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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), 1988-2007

by

Bo Bergström

Greenland Institute of Natural Resources
Box 570, 3900 Nuuk, Greenland

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 350 000 tons now in 2007. 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 after2003 is especially noticeable in the offshore areas in southwest Greenland waters. The shrimp stock in this years survey seemed to be concentrated in an area between 67° 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 2007 was dominated in proportion (95 %), numbers and biomass by only one year class (3+ year old). This age group is composed by mostly males but also contains primiparous females. The proportion of large multiparous females in the stock is generally very small. The abundance of recruits at "age 2" (between 1 and 2 years old) in the survey this year was the lowest in the recent series of very low recruitment values suggesting that a considerable decrease in fishable biomass will off W. Greenland will occur in the coming years.

Mean bottom temperature in the survey area started increasing in the mid-1990s and this relatively warm period continued in 2007, in particular at depths > 300 m off southwest Greenland. In this area average temperatures appear to exceed the temperature level preferred by Northern shrimp.

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 2007 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 Kanneworff, 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 2005, the depth contours in areas U1 to U3, I1 and I2, and W8 and W9 were further revised based on data collected in 2004, and the border between areas U2 and U3 was slightly changed. Due to these revisions, the total survey area (Fig. 1) has increased from about 125000 km² in 1995-2002 to 133000 km² in 2003 and now covers, since 2004, about 137000 km².

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. Since1999 about 50% of the randomly selected stations covered in preceding year, were repeated as fixed stations in 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 years 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 between1998 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 2007, 226 stations at depths between 150 and 600 m were planned in the survey area. Of these 209 were allocated to the various strata according the distribution of Northern shrimp in the previous years while 7 and 10 hauls were allocated based on the distribution of Greenland halibut (GHL) and Atlantic cod respectively. In addition, 30 stations were planned at depths < 150 m in NAFO Div. 1A-1F and 9 extra hauls at depths between 600 and 800 m after GHL in NAFO 1B. CTD casts were also made along standard transects in the offshore and the Disko Bay/Vaigat area. 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 2008.

Survey period and daily sampling period

The trawl surveys has been carried out during the same period each year (June/July to August/September) 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.

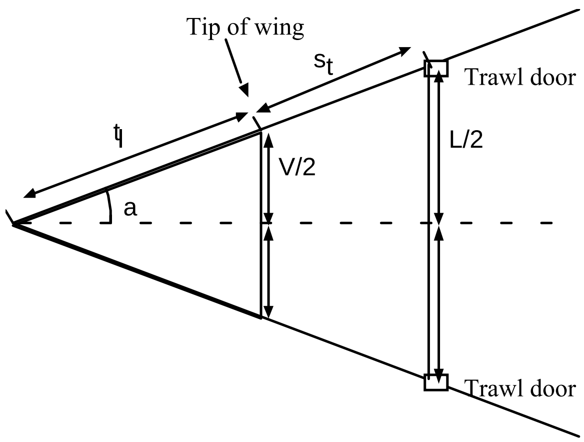
Results reported by Kingsley *et al.* (2002) have so far indicated that 15 min tows do not give more variable results than 30 min tows and hence no weighting was applied to tows of different durations. On the other hand, analyses of survey data from 1999 and 2000 have shown that the effective swept area 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 is 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 also 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 1988-1991estimates 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 1991and 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 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 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 sinus a can be formed and put equal to each other:

$\sin(a) = (L/2) / (t_l + s_t)$ 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:

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

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.

Sampling, weighting and "area expansion"

From each catch a sample of about 1.5 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 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:

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

Were $\hat{N}_l$ 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:

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

Were $\hat{N}_{ls}$ 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 years 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 Kanneworff (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 years report indices of male and female biomass was estimated based on haul by haul length specific densities (# of shrimp/km^2) averaged for each secondary stratum (depth stratum) and converted to biomass density by application of sex specific length/weight relationships (see Figure 9). 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 (353,6 thousand tons) with the catch weight based estimate (349,5 thousand tons) presented in this paper. The difference is about 1.1 %, which I considered acceptable.

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 2007 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, 2006 and 2007 '$R_{(t)}$ 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" .

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 supplement by a length-independent adjustment based on the mean ration 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 2007, 226 stations at depths between 150 and 600 m were planned - 212 of these were successfully covered during the survey.

Total biomass and distribution

Over-all Biomass trends

For all strata biomass estimates have been calculated (Tabs.2a-d) on the basis of the nominal swept area. The biomass estimates (in tons) for the five main regions and the entire survey area in 2007 are:

Region	Biomass estimate (t)	Number of stations	OECV (%)
North (U1-U3)	61 181	27	21.9
Canadian zone	1 711	8	40.0
West (incl. South)	207 711	157	18.0
Disko B./Vaigat (I)	78 854	20	20.9
Total	349 457	212	12.3

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 and now in 2007 to about 349 000 tons (Tab.3, Fig.3 upper panel).
The consecutive yearly difference in survey biomass indices shows a rapid increase over the last 4 years ($B=35.67yr- 27.12$; $R^2 = 0.739$; biomass is denoted B and yr = number of years).
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 the same 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 the past 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.

The total biomass in each of the five main survey regions has shown large biomass changes throughout the last decade (Fig. 4). Conspicuous changes occurred especially in the northernmost offshore region (U) and in the western area (W1-W7) during the period 2002-2004. The biomass indices for the Disko Bay/Vaigat area (I) also increased until 2004/5 but in a more gradual fashion. The biomass indices for the Canadian region (C0) and the southernmost areas were relatively low and stable over most of the survey time span. An exceptional high value was found for the Canadian zone in 2006, but this value is associated with a comparatively high uncertainty (OECV: 79%) and the biomass in this region was very low in 2007. The contribution of the southernmost offshore region (W8 and W9) to the overall biomass shows a negative trend since 1999 and for the remaining offshore area (W1 to W7) a sharp decline since 2004.

The survey biomass index has decreased substantially since 2003 in the West, and Disko/Vaigat and North regions that has historically, contributed to most of the total biomass off W. Greenland. This year's result follows the same general pattern, with the possible exception of the North region. The indices from the Canadian region (C0) and especially the southernmost regions (W8 and W9) show substantial decreases.

This year's survey results also indicate a continued decrease in fishable biomass. This year's total biomass is only 58 % of the biomass observed in 2003 and the fishable biomass in 2007 is 60% of that observed in 2003. Most of the shrimp biomass was concentrated in the areas W1, W2, W3 and the Disko/Vaigat. Moderate biomass values were observed in the area W4. Within this overall decreasing trend the offshore areas W1 and W2 this year show increases in biomass compared to 2006, as do the northern areas (U1-U3). Areas W3 and W4 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 32 thousand tons. Despite this decrease this area still contributes 22 % of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore decreased with 81 thousand tonnes while the decrease in the Disko/Vaigat area was only about 3 thousand tons.

In conclusion 53percent of the total biomass in 2007 was found in areas W1-W4 that covers about 33 percent of the entire survey area. Twenty two percent was found in the Disko/Vaigat area covering about 7 percent of the survey area and about 18 percent in the northern areas (U1-U3) that covers about 38 percent of the survey area. Only seven percent of the biomass was found in the remaining southern areas that covers 22 percent of the survey area. Hence the shrimp biomass in 2007 appeared to be concentrated in the offshore areas W1-W4, in the Disko/Vaigat area and to a slightly lesser degree in the northern areas (U1-U3) according to the survey results.

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. 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 (≈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. Since then the importance of the 200-300 m depth interval has been gradually restored while the importance of the shallower and deeper intervals diminishes.

Shrimp density distribution

Off shore areas (U1-U3,C0, W1-W9)
Not surprisingly the biomass density results agree both generally and in detail with the overall and regional biomass results. The distribution of the Northern shrimp density in 2006 (Fig. 1 and Table 5) followed an earlier observed pattern with high densities in the deeps between the shallow banks along the coast north from about 64°N, i.e. the Sukkertoppen Deep (≈64°30'N) and in particular in the Holsteinsborg Deep (≈66°30'N). High concentrations of Northern shrimp were predominantly found in the area north and west of Store Hellefiske Bank (≈68 to 69°N) as well as in the northern part of Disko Bay and Vaigat (inshore areas I1 and I2, ≈69 to 70°N). In contrast, low densities were observed at the offshore slope of the shelf between 64 and 67°N.

In 2007 the highest off shore densities were generally found further north (between 67°20’ and 69°30’) than in 2006 (Figure 1). The highest densities were found in the primary strata W1 (west of the entrance to Disko Bay),W2(entrance of Disko Bay) and W3 (Northwest slope of St. Hellefisk Bank). Density in the combined area W1-W2 increased in 2007 while in the combined area W3-W4 density remained at the same level as in 2006. Densities in W4 (the Holsteinsborg deep) were generally much lower this year but a couple of hauls in this region gave fairly high catches which is the reason for the somewhat elevated density estimate. 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 2007 the lowest since 1994 (Table 5). A very substantial drop in density this year compared to 2006 was observed in C0 were estimated density dropped from 10.8 tons/km^2 to 0.4 tons/km^2. An explanation for this dramatic drop is difficult to give.

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) and ranged between 8.4 and 14.2 t/km^2 (or g/m^2) in the five recent years. This is about three times higher than the average offshore density during the same period. In 2006 average density was estimated to be 11.3 tons /km^2 but have in 2007 dropped to a level of 8 tons /km^2.

Demography and recruitment

Size distribution by area in 2007compared with 2005 and 2006

Figure 6 gives length density distributions for primary strata in the survey area in 2007, Fig. 8 gives the length frequency for the total area 2002-2006 and Fig. 9 gives the length frequency distribution for the survey area in 2007.

Figure 12 shows the observed and fitted distributions for the male component in the same combined strata as in Table 9. Figure 1 gives the geographical position of primary strata.
All areas except C0, and the southern areas W7-W9 were clearly dominated by a cohort with a modal carapace length of about 20-21 mm (Fig 6) in 2007. This cohort consists mostly of males but overlaps in all cases with an adjacent peak of primiparous females Figs (6, 9 and 10c).

In the analysis of all sexes combined in the total survey area two modes, one at about 19.5mm and one at about 23 mm, are identified. The former consists mainly of males and the latter of primiparous females. These two peaks most likely belong to the same age class and consists of shrimp being just over 3 years old (assuming hatching in March/April) (Bergstrøm, 2006). 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. Since the stock this year was strongly dominated (almost 95%) by this splitting year class the components may easily be misinterpreted as 2 separate age classes. Shrimp of smaller sizes were generally very rare in this year's samples and so were larger/older shrimp. Shrimp of the "recruit" size class (modal length 11-13 mm), ("age 2") are, as in 2006, very rare. Judging the total stock cohort analysis less than 1 % of the shrimp have a modal length of 11.5 mm and shrimp with modal lengths of>24. mm CPL is also extremely rare this year. Males with a modal length of between 12 and 19 mm occur in low-moderate densities in all areas except in the northernmost (U1, U2) and the southernmost (W7, W8, W9) areas were densities are very low.

The results presented in the length density distribution graphs (Fig. 6) supports the notion that this year the stock was concentrated to the Areas W1-W4, the Disko/Vaigat area and to some extent the easternmost north area U3. The results from these areas indicate a slightly wider range of sizes although the 3+ olds still dominate heavily. Large multiparous females ("large shrimp") are still very rare in these areas. Such shrimp were only found in somewhat higher proportions in areas W6 and W9. In the case of W9 however, the overall density is so low that the result should be treated as anecdotal.

Fig. 10a, b and c shows observed length density distributions (LDD), fitted cohort components and expected combined distribution for all sexes combined for 2005, 2006 and 2007 and gives some opportunity to compare these three years. Such comparisons should however be done with caution in this protandric hermaphrodite since varying proportions of sex changing shrimp in different age groups present in different parts of the survey area may complicate the picture.

All three years show a strong-very strong dominance of shrimp with modal lengths ranging between 19 to23 mm (2005, 82 %, 2006, 87 % and in 2007, 95 %). The majority of shrimp in this size range are males and primiparous females i.e. they are shrimp that change sex the present calendar year and are added as females to the female spawning stock in the autumn. A varying but small proportion of these are also multiparous females

All three years show low proportions of small recruiting shrimp –the proportion of shrimp contained in the size class with a mode of about 11-12 mm and below are about 3.4 % in 2005, 12,4 % in 2006 and only about 0.7 % in 2007. This pattern is also illustrated by the yearly values on R(t) and *R(t) given in Tab 10.
The proportion of shrimp with modal lengths between 12 and 19 mm (typically males about to breed in autumn) also appear to be rare and decreasing in the overall survey area (2005, 12%), 2006, 6%), and 2007, 4 %). Shrimp contained in cohorts with larger modal carapace lengths > 24.0mm are generally rare all three years (2005, 4 %, 2006, 5.8% and in 2007, <<1%)).

