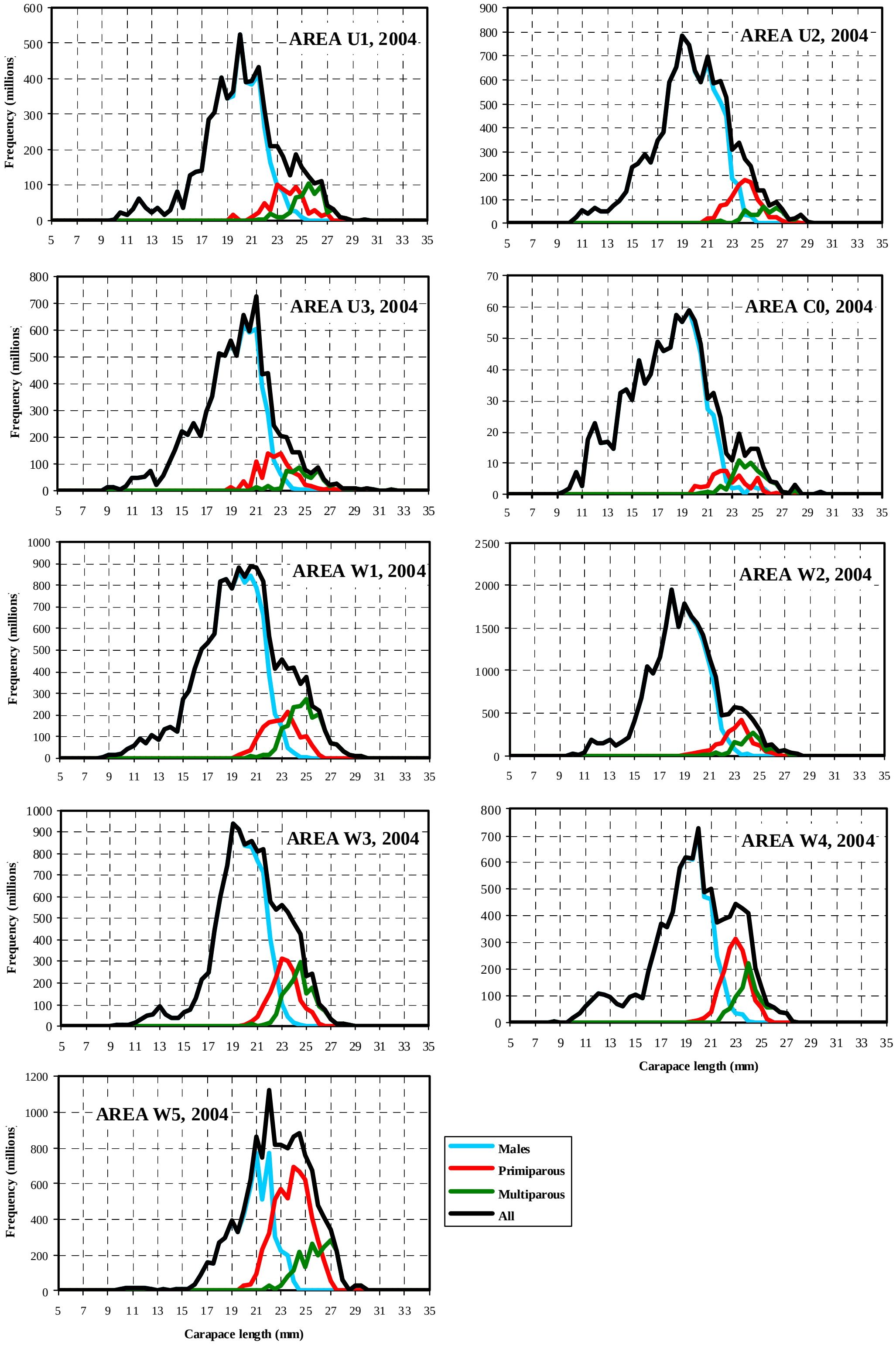

Fig. 7a. Length frequencies of northern shrimp in offshore areas U1-U3, C0 and W1-W5 in 2004.

