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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), 1988-2009

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 278 500 tons in 2009. The biomass is mainly in offshore 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 southern most West Greenlandic waters. The shrimp stock in this year's survey seemed to be concentrated in an area between 67°45' N and 70° 30' 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 Vest off Hare Island. The areas in the south held very few shrimp, only a few were found in Julianehaab Deep.

This year the survey paper introduces two new indexes for spatial distribution and location for shrimp biomass. There is a Latitudinal index which shows the mean rank for the survey, weighting by estimated total survey biomass. And a Spread Index to show how evenly the survey biomass is distributed over the survey area. The spread index is low, around 3.4, meaning the shrimp biomass is mainly concentrated in three areas. The lat. Index shows that the biomass is to be found in northward areas.

The length distribution in 2009 was dominated by two groups of males' component (carapace length (CL) 16.7 and 20.6 mm). The abundance of recruits at "age 2" in the survey this year was low and fairly below series mean , suggesting a poor supply to fishable biomass off W. Greenland will occur in the coming years. The biomass for small shrimps equal or less than 17 mm also confirm that tendency.

Area weighted mean bottom temperature in the survey area started increasing in the beginning of 1990s and this relatively warm period continued in 2009, and is above the series mean (1994-2009). Temperatures mean by various depth strata showed a weak decrease in temperatures in deeper waters and in shallower waters the temperature is continuously rising. There was a slight increase in temperature in the Midgreenlandic area, in Disko Bay the temperature slightly decreased. In the southern areas (W5-W9), where there were a slight 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 2009 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 2009, the depth contours have not changed. Due to revisions in 2007 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 136005 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).

Until this yr the station allocation procedure for shrimps, Cod and GHL were calculated each by it selves. This yr however the allocation procedure has been combined so that the end result is minimising standard errors for all species in the respective order.

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 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 2009, 326 stations at depths between 51 and 600 m were planned in the survey area. Of these some were allocated to the various strata according to the distribution of Northern shrimp in the previous years while others were allocated based on the distribution of Greenland halibut (GHL) and Atlantic cod respectively. In addition, some 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. 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 2010.

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. Trawling is this yr carried out between 0800 and 2000 UTC. The influence of light induced nocturnal vertical migrations of shrimp is not expected to be influenced by the expansion of Trawling period by one hour in both ends of fishing time.

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

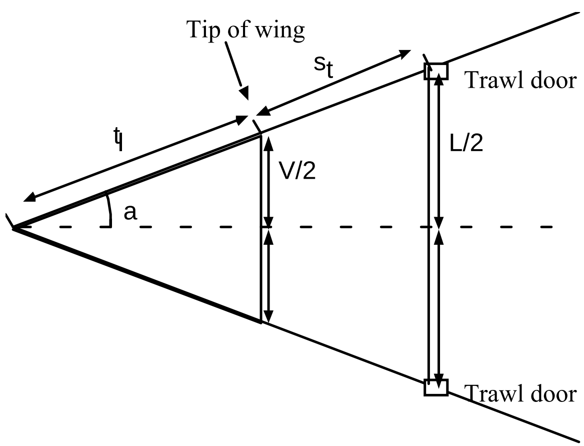
15 and 30 min tows. Thus no indication was found that 15 min tows give less precise results than 30 min tows. Tow duration had no significant effect on mean size and maximum length of catches of both species. These results indicate that the used mixture of 15 and 30 min tows can be replaced by 15 min 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 1988-1991estimates 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.

Indices of distribution and location of shrimp biomass

Data from surveys executed in 1994–2008 was used: there was no survey before 1994 in the southernmost areas and before 1991 in Disko Bay or Vaigat, but since 1994 the series has been consistent. Biomass estimates from the annual survey are customarily presented (e.g Ziemer 2008) for 7 divisions of the survey area:

- a northern division, formerly stratified as N1–N9, and re-stratified according to depth information (Wieland and Kanneworff 2004) as U1–U3 with depth strata;
- Disko Bay and Vaigat, formerly stratified as D1–D9, restratified as I1 and I2 with depth strata;
- Canadian Exclusive Economic Zone, once 2 divisions, now 1;
- 3 subdivisions of the west coast, from the mouth of Disko Bay and adjacent shelf waters to Paamiut;
- an extreme southerly division, comprising Julianehåb Bay and adjacent waters.

These divisions were given southerly ranks: Julianehåb Bay and the adjacent shelf waters were 1; the subdivisions up the coast were given ranks 2, 3 and 4. The small Canadian sub-division was split, half being included with the subdivisions W1 and W2, and the other half included with survey subdivisions W3 and W4. Disko Bay and Vaigat were given rank 5, and the northernmost subdivision of the survey area was ranked 6.

Then a 'lat. index' was calculated as a mean rank for the survey, weighting by estimated total survey biomass. This index summarises how far north a (weighted) centre of gravity of the stock biomass lies, as estimated by the research trawl survey and measured in survey subdivisions. Small values of the index indicate that the centre of gravity of the stock distribution is further south, and larger values indicate a more northerly distribution.

A 'spread index' was calculated as a Simpson diversity index (Simpson 1949) of the distribution of the biomass:

$$SpreadIndex = \left(\sum_{Subdivisions} Biomass_{Subdiv.} \right)^2 \Bigg/ \sum_{Subdivisions} \left(Biomass_{Subdiv.}\right)^2$$

This index summarises how evenly the survey stock biomass is distributed among survey subdivisions. High values (6 is the limit) would show that one-sixth of the biomass was found in each division; low values, near 1, would show that the biomass was concentrated in only one or two subdivisions. The units of both indices are 'subdivisions'.

Sampling, weighting and "area expansion"

From each catch a sample of about 0.5 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.

There has been a new set of rules for subsampling shrimp catches. The new set of rules is designed so the samplesize always is depended of the total catch of shrimps:

Catch (in Kg)	Size of subsample (no of individuals in sample)	Subsample from;
< 0.5	Measure all	A yellow bucket
≥ 0.5 – 250	Measure 100	A yellow bucket
≥ 250 - 500	Measure 150	A yellow bucket
≥ 500	Measure 300	A yellow bucket

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:

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

Were $\widehat{N}_l$ 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:

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

Where $\widehat{N}_{ls}$ is the number of shrimp of CL l in stratum, A_s is the stratum area , $\sum \widehat{N}_l$ 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 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 year's 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 Fig. 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≥ 17 mm) was obtained using the same principles. As a check on the validity of this later calculation method the total biomass for the whole survey area calculated in this fashion (268, 8 thousand tons) is compared with the catch weight based estimate (278, 5 thousand tons) presented in this paper. The difference is about 3, 5 %.

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. This approach need to be evaluated and qualified, and unify the process to calculate throughout the entire period. For evaluation of this method a possible approach is to compare with biomass of small shrimps. As a validation of the biomass of small shrimps this year we calculated the biomass of the small shrimps, defined as being equal or less than 17 mm (corresponds to the rest group of the total biomass minus fishable biomass).

Gross recruitment rate $R_{(t)}$

For this report the proportion of recruits in the W. Greenland *P. borealis* stock, from 1993 to 2009 have been calculated as the gross recruitment rate $R_{(t)}$:

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

where 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

Fig. 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

In 2009, 247 stations at depths between 150 and 600 m were taken.