Long term comparison of size distributions

Overall length distributions for the offshore and the inshore area in 1988 to 2006 are compared in Fig.7a-d. The offshore length frequency distribution for 2006 shows a distinct mode of males at 21 mm CL (Fig. 7d). Abundance of males between 11 and 15 mm CL was higher in 2006 than in 2005 but is low compared to e.g. 2003 and in particular 2001. The primiparous females show a mode at about 23.5 mm CL, and a mode at 24 mm CL is discernable for multiparous females in the offshore areas in 2005 (Fig. 9d). The inshore length frequency for 2005 differed from that recorded in previous years, in particular concerning the presence of a pronounced peak for males at 18.5 mm CL (Fig. 7d). The inshore length frequency distributions were, however, similar to the offshore ones concerning the mode of the primiparous females at 23 mm CL in all years since 2003 (Fig. 7d).

Figure8 shows overall length frequencies for the entire survey area combining the offshore and inshore data for the years 2002 to 2006. A progression of the 1999-year-class from about 17.5 mm CL in 2002 to 19.5 mm CL in 2003 is clearly visible. This year-class began to pass into the female group in 2004 and contributes most likely to the majority of the primiparous females in 2005 and the multiparous females in 2006. 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 2002-year-class at the progressing modes of about 8 mm CL in 2003, 12 mm CL in 2004, 16 mm CL in 2005 and 18 mm CL in 2006 is striking. The corresponding abundance levels were about 0.2×10^{9} at age 1, $1.\times10^{9}$ at "age 2", 4.3×10^{9} at "age 3" and 5.8×10^{9} at "age 4". Several processes, which include mesh selection of the trawl especially for shrimp smaller 11 mm CL (Wieland, 2002b), escapement of juveniles below the footrope (Nilsson *et al.*, 1986) and immigration from nursery areas at depths shallower than intensively covered by the survey (Wieland and Carlsson, 2001) may explain this phenomenon.

The statement made in last years survey report that a high abundance of males between 17 and 21 mm CL in 2006 (Fig. 8) suggests that progression to the female group is secured for 2007 seems to hold true. This years results (Fig 9) also confirms the last years results indicating that no strong year-class will enter the fishable stock in the coming years.

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:	$W = 0.000660 * CL^{2.9461}$

For this years report sex specific data concerning weight at carapace length from the period 2001-2006 were used to determine length weight relationships for "all sexes" pooled, juveniles and males and all females (Fig. 11) Regressions were fitted using the least square method implemented in the software "SigmaPlot".

The resulting expressions are:

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

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

Juveniles and Males: $W=0.0006*CL^{2.9934}$; 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 2006 is below the value for 2005, but still exceeds the long-term mean. This years estimate of 66.4 billions still exceeds the time series mean of 62.1 billions but not considerably. 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 less than 1% from the direct estimates of the total survey biomass (Tab.3), except for 2001 (-6.3%), 2005 (-4.2%) and 2006 (-4.0%). This year's calculations applying the new length weight relationships only give a difference of 1.1 %.

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 2007, the fishable biomass index for the entire survey area amounts to about 285 000 tons (about half what was estimated in 2003). However this years estimate it is still above the long-term average. Worth noting is however that the rate of decrease seems to have been increasing since 2003.

Female biomass decreased with 12.4 thousand tons between 2005 and 2006 but has since 2006 decreased with 62 thousand tons. Male biomass decreased with 52 thousand tons between 2005 and 2006 and has since 2006 decreased further with about 50 thousand tons.

Recruitment and mean length at "age 2"

Observed average length density distribution of juvenile and male *P. borealis* with standard errors by region in 2007 are given together with fitted Gaussian components for age 1, 2, and 3 and composite expected distributions in Figure 10. Results previous the modal analyses, i.e. the mean length at age 2 in the years 1993 to 2007, 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).

During the initial period 1993 to 1995, low estimates of abundance at age 2 were obtained in particular for the inshore area (Fig. 11). This was followed by exceptionally high values in the offshore area in 1996 (Fig. 12) 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 3.4×10^{9} individuals in 2005. The 2006 estimates amounting to 4.5×10^{9} indicates a slight increase in recruitment, but was much below the long-term average of 7.34×10^{9} individuals. This decrease has continued in 2007 to a level of 1.2×10^{9} shrimp.

It is worth noting that the Disko Bay / Vaigat area (inshore regions I1 and I2), which covers only about 7% of the total survey area, contributed between 28 and 45% to the total abundance of this age group in the period 1997 to 2002. Moreover, the proportion of recruits found in the inshore waters increased to 54 and 73% in 2004 and 2005, respectively, whereas the in 2006 the importance of the offshore regions increased again contributing 56% of the total abundance at age 2. In 2007 the contribution from the Disko/Vaigat region is about 76 %.

Table 10 gives estimated abundances of "age 2" shrimp and total stock abundance for the years 1993-2007 together with gross recruitment rate R(t). High R(t) values were observed in 1996, 1999, 2000, and in 2001and 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. I have carried out correlation analyses on the series of yearly R(t) values and estimated fishable biomass 1, 2, 3, and for years later. A positive very weak correlation (r==.1195) was found between R(t) and fishable biomass 2 years later. A stronger but still weak correlation (r=0.3825) was found between R(t) and fishable biomass 3 years later. A moderate–strong correlation was found between R(t) and the fishable biomass lagged 4 years. If one assumes the simplest linear relationship between R(t) and fishable biomass lagged 4 years this relationship can be described by the function F.B.=1028*R(t)+195.6; (R^2 = 0.401) were F.B. denotes fishable biomass.

Earlier survey reports (e.g. Wieland and Bergstrøm2005;Wieland and Bergstrøm 2006) have investigated and reported significant correlations between the abundance indices for age 2 and the fishable biomass (all individuals ≥ 17 mm CL) one, two and three years later .

Against these results the inevitable conclusion is that the decreasing recruitment levels observed since 2004 in the past years will produce a continued decrease of the fishable biomass in coming years to a level that is close to or less than the average recorded in the late 1990s. Although the relationship between recruitment at age 2 and fishable biomass are clear, it should be kept in mind that predictions for coming years are only valid if the combined effect of underlying processes like growth, natural mortality (e.g. predation by Greenland halibut and Atlantic cod) and the removal by the fishery relative to stock size (exploitation rate) do not change substantially.

Bottom temperature

Area weighted bottom temperatures are given in Fig. 13. Bottom temperatures ranged from 1.3 °C in the shallow (< 200 m) water of the Disko Bay to about 5.9 C in the deeper (300-400 m interval) part of the southernmost offshore area in 2007. Values above 4.5 °C were frequently found at the offshore slope of the shelf in the area south of 60°30’N. The observed very pronounced decrease of the mean value for the southern part of the survey area compared to the previous years (Fig.16 upper panel) observed last year was present although mean temperature was lower than in 2005. Mean temperature in W5 and W6 further north has decreased since the maximum in 2003 but in the remaining areas such decreases are not obvious. A transition from a cold to a warm period has been recorded in the mid 1990s and was observed in all depth strata of the survey (Fig. 16 middle panel). The overall area weighted mean bottom temperature amounted to 3.3 C (Fig. 16 lower panel). This is the second highest value in the time series and indicates that the recent relative warm period has continued also in 2007.

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 350 000tons in 2007. Large variations from year to year both geographically and over depth zones have been observed over the time series.

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. This year’s biomass is only 58 % of the biomass observed in 2003 and the fishable biomass in 2007 is about half of that observed in 2003. Most of the shrimp biomass and the fishable biomass were concentrated in the areas W1, W2, W3 and the Disko/Vaigat. Moderate biomass values were observed also in the area W4. The areas W1 and W2 show increases in biomass compared to 2006, as do the northern areas (U1-U3) while W3 and W4 show only a modest decrease. All the southern areas W5-W9 show substantial decreases and shrimp density in these areas were generally very low.

Biomass in the Disko/Vaigat area decreased with about 32 thousand tons. Despite this decrease this area still contributes 22 % of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore decreased with 81 thousand tonnes while the decrease in the Disko/Vaigat area was only about 3 thousand tons.

This years survey demographic results generally indicate a truncated overall size distribution. More than 90 % of the shrimp in the stock appear to be 3+ years old. Most of these were, at the time of the survey, males but many were primiparous females. Smaller and larger shrimp were generally very rare in the survey samples with the possible exception of the Disko/Vaigat area that yielded samples with less truncated size distributions.
Recruitment to the stock is very low this year as indicated by the abundance of “age 2” shrimp and by the gross recruitment index.

Although biomass and abundance levels still are above the time series mean the rates at which biomass and abundance is decreasing and the consistent poor recruitment in recent years raises concerns about the development of the stock. The causes of the observed declines may be many including elevated natural mortality due to cod predation on especially juvenile shrimp, distribution shifts due to changes in the physical environment (temperature increase), a too high exploitation rate, or any combination of these factors.

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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 Kanneworff, 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 - 2007	Paamiut	Cosmos	54.0	28.1 - 28.6	**

Table. 2a. Estimated biomass (tons) and sampling statistics for the survey strata in region U, 2007.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
U1-1	150-200	3302	56.8	2	30.2	53.2
U1-2	200-300	4494	9202.7	2	12586.3	136.8
U1-3	300-400	4646	7455.6	3	10324.4	138.5
U1-4	400-600	5312	2961.4	2	102.7	3.5
U2-2	200-300	6496	3571.0	2	4011.7	112.3
U2-3	300-400	8517	14715.5	3	9135.6	62.1
U2-4	400-600	7946	1742.0	3	460.1	26.4
U3-1	150-200	2179	0.0	2	0.0	
U3-2	200-300	3210	16576.9	5	11300.4	68.2
U3-3	300-400	1639	2261.5	2	145.5	6.4
U3-4	400-600	2658	2637.4	1		
Total		50399	61180.8	27		

Table. 2b. Estimated biomass (tons) and sampling statistics for the survey strata in region C, 2007.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
C0-2	200-300	897	736.9	2	1008.4	136.8
C0-3	300-400	2126	950.9	4	592.1	62.3
C0-4	400-600	1213	23.5	2	15.4	65.3
Total		4236	1711.3	8		

Table. 2c. Estimated biomass (tons) and sampling statistics for the survey strata in region W, 2007

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
W1-1	150-200	2968	1012.2	2	1431.5	141.4
W1-2	200-300	6035	55277.2	15	105890.4	191.6
W1-3	300-400	7515	20725.1	8	10297.0	49.7
W1-4	400-600	877	266.9	2	2.2	0.8
W2-1	150-200	1699	305.2	2	195.1	63.9
W2-2	200-300	2616	37571.7	9	46078.4	122.6
W2-3	300-400	1768	12144.3	5	8035.3	66.2
W2-4	400-600	965	838.9	1		
W3-1	150-200	2160	1706.7	4	2985.7	174.9
W3-2	200-300	4698	32642.4	14	32611.3	99.9
W3-3	300-400	2119	2340.2	1		
W3-4	400-600	2921	2174.2	4	2766.0	127.2
W4-1	150-200	4255	96.4	2	131.8	136.7
W4-2	200-300	1695	6895.9	4	13527.7	196.2
W4-3	300-400	777	11152.9	4	22202.2	199.1
W4-4	400-600	1873	67.8	2	86.0	126.9
W5-1	150-200	3001	1503.8	7	3911.6	260.1
W5-2	200-300	3648	9014.7	11	18847.2	209.1
W5-3	300-400	1950	1451.3	2	2049.9	141.3
W5-4	400-600	3021	1286.5	2	1779.9	138.3
W6-1	150-200	1206	156.1	3	150.5	96.4
W6-2	200-300	2006	6972.9	7	13762.7	197.4
W6-3	300-400	1585	918.6	6	1514.1	164.8
W6-4	400-600	1234	0.0	2	0.0	
W7-1	150-200	2442	5.8	5	13.0	223.6
W7-2	200-300	891	0.1	7	0.1	196.7
W7-3	300-400	265	0.0	2	0.0	
W7-4	400-600	317	0.0	2	0.0	141.4
W8-1	150-200	424	0.0	2	0.0	
W8-2	200-300	567	43.8	2	58.4	133.2
W8-3	300-400	405	676.2	2	912.1	134.9
W8-4	400-600	718	418.6	3	311.3	74.4
W9-1	150-200	1711	0.0	4	0.0	
W9-2	200-300	938	0.7	6	0.7	99.0
W9-3	300-400	516	0.0	1		
W9-4	400-600	430	43.8	2	61.7	140.8
Total		72216	207710.9	157		

Table. 2d. Estimated biomass (tons) and sampling statistics for the survey strata in region I, 2007.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
I1-1	150-200	397	4634.0	2	999.0	21.6
I1-2	200-300	1903	15969.0	1		
I1-3	300-400	2430	26374.5	3	15971.6	60.6
I1-4	400-600	1561	5222.2	2	881.8	16.9
I2-1	150-200	432	4549.2	3	6208.0	136.5
I2-2	200-300	793	13678.2	4	5337.7	39.0
I2-3	300-400	1022	7500.7	2	6789.3	90.5
I2-4	400-600	1295	925.9	3	605.5	65.4
Total		9833	78853.7	20		

Table. 3. Biomass estimates (in '000 tons) for combined strata and standard errors for the entire survey area 1988-2007.