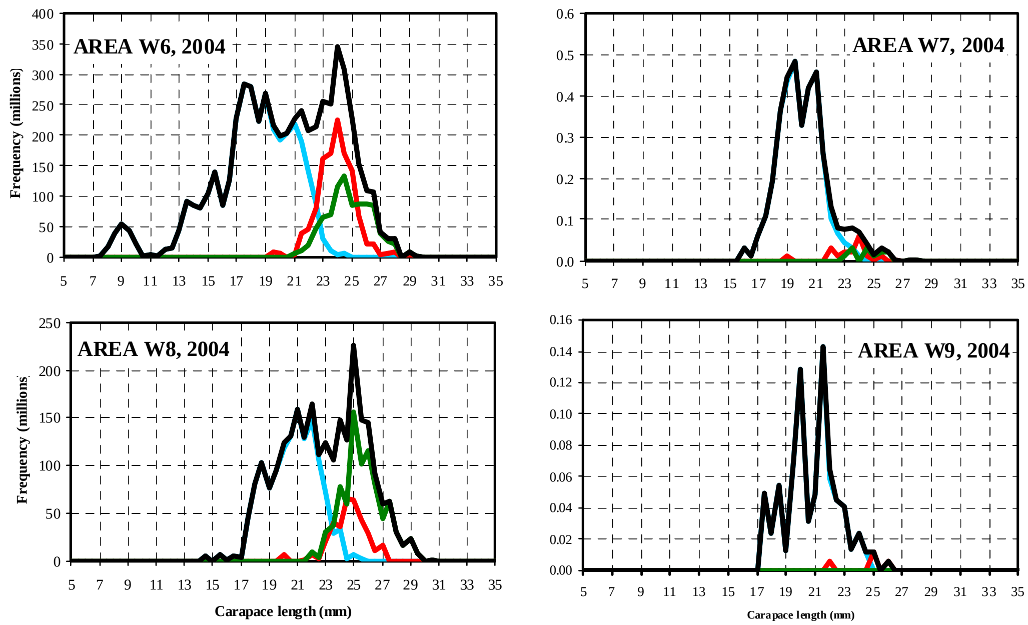

Fig. 7b. Length frequencies of northern shrimp in offshore areas W6-W9 in 2004.

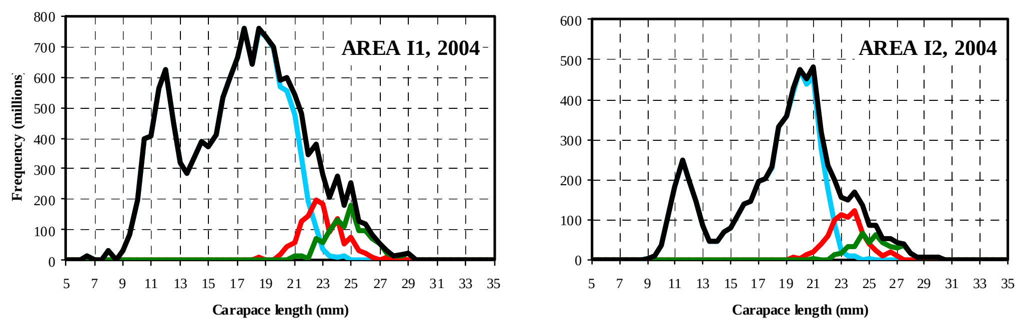

Fig. 7c. Length frequencies of northern shrimp in inshore areas I1 and I2 (Disko Bay / Vaigat) in 2004.

