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**Results of the Greenland Bottom Trawl Survey for Northern shrimp (*Pandalus borealis*)  
Off West Greenland (NAFO Sub area 1 and Division 0A), 1988-2008**

by

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**Abstract**

Stratified random bottom trawl surveys have been carried out since 1988 in NAFO Sub area 1 and a small part of NAFO Division 0A (east of 59°30'W) as a contribution to the assessment of the stock of Northern shrimp (*Pandalus borealis*) in West Greenland waters.

Survey estimates of total biomass of Northern shrimp off West Greenland showed little variation over an initial ten-year period, but after a fairly low estimate of 178 000 tons in 1997 the biomass increased steadily to 598 000 tons in 2003. This record high value has been followed by continuous decline to about 282 000 tons in 2008. 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. The decline in total biomass that began after 2003 is especially noticeable in the offshore areas in southwest Greenland waters. The shrimp stock in this year's survey seemed to be concentrated in an area between 68° N and 70° 15' N from the north-western slope of Store Hellefisk bank, west of and at the entrance of Disko Bay, in the Disko Bay and in Vaigat sound and along the coast from Vaigat up to Upernavik. The off shore areas in the south held very few shrimp.

The length distribution in 2008 was dominated by two groups of males' component (carapace length (CL) 15.6 and 22.6 mm). The abundance of recruits at "age 2" in the survey this year was higher than 2007, but still fairly below series mean, suggesting that a considerable decrease in fishable biomass will off W. Greenland will occur in the coming years.

Area weighted mean bottom temperature in the survey area started increasing in the mid-1990s and this relatively warm period continued in 2008, and is above the series mean (1997-2008). Temperatures mean by various depth strata showed no change from the last three year's, although there were a weak decrease in temperatures in shallower waters. There was a slight increase in temperature in all areas northwards, except in the southernmost area (W7-W9), where there were a decrease in temperature.

**Introduction**

Since 1988, the Greenland Institute of Natural Resources has carried out annual stratified-random trawl surveys off West Greenland between July and September to assess the *Pandalus borealis* stock biomass, recruitment and obtain

information on the size and sex composition of the stock as well as on the environmental conditions. This document presents the results of the 2008 survey, and compares these with a revised survey time series from previous surveys.

From 1988 to 2004 a *Skjervøy 3000* trawl was used in the survey, this trawl was changed to a *Cosmos 2000* trawl in 2005. Prompted by that change in survey trawl this paper also describes dimensions of the used trawls and clarifies the approximations on which the swept area calculation rests.

## Material and Methods

### *Survey design and area coverage*

The offshore survey area for Northern shrimp covers the depths between 150-600 m in the NAFO Sub area 1 and a small part in the eastern part of NAFO Div. 0A. Since 1991 the survey also includes the inshore areas Disko Bay and Vaigat in NAFO Div. 1A.

The survey area is divided in primary and secondary strata. The survey primary strata correspond to geographical areas that were identified by Carlsson *et al.*, (2000). based on logbook information on the distribution of the commercial fishery. These primary areas are each sub-stratified in four depth zones (secondary strata), 150-200 m, 200-300 m, 300-400 m, and 400-600 m. Based on survey depth data logged 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 Kannevorff, 2004). Major changes affected region U and the Disko/Vaigat area. In region U geographical borders were changed, and the former areas D1 to D9 (Disko Bay/Vaigat) is now combined into only two areas (I1 and I2). Moreover, the former two areas C1 and C3 in the Canadian EEZ (NAFO Sub area 0) were combined into one (C0).

For the survey in 2008, the depth contours in areas U1, I2, and W7 and W9 were further revised based on data collected in 2007. Due to these revisions, the total survey area (Fig. 1) has increased from about 125000 km<sup>2</sup> in 1995-2002 to 133000 km<sup>2</sup> in 2003 and now covers, since 2004, about 136005 km<sup>2</sup>.

From 1988 through 1999, trawl stations were allocated to strata in proportion to stratum area, but since 2000 more stations have been allocated to strata where high densities and high biomass variances of Northern shrimp were observed in previous years in order to improve the precision of the overall biomass estimate. In 2000 (Kingsley *et al.*, 1999) an exponential smoothing technique for the allocation procedure was applied to give higher influence of more recent observations in the weight factors.

Generally the station allocation procedure is based on a division of the survey area into elements with a spacing of about 2 nautical miles. Until 1998, trawl locations were selected by an adjusted random procedure, in which stations were rejected when allocated to adjacent elements. In 1999 an improved method of choosing station positions for the survey was introduced. This method combines the use of a minimum between-station-distance rule ("buffer zone" rule) with a random allocation scheme (Kingsley *et al.*, 2004).

From 1988 through 1998, all stations have been selected by replacing sampling sites each year. Since 1999 about 50% of the randomly selected stations covered in the preceding year, were repeated as fixed stations in the following year. This was done to evaluate the stability of the stock distribution and to assess the performance of a fixed-station design relative to that of re-sampling (Kingsley, 2001a). 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 present analysis, i.e. data from the fixed and the replaced stations have been used without distinction and the analysis is therefore similar to the ones carried out in years in which all stations were selected at random.

Prior to 1998 the observed densities of Northern shrimp in the region north of 69°30'N were consistently low. Furthermore it was very difficult and time consuming to find suitable bottom for trawling in this region. Against this background a fixed-station sampling design in this area was used between 1998 and 2002. In order to cover all nine secondary strata with a minimum of two stations in each in this area, 20 possible trawl tracks were identified and used as a "track pool" from which stations were chosen at random. Based on this process, between 10 and 18

stations were sampled annually. Since 2003, after having obtained better bathymetric information, the same procedure for stratification and selection of stations as in the other offshore areas has been applied.

In 2008, 214 stations at depths between 150 and 600 m were planned in the survey area. Of these 200 were allocated to the various strata according to the distribution of Northern shrimp in the previous years while 4 and 10 hauls were allocated based on the distribution of Greenland halibut (GHL) and Atlantic cod respectively. In addition, 48 stations were planned at depths < 150 m in NAFO Div. 1A-1F and 11 extra hauls at depths between 600 and 800 m after GHL in NAFO 1B. CTD casts were made along standard transects in the offshore and the Disko Bay/Vaigat area. But due to complications with machinery, not all transects this year were taken. Both, the results of fish catches and the observations from the hydrographical transects will be reported as usual elsewhere, i.e. at the NAFO Scientific Council Meeting in June 2009.

#### *Survey period and daily sampling period*

The trawl surveys has been carried out during the period of mid June to the end of August) to minimize the effect of seasonal variations. In order to reduce the possible influence of light induced nocturnal vertical migrations of shrimp, trawling is carried out only between 0900 and 1930 UTC.

#### *Tow duration*

Survey tow duration 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 but in 2005 standard tow duration was set to 15 minutes at all stations against considerations noted below.

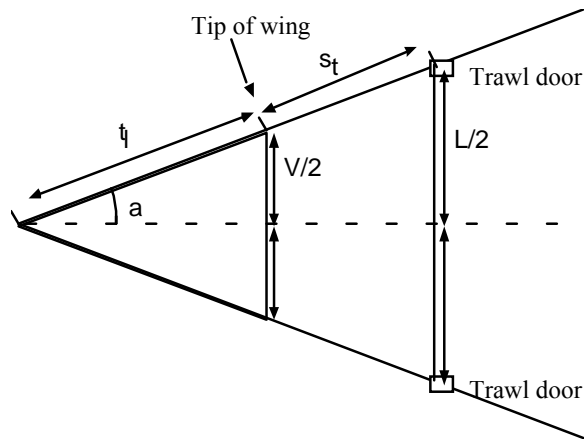
Results reported by Kingsley *et al.* (2002) have so far indicated that 15 min tows do not give more variable results than 30 min tows and hence no weighting was applied to tows of different durations. On the other hand, analyses of survey data from 1999 and 2000 have shown that the effective swept area is somewhat larger than estimated corresponding to 2.78 minutes in duration per haul (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, 2001b). Assumedly the difficulty in determining the precise time of the beginning of a tow is the major cause for this considerable variability of this 'end-error'. The start point of a tow is estimated on information from an acoustic sensor ('trawl eye') that measures the distance between the headline and the ground gear at the bottom. Because it takes some time for the trawl to 'land/stabilize' 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 the unknown part of the shrimp stock that swims above the bottom at the time of setting the trawl. This factor is very difficult to assess and may vary substantially with time of day, composition of the stock etc. However, based on a more extended data set than previously available, Wieland and Storr-Paulsen (2006) demonstrated that for Northern shrimp and Greenland halibut, neither total biomass density nor numerical densities of different size groups differed significantly between 15 and 30 min tows. Thus no indication was found that 15 min tows give less precise results than 30 min tows. Tow duration had no significant effect on mean size and maximum length of catches of both species. These results indicate that the used mixture of 15 and 30 min tows can be replaced by 15 min tows on all stations without any impact on the continuity of the time series of survey estimates. This practice was consequently implemented in 2005 and no corrections for different tow durations in the previous years have been included in the present analysis of the status of the stock.

### Fishing practices

The survey have been conducted with the research trawler *Paamiut* (722 GRT) since 1991 or similar vessels in the years 1988 to 1990. Initially, a 3000/20-mesh *Skjervøy* bottom trawl with a twin cod-end has been used. 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. From 1988-1991 estimates of door spread and height of the head rope over the bottom were based on results from tank experiments performed by the Danish Institute for Fisheries Technology and Aquaculture. From 1991 and onwards these dimensions have been measured with *Scanmar* acoustic sensors mounted on the trawl doors, and a *Furuno* trawl eye mounted on the head rope. From 1988 through 2003 the trawl doors were of the type *Greenland Perfect*, measuring 9.25 m<sup>2</sup> and weighing 2 420 kg. They were replaced in 2004 by *Injector International* 7.5 m<sup>2</sup> trawl doors with a weight of 2 800 kg to facilitate a change of survey trawl in 2005. In 2005 the *Skjervøy* 3000 trawl equipped with a heavy bobbin footrope was replaced by a ‘rock hopper’ *Cosmos* 2000 trawl with a bobbin / rubber disk ground gear. Towing speed have been about 2.5 knots in all cases.

### Swept area calculation

For both trawls the wingspread (i.e. the width of the swept area)  $V$  have been calculated based on the following principles, assumptions and approximations. The trawl and the trawl plus bridles are assumed to form two similar triangles:



The width between trawl doors ( $L$ ) is monitored during towing by sensors (“SCANMAR HC4”). The total length of the trawl excluding the cod end ( $t_l$ ) is known (measured on land) as well as the total length between the trawl door and the tip of the wing “bridle length” ( $s_t$ ) (measured on land). Two expressions for  $\sin a$  can be formed and put equal to each other:

$$\sin(a) = (L/2) / (t_l + s_t) \text{ and } \sin(a) = (V/2) / t_l$$

This gives the opportunity to form an expression for  $V$ , the width of the swept area, as:

$$V = (t_l * L) / (t_l + s_t).$$

The length of the *Skjervøy* trawl is 67.15 m and the length of the *Cosmos* trawl is 71.8 m, both measures exclude the cod ends. In 2004 and thereafter, the bridle length, i.e. the total length of lines, chains and shackles between the trawl doors and the tip of the trawl wing, was 54 m for both trawls whereas other bridle lengths were used in earlier years (Tab. 1). In the case of the *Skjervøy* trawl a factor of 0.7 m have been added to the expression for  $V$ . This

factor was added since the *Skjervøy* trawl is a three-winged trawl and the lower wings (the wings directly attached to the ground-rope) were estimated to spread 0,35 meters wider than the middle wings on each side in tank experiments at the Danish Institute for Fisheries Technology and Aquaculture (Per Kanneworff, pers. com.).

The distance between the trawl doors was recorded 3 or 5 times during each haul and mean wingspread for each tow was calculated from average door spread and the geometry of the trawl as described above. Nominal swept area was calculated as the straight-line track length between start and end-positions (GPS) multiplied by the mean wingspread for each tow.

#### *Biomass estimation*

For each tow, the catch was divided by the estimated swept area calculated from wingspread and track length to estimate haul by haul biomass 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:

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

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  $B \times 0.985$  in cases in which only one tow per stratum has been available.

#### *Sampling, weighting and “area expansion”*

From each catch a sample of about 1.5 to 3 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 according to Allen (1959) and McCrary (1971). The oblique carapace length (CL) of each shrimp in the sub sample was furthermore measured to the nearest 0.1 mm using callipers.

To estimate the total number of shrimp by sex and length group (0.5 mm intervals) for each stratum the number of Northern shrimp in the samples was weighted by total catch according to the expression:

$$\hat{N}_l = n_l \times \frac{C}{S}$$

Where  $\hat{N}_l$  denotes number of shrimp of carapace length (CL)  $l$  at each station,  $n_l$  equals the number of shrimp of CL  $l$  in a sub sample with a weight of  $S$  from a haul with a total catch of  $C$ .