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 2009 are:

Region	Biomass estimate (t)	Number of stations	OECV (%)
North (U1-U3)	92 131	28	22,0
Canadian zone	4278	8	59,6
West (incl. South)	112 015	186	12,7
Disko B./Vaigat (I)	70 062	25	15,9
Total	278 486	247	9.79

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. In 2009 it has declined to about 279 486 tons (Tab.3, Fig.3 upper panel), which is approx. 1% 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%. In 2009 it is 9.7% so the expansion of fishing time and the more stations pr day fished didn´t have a negative effect.

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, as last year. These areas contributed more than 80% of the total biomass in West Greenland. 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 continuous decline since 2004.

The overall survey biomass index has decreased since 2003 in the West Greenland. This year’s result follows the same general pattern, with a trend that the biomass concentration has gone northwards (Fig. 4).

This year the survey paper introduces two new indexes for spatial distribution and location for shrimp biomass, see both indexes in fig. 4b. There is a Lat. index which shows the mean rank for the survey, weighting by estimated total survey biomass. And a Spread Index to show how evenly the survey biomass is distributed over the survey area.

As can be seen from fig. 4b the spread index is low, which means that the shrimp biomass is mainly concentrated in three areas. The lat. Index shows that the biomass is heading northwards.

This year’s survey results indicate a slight decline in fishable biomass (tab. 8), although the decline is only 3%. This year’s total biomass is only 47 % of the biomass observed in 2003 and the fishable biomass in 2009 is 47% of that observed in 2003. Most of the shrimp biomass is 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 and U1 – U3 this year didn´t change compared to last year. Areas W3 – W7 there were a decrease in biomass. All the southern areas W5 – W9 show decreases and shrimp density in these areas were generally very low to nearly absent.

Biomass in the Disko/Vaigat area increased with about 20 thousand tons compared to last year. That area contributes 25% of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore decreased while the increase in fishable biomass in Disko/Vaigat area was about 33% more than last year.

In conclusion 33 % of the total biomass in 2009 was found in areas U1 – U3 that covers about 38 % of the survey area. W1 – W2 contributed with 22% of the total biomass and Disko/Vaigat 25%. W3 – W4 contributed with 8%, W5 – W6 contributed with 7% and W7 – W9 approx. null. Hence the shrimp biomass in 2009 appeared to be concentrated in the U1 – U3, in offshore areas W1 – W2 and in the Disko/Vaigat area, as the two new indices also confirm.

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 approx. 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 60% of the 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 2009 the highest off shore densities were found in the W1-2 and the U1-3 area (Fig. 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 2009 are very low (Table 5).

C0 had a low shrimp density distribution this year, and the overall error of coefficient of variation (OECV) for C0 is high (60%), so the results is not reliable (see table 4).

The shrimp density distribution results follow the general trend, and almost all areas haven´t changed, see table 5 and fig. 3 lower panel. But the densities in W3-W4 had a drop down 25% compared to last year and in Disko there were a 38% increase in density.

Thus the density in W1-W2 is almost the same as last year (2% increase) compared to last year. Density in W3-4 showed no change and W8-9 had the same low density as last year whereas the density in W5-7 had a slight decrease. The U1-3 has an increased density at 52% compared to last year. The average density for off shore areas is 1.32 tons/km^2.

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). This year the density estimate for Inshore area is the above the long term average. For the

Disko/Vaigat the overall average density is 6.87 for the time period 1991-2009 and the average density is 7.03 tons/km^2.

Conclusion

In conclusion the shrimp density distribution is lower in the off shore areas than the long term average, but in inshore areas the shrimp density is above long term level. The shrimp density overall is lower than the long term average. Thus it can be expected that the density the coming years will decrease further.

Demography and recruitment

Size distribution by area in 2009

Fig. 6 gives length density distributions for males in combined strata in the survey area in 2009, Fig.7a-d 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.

Fig. 7e gives the length frequency distribution for all shrimp sexes combined (juveniles/males, primiparous and females) in the survey area in 2009. Fig. 8 gives the overall West Greenlandic length frequency distribution in the period from 2004 till 2009.

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 that the range of sizes of males this year doesn´t include small shrimps.

In the analysis of all sexes combined in the total survey area four modes, one at about 12 mm and one at about 17 mm, one about 21 mm and 24 mm are identified for 2009 (fig. 8 lowest graph). The first three consists mainly of males and the latter of primiparous and multiparous 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:

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 2009 is approximately the same as last year, and is below the long-term mean. This year's estimate of 53.7 billion is 13% below the time series mean of 61.4 billion. Abundance of shrimps at "age 2" were very low compared to last year (table 10), way below long time average on $7.65*10^9$ (Bergstrøm, 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 255 500 tons, which is below the long-term average (282 700). Worth noting is that the rate of decrease seems to have been increasing since 2003.

Female biomass estimates is high and has 39% proportion of total, it is interesting to see that the female biomass is 10% higher than long term avg. Male biomass decreased with 5%.

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 Fig. 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 1993-2009 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.

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.

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 3.4×10^9 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. In 2008 the abundance of “age 2” is higher ($4.91*10^9$), but still below long term average.

Fig. 10 shows the contribution of recruits from inshore and offshore areas and the inshore area contributes with 50% of the total recruitment stock that year, although the inshore area only consists of 7% of the total area. But compared to last year where Disko contributed with 64%, there could be reason for precautions regarding the future stock.

In 2009 the recruitment stock is very low at about 2.3×10^9 shrimp. But the results must be evaluated.

As a validation of the biomass of small shrimps this year we calculated the biomass of the small shrimps, defined as being equal or less than 17 mm (corresponds to the rest group of the total biomass minus fishable biomass), the result is displayed in fig. 11. The biomass for small shrimps equal or less than 17 mm also confirm that tendency that the recruitment is to be expected to be low.

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. 12. Bottom temperatures this year was above average.

Regionally the temperature was a bit lower in the southern most areas (W5-W9). In Canadadian zone and W1-W4 it is slightly higher. In Disko and in U1-U3 it was approx. the same as last year.

In depths between 151-300 m the area weighted average bottom temperature is continuously rising since 2007. In conclusion the temperature was the same as last year 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 278 500 tons in 2009.

This year’s survey results indicate that the total biomass index and fishable biomass is approx. the same as last year. Biomass in the Disko/Vaigat area increased with 20 thousand tonnes compared to last year. That area contributes to 25% of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore is 16% lower than long term average, while the increase in fishable biomass in Disko/Vaigat area is about 15% higher than long term average. The proportion of males has decreased with 5% and the female proportion has increased with 10% compared to long term average.

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, as last year. These areas contributed more than 80% of the total biomass in West Greenland. 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 continuous decline since 2004.

Two new indices have been introduced this year to illustrate the geographical migration of the shrimp and the tendency that the shrimps are contracting northwards is continuing.