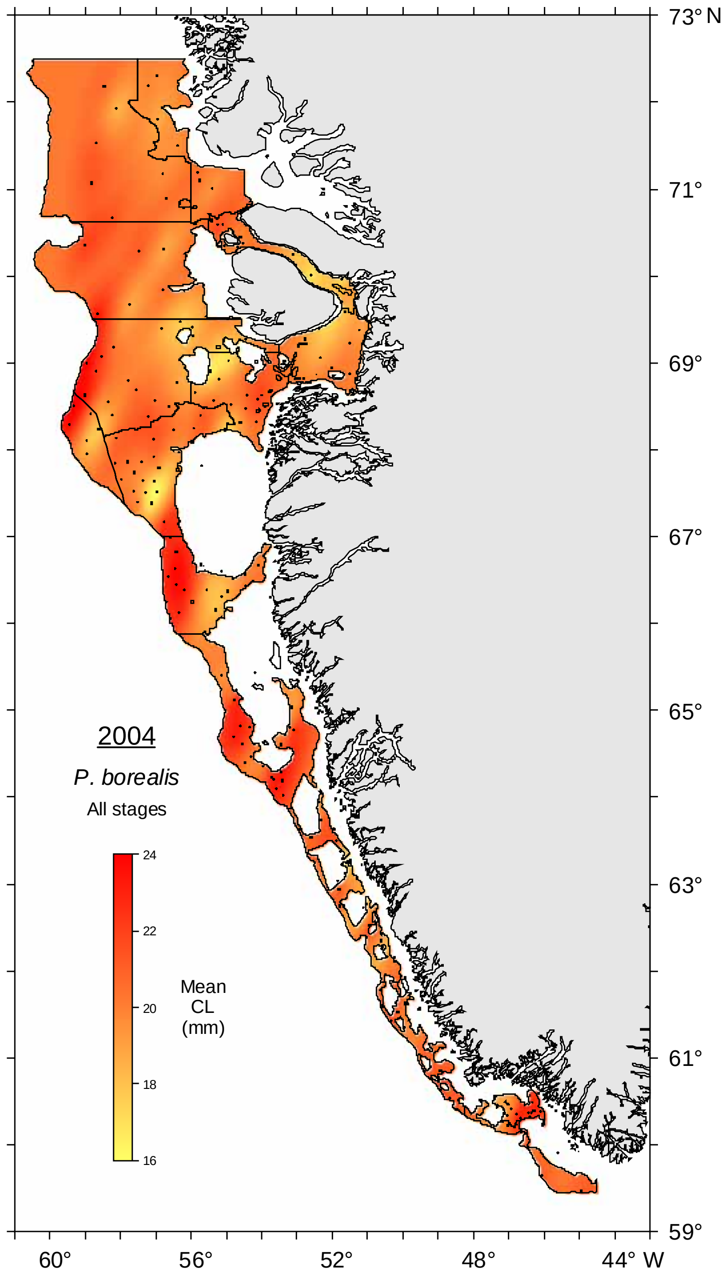

Fig. 8. Geographical distribution of mean size of northern shrimp in 2004.

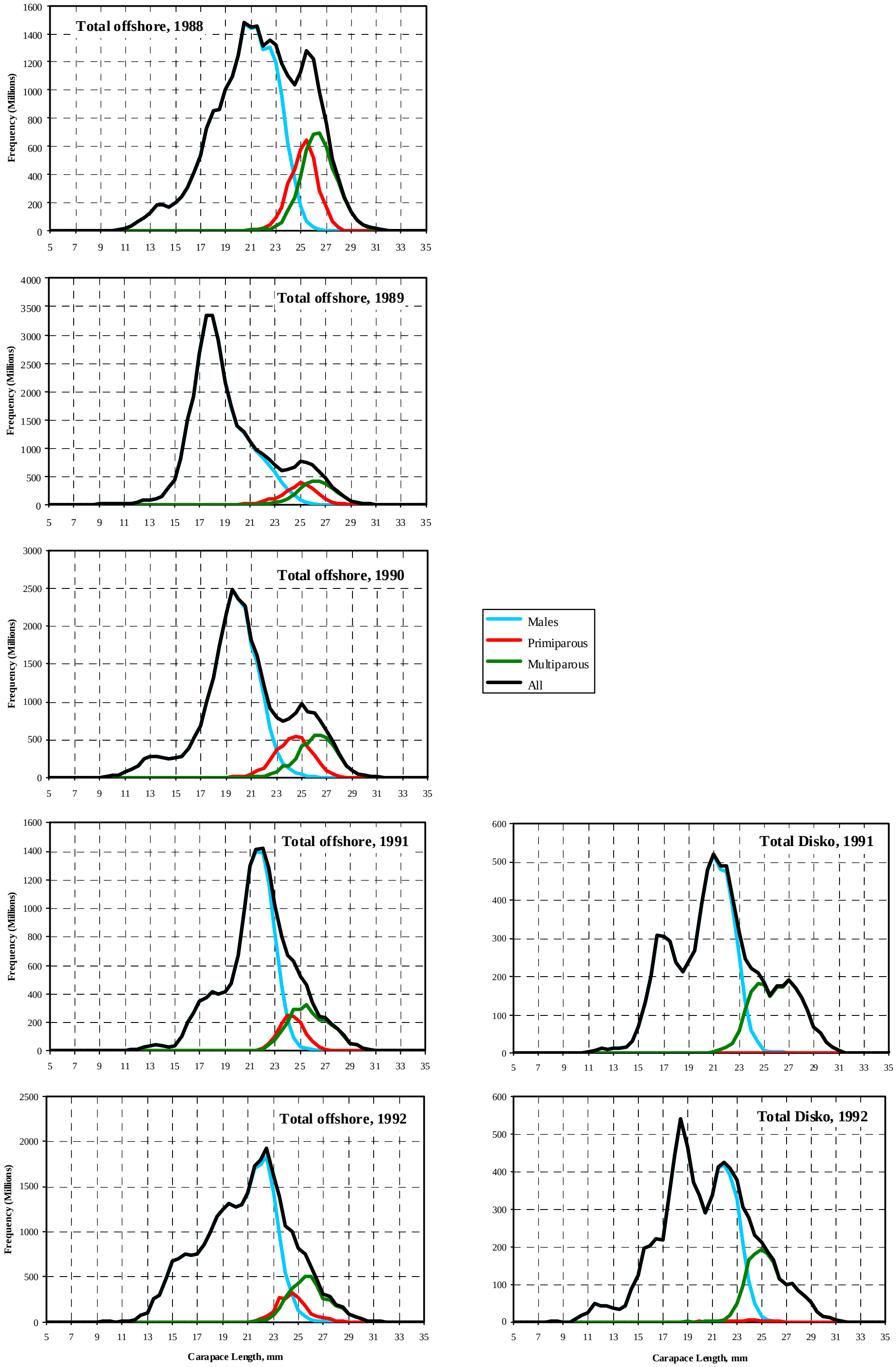

Fig. 9a. Length frequencies of northern shrimp in total offshore area 1988-1992 and Disko Bay/Vaigat area 1991-1992 (no surveys in Disko Bay/Vaigat area 1998-1990).