Weighting by stratum area was achieved according to the expression:

$$\hat{N}_{ls} = A_s \times \frac{\sum \hat{N}_l}{\sum sa}$$

Where  $\hat{N}_{ls}$  is the number of shrimp of CL  $l$  in stratum,  $A_s$  is the stratum area,  $\sum \hat{N}_l$  is the sum of all shrimp in all hauls within stratum  $A$  and  $\sum sa$  the sum of swept areas in stratum  $A$ .

Results from these calculations were subsequently used to construct area-specific length frequencies distributions (LFD) (until 2006) and for this year's study length density distributions (LDD). Both LFD results and LDD results was used to calculate abundance indices for males and females as well as for small (<17 mm) specimens, which are expected to enter the fishery in the coming year.

Until 2006 indices of male and female biomass were 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 specimens with a length equal to and greater than 17 mm CL converted to weight. In both cases length-weight relationships given in Carlsson and Kannevorf (2000) and Wieland (2002a) were used for the period prior to 2001 and the years 2001 and 2002, respectively. In 2003, 2004, 2005 and 2006 new length-weight data were collected from all parts of the survey area and male, female and fishable biomass were calculated from these annual length-weight relationships.

For this year's report indices of male and female biomass was estimated based on haul by haul length specific densities (# of shrimp/km<sup>2</sup>) averaged for each secondary stratum (depth stratum) and converted to biomass density by application of sex specific length/weight relationships (see Figure 8). Biomass for each depth stratum were calculated by multiplying average biomass density with relevant areas of depth strata and biomass estimates for primary strata were obtained by summing biomasses from each depth stratum contained in the primary strata and finally the entire survey area. The estimate of fishable biomass (CL  $\geq$  17 mm) was obtained using the same principles. As a check on the validity of this later calculation method I compared the total biomass for the whole survey area calculated in this fashion (270,5 thousand tons) with the catch weight based estimate (282,1 thousand tons) presented in this paper. The difference is about 11 %.

In previous years abundance indices for age 2 were obtained by modal analysis of regional length frequencies for juveniles and males using the MIX 3.1A software (MacDonald and Pitcher, 1979; MacDonald and Green, 1988; release 3.1A by Ichthus Data Systems in 1993). The regions for pooling the original length frequencies were defined considering latitudinal gradients in bottom temperature (Wieland, 2004a). No smoothing of the length frequency histograms was applied prior to the analysis. Initial estimates of the modes and the number of age groups to be considered were obtained by visual inspection of the length frequencies. A constant coefficient of variation for length at age was used in the MIX analysis during a first run. However, because the first age group was not well represented in many of the samples, a part of the larger males had already changed sex and differences in growth between cohorts were likely, varying coefficients of variation were finally used.

Modal analysis on data from this year's survey is based on the use of the CMIX software (de la Mare, 1994, CMIX.EXE 1997, © Australian Antarctic Division) implemented as an Excel Add-In. This program is designed to fit a mixture of normal distributions to length-density distributions derived from net/trawl survey data. In its function it is similar to the previously used method, MIX, (MacDonald and Pitcher, 1979) but CMIX uses a maximum likelihood estimator that assumes that the length-density data have an Aitchison delta distribution. This distribution is more suitable for describing densities estimated from trawl surveys since it provides for the possibility that some survey hauls will be empty (zero-catches) (Aitchison, 1955; Pennington, 1983). Input data consists of haul by haul length density data and output consists of estimates of normal component mean length and standard deviation together with mean densities and standard deviations. For further details see the CMIX user manual & specifications that can be downloaded along with the program from <http://www.aad.gov.au/default.asp?casid=4709>.

#### *Gross recruitment rate $R_{(t)}$*

For this report the proportion of recruits in the W. Greenland *P. borealis* stock, from 1993 to 2008 have been calculated as the gross recruitment rate  $R_{(t)}$ :

$$R_{(t)} = \frac{A_0}{\sum_{i=t}^n A_i}$$

were  $A_i$  is the number of animals in the age class  $i$ , and  $n$  is the age of the oldest animals in the population in non-negligible numbers. In the case of this study  $A_0$  denotes the number of “age 2” shrimp in the survey area.

For the years 2005 through 2008 ' $R_{(t)}$ ' has also been calculated with the aid of CMIX according to (de la Mare 1994) using the expression:

$$'R_{(t)} = \frac{D_t}{\sum_{i=t}^n D_i}$$

were  $D_i$  is the total density of animals aged  $i$  in the population and  $D_t$  the density of, in the case of this study the “age 2” (1+ year old) shrimp.

### *Bottom temperature*

Until 1994 bottom temperatures were measured with a *Seabird* CTD and thereafter with a *Seamon* sensor mounted on one of the trawl doors. The *Seamon* sensor records data in intervals of 30s with a resolution of 0.01°C. Average temperatures for each haul 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 the change of the survey trawl**

Figure 2 compares wingspread and vertical opening of the *Skjervøy* trawl with the *Cosmos* trawl during experimental hauls conducted for calibration purposes (Rosing and Wieland, 2005). For the *Cosmos* trawl, average wingspread was about 8 m wider than that of *Skjervøy* trawl and the vertical opening was about 1.5 m higher. Both differences being statistically significant (Paired t-test,  $P < 0.001$ ). The calculation of the swept area takes the difference in wingspread into account while the vertical opening of the trawl has, as in previous years, not been considered in the biomass estimates. In addition to the trawl dimension, the change of the type of the ground gear seems to induce a size dependent effect on the catchability for Northern shrimp and length-dependent conversion factors were provided by Rosing and Wieland (2005). These values, however, were based on total catches in numbers by length class in a tow (and not numerical densities by length class) and did thus not include the effect of the different dimensions of the two trawls. Therefore, the length-dependent conversion factors were supplemented by a length-independent adjustment based on the mean ratio of the swept areas fished by the two trawls in the paired tows of the calibration experiment, which amounted to 0.8708 (s.e.: 0.0075).

### **Area coverage**

As usual, a number of planned trawling sites had to be cancelled due to combinations of unfavourable bottom conditions, sea ice coverage and/or time restrictions although the new trawl is much less sensitive to rough bottom conditions than the previous survey trawl. In 2008, 214 stations at depths between 150 and 600 m were planned – 205 of these were successfully covered during the survey.

## Total biomass and distribution

### *Over-all Biomass trends*

For all strata biomass estimates have been calculated (Tab.2) on the basis of the nominal swept area. The biomass estimates (in tons) for the five main regions and the entire survey area in 2008 are:

Region	Biomass estimate (t)	Number of stations	OECV (%)
North (U1-U3)	91 700	22	17,3
Canadian zone	16 700	6	80,7
West (incl. South)	122 900	157	14,8
Disko B./Vaigat (I)	50 800	20	31,1
Total	282 100	205	11,28

The estimated total biomass for the period 1988 to 1997 remained fairly stable around a mean of 200 000 tons. After 1997, the biomass increased to a record high estimate of 598 000 tons in 2003 followed by a decline to 575 000 tons in 2004, 552 000 tons in 2005, 484 200 tons in 2006, 349 000 tons in 2007. In 2008 it has declined to about 282 100 tons (Tab.3, Fig.3 upper panel), which is 36% lower than last year.

Survey indices of biomass per unit area, which accounts for the extension of the survey area in 2003 and thereafter, as well as the swept area estimates of total abundance (Fig. 3 lower panel) indicate a decreasing trend.

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 (Tab. 4). The OECV for the total survey in 2004 and in 2005, however, was 16%, which is 1.5% above the average since all regions were included in the survey area in 1994. This is most likely due to the relative low number of stations covered in these two years with a change in the distribution of Northern shrimp towards shallower depths (see below). In 2006 and 2007, the number of stations was increased and the OECV declined again to 13.4% and 12.26% respectively. In 2008 the OECV was lower than the previous four years, on a level at 11.3%.

The total biomass in each of the main survey regions has shown large biomass changes throughout the last decade (tab. 3 and fig. 4). Until the middle of the decade a remarkable contribution to the biomass came from all regions south of U1 - U3. This year the contributions came mainly from area W1-W2, the Disko Bay and area U1-U3. The contribution of the southernmost offshore region (W8 and W9) to the overall biomass shows an almost null biomass and for the remaining offshore area (W1 to W7) a sharp decline since 2004.

The overall survey biomass index has decreased substantially since 2003 in the West Greenland. This year's result follows the same general pattern, but with a trend that the biomass concentrations has gone northwards (Fig. 4). Thus U1-U3 and C0 have an increased biomass estimates, although C0 have a very high OECV (80.7%), indicating a high uncertainty for the Canadian results (tab. 4).

This year's survey results indicate a continued decrease in fishable biomass (tab. 8). This year's total biomass is only 47 % of the biomass observed in 2003 and the fishable biomass in 2008 is 48% of that observed in 2003. Most of the shrimp biomass was concentrated in the areas U1-U3, W1- W2 and the Disko/Vaigat. Moderate biomass values were observed in the area W3-W4. Within this overall decreasing trend the offshore areas W1 and W2 this year show a decrease in biomass to half of what was found in 2007. In the northern areas (U1-U3) there was an increase of 33% compared to last year's results. Areas W3 – W7 show a modest decrease. All the southern areas W5-W9 show substantial decreases and shrimp density in these areas were generally very low to nearly absent.

Biomass in the Disko/Vaigat area decreased with about 28 thousand tons compared to last year. That area contributes 19% of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore decreased with 53 thousand tonnes while the decrease in fishable biomass in Disko/Vaigat area was about 38 thousand tons.



In conclusion 35 % of the total biomass in 2008 was found in areas U1-U3 that covers about 38 % of the survey area. W1-W2 contributed with 23% of the total biomass and Disko/Vaigat 18%. W3-W4 contributed with 15%, W5-W6 contributed with 8% and W7-W9 approx. null. Hence the shrimp biomass in 2008 appeared to be concentrated in the U1-U3, in offshore areas W1-W2 and in the Disko/Vaigat area.

#### *Depth distribution of the shrimp biomass.*

Figure 5 shows how the biomass has been distributed into the four investigated depth intervals over the survey period. The biggest proportion of the biomass is still to be found in the depth between 200-300 m, but the amount has decreased since 2004. 2004 was the year where the biomass had the highest peak in depth between 200-300m, since then the proportion has fallen to 60% today. Prior to 1994 the bulk of the biomass was found between 300 and 400 m depth. This gradually changed during the period 1994 to 2001 and now most of the biomass ( $\approx 70\%$  of the overall biomass) is found in the 200-300 m irrespective of observed total stock biomass changes. During the same period of time, the relative importance of the 300-400 m (and to a minor extent the 400-600 m interval) interval seems to have decreased proportionally. In 2005 the biomass proportion present in the important 200-300 m depth interval decreased substantially while simultaneously it increased in the 150-200 m interval.

#### *Shrimp density distribution*

##### **Off shore areas (U1-U3, C0, W1-W9)**

In 2008 the highest off shore densities were found in the W1-2 and the U1-3 area (Figure 3 lower panel and table 5). The highest densities were found in the combined area of strata W1-2 (West of Disko Bay), and W3-W4 (Northwest slope of St. Hellefisk Bank). In the northern offshore regions (regions U1-U3) the highest densities were observed in the easternmost region (U3). Shrimp densities in the remaining southerly offshore areas (W5-W9) generally showed substantial decreases and densities observed in 2008 are the lowest ever (Table 5).

C0 had a very high shrimp density distribution, but the overall error of coefficient of variation (OECV) for C0 is also very high (80%), so the results is not reliable (see table 4).

The shrimp density distribution results follow the general trend, that biomass is going downwards, see table 5 and figure 3 lower panel. Thus the biomass in W1-W2 has decreased with 52% compared to last year. Density in W3-4 had decreased 30% and W8-9 had a decrease of about 39%, whereas the density in W5-7 didn't change. The U1-3 has an increased density at 52% compared to last year. The overall average density is 2.074 for the time period 1991-2008 and the density for offshore is 1.8 tons/km.

##### **Inshore areas I1 and 2 (Disko/Vaigat)**

Estimated density of Northern shrimp in the Disko Bay/Vaigat region has always been very high compared to the offshore areas (Tab.5). But this year the density estimate for Inshore area is the lowest since 1997 (5.10 tons/km). That is 36% lower than last year. For the Disko/Vaigat the overall average density is 6.9 for the time period 1991-2008 and the result for this year is lower than the average over time.

#### **Conclusion**

In conclusion the shrimp density distribution is low, overall is a steadily declining trend to be found. Thus it can be expected that the density the coming years will decrease further.