In 2009 the abundance of “age 2” is very low (2.32×10^9) and way below long term average 7.34×10^9 individuals. 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 50% 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 the three last year's 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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Tab. 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 - 2009	Paamiut	Cosmos	54.0	27.4 - 28.6	**

Tab. 2. 2009 Basics for all strata.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
W1-1	150-200	2873	1116.41	1	-	-
W1-2	200-300	6099	13582.35	13	17563	130
W1-3	300-400	7520	12699.58	5	15322	121
W1-4	400-600	816	0.99	2	0	33
W2-1	150-200	1674	3349.29	2	2376	71
W2-2	200-300	2612	25701.28	14	24539	96
W2-3	300-400	1741	4937.55	7	3876	79
W2-4	400-600	916	1115.79	3	817	73
W3-1	150-200	2122	767.74	5	1399	182
W3-2	200-300	4725	14038.45	20	20725	148
W3-3	300-400	2085	7333.15	3	4127	56
W3-4	400-600	2994	3417.93	6	2120	62
W4-1	150-200	4119	4.26	1	-	-
W4-2	200-300	1818	2303.15	6	3479	151
W4-3	300-400	821	2211.21	5	2577	117
W4-4	400-600	1961	60.48	3	70	116
W5-1	150-200	3001	0.82	7	1	127
W5-2	200-300	3648	9952.87	12	23160	233
W5-3	300-400	1950	2.64	2	3	120
W5-4	400-600	3021	429.75	3	467	109
W6-1	150-200	1206	2.66	4	5	189
W6-2	200-300	2006	4067.51	9	4940	122
W6-3	300-400	1585	2528.3	3	2715	107
W6-4	400-600	1234	172.79	2	244	141
W7-1	150-200	2442	0.1	7	0	265
W7-2	200-300	891	1227.84	8	3461	282
W7-3	300-400	265	0.27	2	0	141
W7-4	400-600	317	0.3	2	0	103
W8-1	150-200	424	17.63	2	23	130
W8-2	200-300	567	239.3	2	336	140
W8-3	300-400	405	325.31	3	411	126
W8-4	400-600	718	405.64	3	696	172
W9-1	150-200	1711	0.1	7	0	184
W9-2	200-300	938	0.42	8	1	109
W9-3	300-400	516	0.29	2	0	96
W9-4	400-600	430	0.6	2	1	127
Total		72170	112015	186		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
U1-1	150-200	2486	807.5	1	-	-
U1-2	200-300	4633	17602.8	2	23429	133
U1-3	300-400	4785	20380.5	4	18786	92
U1-4	400-600	5129	214.32	1	-	-
U2-2	200-300	6710	20453.54	2	3177	16
U2-3	300-400	8481	6402.59	2	704	11
U2-4	400-600	7994	5280.59	3	4761	90
U3-1	150-200	2012	1712.79	2	1786	104
U3-2	200-300	3017	9756.51	6	7648	78
U3-3	300-400	1676	7190.65	3	8186	114
U3-4	400-600	2710	2329.46	2	500	22
Total		49632	92131	28		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
C0-2	200-300	903	2844.26	2	3581	126
C0-3	300-400	2179	1422.12	5	692	49
C0-4	400-600	1154	11.35	1	-	-
Total		4236	4278	8		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
I1-1	150-200	407	8933.31	2	3555	40
I1-2	200-300	1963	21149.32	4	14095	67
I1-3	300-400	2441	8998.48	5	5787	64
I1-4	400-600	1499	2650.6	3	1277	48
I2-1	150-200	419	9884.23	3	7796	79
I2-2	200-300	815	11877.96	3	10516	89
I2-3	300-400	1085	5591.97	4	3293	59
I2-4	400-600	1338	975.8	1	-	-
Total		9967	70062	25		

Tab. 3. Biomass estimates (in ‘000 tons) for combined strata and standard errors for the entire survey area 1988-2009.

Year	N1-N9	U1-U3 1	C1+C3	C0 1	W1-W2	W3-W4	W5-W7 2	S1+S2	W8-W9 1	D1-D9 3	I1-I2 1	Total	SE 4
1988	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
2009		92.1		4.3	62.5	30.1	18.4		1.0		70.1	278.5	27.3

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 1988-2009.

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
2009	22.0	59.6	12.8	53.9	15.9	9.79	247

Table 5. Estimated mean densities (t/km^2) for combined strata in 1988-2009.

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
2009	1.86	1.01	2.58	1.46	0.85	0.17	7.03
avg	**0.78**	**2.18**	**3.17**	**2.81**	**2.88**	**2.84**	**6.87**

Table 6. Abundance estimates (billions) for males and females from overall length distributions for the total survey area 1988-2009 (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
2009	41.5	12.2	53.7	77.3	22.7
Average	49.2	12.2	61.4	80.2	19.8

Table 7. Biomass estimates for males and females ('000 tons) in the total survey area based on length-weight distributions 1988-2009 (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
2009	165.4	103.4	268.8	61.5	38.5
Average	197.2	106.8	304.0	65.0	35.0

Table 8. Estimates of fishable biomass (<=17mm CL, ´000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2009 (mean values for Disko/Vaigat area in 1991-1997 used for 1988-1990).

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
2008	215.1	47.2	262.4
2009	192.2	63.0	255.5
Average	228.7	54.9	282.7

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).

Year	U1 to U3 150-600 m	I1 and I2 150-600 m	C0 and W1 to W4 150-300 m	Region / Depth 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
2009	12.7	12-0	12.7	12.6	16.3	18.9	19.5

standard deviation:

Year	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	0.79	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	1.6	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
2009	1.3	1.2	1.00	1.2	1.3	0.9	1.3

coefficent of variation:

Year	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	0.07	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
2009	0.11	0.10	0.08	0.10	0.08	0.05	0.07

Table 9 continued.

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
2008	4.91	54.0	0.09	0.0034
2009	2.32	53.7	0.04	0.0884
Average	7.34	68.80	0.12	0.02