Year	N1-N9	U1-U3 [#]	C1+C3	C0 [1.0]	W1-W2	W3-W4	W5-W7 [2.0]	S1+S2	W8-W9 [1.0]	D1-D9 [3.0]	I1-I2 [1.0]	Total	SE [4.0]	OECV (%)[4]
1988	22.6		9.5		55.1	85.5	17.7	-		39.2		229.7	24.7	13.5
1989	11.1		3.7		50.0	82.7	39.0	-		39.2		225.7	32.3	17.8
1990	11.0		9.1		78.6	53.9	23.5	-		39.2		215.3	32.6	17.9
1991	5.1		4.2		26.8	47.4	23.3	-		43.1		149.9	23.0	13.4
1992	18.1		22.2		46.2	30.6	45.8	-		41.4		204.4	32.5	13.8
1993	6.9		2.9		93.8	36.7	62.2	-		28.3		230.8	30.9	11.7
1994	6.6		6.0		95.0	44.5	32.6	16.7		34.0		235.4	51.7	19.1
1995	6.8		3.9		39.0	52.4	48.7	1.6		39.1		191.4	30.6	13.9
1996	8.8		1.5		46.4	31.5	80.0	3.3		44.3		215.9	40.4	16.3
1997	5.7		0.2		34.7	13.1	57.9	21.8		44.3		177.7	31.1	15.3
1998	7.0		0.4		37.8	100.6	45.1	18.6		51.8		261.2	57.6	19.2
1999	17.6		10.5		50.1	23.2	50.5	56.0		52.6		260.6	42.1	14.1
2000	8.4		10.7		62.1	69.8	71.0	21.8		73.0		316.9	40.3	11.1
2001	34.1		3.7		74.3	47.6	58.5	36.3		72.1		326.7	44.2	11.8
2002	17.4 [#]		5.4		114.0	62.1	94.9	40.5		85.8		420.2	60.0	12.4
2003		109.3	5.9		148.6	93.3	98.0		35.0	107.7		597.8	77.0	11.2
2004		111.2		3.5	152.8	96.5	102.6		15.4		81.4	563.4	103.7	16.0
2005		100.5		9.3	159.9	87.2	53.4		1.9		139.6	551.9	88.4	16.0
2006		54.7		45.8	108.9	60.6	90.8		12.5		110.7	484.0	64.6	13.4
2007		61.2		1.7	128.1	57.1	21.3		1.2		78.9	349.5	42.8	12.3

[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 1988-2007

Year	N/U	C	W1-W7	S/W8-W9	D/I	Total suvey	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	53.8	34.6	16.02	194
2006	20.5	79.0	19.0	30.1	12.9	13.36	221
2007	21.9	40.0	18.0	415.6	20.9	12.26	212

Table. 5. Estimated mean densities (t/km²) for combined strata in 1988-2006.

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

Table. 6. Abundance estimates (billions) for males and females from overall length distributions for the total survey area 1988-2006 (mean values for Disko Bay/Vaigat area in 1991-1997 used for 1988-1990.). Results for 2007 were calculated based on average estimates density of males and females for regional depth strata. These estimates were multiplied with the area of relevant depth strata and resulting numbers summed regionally to obtain abundance estimates for the entire survey area

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	77.5	22.5
Average	49.9	12.2	62.1	80.4	19.6

Table. 7. Biomass estimates for males and females ('000 tons) in the total survey area based on length-weight relationships applied to overall length-frequency distributions 1988-2006 (mean values for Disko Bay/Vaigat area in 1991-1997 used for 1988-1990. Results for 2007 were calculated based on average Length Density Distribution (LDD) estimates for each regional depth strata and relevant sex separated Length/ Weight relationships for the period 2001-2006. Average biomass density in each depth strata was multiplied with the area of the stratum and to give average stratum biomass. These were subsequently summed regionally in order to get biomass estimates for the total survey area.

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
Average	199.9	107.5	307.4	65.2	34.8

Table. 8. Estimates of fishable biomass (≥17 mmCL, '000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2007 (mean values for Disko Bay/Vaigat area in 1991-1997 used for 1988-1990)

		I1(Disko) + I2(Vaigat)	
Year	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
Average	231.2	54.9	285.0

Table. 9. Mean carapace length (mm) for Northern shrimp at "age 2" off West Greenland 1993-2007 and corresponding standard deviations and coefficients of variation from modal analysis (-: not present, ( ): fixed in the final MIX run).

	Region / Depth						
	U1 to U3	I1 and I2	C0 and W1 to W4		W5 and W6		W7 to W9
Year	150-600 m	150-600m	150-300m	300-600 m	150-300 m	300-600 m	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 (?)	-

standard deviation:

	U1 to U3	I1 and I2	C0 and W1 to W4		W5 and W6		W7 to W9
Year	150-600 m	150-600m	150-300m	300-600 m	150-300 m	300-600 m	150-600 m
1993	0.79	1.32	1.03	1.08	0.84	0.87	(0.80)
1994	(0.70)	1.04	1.17	1.20	1.09	1.54	-
1995	0.81	1.03	1.40	1.45	0.81	1.48	(0.70)
1996	0.79	1.09	0.91	1.23	1.48	1.29	(0.70)
1997	1.04	1.13	1.18	1.17	1.31	1.43	(0.70)
1998	1.07	1.40	1.03	1.35	1.31	1.10	(0.80)
1999	1.46	1.40	1.24	1.39	1.35	1.32	(0.70)
2000	1.30	1.39	1.26	1.44	1.46	1.26	(0.80)
2001	1.35	1.32	1.38	1.46	1.13	(0.80)	(0.70)
2002	1.33	1.49	1.37	1.46	1.52	(0.90)	(0.70)
2003	0.98	1.26	1.20	1.50	1.19	1.25	(0.90)
2004	1.05	1.01	1.14	1.49	1.27	(0.70)	(0.90)
2005	0.71	0.96	0.73	1.38	1.05	0.90	(0.85)
2006	1.14	1.28	1.11	1.15	1.17	(0.90)	(0.85)
2007	1.60	1.60	1.40	1.20	1.70	1.10	-

coefficent of variation:

	U1 to U3	I1 and I2	C0 and W1 to W4		W5 and W6		W7 to W9
Year	150-600 m	150-600m	150-300m	300-600 m	150-300 m	300-600 m	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	-

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 (*10^9)	Abundance of (shrimp) 10^9	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
Average	7.84	70.80	0.12	0.01

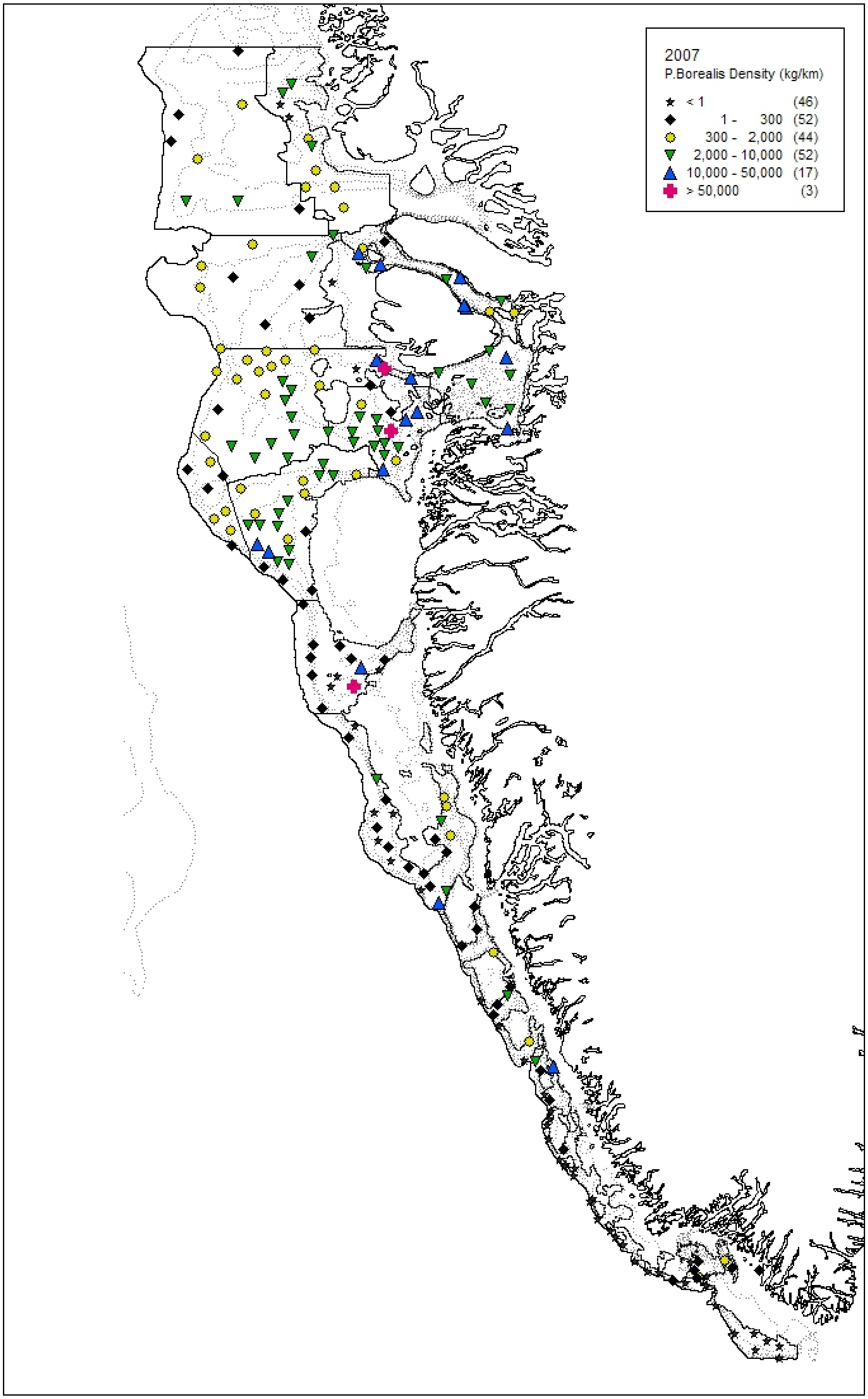


Fig.1.Survey stratification and shrimp density in W. Greenland 2007

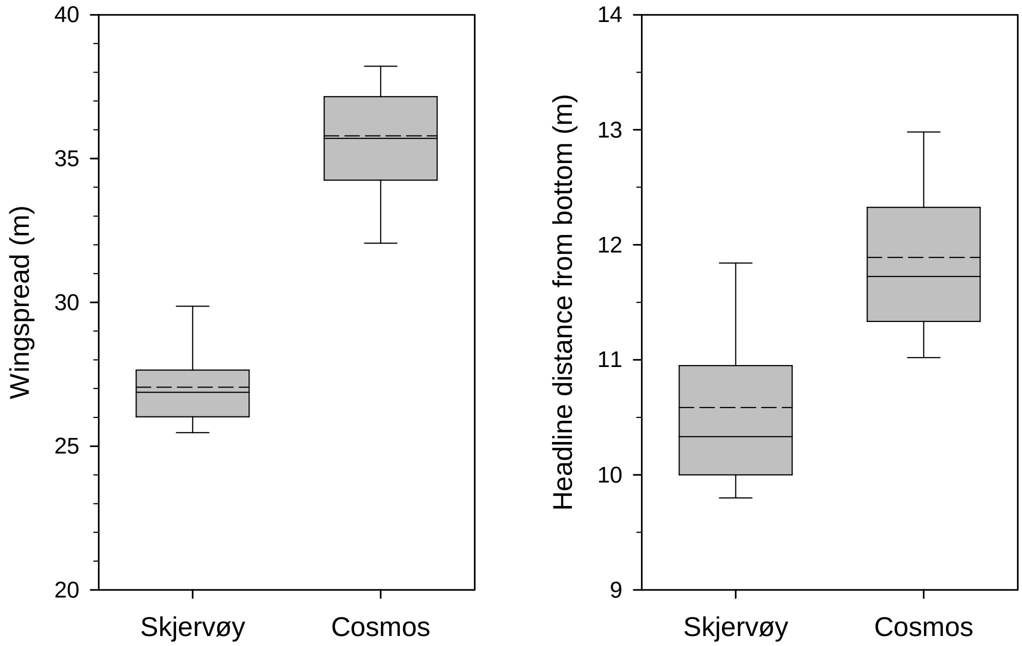


Fig. 2. Box whisker plots showing arithmetic means (stippled line) and medians (solid lines) of wingspread and headline distance to bottom for the two trawl types (*Skjervøy* 3000 and *Cosmos* 2000) with 95% confidence interval (upper and lower borders of grey box) and lower and upper quartiles (error 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).