## Demography and recruitment

### *Size distribution by area in 2008*

Figure 6 gives length density distributions for males in combined strata in the survey area in 2008, Fig. 7 gives the length frequency distribution for all shrimp sexes combined (juveniles/males, primiparous and females) in the survey area in a time span of 1993 to 2006. Figure 8 gives the length frequency distribution in the period from 2004 till 2008.

The results presented in the length density distribution graphs (Fig. 6) supports the notion that this year the stock was concentrated to the Areas within C0, W1-W4, the Disko/Vaigat area and to some extent the easternmost north area U3. The results from these areas indicate a wider range of sizes of males than last year.

In the analysis of all sexes combined in the total survey area four modes, one at about 11 mm and one at about 16 mm, one about 21mm and 24 mm are identified for 2008. Last year two modes were found, one at about 19.5mm and one at about 23 mm, and the former consisted mainly of males and the latter of primiparous females (fig. 8 two lowest graphs). The first three consists mainly of males and the latter of primiparous females (Bergstrøm, 2007). The splitting of a year class in connection with changing sex from male stage to primiparous female stage is a well documented phenomenon (Rasmussen, 1953; Bergstrøm, 2000) within the species distribution area.

### *Length-weight relationship*

Until 2006 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 and the resulting length-weight relationship for 2006 differed not very much from those used in previous years :

1988-2000:	$W = 0.000669 * CL^{2.96}$
2001-2002:	$W = 0.000483 * CL^{3.0576}$
2003:	$W = 0.000752 * CL^{2.9177}$
2004:	$W = 0.000765 * CL^{2.9092}$
2005:	$W = 0.000529 * CL^{3.0213}$
2006:	$W = 0.000660 * CL^{2.9461}$

In 2007 and 2008 the length-weight relationship, calculated for the period 2001-2006, were used to determine length weight relationships for “all sexes” pooled, juveniles and males and all females (Fig. 9) Regressions were fitted using the least square method implemented in the software “Sigma Plot”.

The resulting expressions are:

$$\text{All sexes:} \quad W=0.0006*CL^{2.9941}; n= 6737; R^2= 0.9724$$

$$\text{All females:} \quad W=0.0006*CL^{2.9635}; n= 3590; R^2= 0.8998$$

$$\text{Juveniles and Males:} \quad W=0.0006*CL^{2.9934}; n= 3147; R^2= 0.9760$$

Weight (W) is weight in g and CL is carapace length in mm.

### *Total abundance, spawning stock biomass and fishable biomass*

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 6. The total number of males and females together for 2008 is below the value for 2007, and is below the long-term mean. This year's estimate of 54.0 billion

is 12% below the time series mean of 62.1 billion. Abundance of shrimps at “age 2” were almost four times higher this year compared to last year (table 10), but still below long time average on  $7.65 \times 10^9$  (Bergström, 2007).

Estimates of total stock biomass derived from a conversion of the length frequencies to weight are listed in Table 7. Total biomass calculated in this way has differed by 4% from the direct estimates of the total survey biomass (Tab.3).

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 was in 2003 at the record high level of 548 000 tons for the entire survey area. In 2008, the fishable biomass index for the entire survey area amounts to about 262 400 tons, which is below the long-term average (284 000). Worth noting is that the rate of decrease seems to have been increasing since 2003.

Female biomass estimates decreased with 17% this year compared to last year. Male biomass decreased with 27% and there has been a decrease at 24% in overall fishable biomass.

#### *Recruitment and mean length at age 2(age1+)*

Observed average length density distribution of juvenile and male *P. borealis* with standard errors by region in 2008 are given together with fitted Gaussian components for age 1, 2, and 3 and composite expected distributions in Figure 6 a-6e. Results from 1993-2008 are listed in Table 9. The Gaussian components fitted the observed distribution in the size range of the different age groups reasonably well in almost all cases. Regional differences and annual changes in the mean length at age 2 have been noted and related to shifts in average temperature and changes in density of shrimp (Wieland, 2005).

Table 10 gives estimated abundances of “age 2” shrimp and total stock abundance for the years 1993-2008 together with gross recruitment rate  $R(t)$ . High  $R(t)$  values were observed in 1996, 1999, 2000, and in 2001 and very low values have been observed since 2003-the lowest in 2007. The high recruitment rate values in 1996 most likely caused increasing abundance values during the period 1997-2000 and the high and increasing recruitment rate values during the period 1999-2001 probably are behind the very high abundance values (and resulting biomasses) the following couple of years.

Earlier survey reports (e.g. Wieland and Bergström 2005; Wieland and Bergström 2006) have investigated and reported significant correlations between the abundance indices for age 2 and the fishable biomass (all individuals  $\geq 17$  mm CL) one, two and three years later.

During the initial period 1993 to 1995, low estimates of abundance at age 2 were obtained in particular for the inshore area. This was followed by exceptionally high values in the offshore area in 1996 but dropped again in 1997. However since 1997 “Age 2” abundance increased steadily until a record high value in 2001. Thereafter it has steadily declined to  $3.4 \times 10^9$  individuals in 2005. The 2006 estimates amounting to  $4.5 \times 10^9$  indicates a slight increase in recruitment, but was much below the long-term average of  $7.34 \times 10^9$  individuals. This decrease has continued in 2007 to a level of  $1.2 \times 10^9$  shrimp. In 2008 the abundance of “age 2” is higher ( $4.91 \times 10^9$ ), but still below long term average. Figure 10 shows the contribution of recruits from inshore and offshore areas and the inshore area contributes with 64% of the total recruitment stock this year, although the inshore area only consists of 7% of the total area.

The conclusion is that the recruitment levels observed this year did not get up to level with long term recruitment levels. Thus a continued decrease of the fishable biomass in coming years will be expected.

#### **Bottom temperature**

Area weighted bottom temperatures are given in Fig. 11. Bottom temperatures this year was above average.

Regionally the temperature was higher in all regions compared to last year. In the northernmost region (U1-U3) the temperature was 3.1 °C, in Disko/Vaigat area 3.1 °C, in C0 and W1-W4 it was 3.2 °C, W5-W6 it was 4.2 °C and in southernmost region W7-W9 it was 4.2 °C.

In depths between 151-200 m the area weighted average bottom temperature was 2.3 °C, in depths between 201-300 m it is 3.2 °C, in depths between 301-400 m it is 5.0 °C and in depths between 401-600 m 4.0 °C. The difference between the long term average temperature for 1990-2007 and the results for 2008 gives an increase for 151-200 m on 1%, 201-300 m on 18%, 301-400 m 35% and for 401-600 m it is 10%.

In conclusion the temperature has increased for the area weighted average temperature for West Greenland.

## Conclusions

Estimates of Northern shrimp (*Pandalus borealis*) biomass derived from stratified random surveys performed in West Greenland waters since 1988 showed little variation until 1997 with annual estimates of the standing stock of between 150 000 and 235 000 tons. Since 1997 a continuous increase in survey biomass was observed to a record high value of 598 000 in 2003, followed by a decline to 282 000 tons in 2008.

This year's survey results indicate that the decrease in total biomass index and in fishable biomass, that started after the record high values observed in 2003, continues. Biomass in the Disko/Vaigat area decreased with 38% compared to last year. That area still contributes 19% of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore decreased with 21%, while the decrease in fishable biomass in Disko/Vaigat area was about 44%. The proportion of males has decreased with 27% and the female proportion fell with 17% compared to 2007.

Regionally 35 % of the total biomass in 2008 was found in areas U1-U3 that covers about 38 % of the survey area. W1-W2 contributed with 23% of the total biomass and Disko/Vaigat 18%. W3-W4 contributed with 15%, W5-W6 contributed with 8% and W7-W9 approx. null. Hence the shrimp biomass in 2008 appeared to be concentrated in the U1-U3, in offshore areas W1-W2 and in the Disko/Vaigat area.

In 2008 the abundance of "age 2" is higher ( $4.91 \cdot 10^9$ ) than in 2007, but still below long term average. A notice on 2007 data for abundance shows that that year had the lowest amount of shrimps since 1993. The contribution of recruits from inshore area contributes with 64% of the total recruitment stock this year, although the inshore area only consists of 7% of the total area.

The conclusion is that the recruitment levels observed this year did not get up to level with long term recruitment levels. Thus a continued decrease of the biomass and fishable biomass in coming years will be expected.

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Table 1. Vessel, trawl types and rigging parameters used in the West Greenland Bottom Trawl Survey for shrimp and fish (\*: from tank experiments (Per Kannevorff, pers.com.), \*\*: average for all valid tows calculated from measures of door spread and approximated geometry of the trawl).

Year / period	Vessel name	Trawl type	Bridle total length (m)	Wingspread (m)	
1988	Elias Kleist	Skjervøy	59.9	23.1	*
1989	Sisimiut	Skjervøy	81.1	17.9	*
1990	Maniitsoq	Skjervøy	59.9	23.1	*
1991	Paamiut	Skjervøy	75.1	28.3	**
1992 - 2003	Paamiut	Skjervøy	60.1	20.1 - 25.2	**
2004	Paamiut	Skjervøy	54.0	25.7	**
2005 - 2008	Paamiut	Cosmos	54.0	28.1 - 28.6	**

Tab. 2. Basics for all strata.

Stratum	Depth	Area (km <sup>2</sup> )	Biomass	Hauls	STD	CV (%)
W1-1	150-200	2873	2410	2	1170	49
W1-2	200-300	6099	15700	18	17723	113
W1-3	300-400	7520	13212	8	10838	82
W1-4	400-600	816	50	1 -	-	
W2-1	150-200	1674	0	1 -	-	
W2-2	200-300	2612	23155	9	17750	77
W2-3	300-400	1741	6496	5	5691	88
W2-4	400-600	916	259	1 -	-	
W3-1	150-200	2122	61	4	118	192
W3-2	200-300	4725	30735	17	50377	164
W3-3	300-400	2085	6411	3	8727	136
W3-4	400-600	2994	1827	4	1620	89
W4-1	150-200	4119	950	1	-	
W4-2	200-300	1818	8	2	6	70
W4-3	300-400	821	31	4	48	157
W4-4	400-600	1961	19	2	19	101
W5-1	150-200	3001	170	5	332	196
W5-2	200-300	3648	4295	10	12354	288
W5-3	300-400	1950	4428	2	6259	141
W5-4	400-600	3021	7	2	5	68
W6-1	150-200	1206	71	3	60	84
W6-2	200-300	2006	11250	6	16926	151
W6-3	300-400	1585	688	7	885	129
W6-4	400-600	1234	0	2	0	141
W7-1	150-200	2442	0	5	0 -	
W7-2	200-300	891	0	6	0	245
W7-3	300-400	265	0	2	0	141
W7-4	400-600	317	0	2	0 -	
W8-1	150-200	424	119	2	168	141
W8-2	200-300	567	121	2	169	139
W8-3	300-400	405	303	2	355	117
W8-4	400-600	718	174	2	156	90
W9-1	150-200	1711	0	5	0 -	
W9-2	200-300	938	0	6	0	245
W9-3	300-400	516	0	2	0	141
W9-4	400-600	430	0	2	0	141
Total		72170	122947	157		

Stratum	Depth	Area (km <sup>2</sup> )	Biomass	Hauls	STD	CV (%)
U1-1	150-200	2486	4147	2	5188	125
U1-2	200-300	4633	5636	1 -	-	-
U1-3	300-400	4785	14506	2	18533	128
U1-4	400-600	5129	4164	2	3777	91
U2-2	200-300	6710	17774	2	385	2
U2-3	300-400	8481	10072	2	6290	62
U2-4	400-600	7994	3150	2	4443	141
U3-1	150-200	2012	204	2	139	68
U3-2	200-300	3017	26690	2	2961	11
U3-3	300-400	1676	3737	3	3900	104
U3-4	400-600	2710	1597	2	1262	79
Total		49632	91677	22		

Stratum	Depth	Area (km <sup>2</sup> )	Biomass	Hauls	STD	CV (%)
C0-2	200-300	903	13471	2	18912	140
C0-3	300-400	2179	3186	3	2775	87
C0-4	400-600	1154	40	1 -	-	-
Total		4236	16697	6		

Stratum	Depth	Area (km <sup>2</sup> )	Biomass	Hauls	STD	CV (%)
I1-1	150-200	407	4354	2	999	22
I1-2	200-300	1963	14584	1		
I1-3	300-400	2441	10312	3	15972	61
I1-4	400-600	1499	2367	2	882	17
I2-1	150-200	419	2022	3	6208	137
I2-2	200-300	815	14400	4	5338	39
I2-3	300-400	1085	1214	2	6789	91
I2-4	400-600	1338	1530	3	606	65
Total		9967	50784	20		

Total		136005	282105	205		
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Tab. 3. Biomass estimates (in '000 tons) for combined strata and standard errors for the entire survey area 1988-2008.