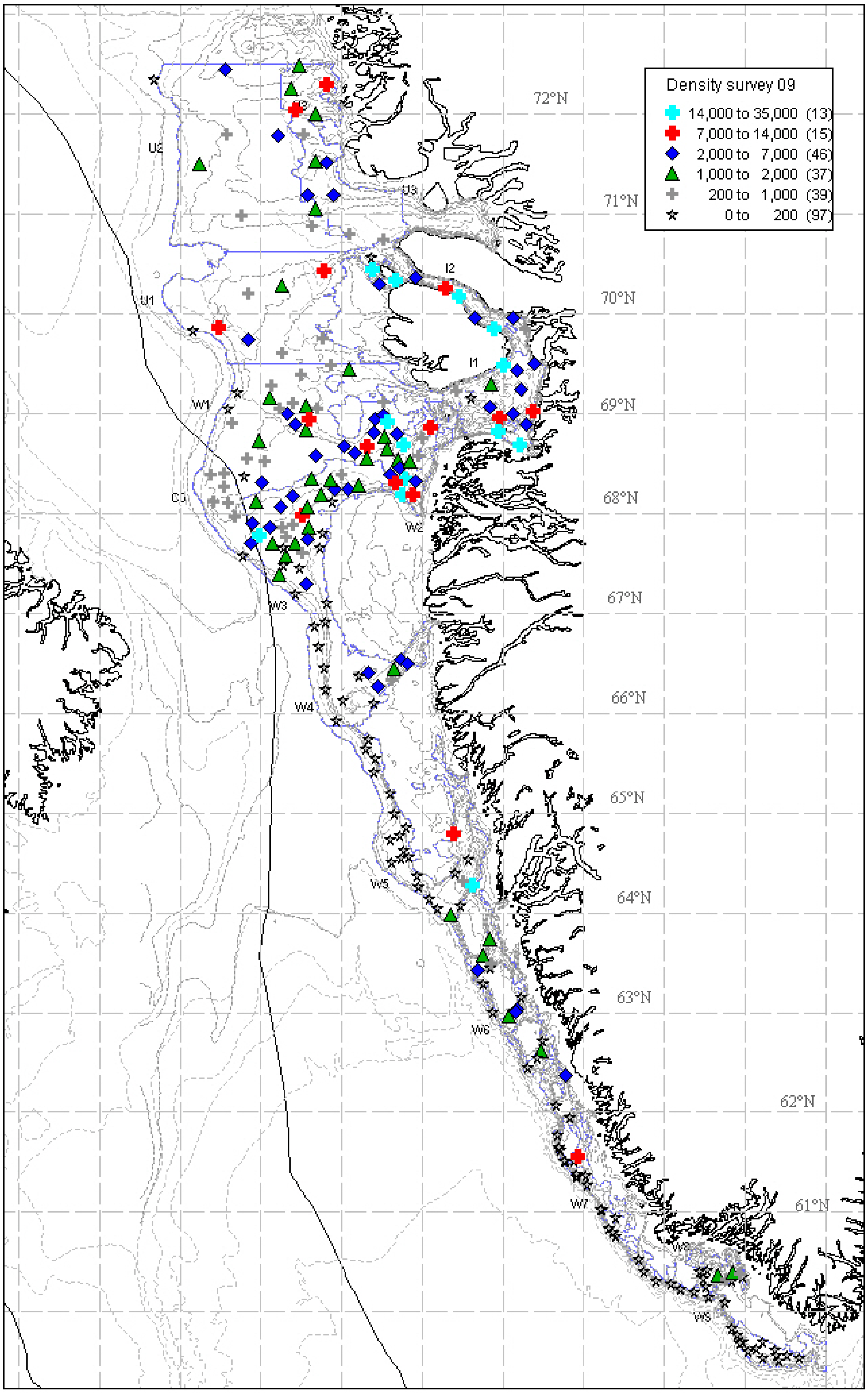


Fig.1.Survey stratification and shrimp density in W. Greenland 2008.

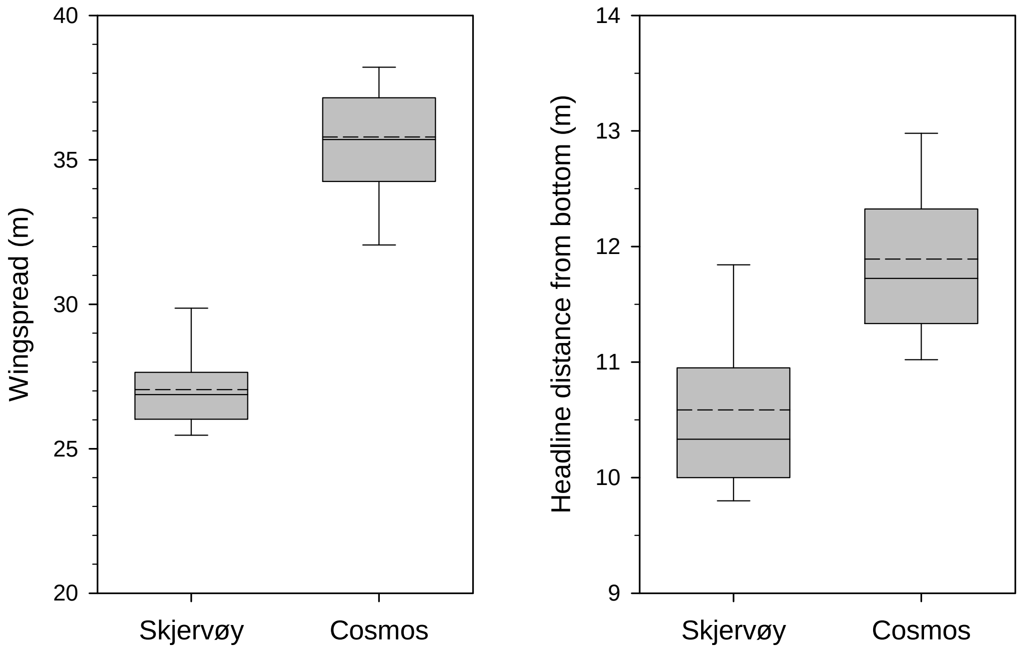
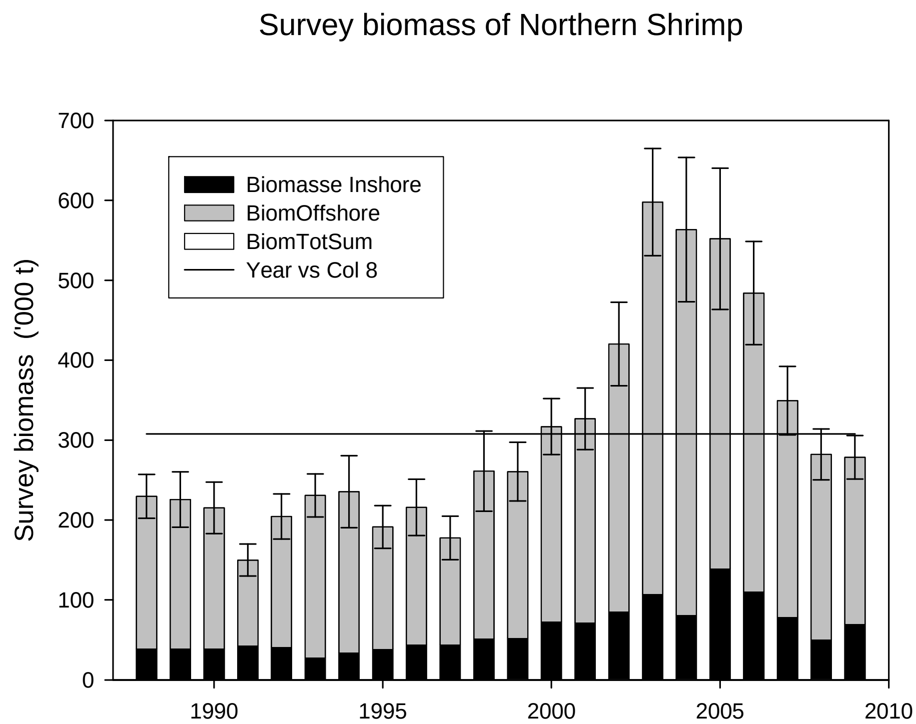


Fig. 2. Box whisker plots showing arithmetic means (stippled line) and medians (solid lines) of wingspread and headline distance to bottom for the two trawl types (*Skjervøy* 3000 and *Cosmos* 2000) with 95% confidence interval (upper and lower borders of grey box) and lower and upper quartiles (error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