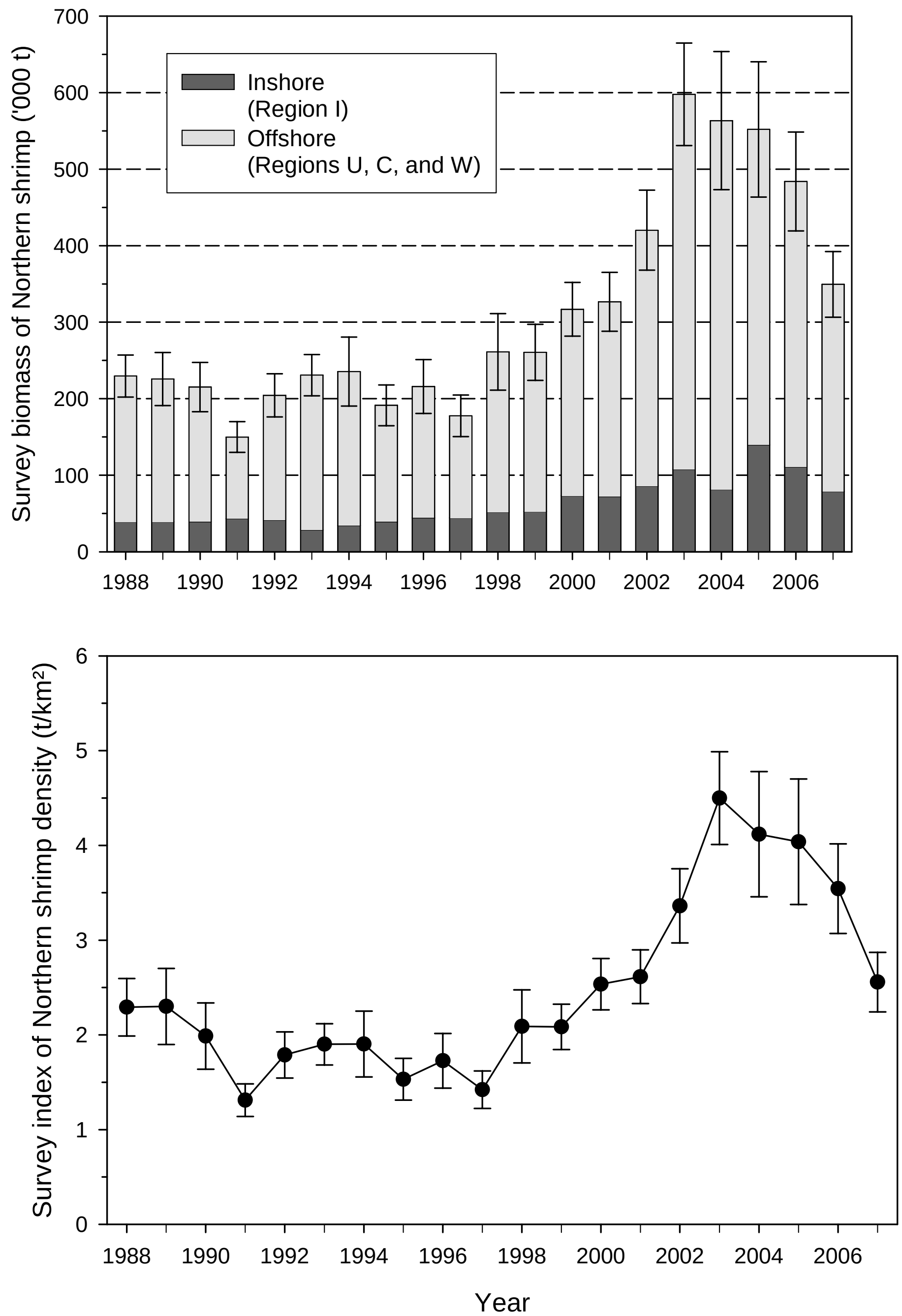


Fig. 3. Estimated total survey biomass and average survey biomass density of Northern shrimp with standard errors 1988-2007 (Average biomass estimate for inshore areas 1991-1997 are used for 1988-1990 to facilitate between-year comparisons, see Tab. 3 for details).

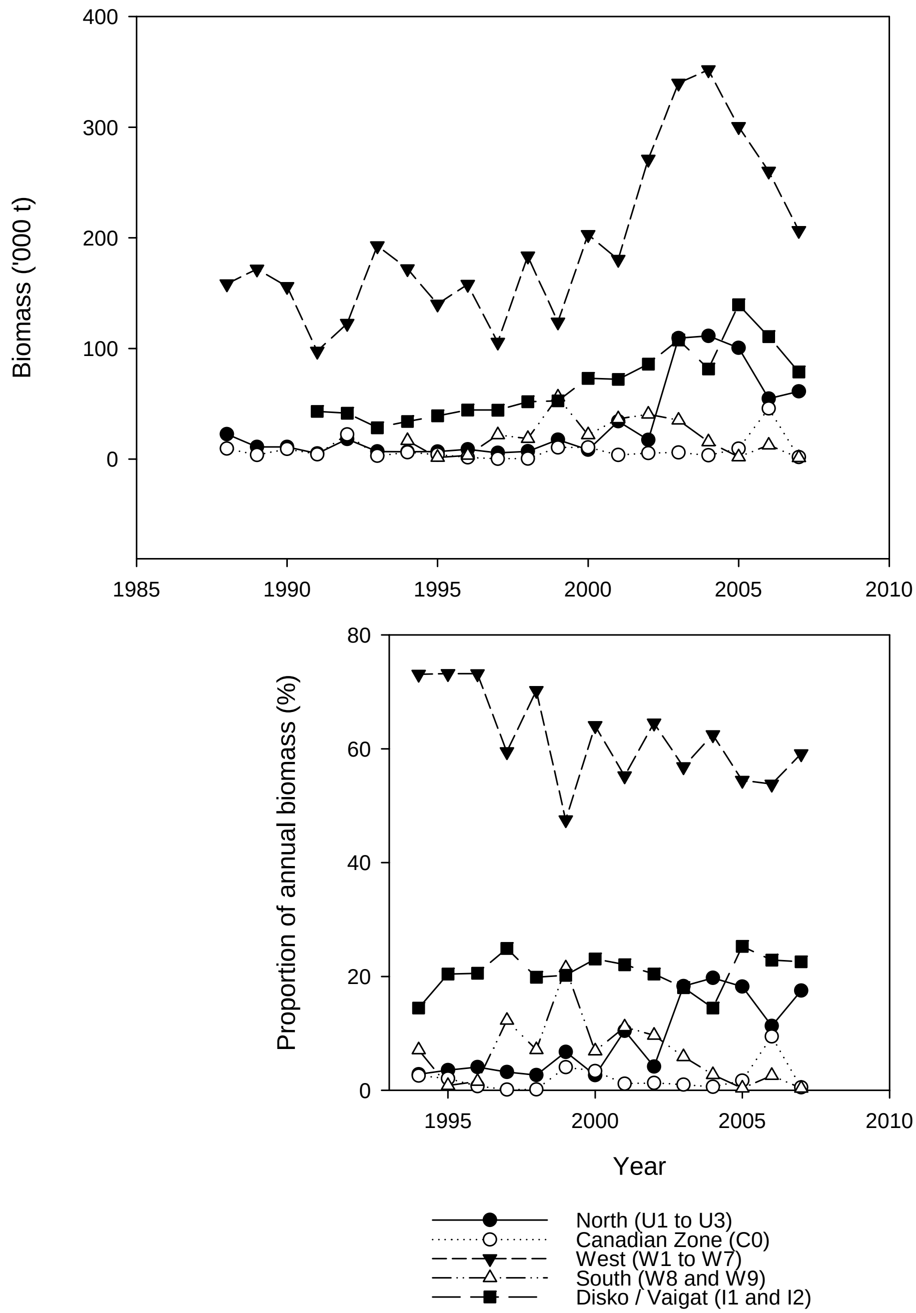


Fig. 4.Biomass in the five main survey regions 1988-2007 (area names are given in brackets, see Fig. 1 for location) and contribution of these regions to the total biomass 1994-2007.

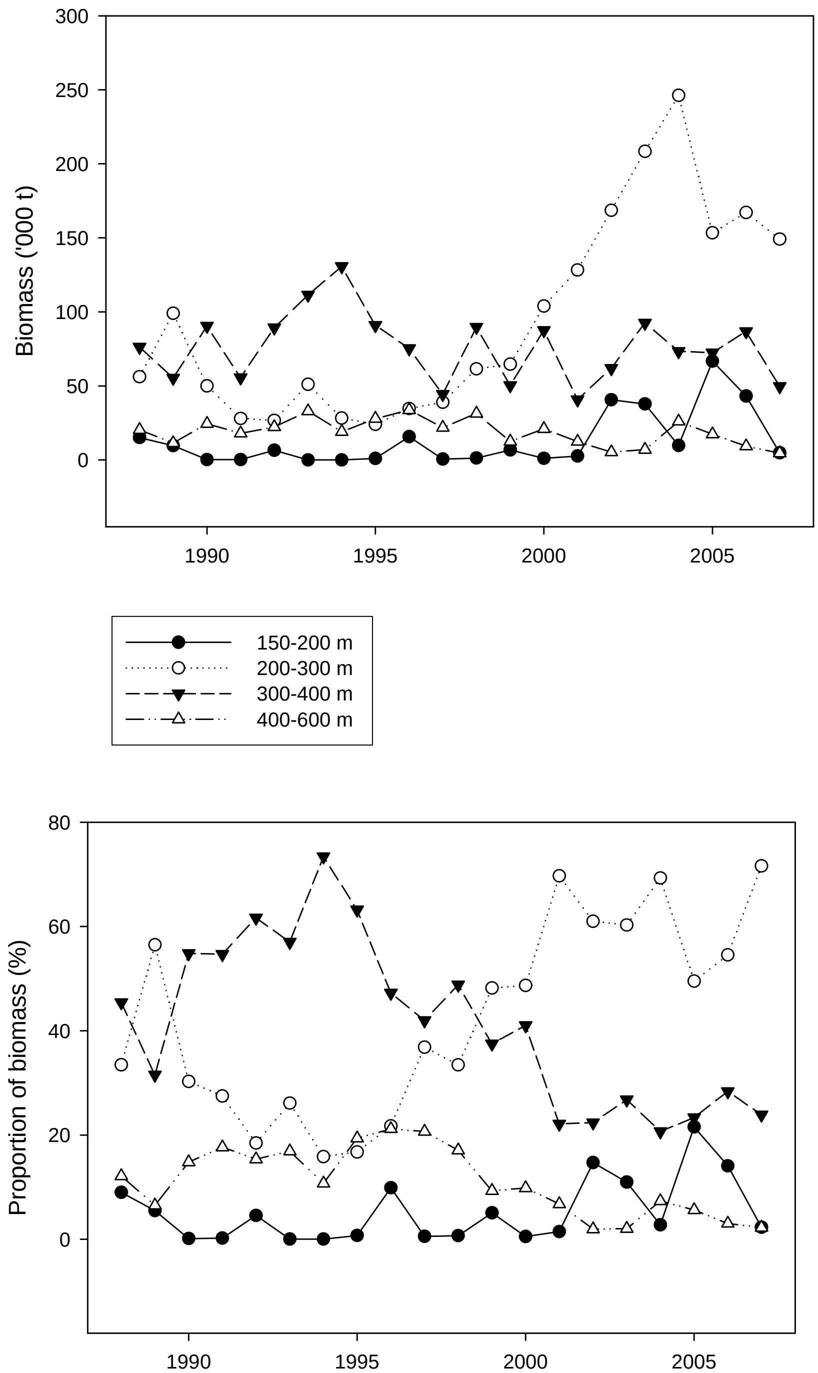


Fig. 5. Biomass distribution in the four depth strata in areas C and W1-W7 1988-2007

Fig. 6a.Length densities (#/km^2) of Northern shrimp in offshore areas U1 to U3, C0 and W1 to W9 in 2007. Note differences in scale on vertical axis!