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 <sup>4</sup>
1988	22.6			9.5			55.1	85.5	17.7					39.2				229.7	24.7
1989	11.1			3.7			50.0	82.7	39.0					39.2				225.7	32.3
1990	11.0			9.1			78.6	53.9	23.5					39.2				215.3	32.6
1991	5.1			4.2			26.8	47.4	23.3					43.1				149.9	23.0
1992	18.1			22.2			46.2	30.6	45.8					41.4				204.4	32.5
1993	6.9			2.9			93.8	36.7	62.2					28.3				230.8	30.9
1994	6.6			6.0			95.0	44.5	32.6		16.7			34.0				235.4	51.7
1995	6.8			3.9			39.0	52.4	48.7		1.6			39.1				191.4	30.6
1996	8.8			1.5			46.4	31.5	80.0		3.3			44.3				215.9	40.4
1997	5.7			0.2			34.7	13.1	57.9		21.8			44.3				177.7	31.1
1998	7.0			0.4			37.8	100.6	45.1		18.6			51.8				261.2	57.6
1999	17.6			10.5			50.1	23.2	50.5		56.0			52.6				260.6	42.1
2000	8.4			10.7			62.1	69.8	71.0		21.8			73.0				316.9	40.3
2001	34.1			3.7			74.3	47.6	58.5		36.3			72.1				326.7	44.2
2002	17.4	5		5.4			114.0	62.1	94.9		40.5			85.8				420.2	60.0
2003		109.3		5.9			148.6	93.3	98.0			35.0		107.7				597.8	77.0
2004		111.2			3.5		152.8	96.5	102.6			15.4			81.4			563.4	103.7
2005		100.5			9.3		159.9	87.2	53.4			1.9			139.6			551.9	88.4
2006		54.7			45.8		108.9	60.6	90.8			12.5			110.7			484.0	64.6
2007		61.2			1.7		128.1	57.1	21.3			1.2			78.9			349.5	42.8
2008		91.7			16.7		61.3	40.0	20.9			0.7			50.8			282.1	31.8

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 N



Table 4. Overall error coefficients of variation (%) for the biomass estimates of the five main survey regions and the entire survey area together with the corresponding number of hauls 1988-2008.

Year	N/U	C	W1-W7	S/W8-W9	D/I	Total survey	Number of hauls
1988	31.4	40.0	16.6	-	-	14.41	131
1989	22.2	42.8	20.1	-	-	18.60	130
1990	43.5	39.9	20.3	-	-	18.30	109
1991	40.2	27.1	17.7	-	22.9	13.37	194
1992	16.9	68.9	18.5	-	15.7	13.84	167
1993	51.6	53.3	13.5	-	19.4	11.66	146
1994	48.7	18.3	23.7	99.2	26.0	19.11	157
1995	47.1	44.7	18.2	74.0	17.7	13.93	163
1996	52.6	91.0	21.8	95.0	10.6	16.31	148
1997	37.9	61.9	24.7	14.6	14.5	15.26	167
1998	40.4	44.0	26.1	58.8	18.4	19.19	209
1999	51.1	80.0	13.7	52.1	14.2	14.08	227
2000	36.1	7.8	15.4	56.8	12.9	11.08	198
2001	26.5	44.5	18.8	22.8	18.6	11.77	224
2002	56.0	45.4	16.0	55.0	18.7	12.44	216
2003	26.8	44.4	16.0	49.9	17.5	11.21	172
2004	24.9	22.6	24.1	71.4	11.6	16.03	187
2005	22.1	41.4	23.5	48.7	34.6	16.02	194
2006	20.5	79.0	19.0	79.4	12.9	13.36	221
2007	21.9	45.1	18.0	56.8	20.9	12.26	212
2008	17.3	80.7	14.9	44.8	31.1	11.28	205

Table 5. Estimated mean densities (t/km<sup>2</sup>) for combined strata in 1988-2008.

Year	N1-N9/U1-U3	C1+C3/C0	W1-W2	W3-W4	W5-W7	S1-S2/W8-W9	D1-D9/I1-I2
1988	0.54	2.77	2.34	3.94	1.76	-	-
1989	0.25	1.08	2.76	3.81	3.88	-	-
1990	0.25	2.65	3.33	2.48	1.59	-	-
1991	0.12	1.23	1.14	2.18	1.57	-	4.60
1992	0.44	6.46	1.96	1.41	3.09	-	4.42
1993	0.17	0.85	3.55	1.68	3.32	-	3.02
1994	0.17	1.76	3.59	2.03	1.74	3.22	3.63
1995	0.18	1.15	1.47	2.39	2.60	0.24	4.17
1996	0.23	0.44	1.75	1.44	4.27	0.51	4.73
1997	0.15	0.06	1.31	0.60	3.09	3.35	4.73
1998	0.18	0.11	1.43	4.59	2.41	2.85	5.54
1999	0.46	3.06	1.89	1.06	2.70	8.59	5.62
2000	0.22	3.10	2.35	3.18	3.79	3.35	7.80
2001	0.89	1.08	2.81	2.17	3.12	5.57	7.70
2002	0.45	1.57	4.31	4.46	5.07	6.21	9.16
2003	2.22	1.39	6.11	6.25	5.23	5.80	11.49
2004	2.20	0.82	6.25	4.71	4.76	2.65	8.37
2005	1.99	2.20	6.54	4.25	2.48	0.34	14.19
2006	1.08	10.81	4.46	2.96	4.21	2.20	11.26
2007	1.21	0.40	5.24	2.78	0.99	0.21	8.02
2008	1.85	3.94	2.53	1.94	0.97	0.13	5.10

Table 6. Abundance estimates (billions) for males and females from overall length distributions for the total survey area 1988-2008 (mean values for Disko/Vaigat area in 1991-1997 used for 1988-1990).

Year	Males	Females	Total	Males %	Females %
1988	26.8	9.3	36.1	74.3	25.7
1989	39.0	6.9	45.9	85.0	15.0
1990	29.3	8.9	38.1	76.8	23.2
1991	19.6	5.1	24.7	79.3	20.7
1992	29.4	6.5	35.9	81.9	18.1
1993	34.8	8.3	43.1	80.7	19.3
1994	32.0	8.9	40.9	78.3	21.7
1995	27.7	6.5	34.2	80.9	19.1
1996	38.2	6.6	44.8	85.2	14.8
1997	27.2	6.3	33.5	81.2	18.8
1998	41.0	9.9	50.9	80.5	19.5
1999	42.5	9.9	52.3	81.1	18.9
2000	62.4	11.1	73.4	84.9	15.1
2001	56.6	11.8	68.4	82.7	17.3
2002	85.3	14.9	100.1	85.1	14.9
2003	99.4	24.9	124.4	80.0	20.0
2004	89.4	26.3	115.8	77.3	22.7
2005	91.3	24.2	115.5	79.0	21.0
2006	75.2	23.1	98.3	76.5	23.5
2007	51.4	15.0	66.4	77.4	22.6
2008	42.5	11.5	54.0	78.7	21.3
Average	49.6	12.2	61.7	80.3	19.7

Table 7. Biomass estimates for males and females ('000 tons) in the total survey area based on length-weight distributions 1988-2006 (mean values for Disko Bay/Vaigat area in 1991-1997 used for 1988-1990).

Year	Males	Females	Total	Males %	Females %
1988	134.7	94.8	229.5	58.7	41.3
1989	157.1	68.6	225.7	69.6	30.4
1990	129.4	85.4	214.9	60.2	39.8
1991	100.5	49.4	149.9	67.0	33.0
1992	141.3	63.1	204.4	69.1	30.9
1993	149.2	81.9	231.1	64.6	35.4
1994	146.5	88.9	235.4	62.2	37.8
1995	124.5	66.9	191.4	65.0	35.0
1996	147.9	68.0	215.9	68.5	31.5
1997	114.7	62.9	177.7	64.6	35.4
1998	170.4	90.9	261.3	65.2	34.8
1999	166.7	93.9	260.6	64.0	36.0
2000	213.8	100.2	314.0	68.1	31.9
2001	199.1	108.3	307.4	64.8	35.2
2002	293.6	126.6	420.2	69.9	30.1
2003	389.2	208.6	597.8	65.1	34.9
2004	353.1	210.3	563.4	62.7	37.3
2005	340.1	189.6	529.7	64.2	35.8
2006	288.0	177.2	465.2	61.9	38.1
2007	238.9	114.7	353.6	67.6	32.4
2008	174.9	95.6	270.5	64.7	35.3
Average	198.7	106.9	305.7	65.1	34.9

Table 8. Estimates of fishable biomass ( $\leq 17$ mm CL, '000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2008 (mean values for Disko/Vaigat area in 1991-1997 used for 1988-1990).

Year	I1(Disko) + I2(Vaigat)		
	Offshore	Disko	Total
1988	186.2	37.0	223.2
1989	171.9	37.0	209.0
1990	170.0	37.0	207.0
1991	104.7	41.3	146.0
1992	154.8	39.4	194.2
1993	189.4	27.1	216.5
1994	191.0	32.1	223.1
1995	144.9	38.3	183.2
1996	150.6	41.5	192.1
1997	127.7	39.4	167.1
1998	197.2	47.1	244.3
1999	195.0	42.3	237.3
2000	219.8	60.6	280.3
2001	216.8	63.7	280.5
2002	302.2	67.2	369.5
2003	454.0	94.3	548.3
2004	457.5	70.8	528.3
2005	371.3	108.2	479.5
2006	349.7	87.7	437.5
2007	268.5	85.1	334.1
2008	215.1	47.2	262.4
Average	230.4	54.5	284.0

Table 9. Mean carapace length (mm) for Northern shrimp at “age 2” off West Greenland 1993-2008 and corresponding SD and COEV from modal analysis (- : not present, () : fixed in the final MIX run).

mean:

Year	Region / Depth						
	U1 to U3 150-600 m	I1 and I2 150-600 m	C0 and W1 to W4 150-300 m	300-600 m	W5 and W6 150-300 m	300-600 m	W7 to W9 150-600 m
1993	11.1	12.6	12.1	13.2	14.8	13.6	(14.0)
1994	12.4	11.6	12.3	13.1	14.8	13.7	-
1995	11.2	12.5	13.5	14.3	15.3	13.1	(12.5)
1996	11.9	13.0	14.2	14.0	13.7	14.9	(14.0)
1997	12.6	12.9	14.3	12.4	14.7	13.5	(13.0)
1998	11.0	14.0	14.0	14.9	15.8	16.4	(15.0)
1999	14.7	15.4	15.1	15.0	15.4	16.1	(15.5)
2000	13.3	14.9	15.0	15.0	14.8	16.7	(13.0)
2001	13.6	13.1	13.2	13.8	13.8	14.0	(13.5)
2002	13.1	12.6	12.8	12.6	14.9	15.3	(13.5)
2003	11.9	12.2	13.0	12.9	14.4	13.8	14.6
2004	11.9	11.6	12.3	13.0	14.3	(15.5)	(14.5)
2005	11.1	11.4	12.0	11.9	13.2	12.5	(16.0)
2006	11.8	11.3	11.8	12.3	12.9	14.0	(14.8)
2007	12.1	11.6	11.9	11.6	11.6	14.5 (?)	-
2008	14.6	12.4	12.0	12.5	11.4	20.9	19.0

standard deviation:

Year	Region / Depth						
	U1 to U3 150-600 m	I1 and I2 150-600 m	C0 and W1 to W4 150-300 m	300-600 m	W5 and W6 150-300 m	300-600 m	W7 to W9 150-600 m
1993	0.8	1.3	1.0	1.1	0.8	0.9	(0.80)
1994	(0.70)	1.0	1.2	1.2	1.1	1.5	-
1995	0.8	1.0	1.4	1.5	0.8	1.5	(0.70)
1996	0.8	1.1	0.9	1.2	1.5	1.3	(0.70)
1997	1.0	1.1	1.2	1.2	1.3	1.4	(0.70)
1998	1.1	1.4	1.0	1.3	1.3	1.1	(0.80)
1999	1.5	1.4	1.2	1.4	1.3	1.3	(0.70)
2000	1.3	1.4	1.3	1.4	1.5	1.3	(0.80)
2001	1.4	1.3	1.4	1.5	1.1	(0.80)	(0.70)
2002	1.3	1.5	1.4	1.5	1.5	(0.90)	(0.70)
2003	1.0	1.3	1.2	1.5	1.2	1.3	(0.90)
2004	1.0	1.0	1.1	1.5	1.3	(0.70)	(0.90)
2005	0.7	1.0	0.7	1.4	1.0	0.9	(0.85)
2006	1.1	1.3	1.1	1.1	1.2	(0.90)	(0.85)
2007	1.6	1.6	1.4	1.2	1.7	1.1	-
2008	2.0	1.1	0.9	1.1	1.3	1.3	1.9

coefficient of variation:

Year	U1 to U3	I1 and I2	C0 and W1 to	300-600 m	W5 and	300-600 m	W7 to
	150-600 m	150-600 m	W4 150-300 m		W6 150-300 m		W9 150-600 m
1993	0.07	0.10	0.08	0.08	0.06	0.06	(0.05)
1994	(0.06)	0.09	0.10	0.09	0.07	0.11	-
1995	0.07	0.08	0.10	0.10	0.05	0.11	(0.05)
1996	0.07	0.08	0.06	0.09	0.11	0.09	(0.05)
1997	0.08	0.09	0.08	0.09	0.09	0.11	(0.05)
1998	0.10	0.10	0.07	0.08	0.08	0.07	(0.05)
1999	0.10	0.09	0.08	0.09	0.09	0.08	(0.05)
2000	0.10	0.09	0.08	0.10	0.10	0.08	(0.07)
2001	0.10	0.10	0.10	0.11	0.08	(0.06)	(0.05)
2002	0.10	0.12	0.11	0.12	0.10	(0.06)	(0.05)
2003	0.08	0.10	0.09	0.12	0.08	0.09	(0.06)
2004	0.09	0.09	0.09	0.11	0.09	(0.05)	(0.06)
2005	0.06	0.08	0.06	0.12	0.08	0.07	(0.05)
2006	0.10	0.11	0.09	0.09	0.09	(0.06)	(0.06)
2007	0.13	0.13	0.12	0.11	0.14	0.07	-
2008	0.14	0.09	0.07	0.09	0.12	0.07	0.10

Table 10. Abundance (estimated number of shrimp in the total survey area) of “age 2” shrimp, total abundance and yearly gross recruitment rate  $R(t)$ .

Year	Abundance of "age 2" shrimp (*10 <sup>9</sup> )	Abundance of (shrimp) 10 <sup>9</sup>	R(t)	R(t) (CMIX)
1993	4.91	43.1	0.11	-
1994	3.36	40.9	0.08	-
1995	2.67	34.2	0.08	-
1996	11.50	44.8	0.26	-
1997	3.70	33.5	0.11	-
1998	7.40	50.9	0.15	-
1999	13.04	52.3	0.25	-
2000	16.41	73.4	0.22	-
2001	18.26	68.4	0.27	-
2002	11.97	100.1	0.12	-
2003	7.44	124.4	0.06	-
2004	7.75	115.8	0.07	-
2005	3.45	115.5	0.03	0.012
2006	4.50	98.3	0.05	0.0062
2007	1.21	66.4	0.02	0.0074
2008	4.91	54.0	0.09	0.0034
Average	7.65	69.75	0.12	0.01

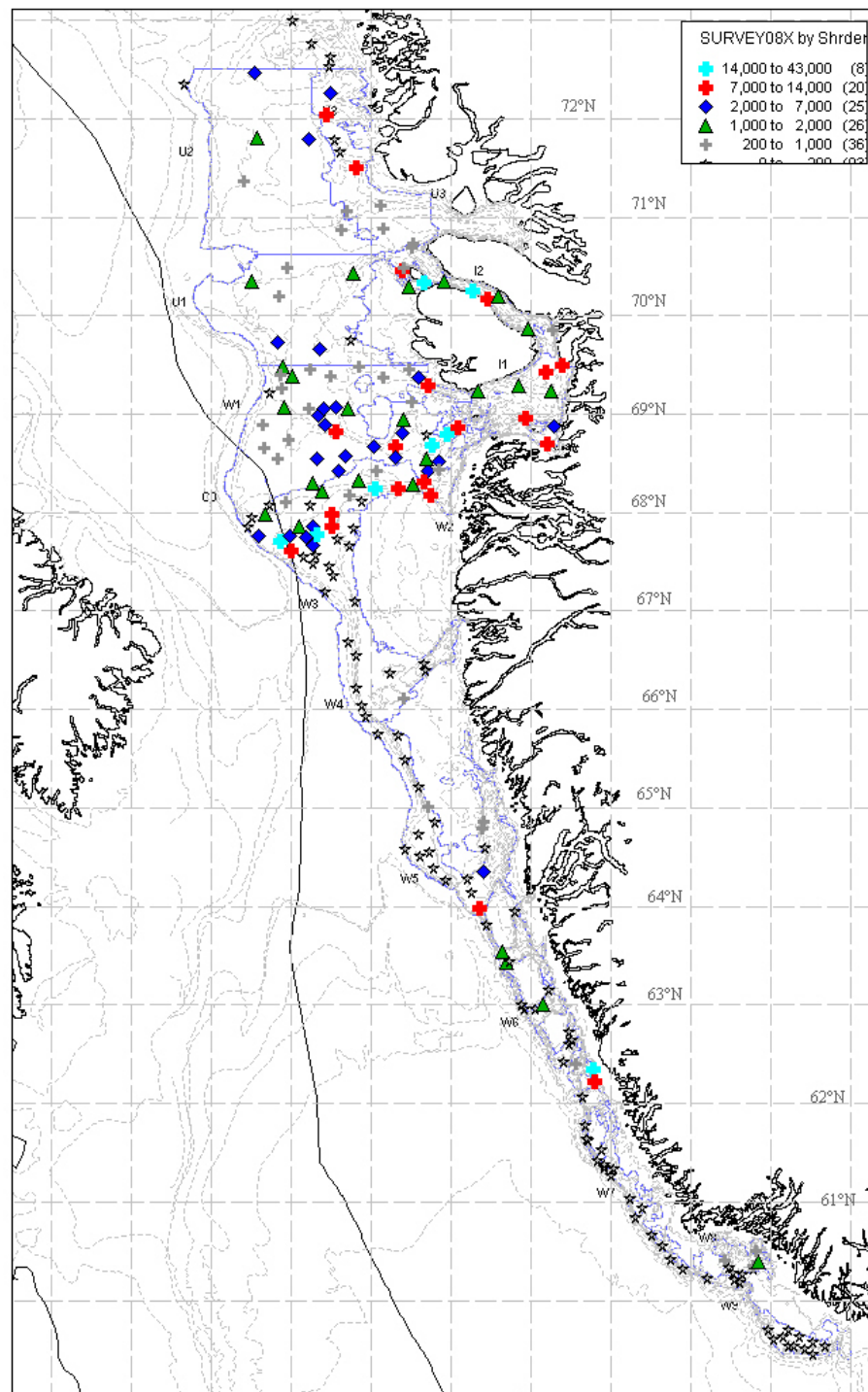


Fig.1. Survey stratification and shrimp density in W. Greenland 2008.

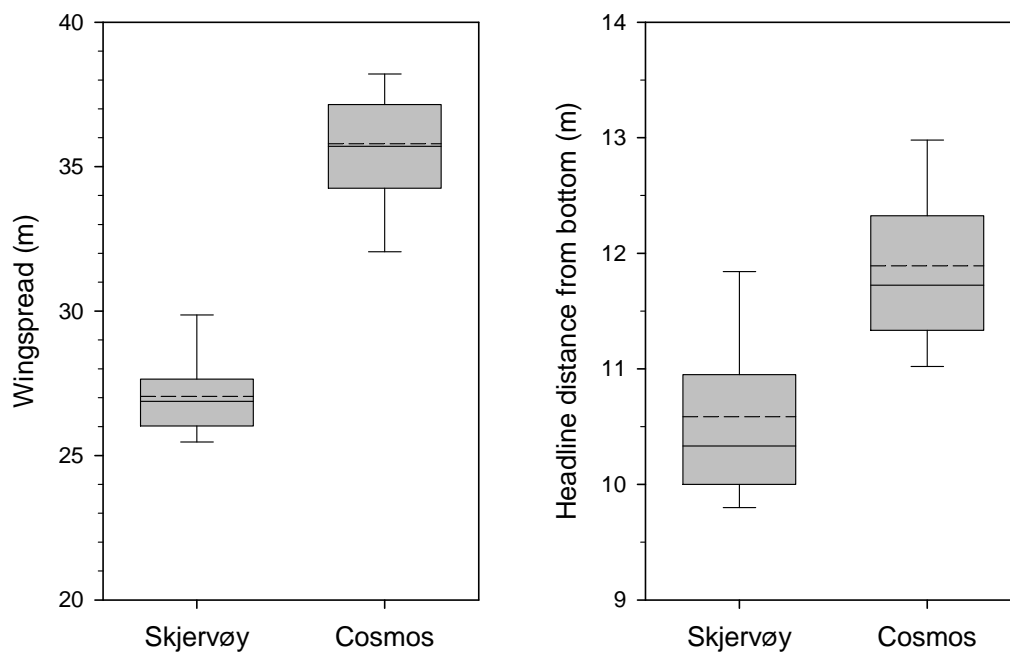
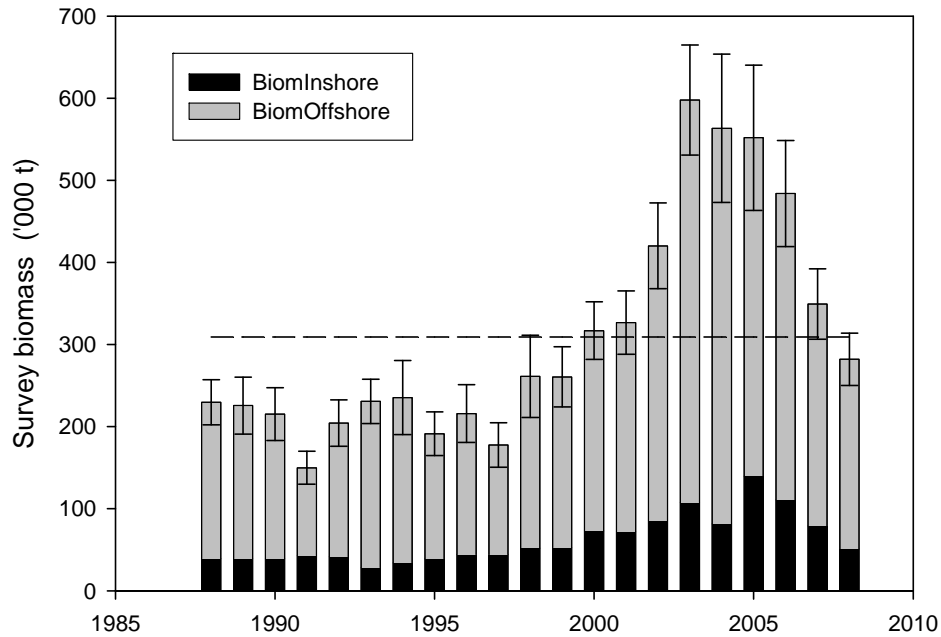


Fig. 2. Box whisker plots showing arithmetic means (stippled line) and medians (solid lines) of wingspread and headline distance to bottom for the two trawl types (*Skjervøy* 3000 and *Cosmos* 2000) with 95% confidence interval (upper and lower borders of grey box) and lower and upper quartiles (error bars) respectively. Results based on 39 hauls for each trawl (pairs of hauls made on the same track either with the *Skjervøy* or the *Cosmos* trawl first).



### Survey biomass of Northern Shrimp



### Survey index of Northern Shrimp density

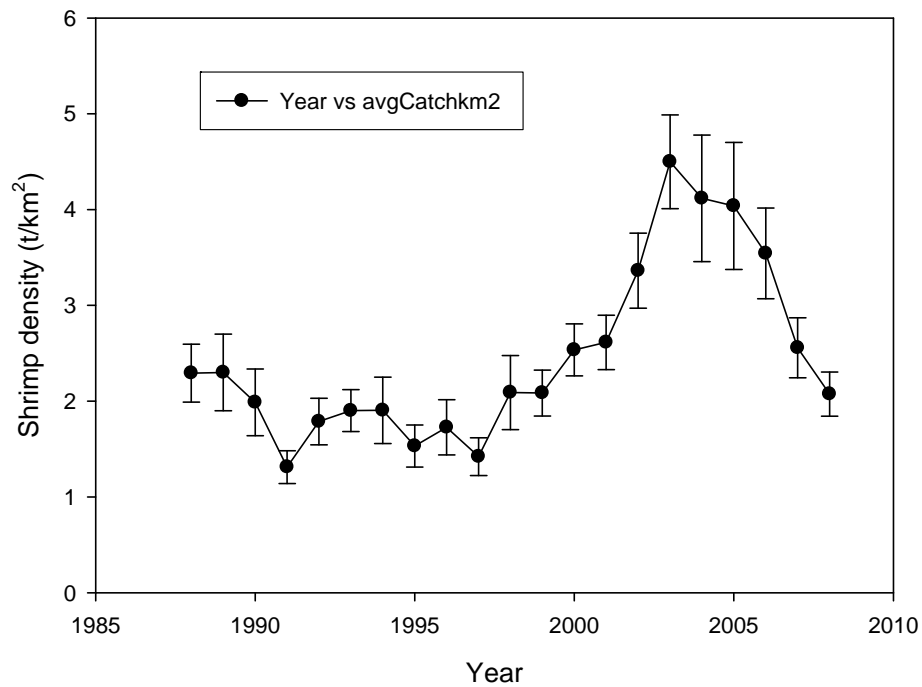


Fig. 3. Estimated total survey biomass and average survey biomass density of Northern shrimp with standard errors 1988-2008 (Average biomass estimate for inshore areas 1991-1997 are used for 1988-1990 to facilitate between-year comparisons, see tab. 3 for details).