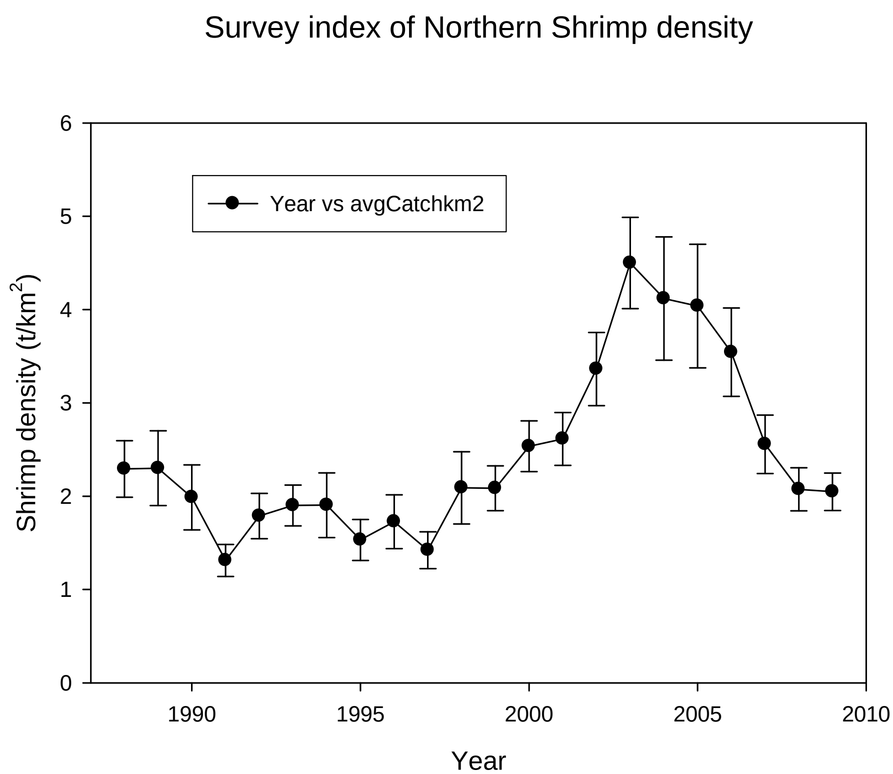


Fig. 3. Estimated total survey biomass and average survey biomass density of Northern shrimp with standard errors 1988-2008 (Average biomass estimate for inshore areas 1991-1997 are used for 1988-1990 to facilitate between-year comparisons, see tab. 3 for details).

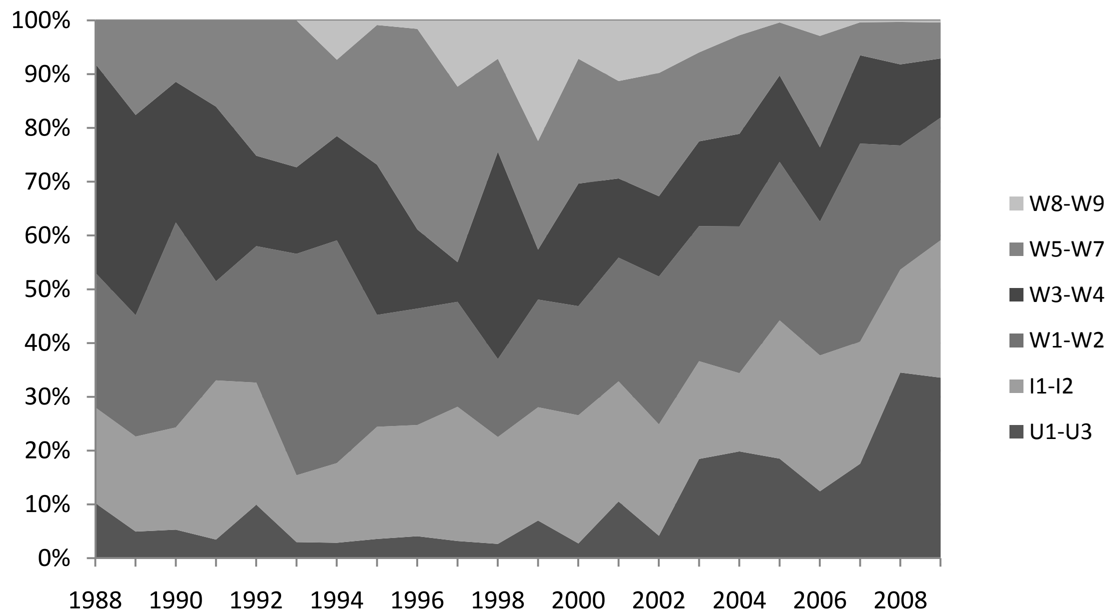


Fig. 4a. Biomass contributions from different primary survey regions 1988-2009 (area names are given in brackets, see fig. 1 for location).

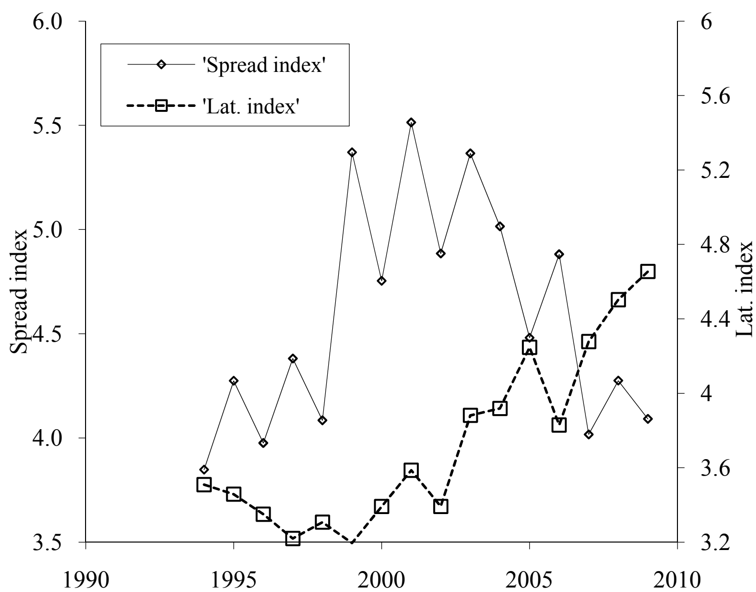


Fig. 4b. Indices of distribution and location of shrimp biomass for the West Greenlandic trawl survey 1993-2009.