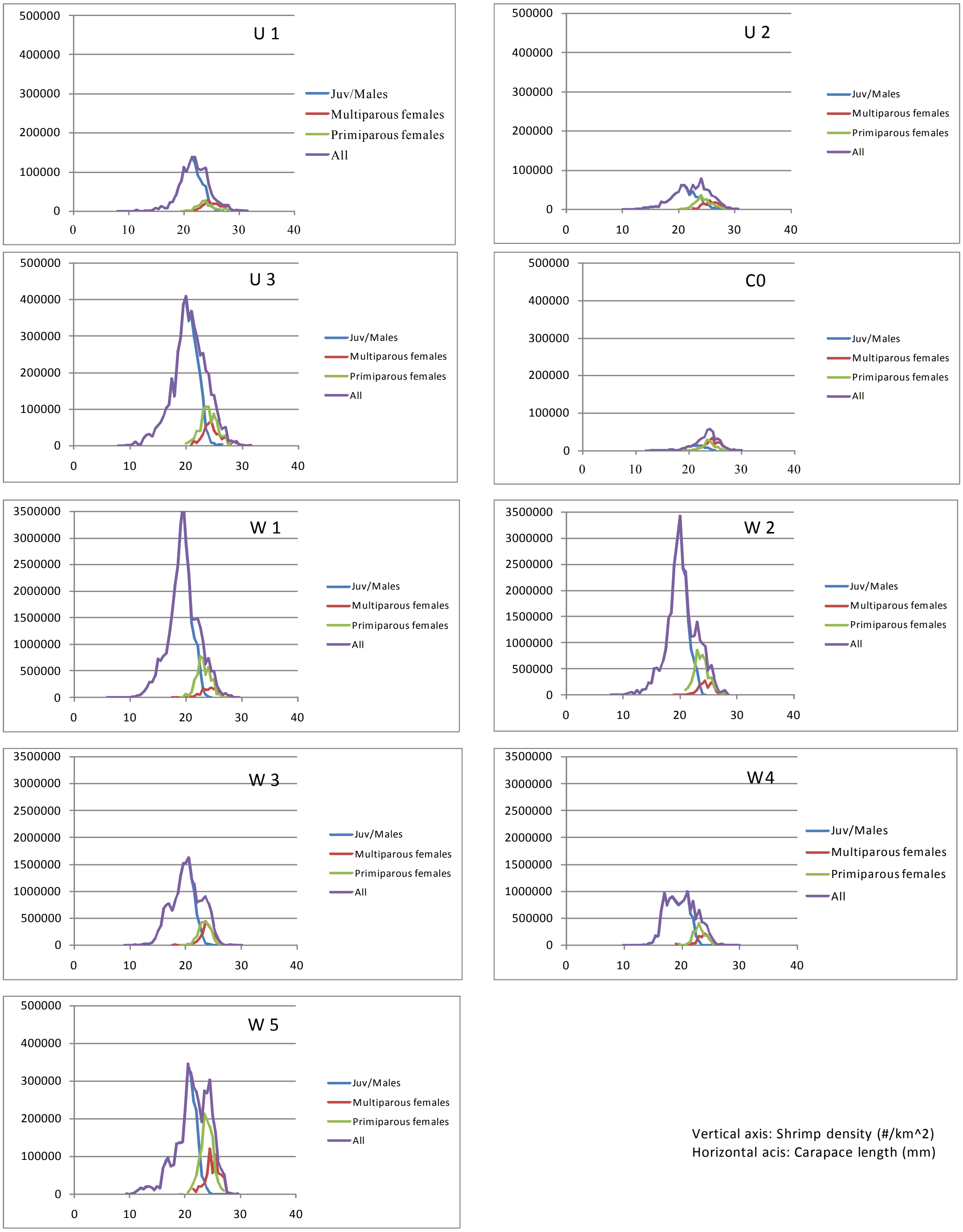
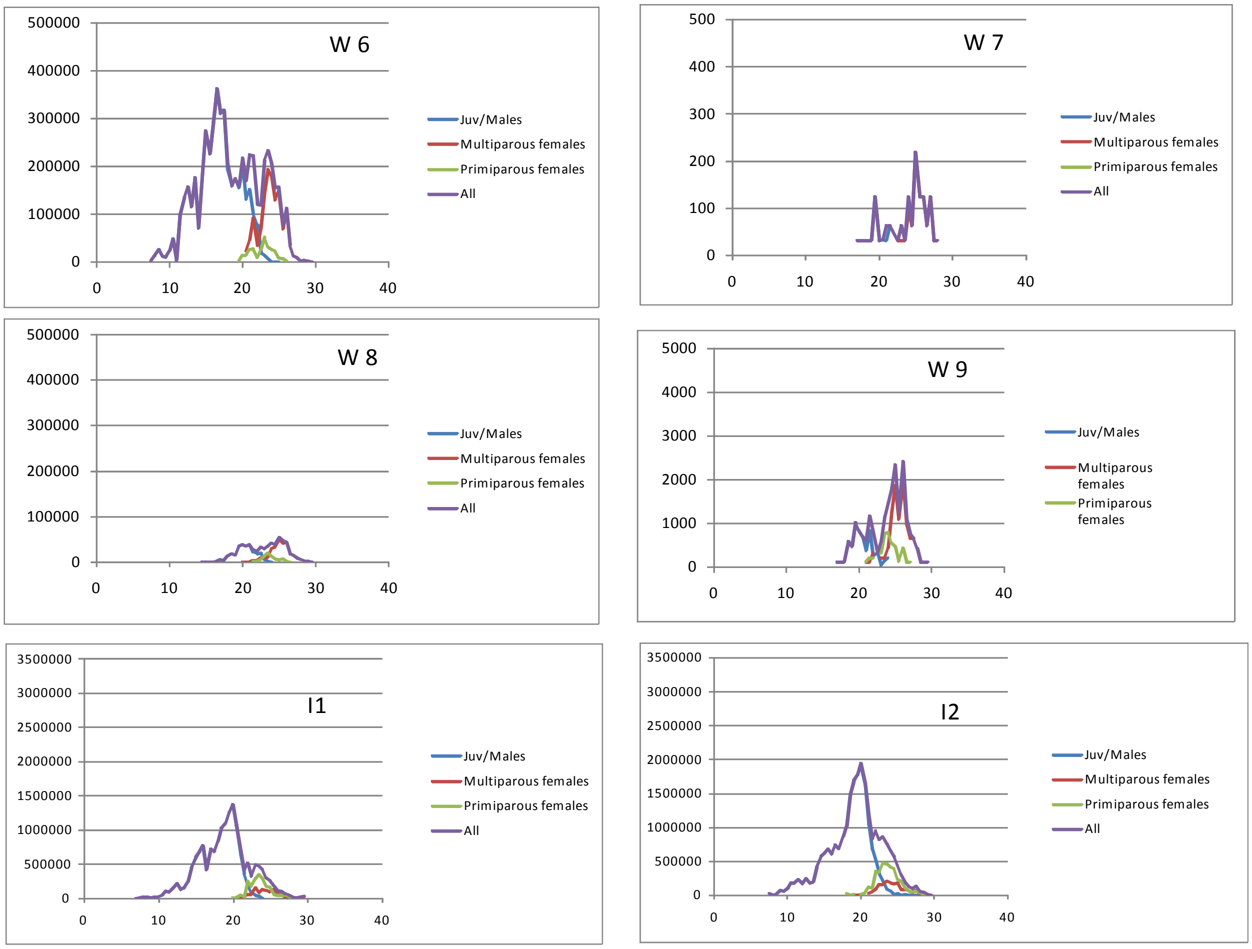


Fig. 6b.Length densities (#/km^2) of Northern shrimp in off shore areas W6-W9 and inshore areas I1 and I2 (Disko Bay / Vaigat) in 2007. Note the difference in scale on vertical axis!



Vertical axis: Shrimp density (#/km^2)
Horizontal acis: Carapace length (mm)

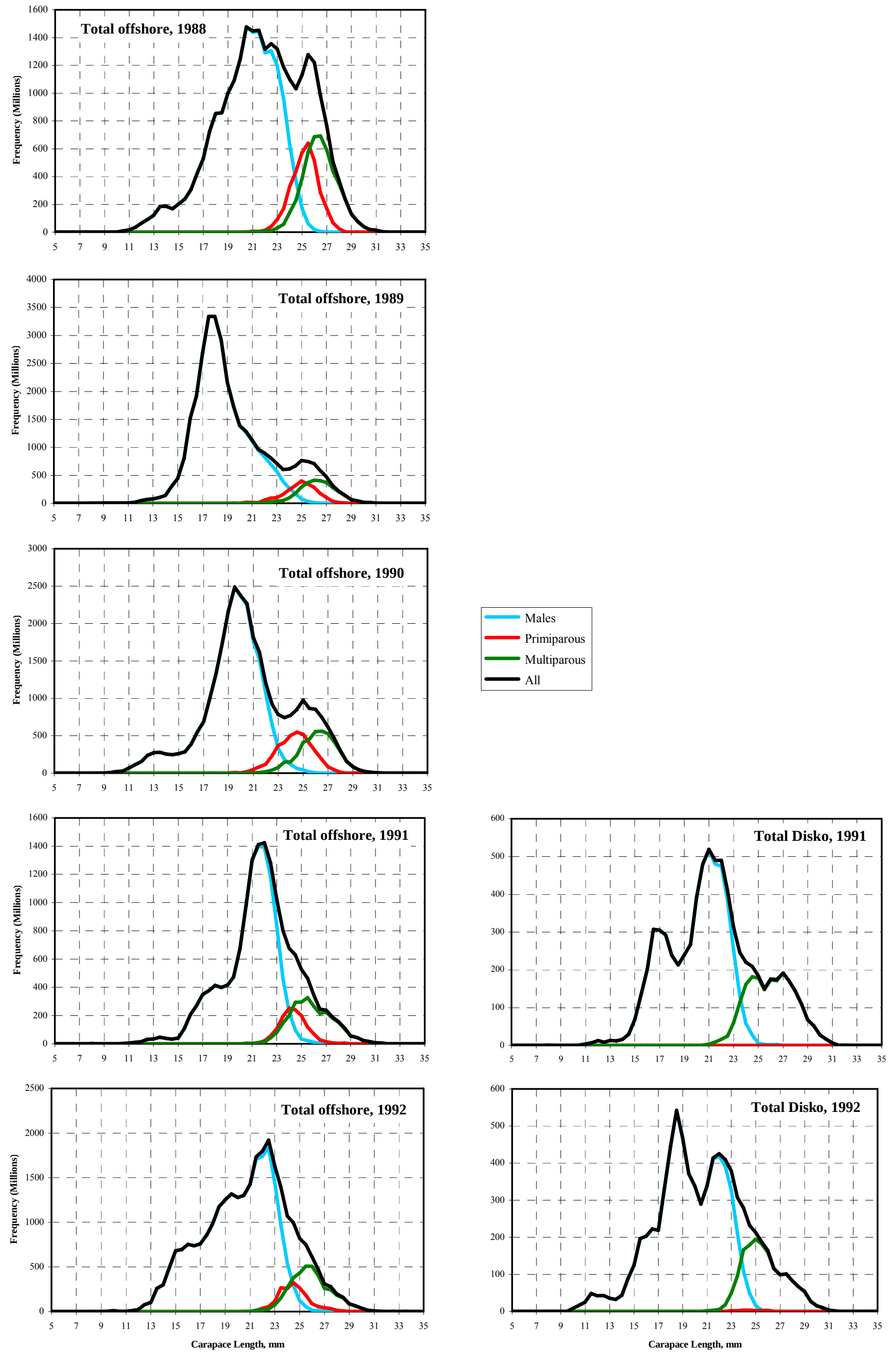


Fig. 7a. Length frequencies of Northern shrimp in the total offshore area, 1988 to 1992, and in the Disko Bay/Vaigat area, 1991 to 1992 (no surveys in Disko Bay/Vaigat area 1998-1990; unconverted data).

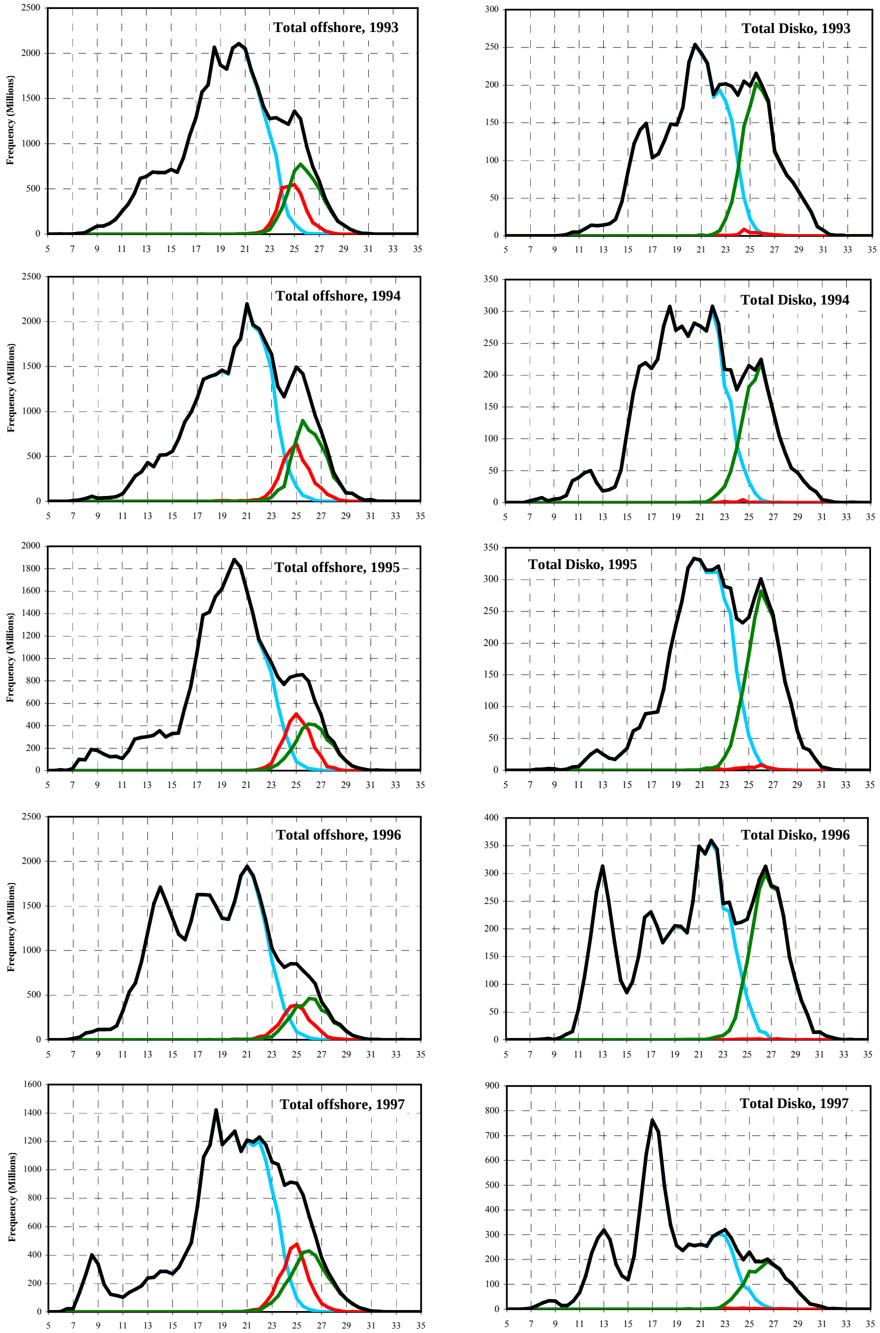


Fig. 7b. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1993 to 1997 (unconverted data).