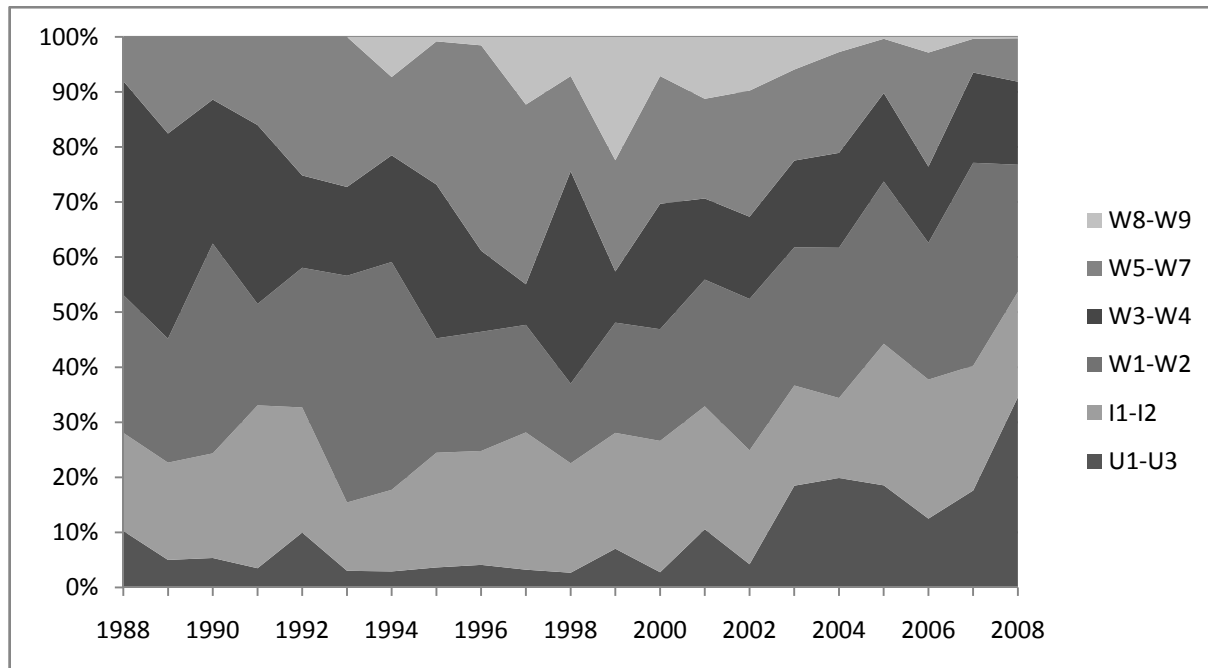


Fig. 4. Biomass contributions from different primary survey regions 1988-2008 (area names are given in brackets, see fig. 1 for location).

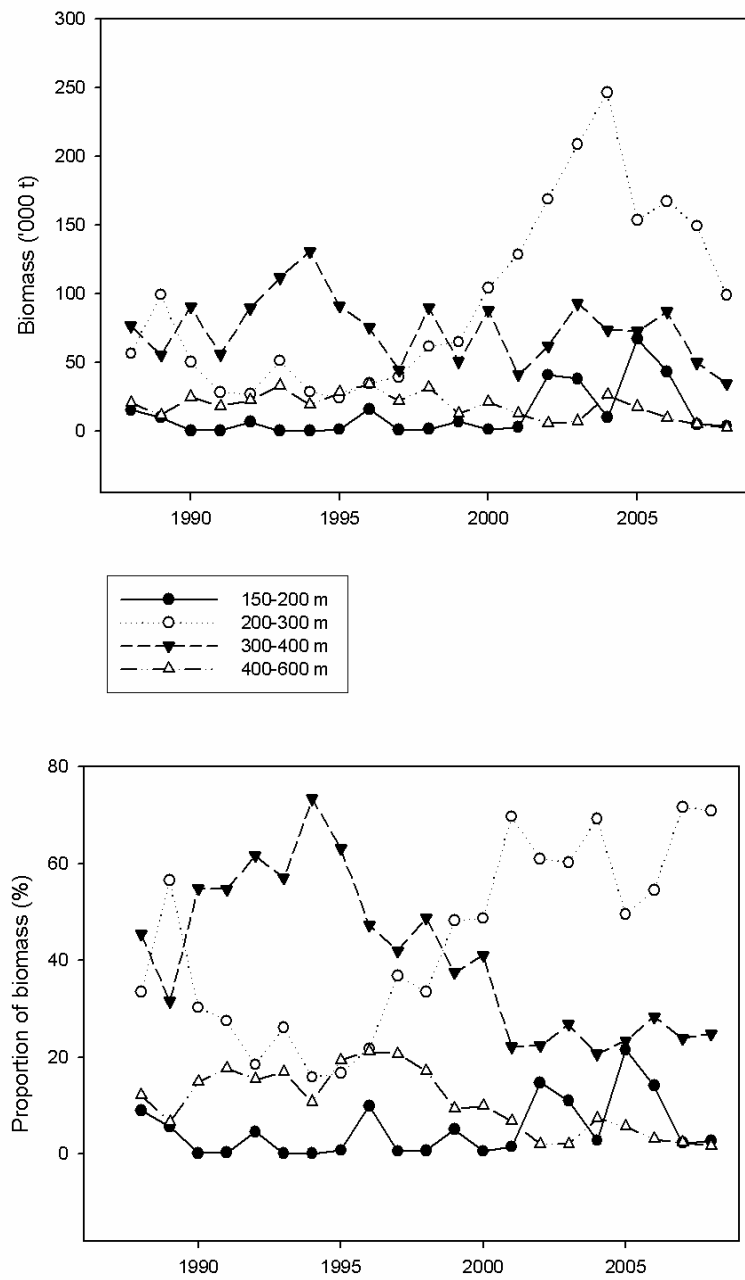


Fig. 5. Biomass distribution in the four depth strata in areas C and W1-W9 1988-2008.

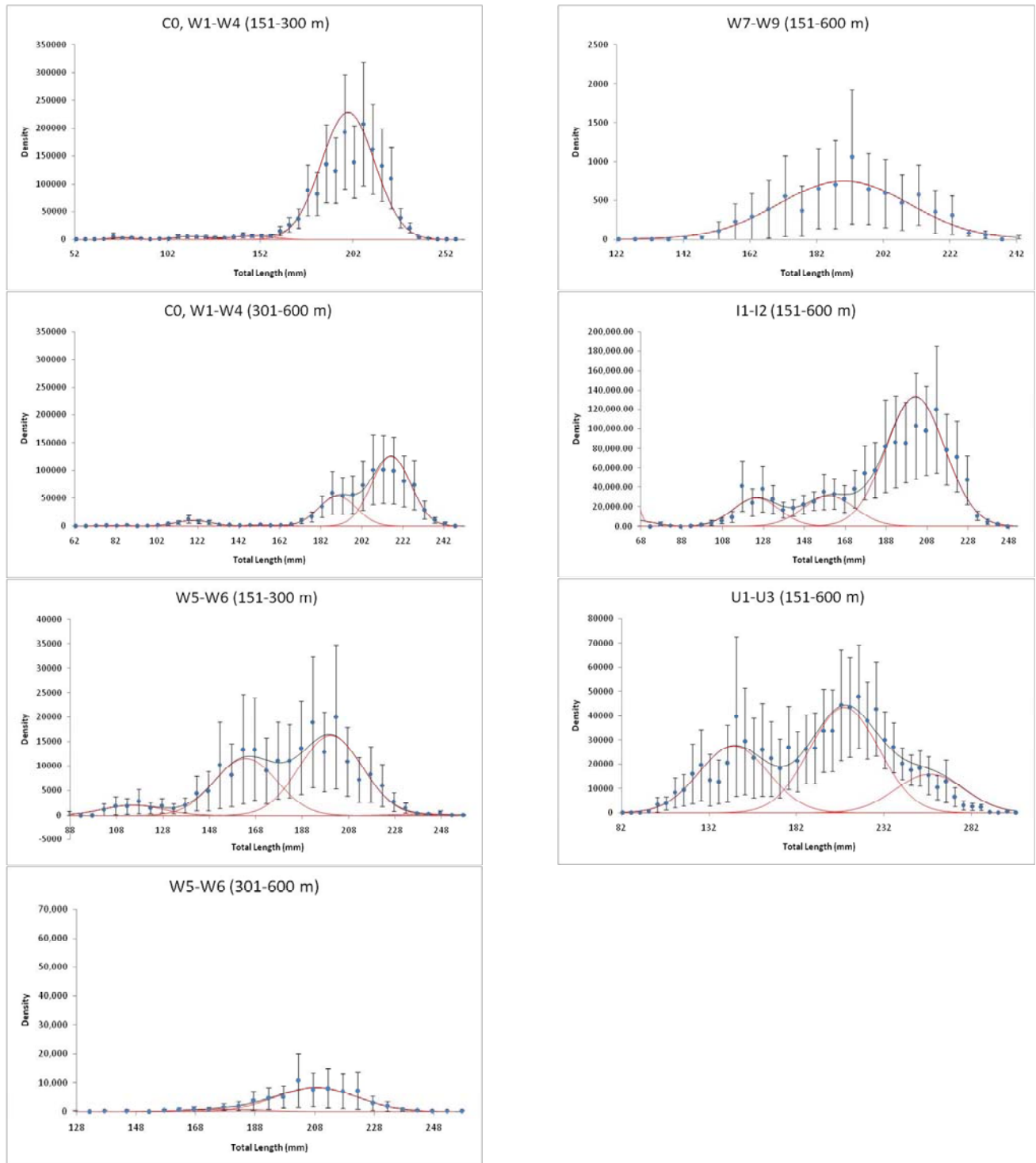


Figure 6. Length density distributions for males in all areas (151-600 m).