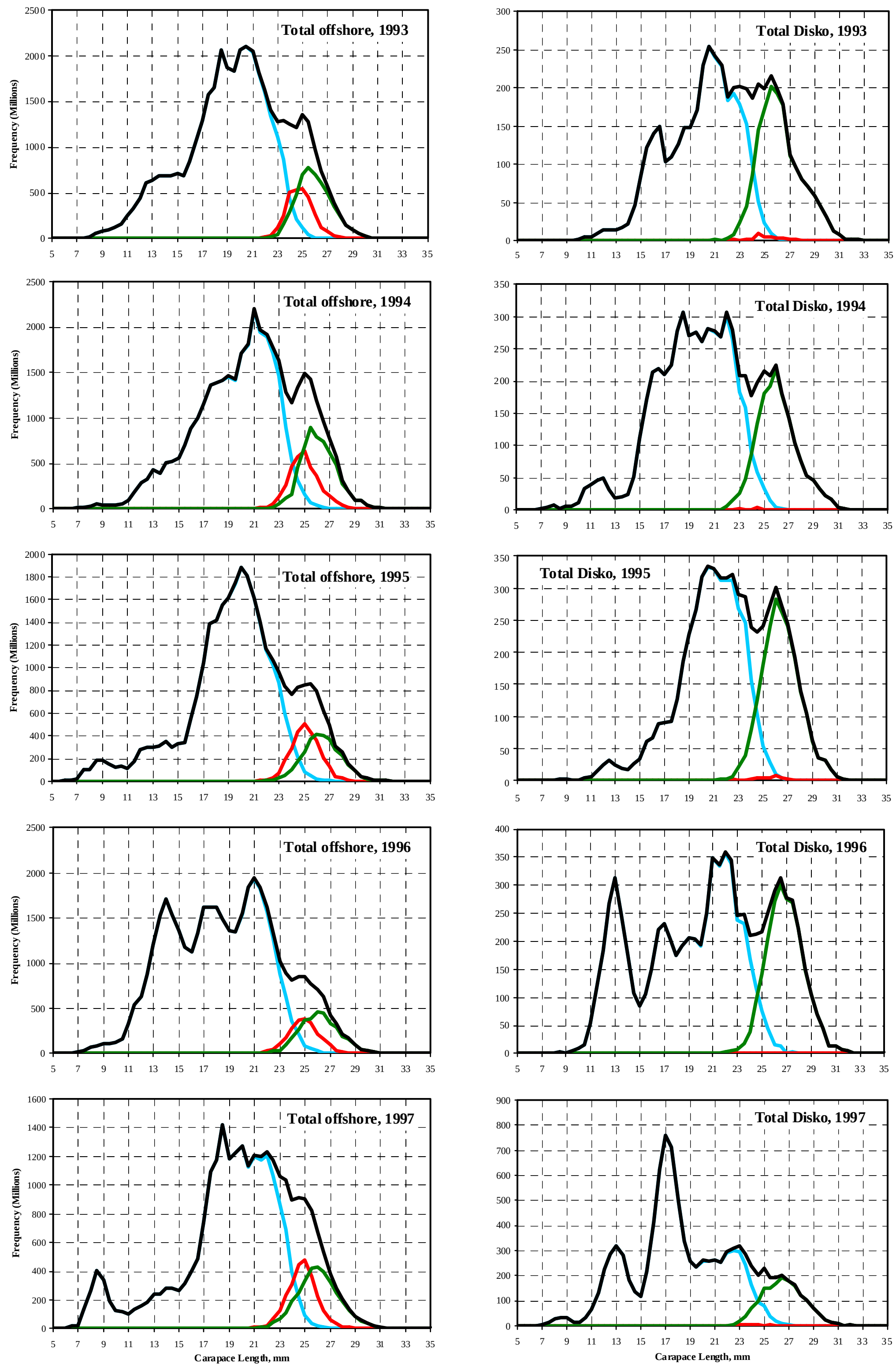

Fig. 9b. Length frequencies of northern shrimp in total offshore and Disko Bay/Vaigat area 1993-1997.