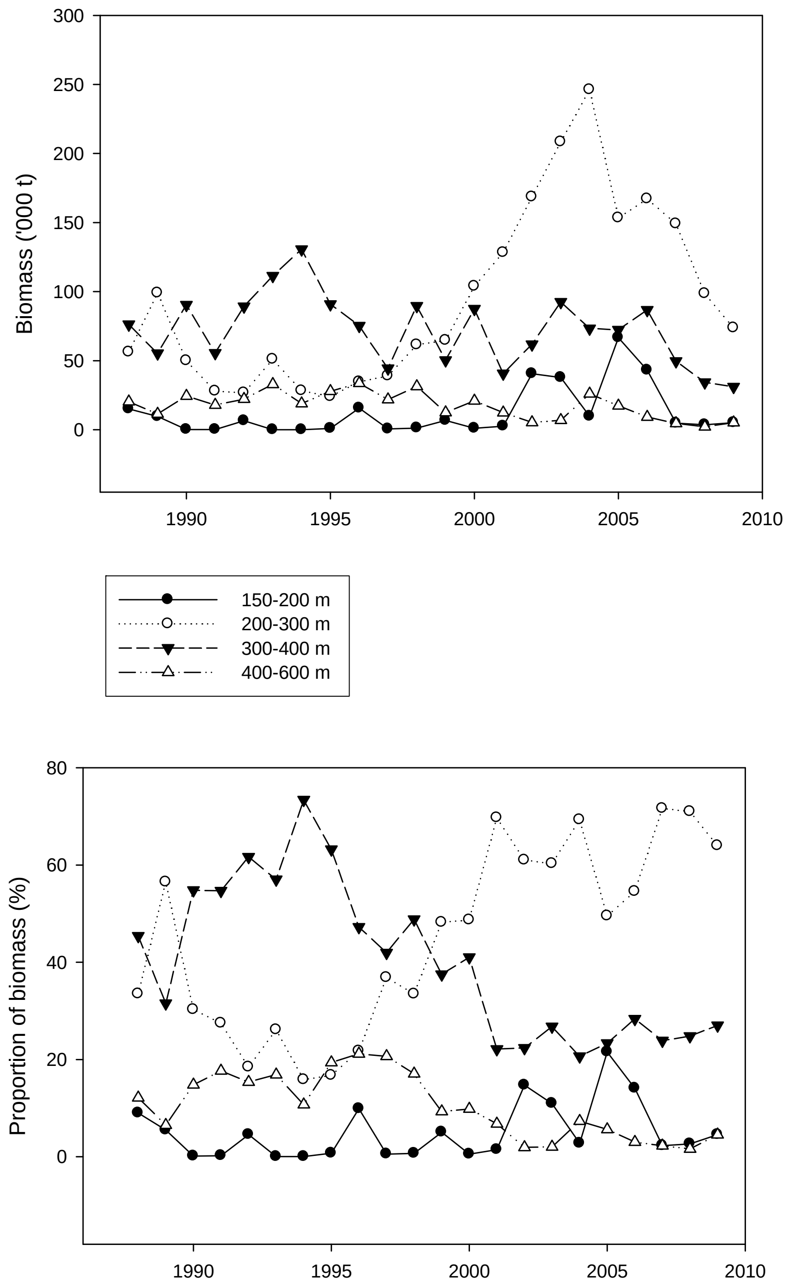


Fig. 5. Biomass distribution in the four depth strata in areas C and W1-W9 1988-2009.

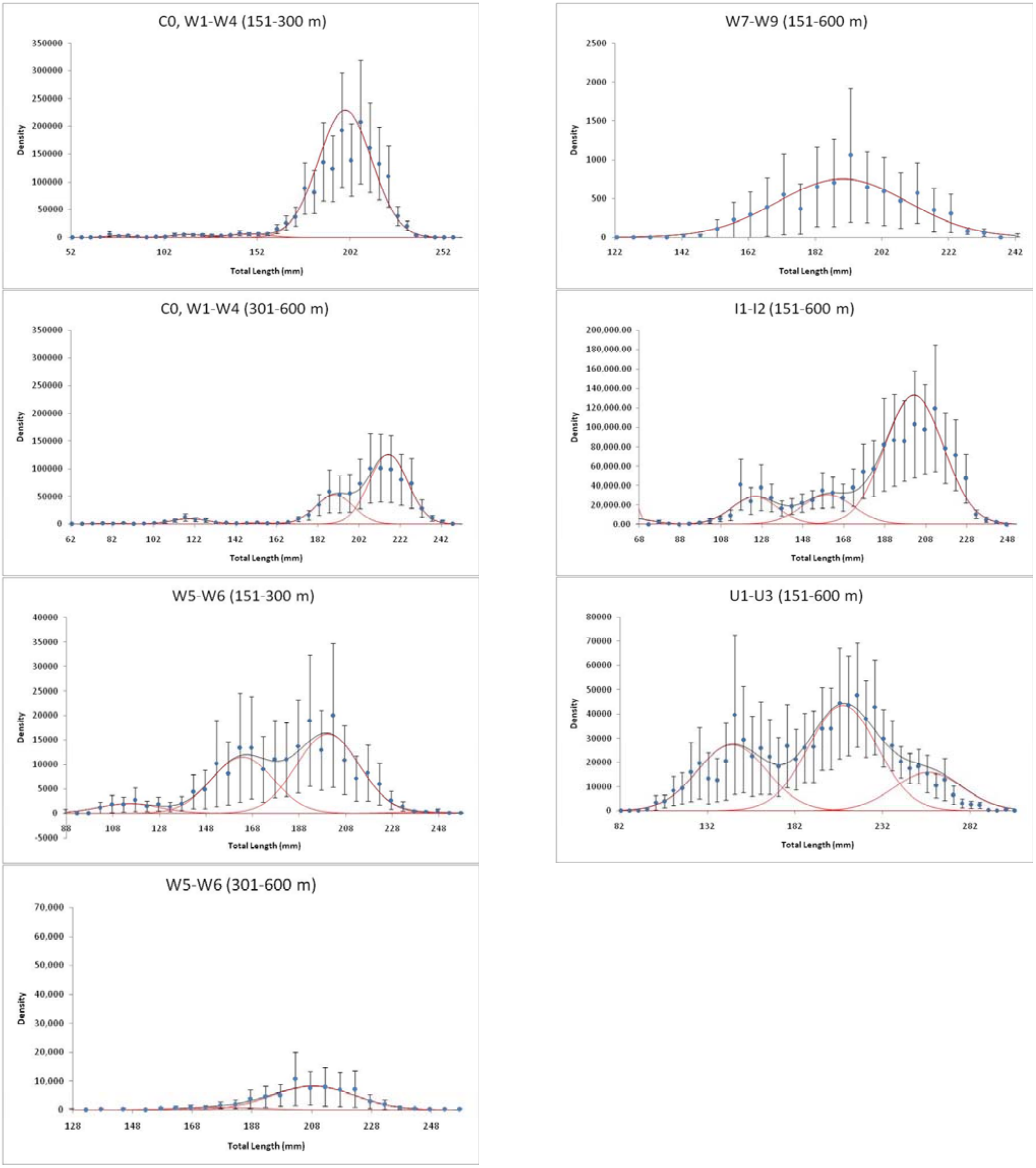


Figure 6. Length density distributions for males in all areas (151-600 m).