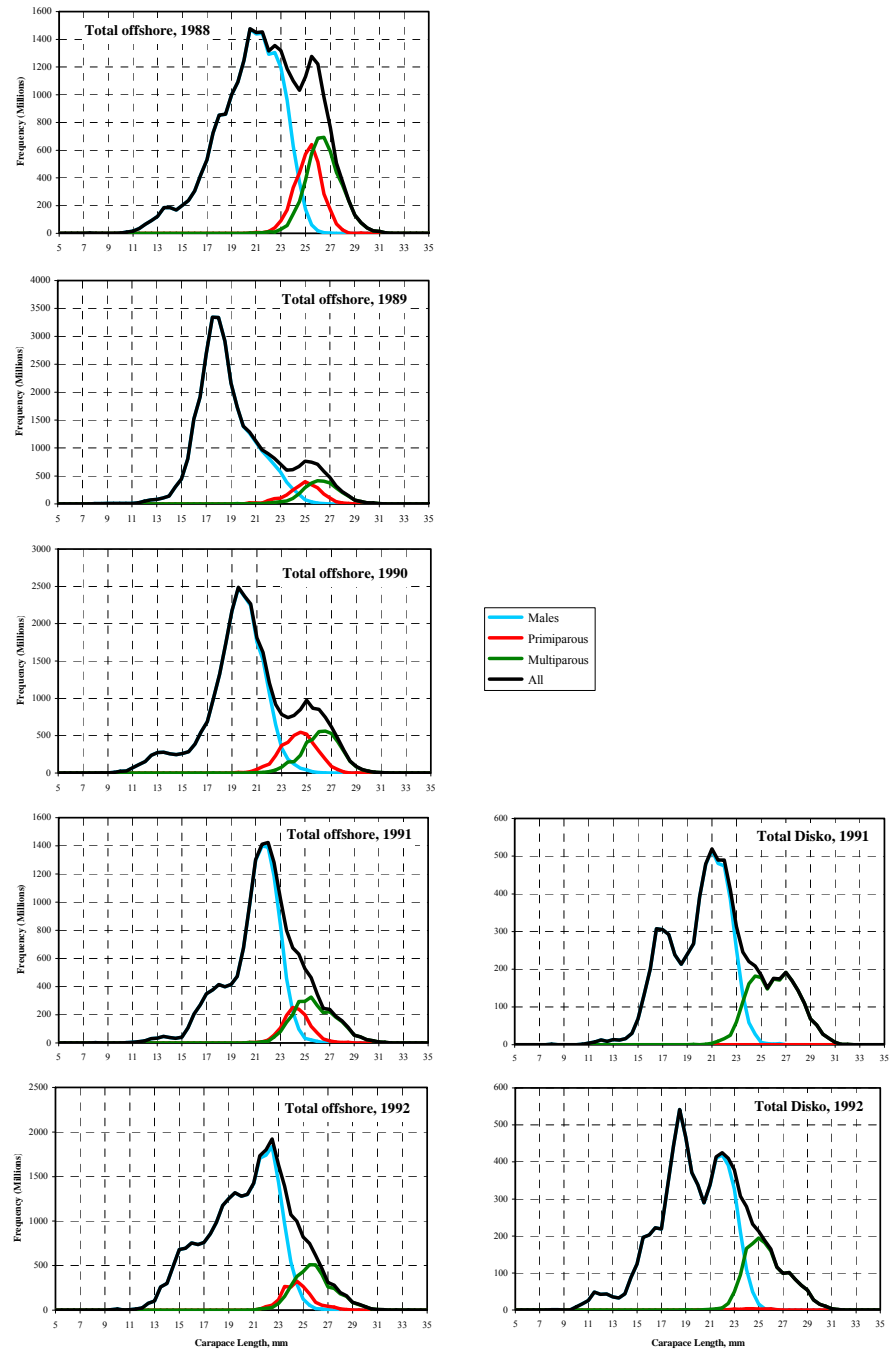


Fig. 7a. Length frequencies of Northern shrimp in the total offshore area, 1988 to 1992, and in the Disko Bay/Vaigat area, 1991 to 1992 (no surveys in Disko Bay/Vaigat area 1998-1990; unconverted data).

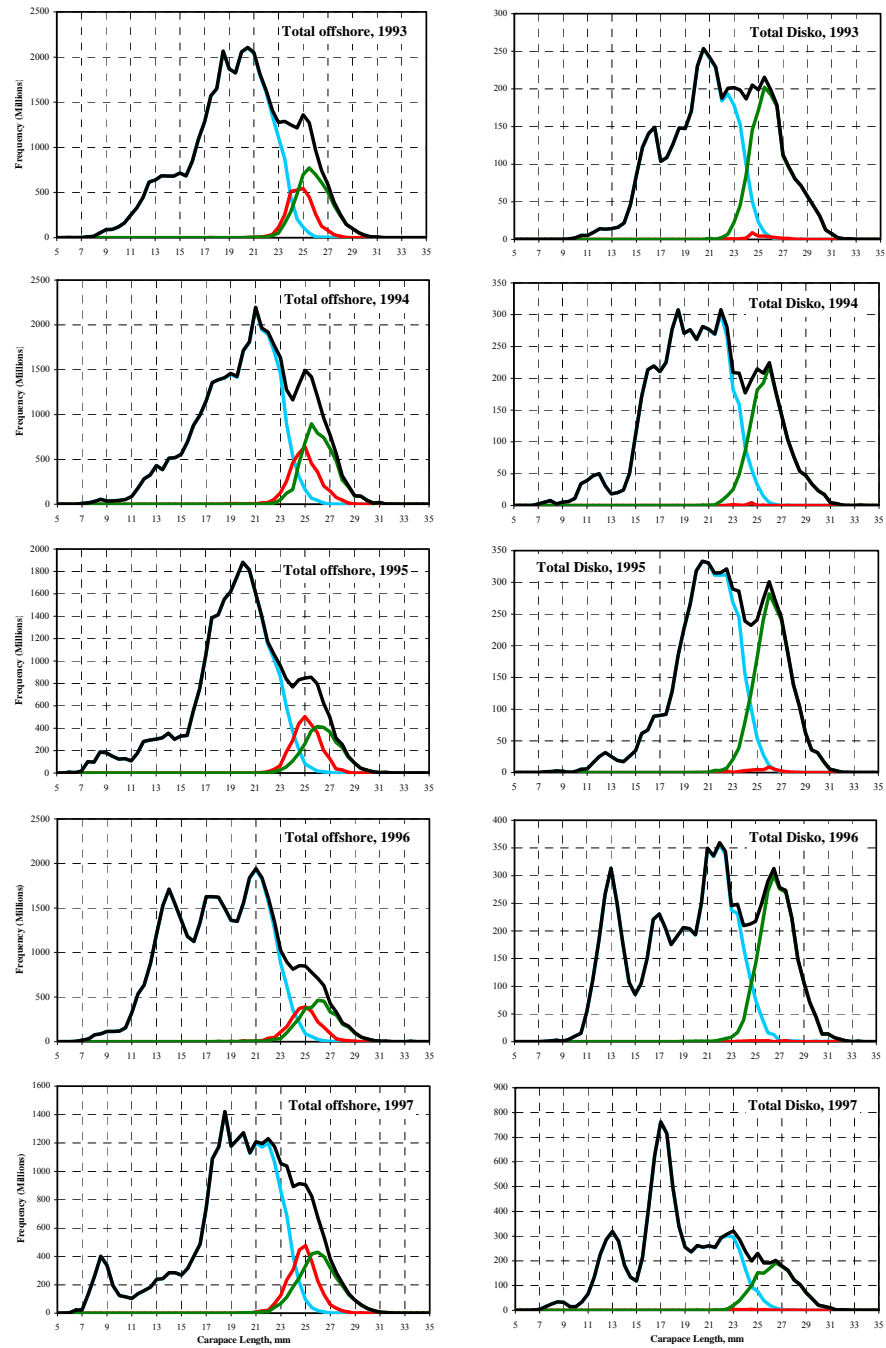


Fig. 7b. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1993 to 1997 (unconverted data).

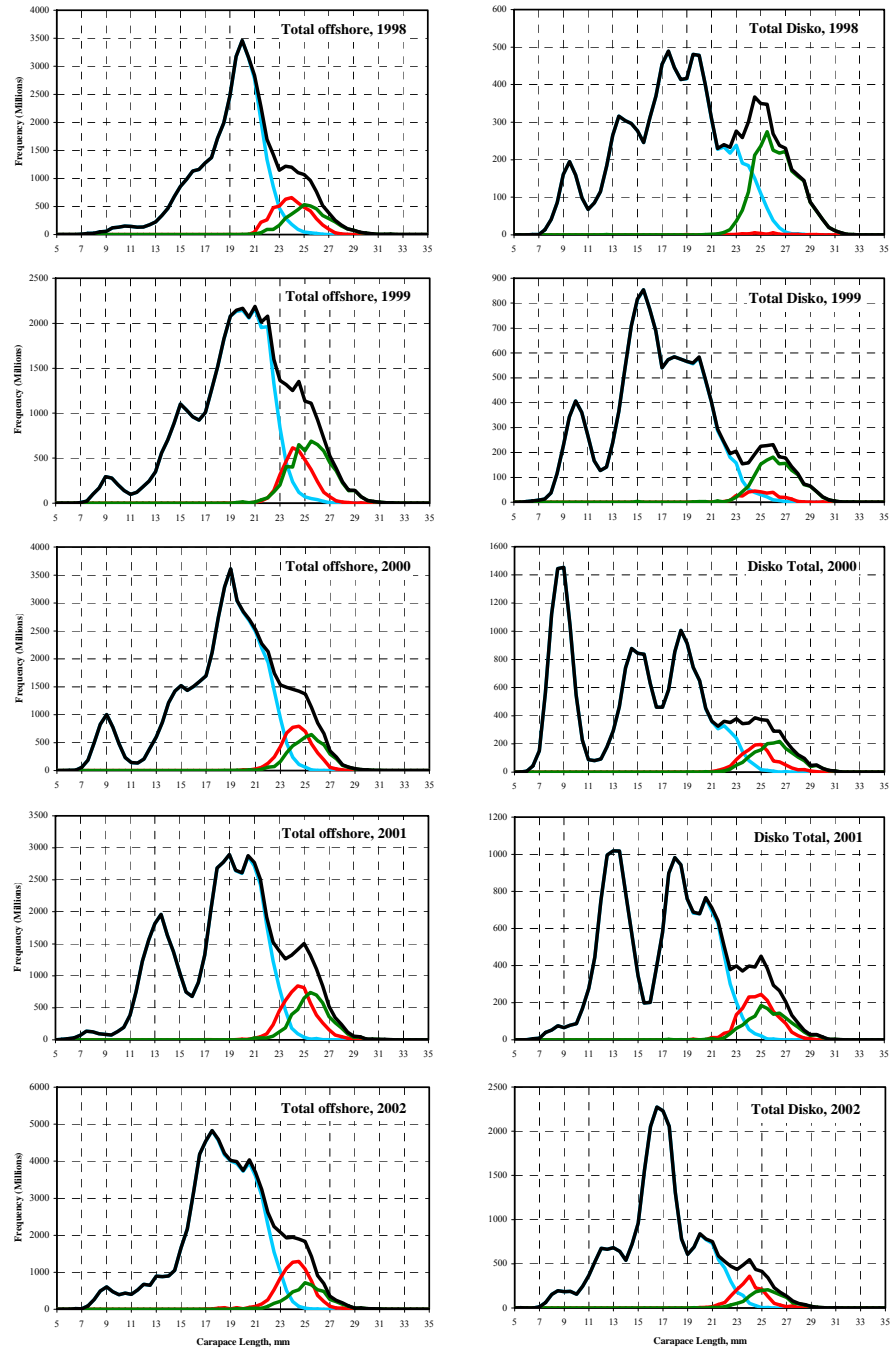


Fig. 7c. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1998 to 2002 (unconverted data).

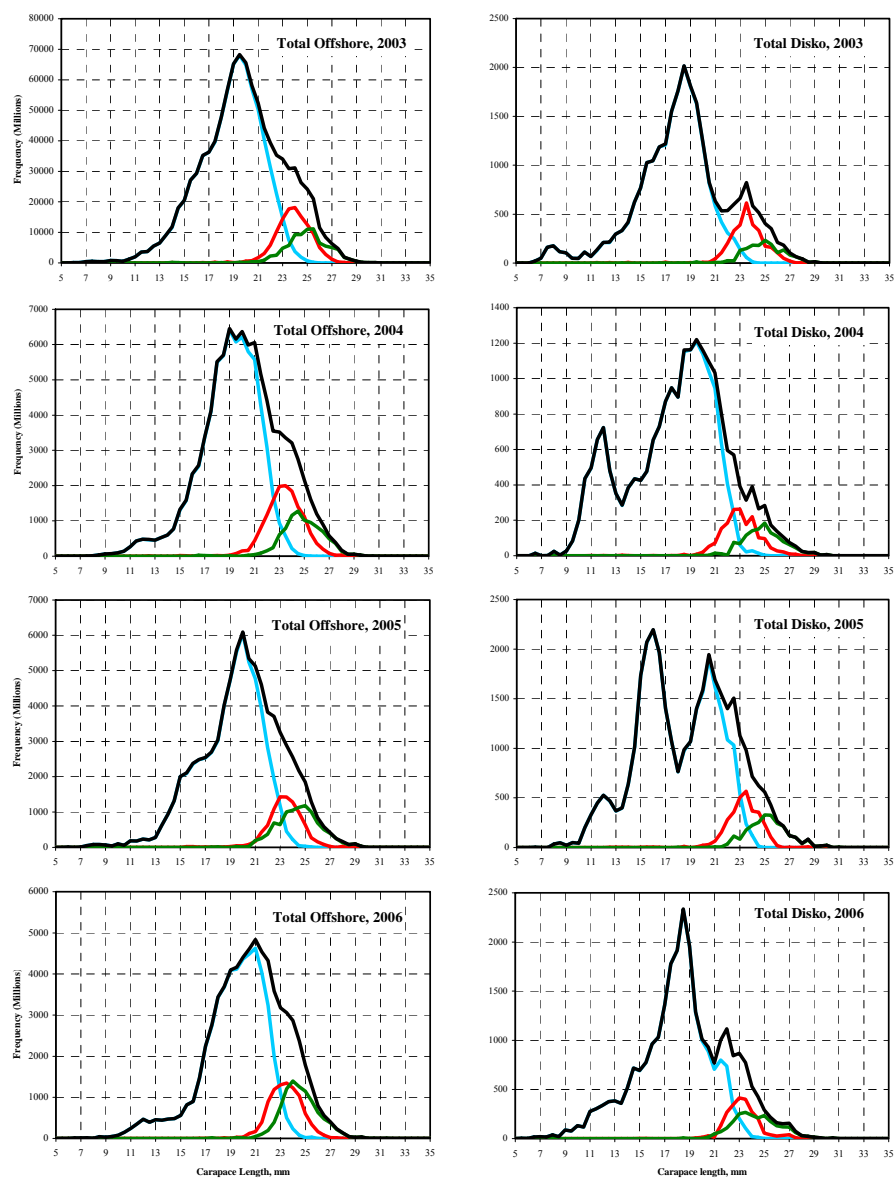


Fig. 7d. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2003 to 2006 (2003 and 2004 data converted from *Skjervøy* to *Cosmos* trawl).