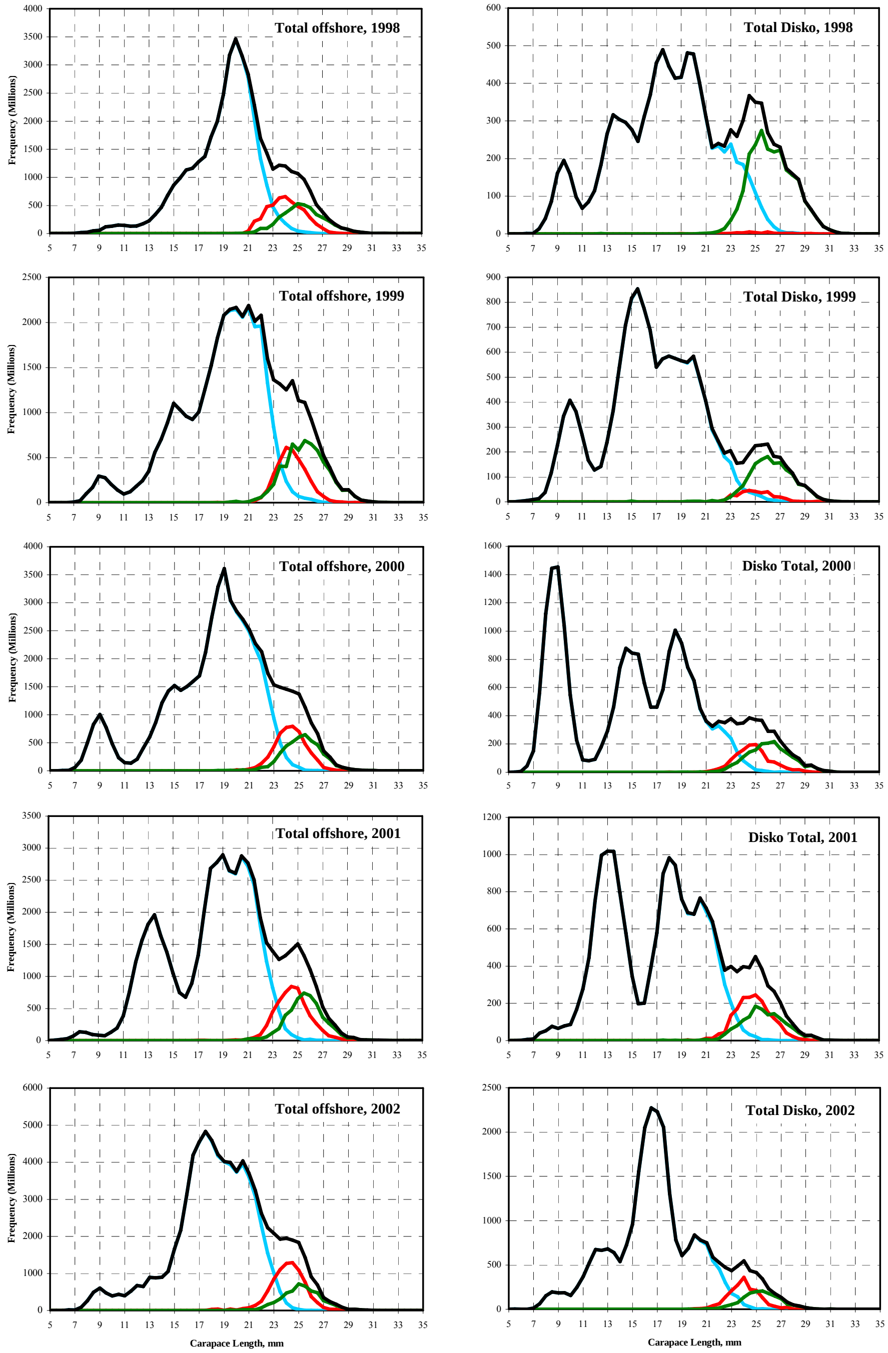


Fig. 7c. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1998 to 2002 (unconverted data).

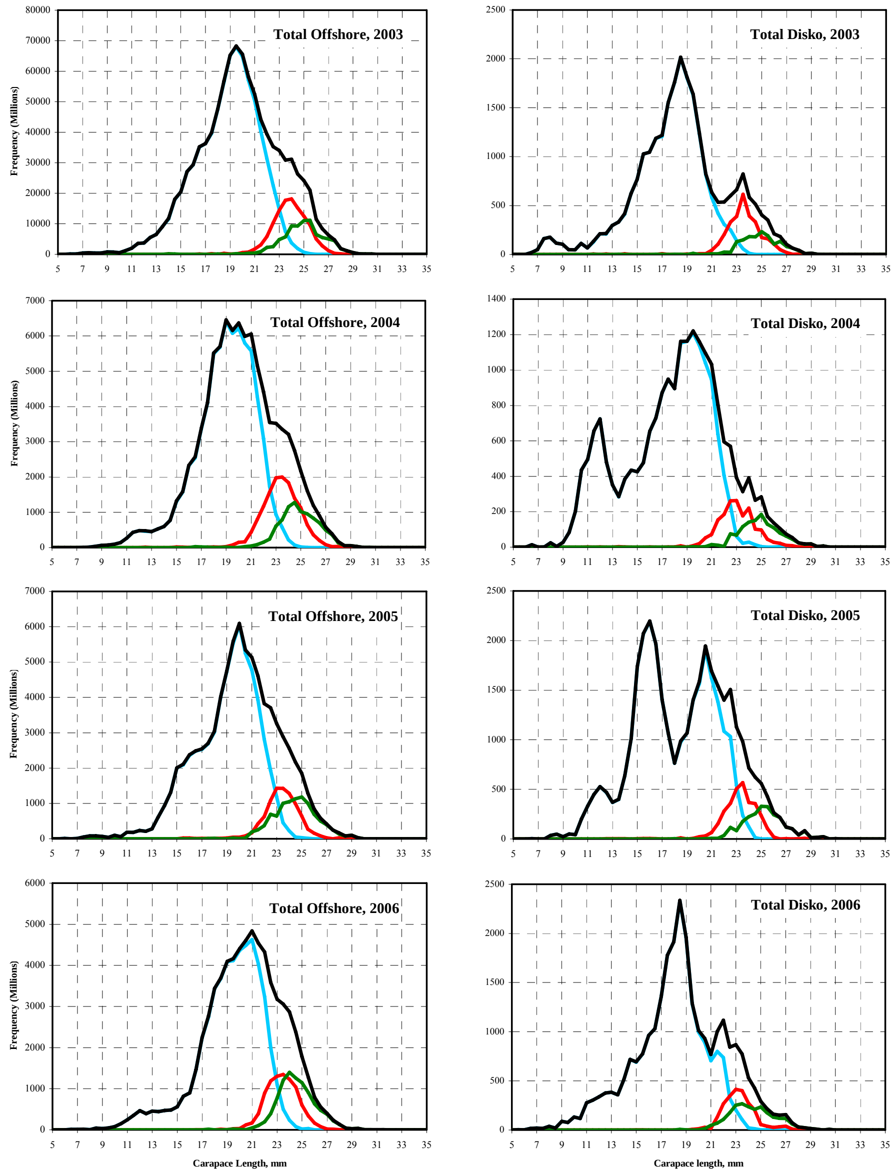


Fig. 7d. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2003 to 2006 (2003 and 2004 data converted from *Skjervøy* to *Cosmos* trawl).

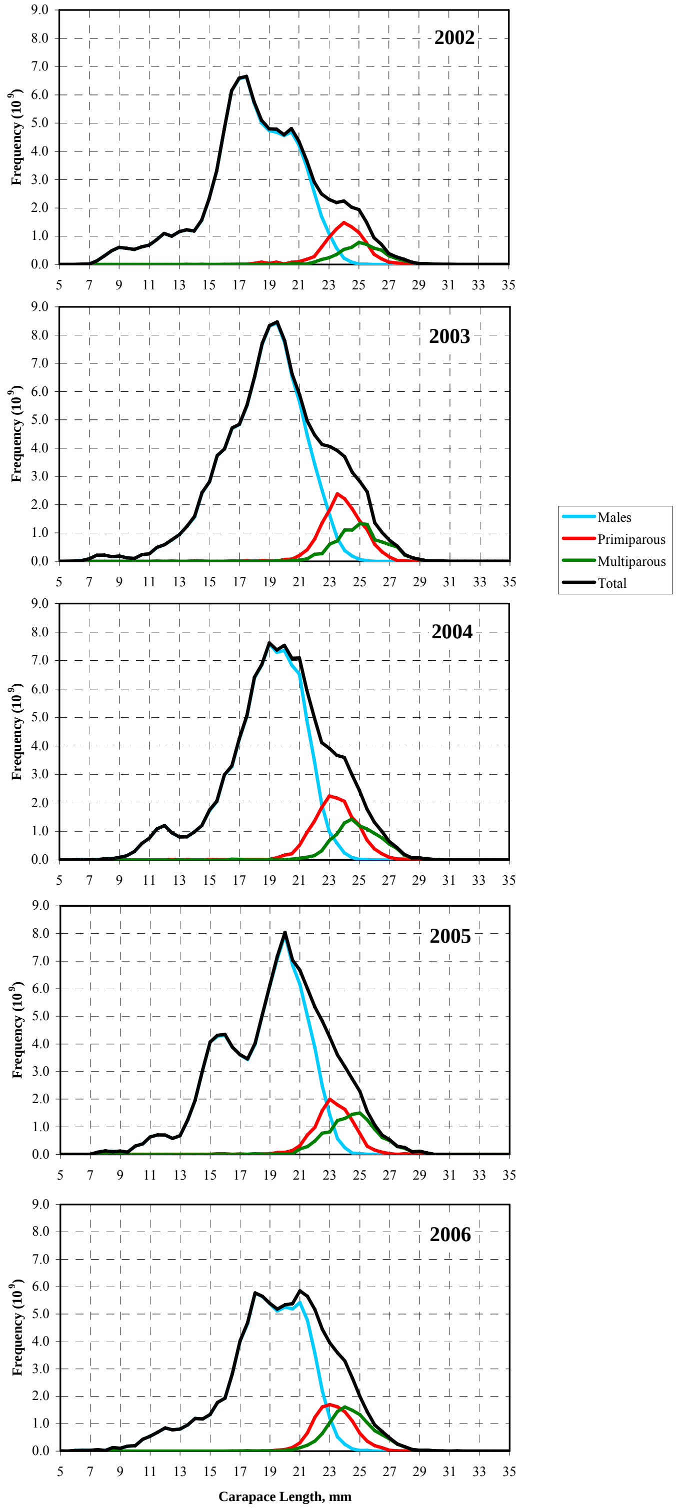


Fig. 8.Length frequencies of Northern shrimp in the total survey area (offshore and Disko Bay/Vaigat combined), 2002 to 2006 (Data from 2002 and 2004 converted from *Skjervøy* to *Cosmos* trawl)