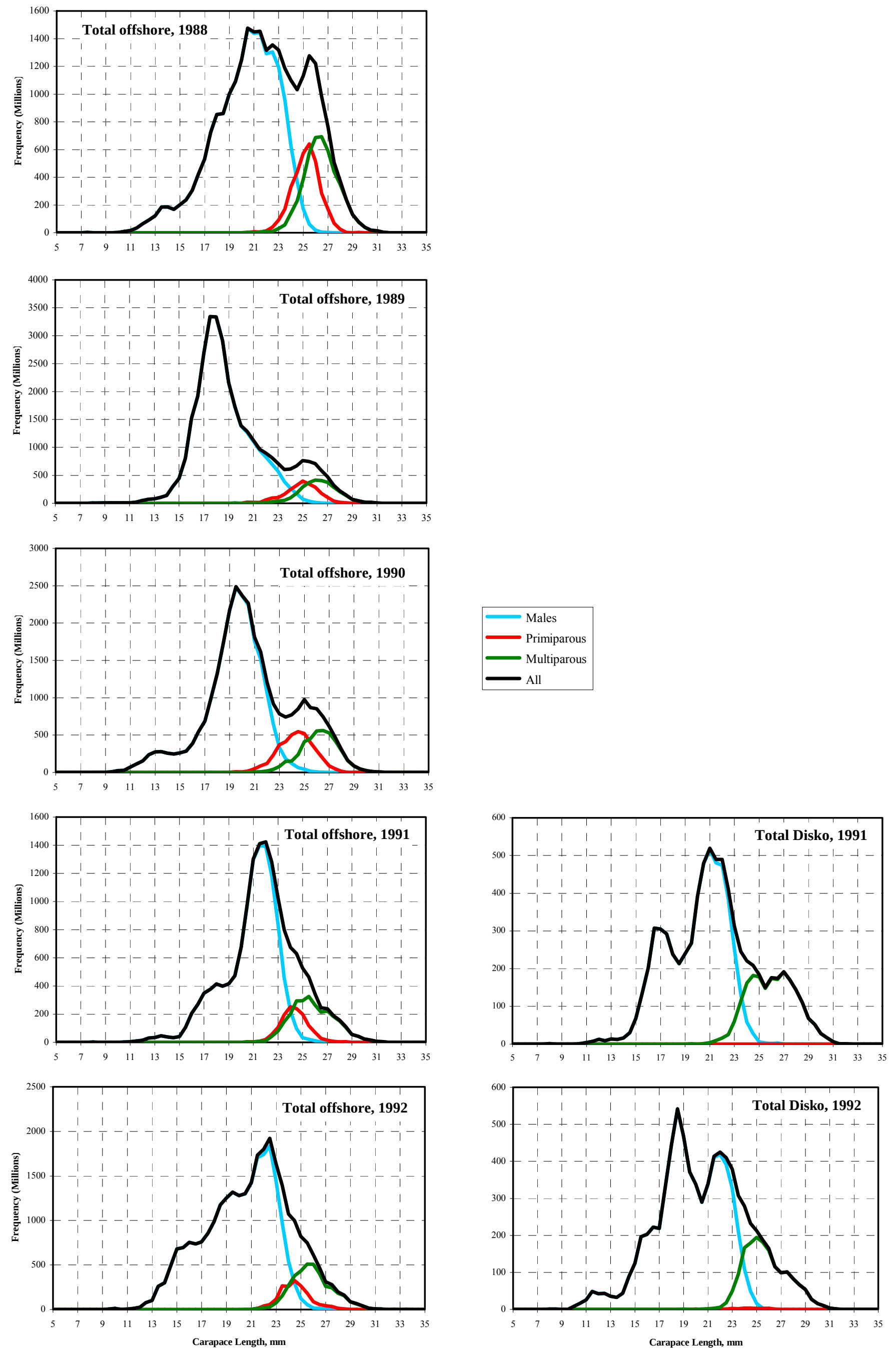


Fig. 7a. Length frequencies of Northern shrimp in the total offshore area, 1988 to 1992, and in the Disko Bay/Vaigat area, 1991 to 1992 (no surveys in Disko Bay/Vaigat area 1998-1990; unconverted data).

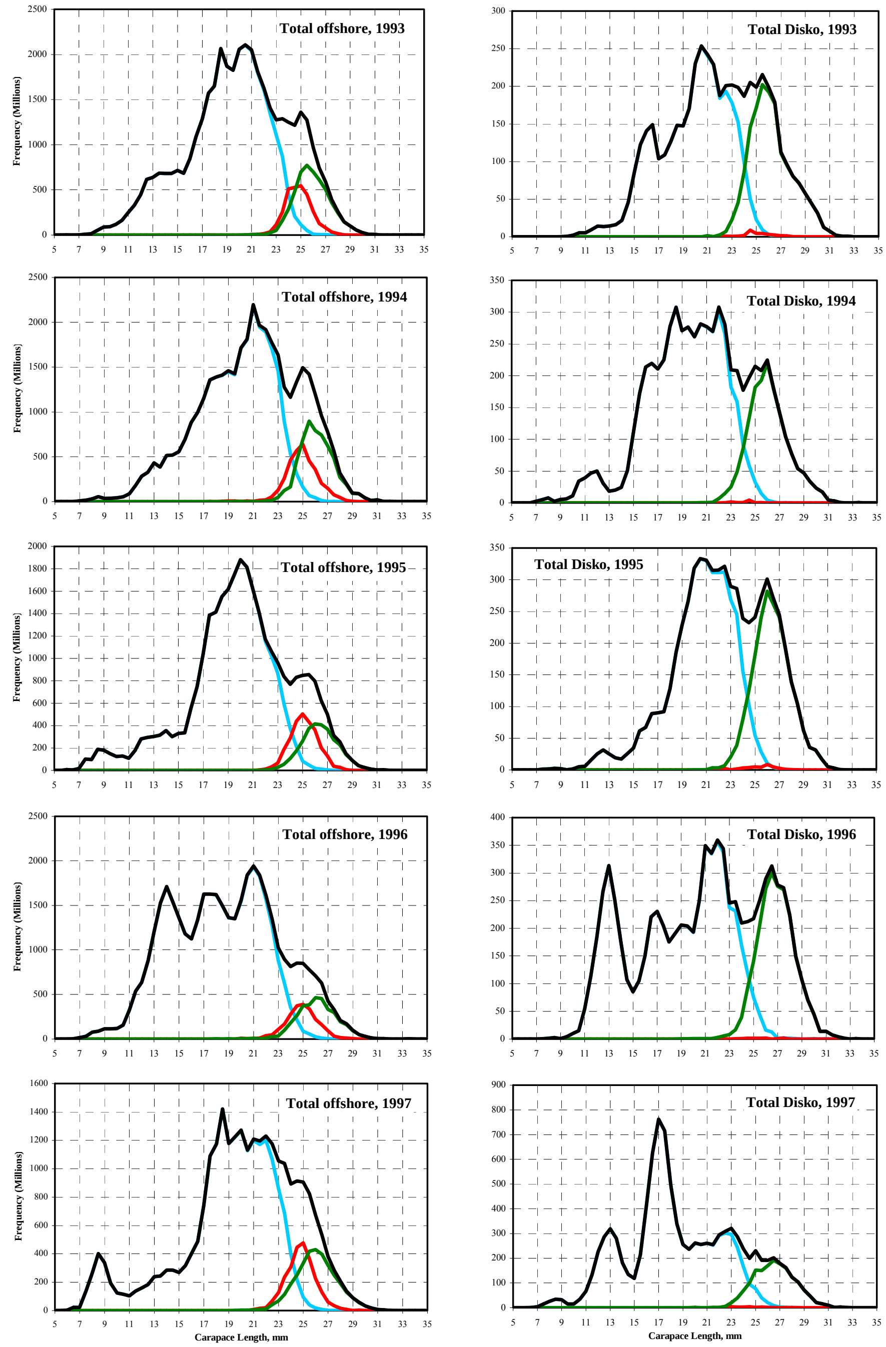


Fig. 7b. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1993 to 1997 (unconverted data).