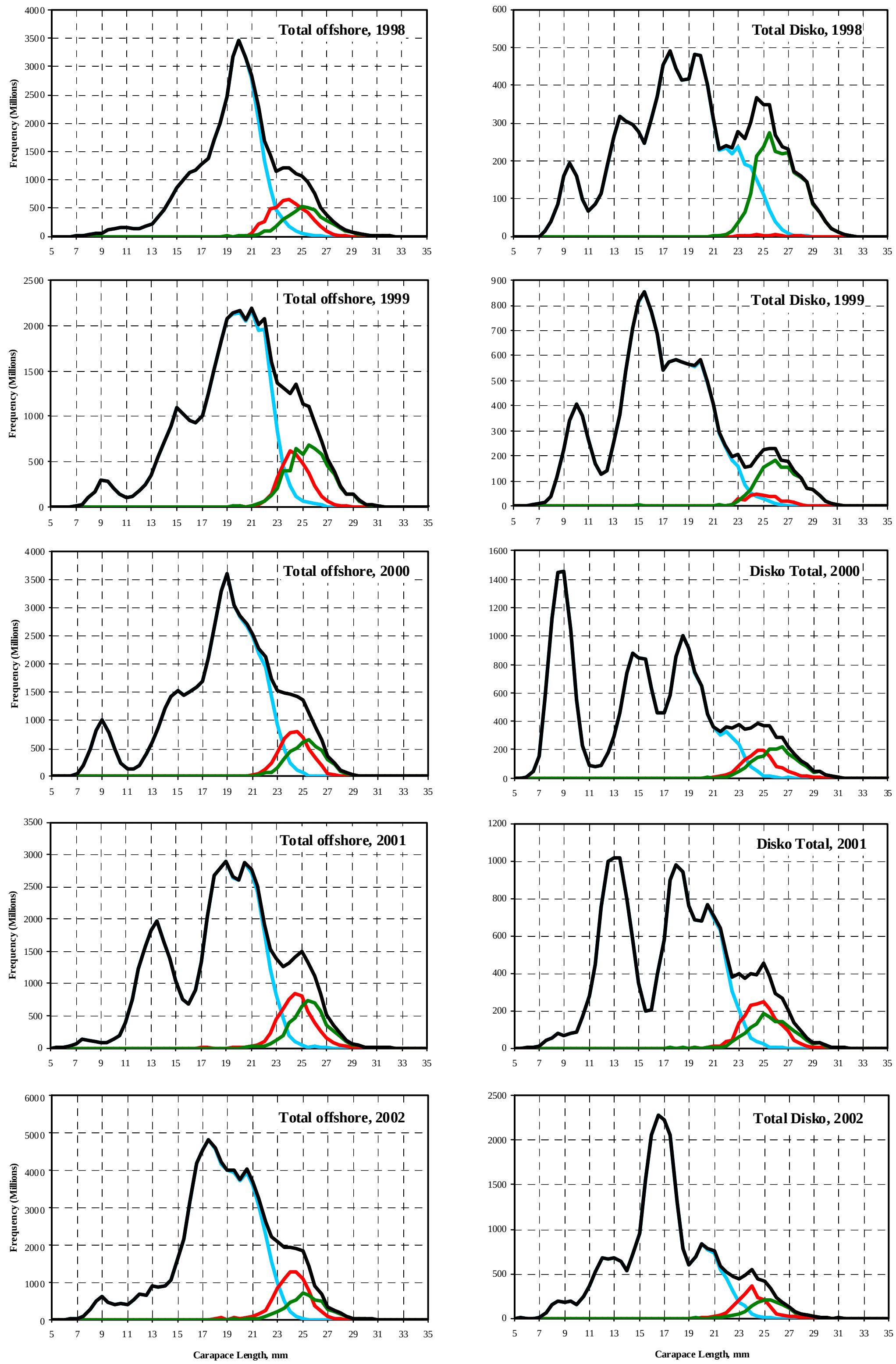

Fig. 9c. Length frequencies of northern shrimp in total offshore and Disko Bay/Vaigat area 1998-2002.