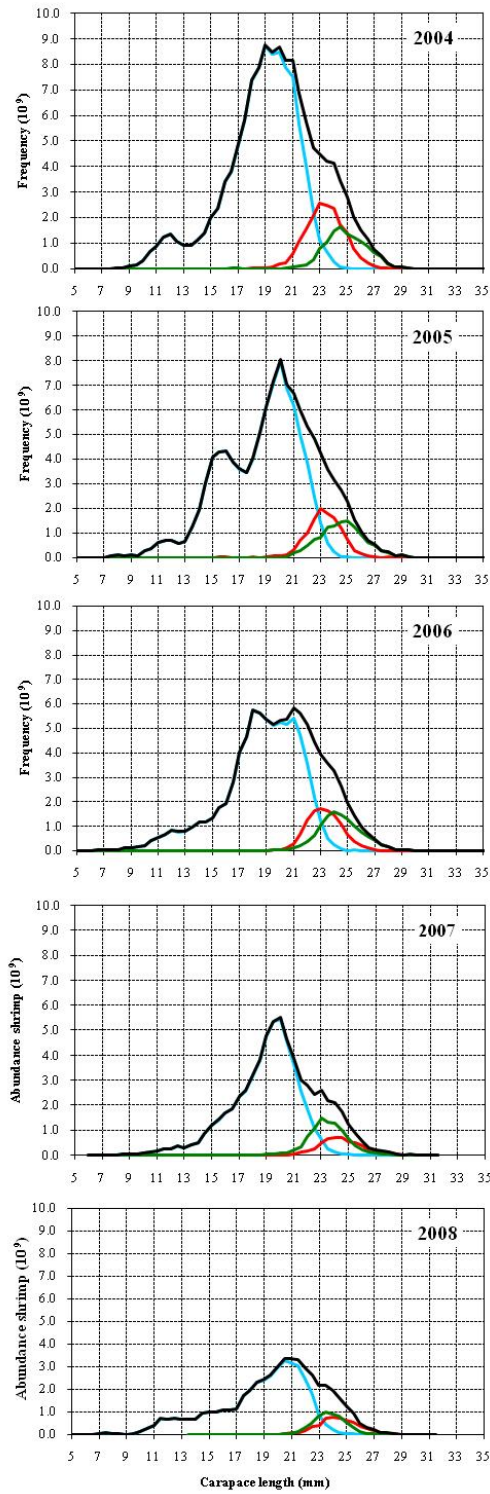


Fig. 8. Length frequencies of Northern shrimp in the total survey area (offshore and Disko/ Vaigat combined, 2004-2008).

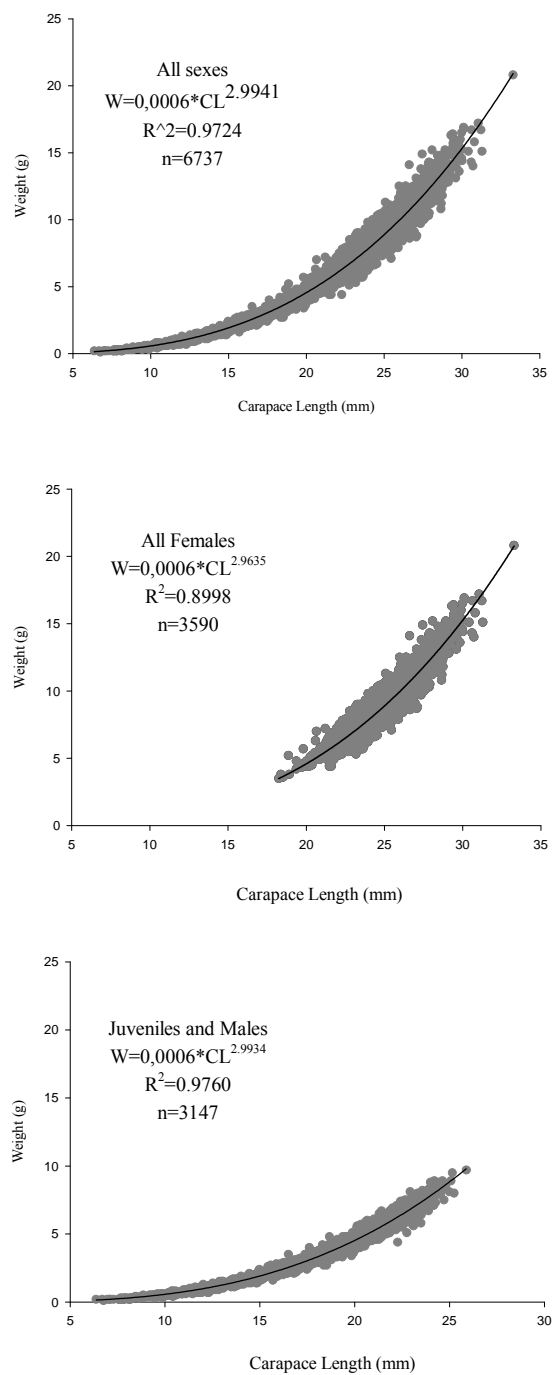


Fig. 9. Length-weight relationships of *P. borealis* off West Greenland. Data from 2001-2006.

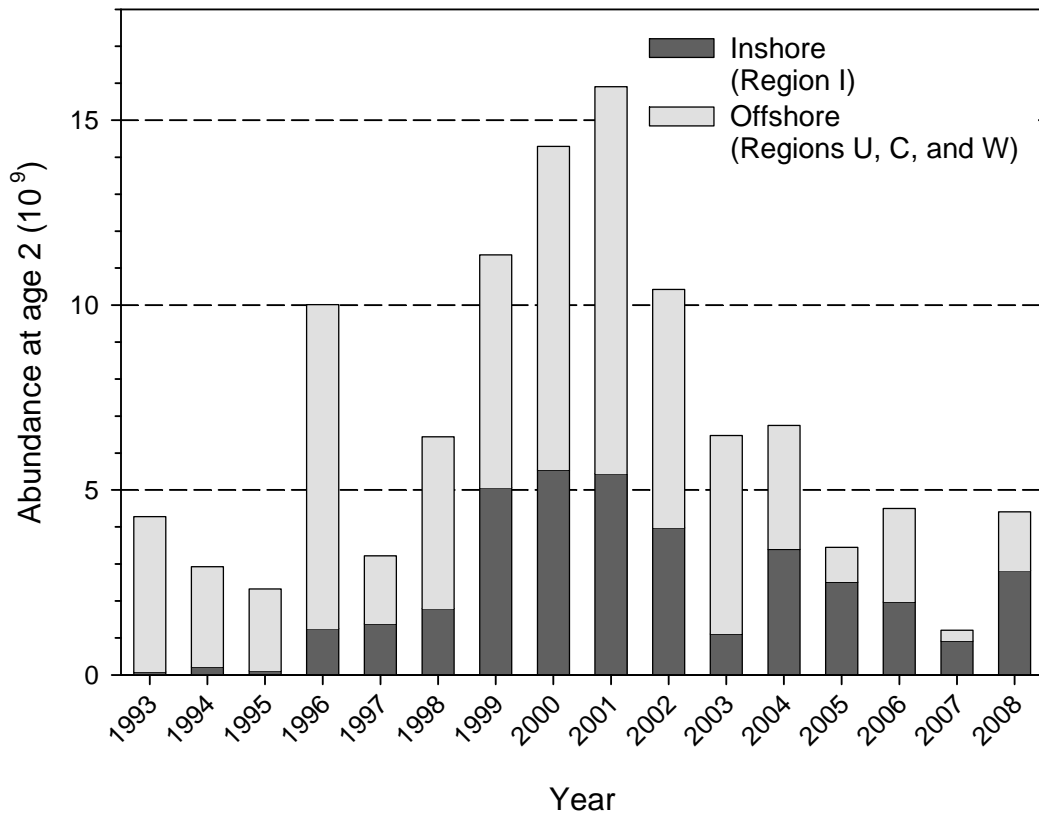


Figure 10. Abundance indices for Northern shrimp at age 2 off West Greenland, 1993-2008.

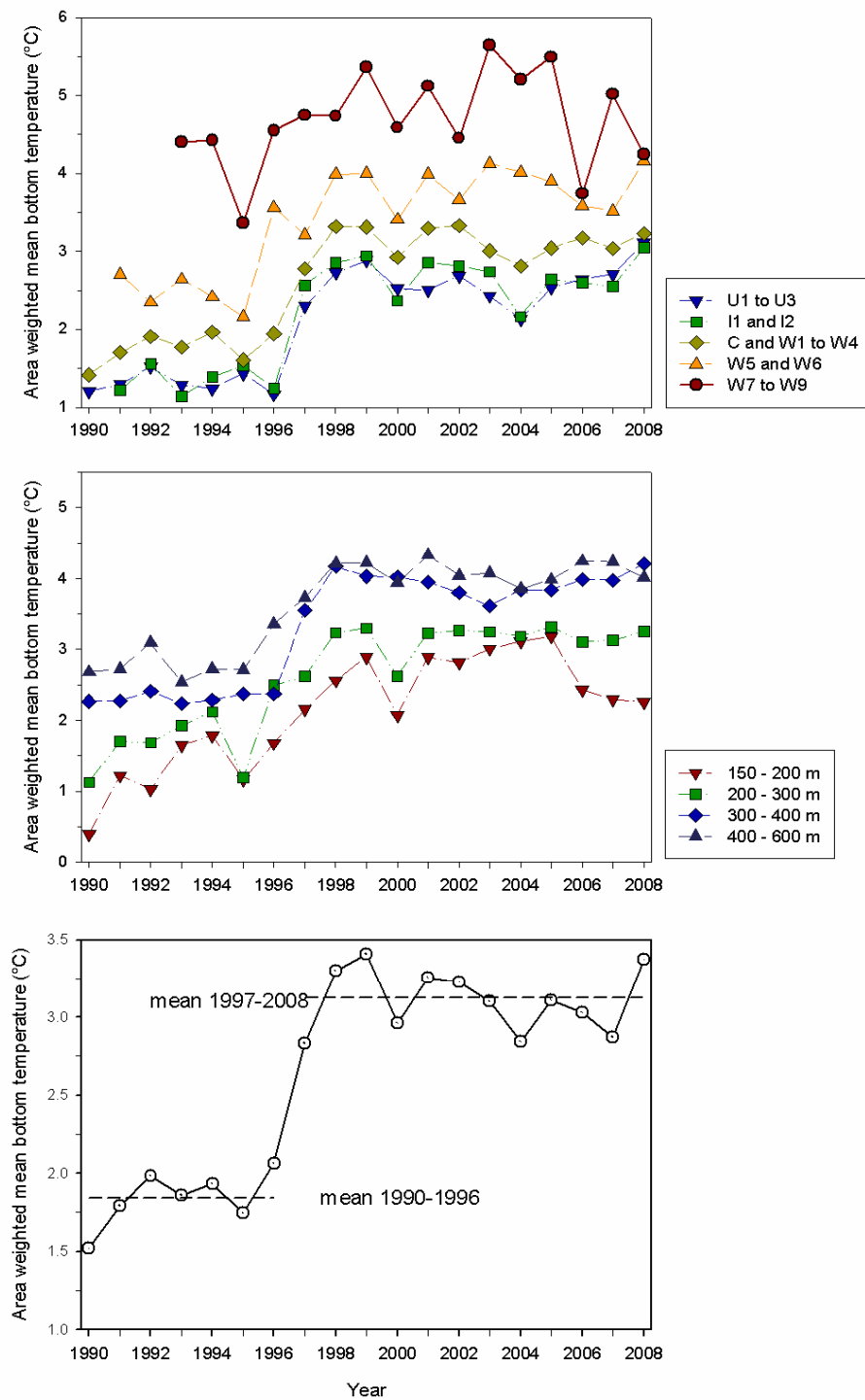


Fig. 11. Area weighted mean bottom temperature for the different survey regions (see Fig. 1 for locations), the various depth strata in offshore areas C and W1-W7 and the entire survey area in 1990 to 2007.