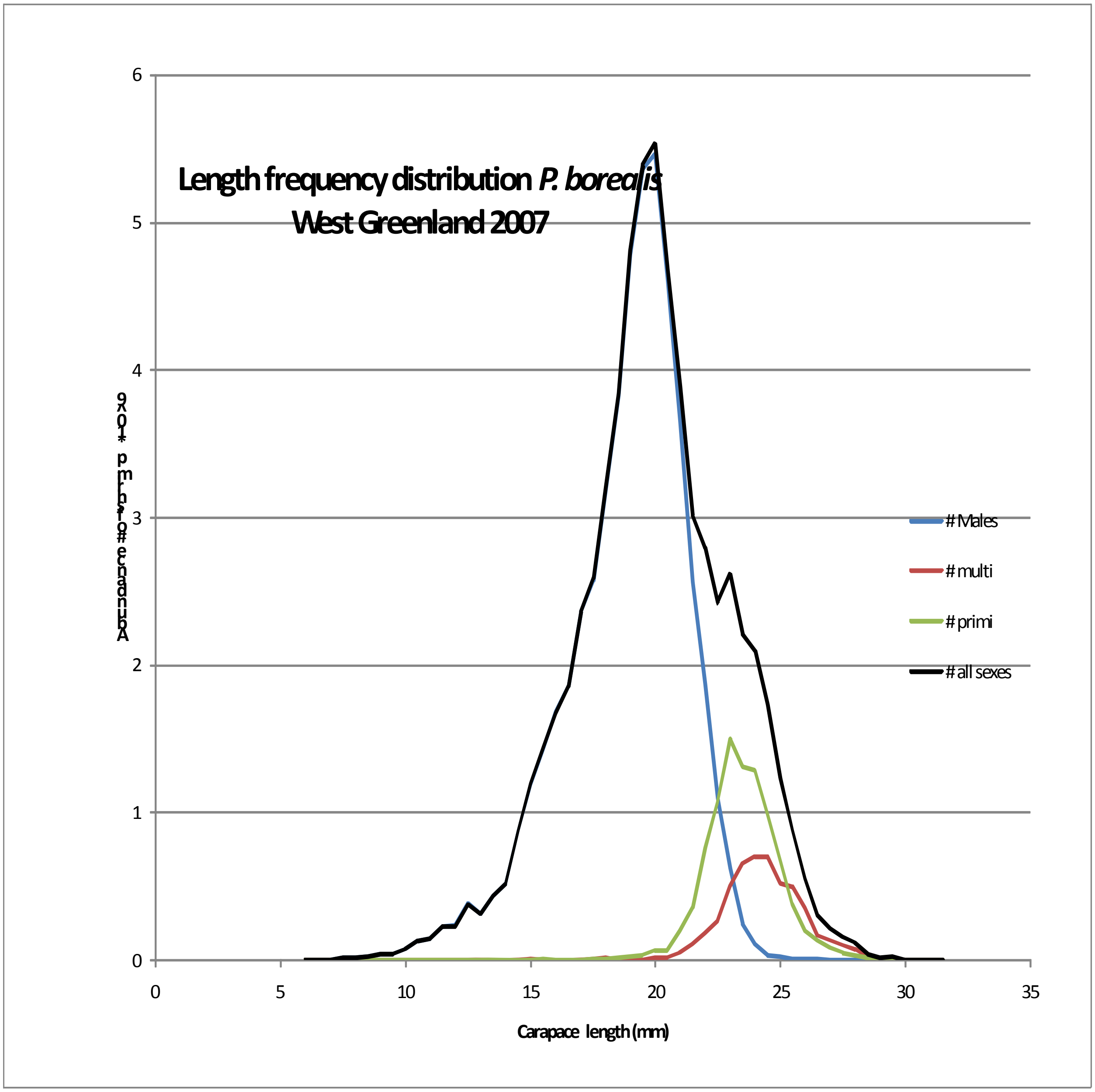


Fig. 9.Length frequencies of Northern shrimp in the total survey area (offshore and Disko Bay/Vaigat combined), 2007 (

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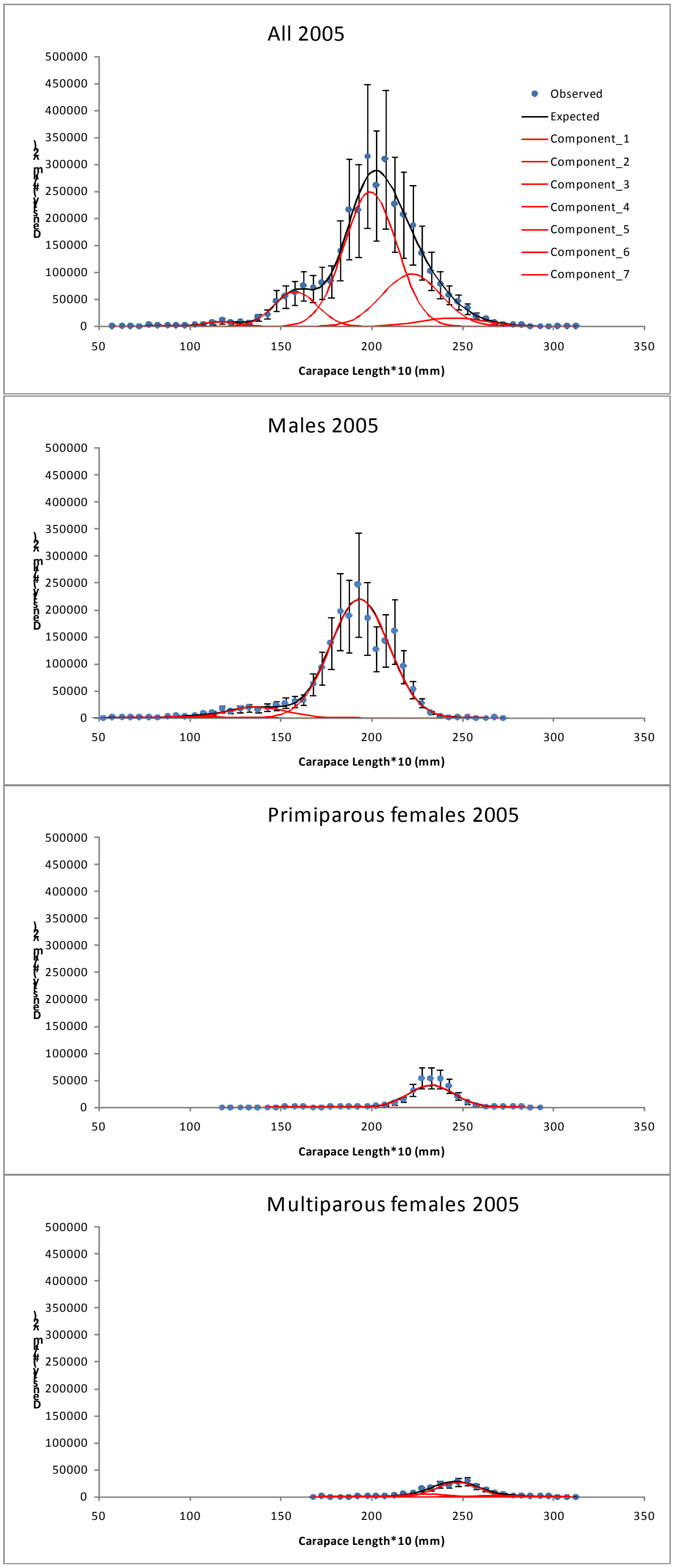

Fig. 10a Average length density distributions of *P. borealis* off West Greenland 2005. Observed average densities in 0.5 mm length bins are depicted with standard error bars together with fitted component distributions and composite expected distribution.

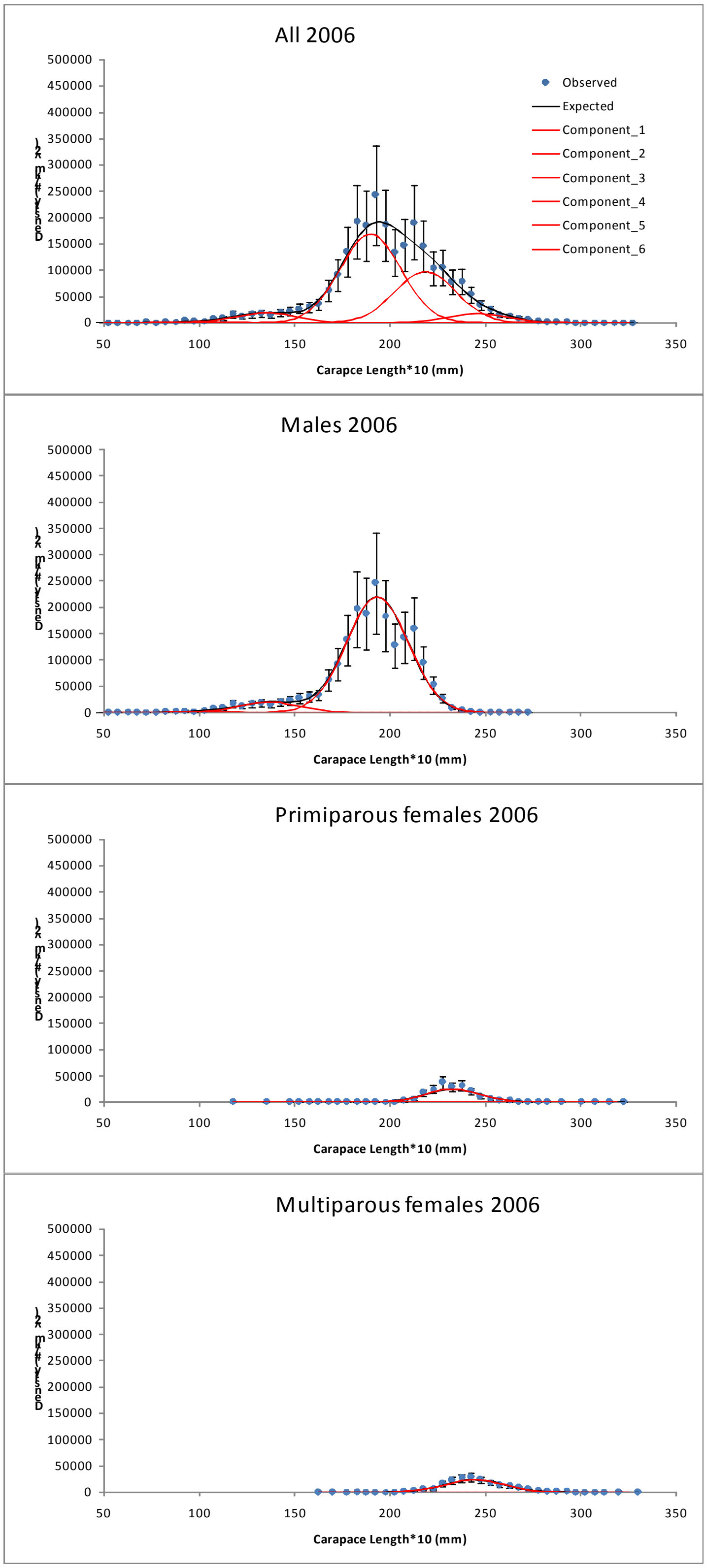

Fig. 10b Average length density distributions of *P. borealis* off West Greenland 2006. Observed average densities in 0.5 mm length bins are depicted with standard error bars together with fitted component distributions and composite expected distribution.

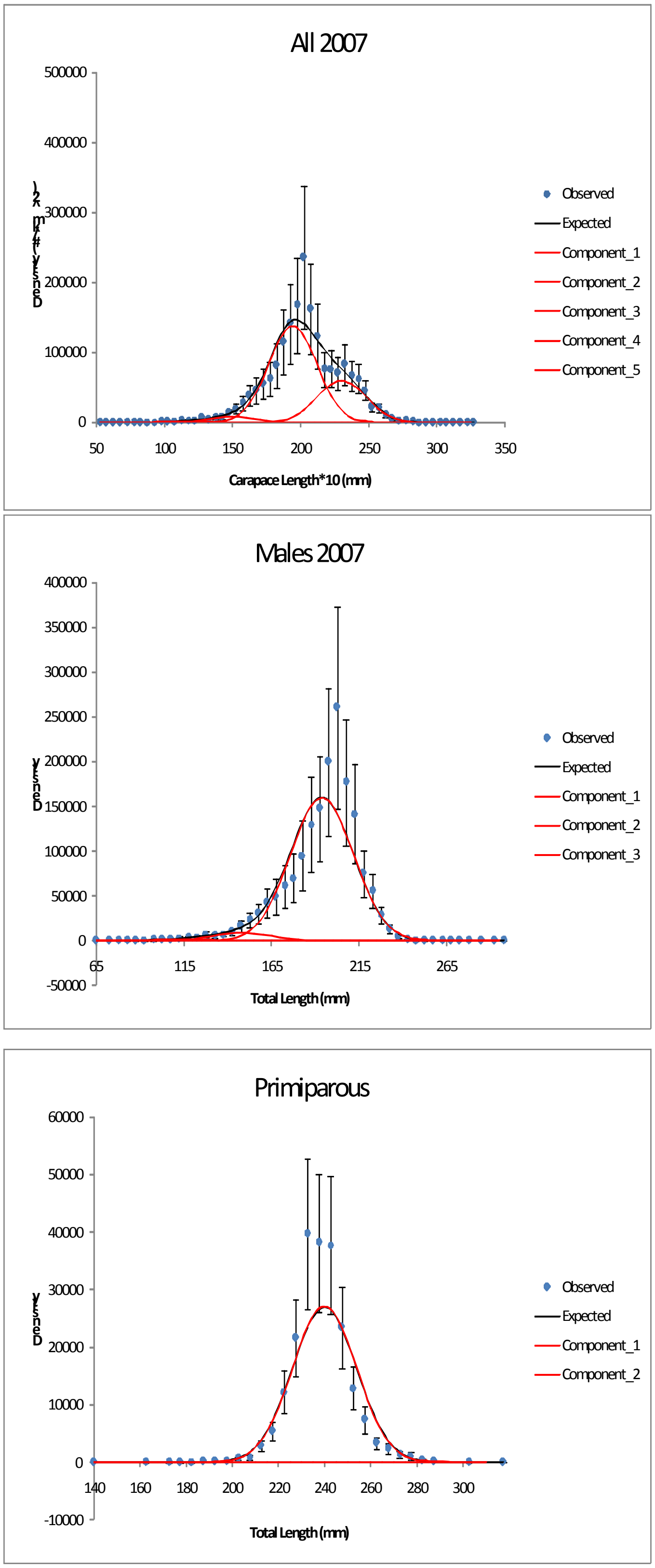

Fig. 10c Average length density distributions of *P. borealis* off West Greenland 2007. Observed average densities in 0.5 mm length bins are depicted with standard error bars together with fitted component distributions and composite expected distribution. Note difference in scale between graphs!