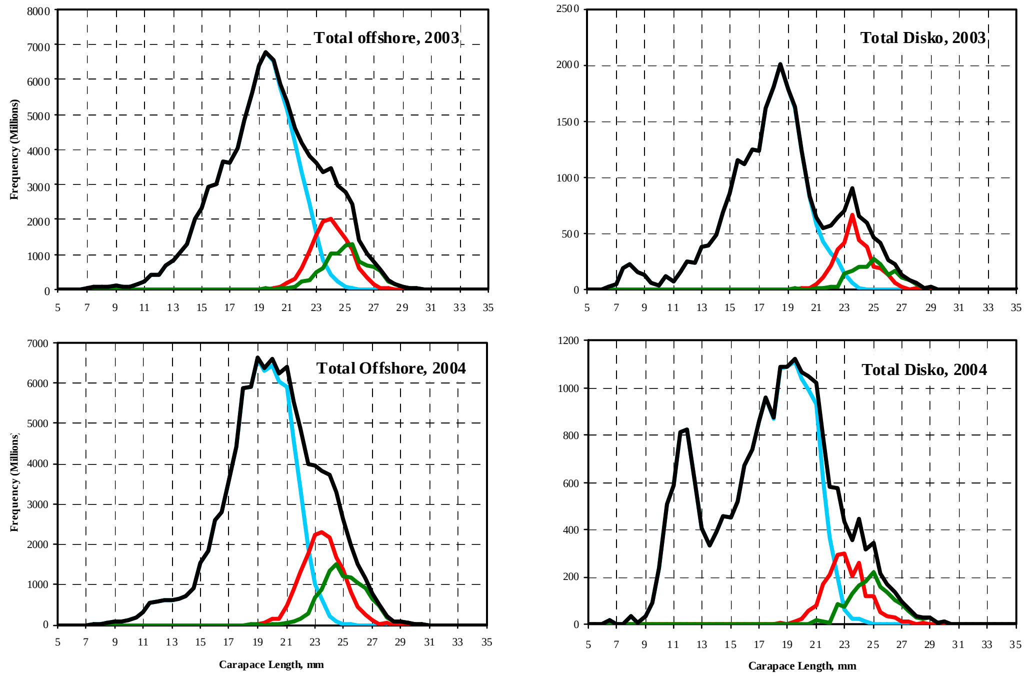

Fig. 9d. Length frequencies of northern shrimp in total offshore and Disko Bay/Vaigat area 2003 and 2004.

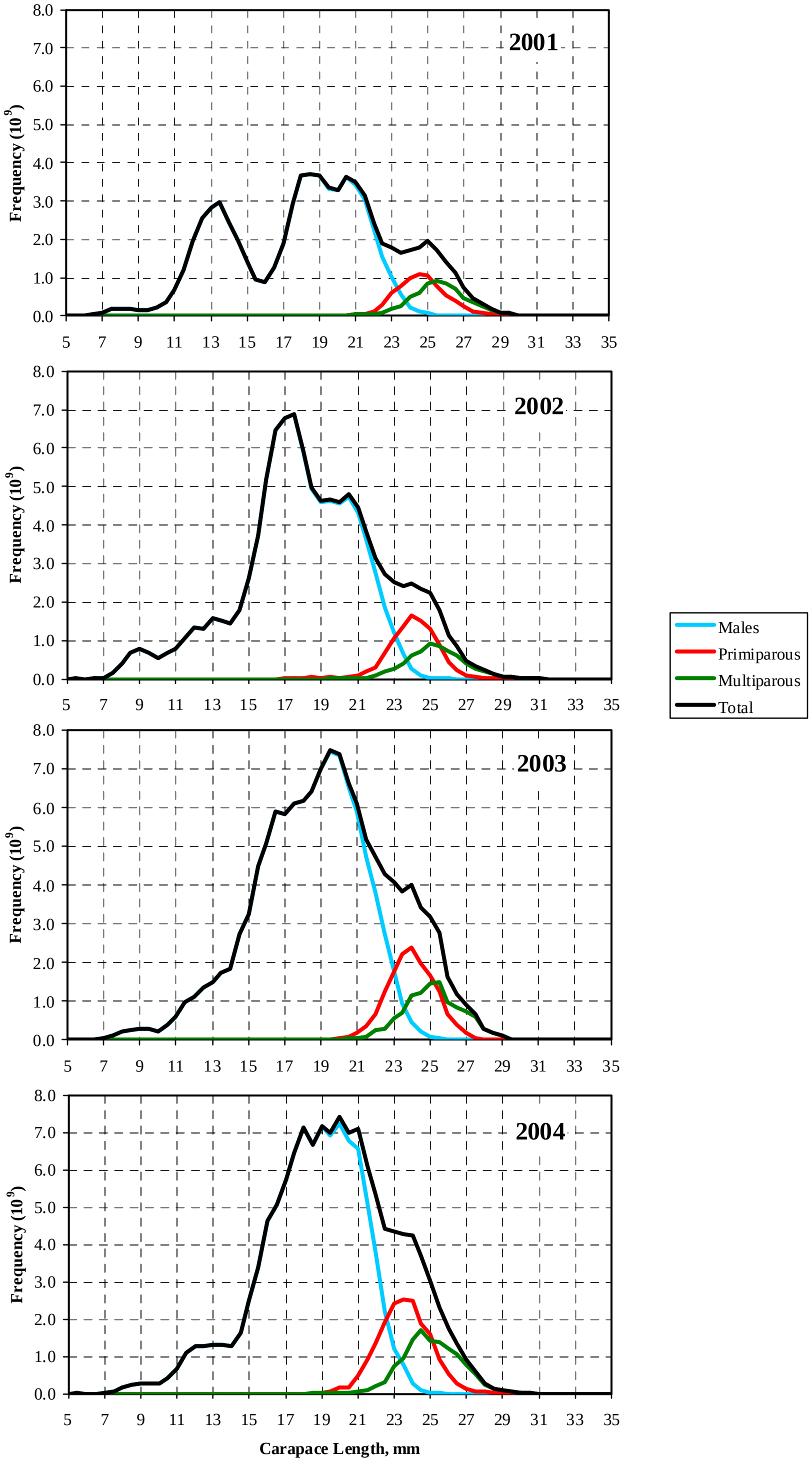

Fig. 10. Length frequencies of northern shrimp in the total survey area (offshore and Disko Bay/Vaigat combined).

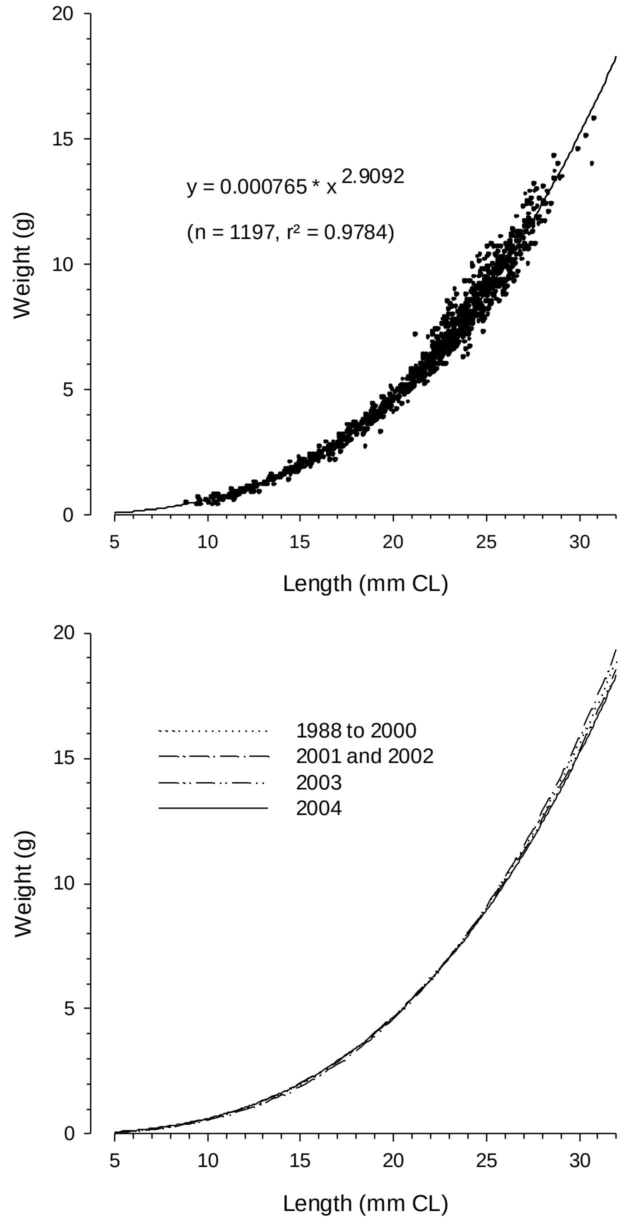

Fig. 11. Length-weight relationship of northern shrimp off West Greenland in 2004 and comparison with length-weight relationships used in previous years.