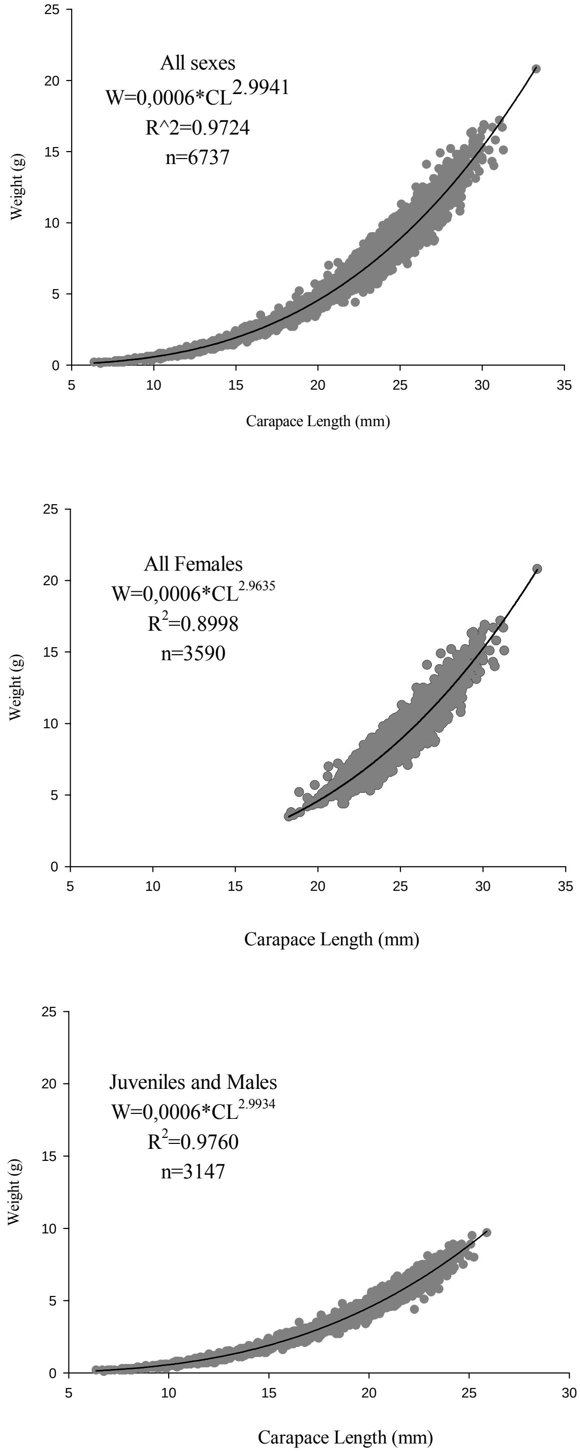

Fig. 11. Length-weight relationships of *P. borealis* off West Greenland. Data from 2001-2006.

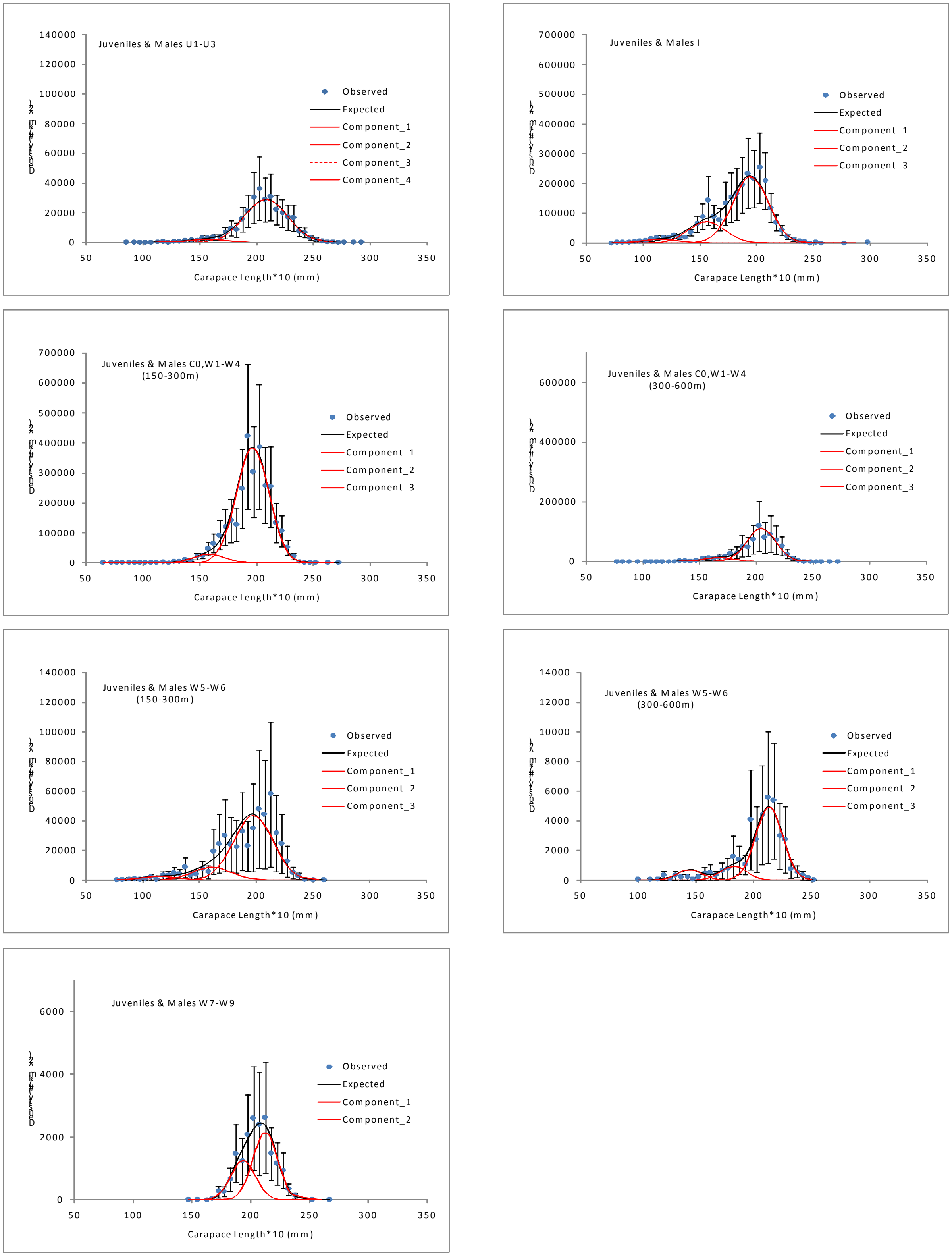

Fig. 12. Regional observed and expected length density distributions with fitted normal components of Northern shrimp (juveniles and males) off West Greenland in 2007. Note difference in density scale in plots!

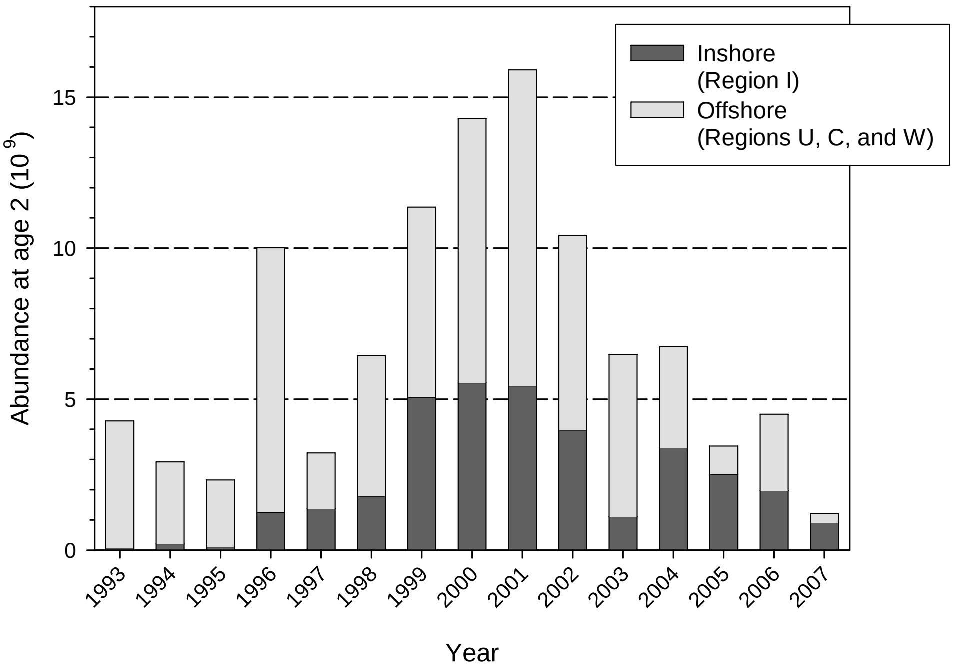

Fig. 13. Abundance indices for Northern shrimp at age 2 off West Greenland, 1993-2007.

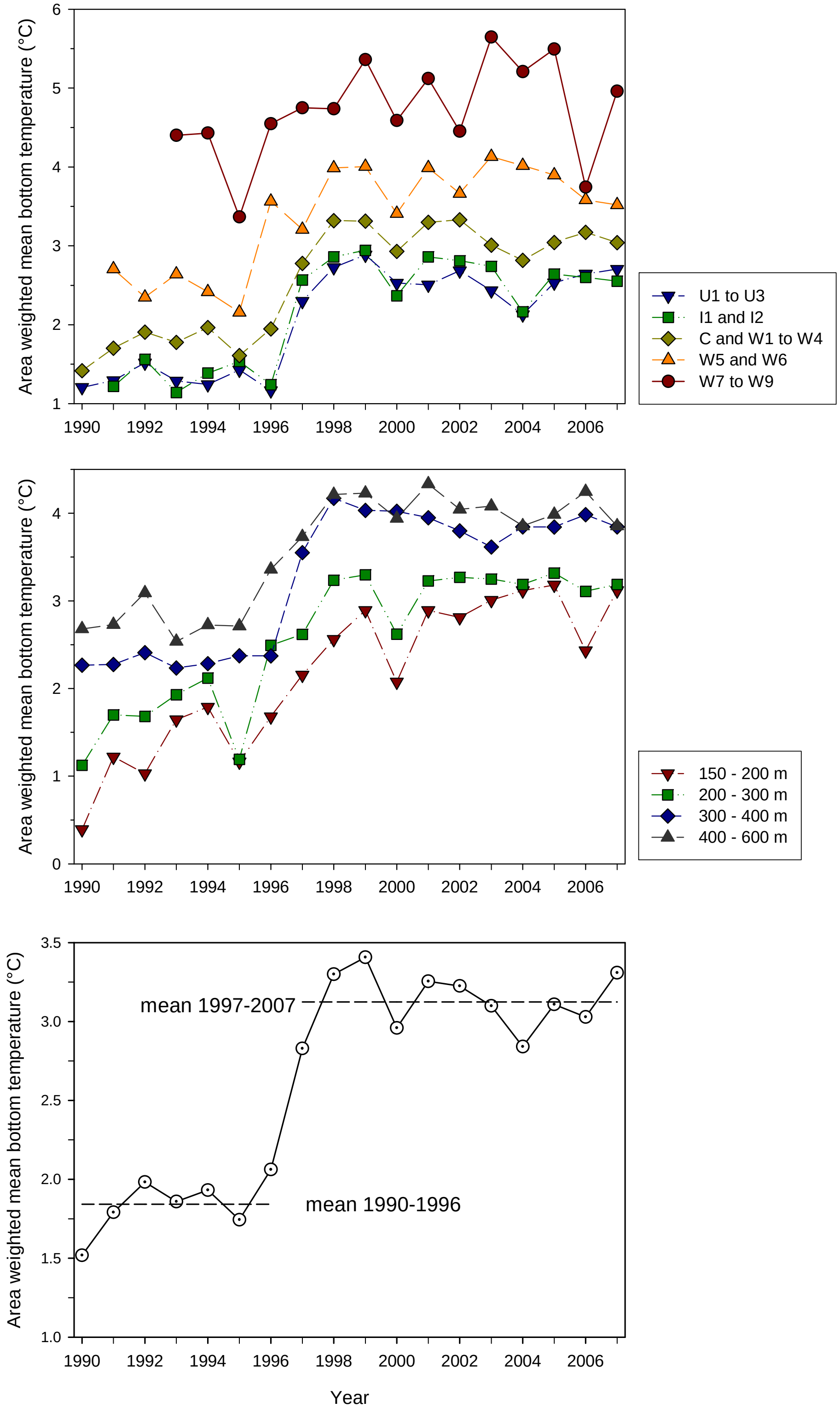

Fig. 14. Area weighted mean bottom temperature for the different survey regions (see Fig. 1 for locations), the various depth strata in offshore areas C and W1-W7 and the entire survey area in 1990 to 2007.