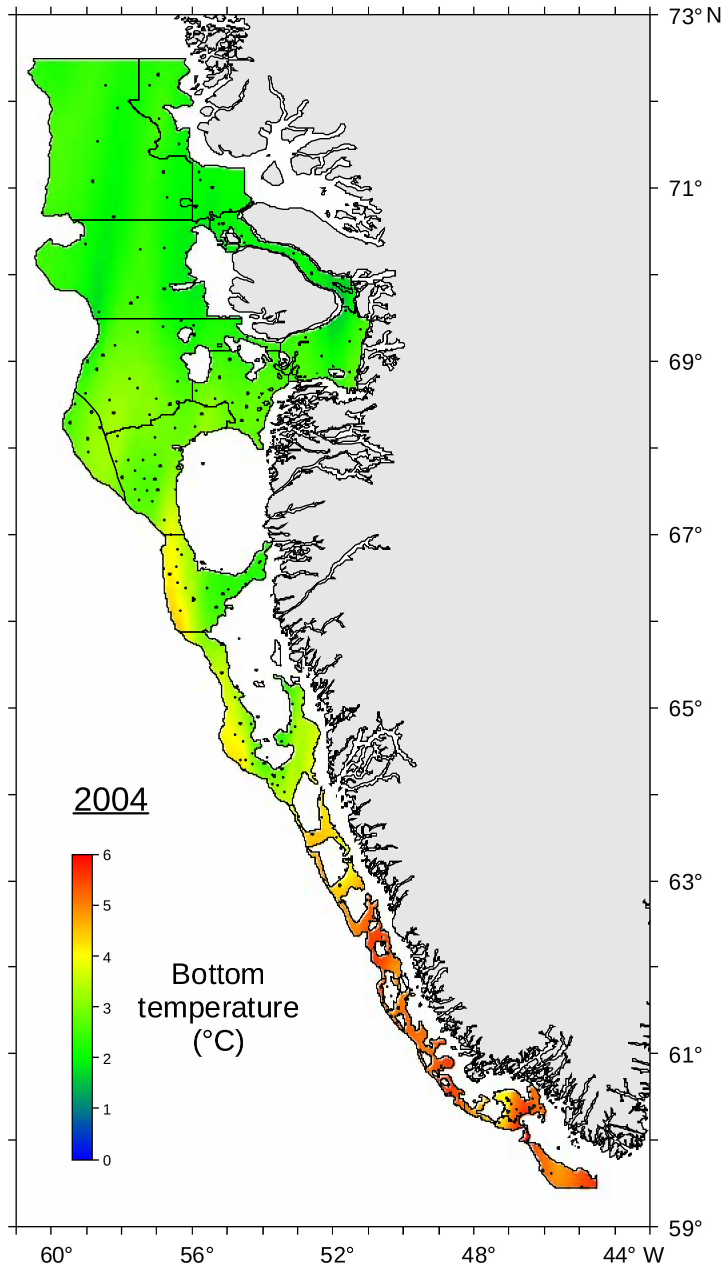

Fig. 12. Distribution of bottom temperature in the survey area between 150 and 600 m depth in 2004.

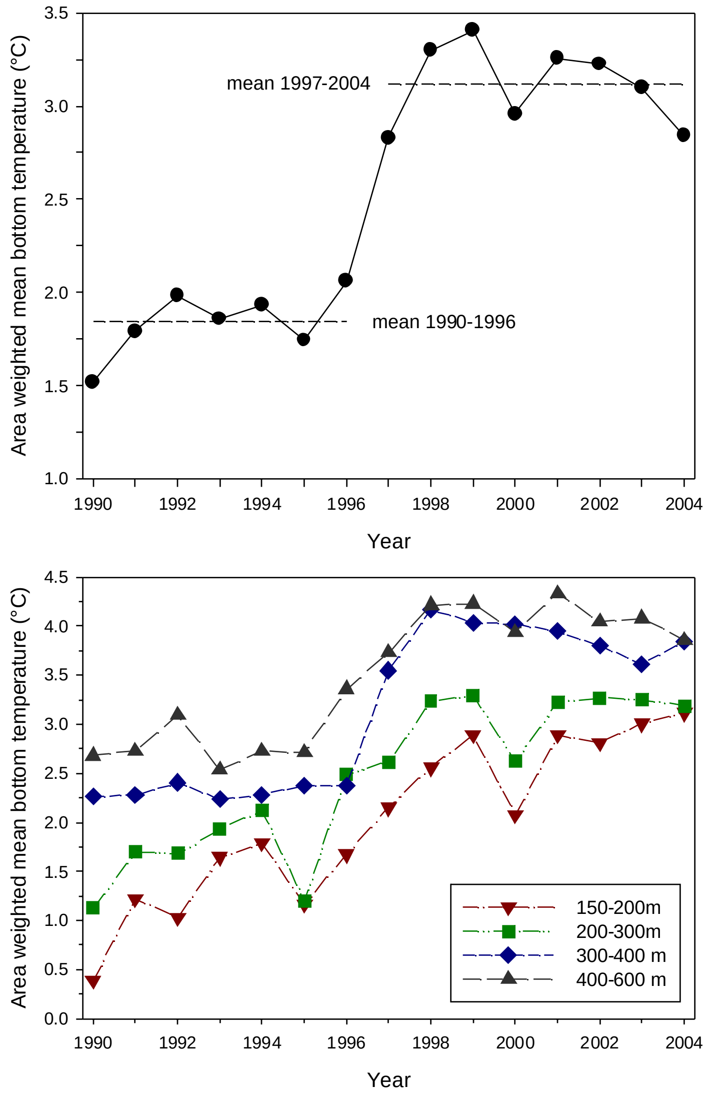

Fig. 13. Area weighted mean bottom temperature for the entire survey area and in the different depth strata in offshore areas C and W1-W7 in 1990 to 2004.