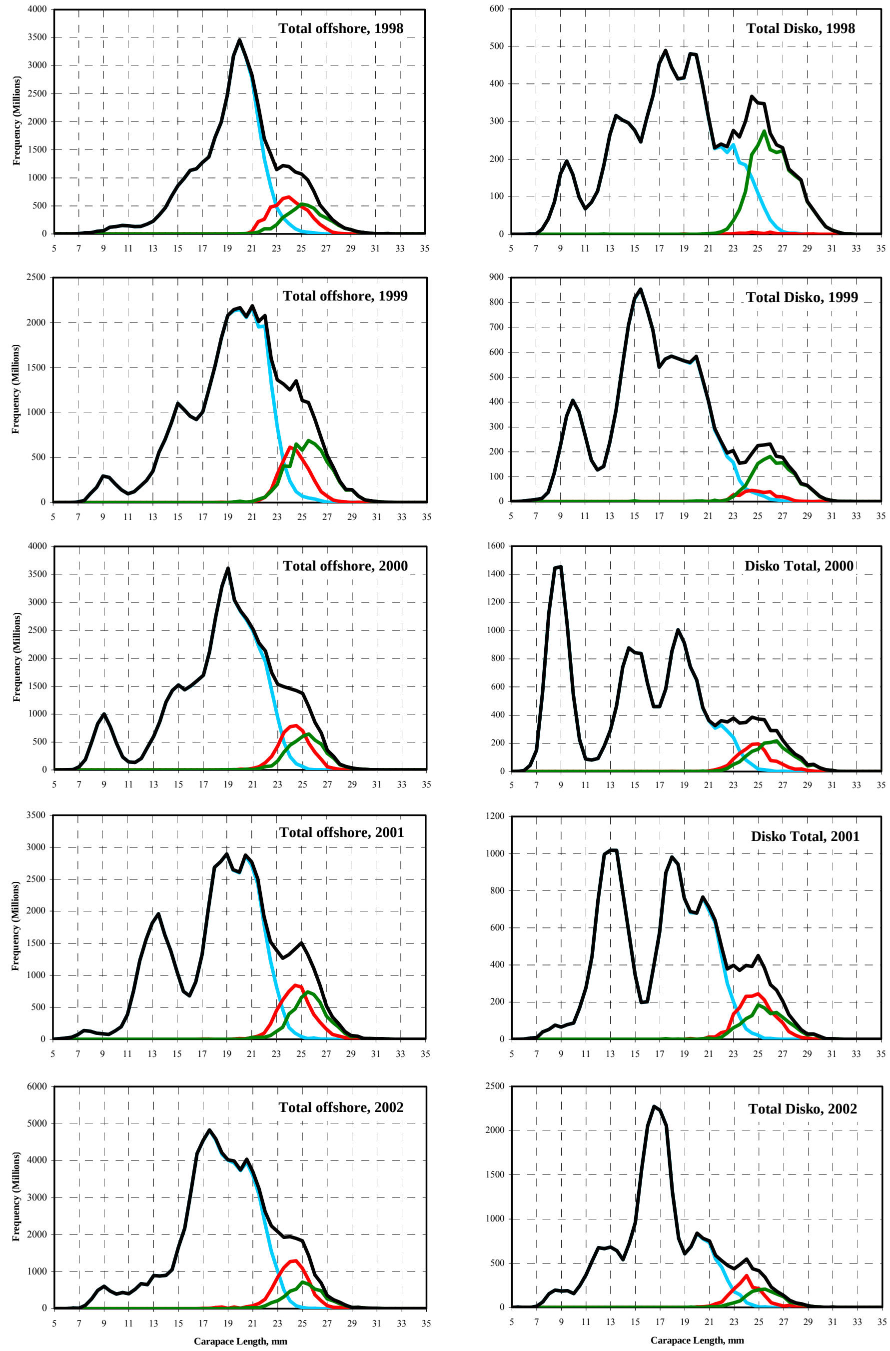


Fig. 7c. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 1998 to 2002 (unconverted data).

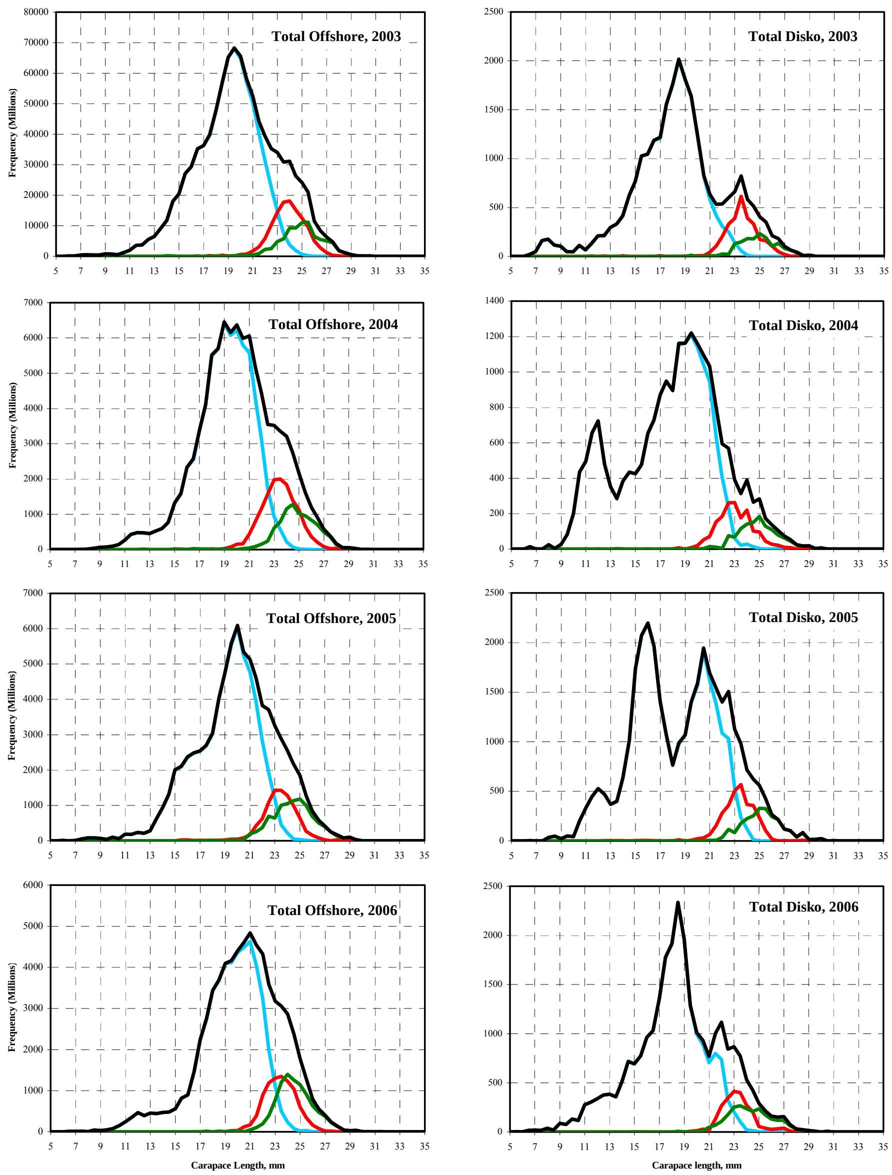


Fig. 7d. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2003 to 2006 (2003 and 2004 data converted from *Skjervøy* to *Cosmos* trawl).

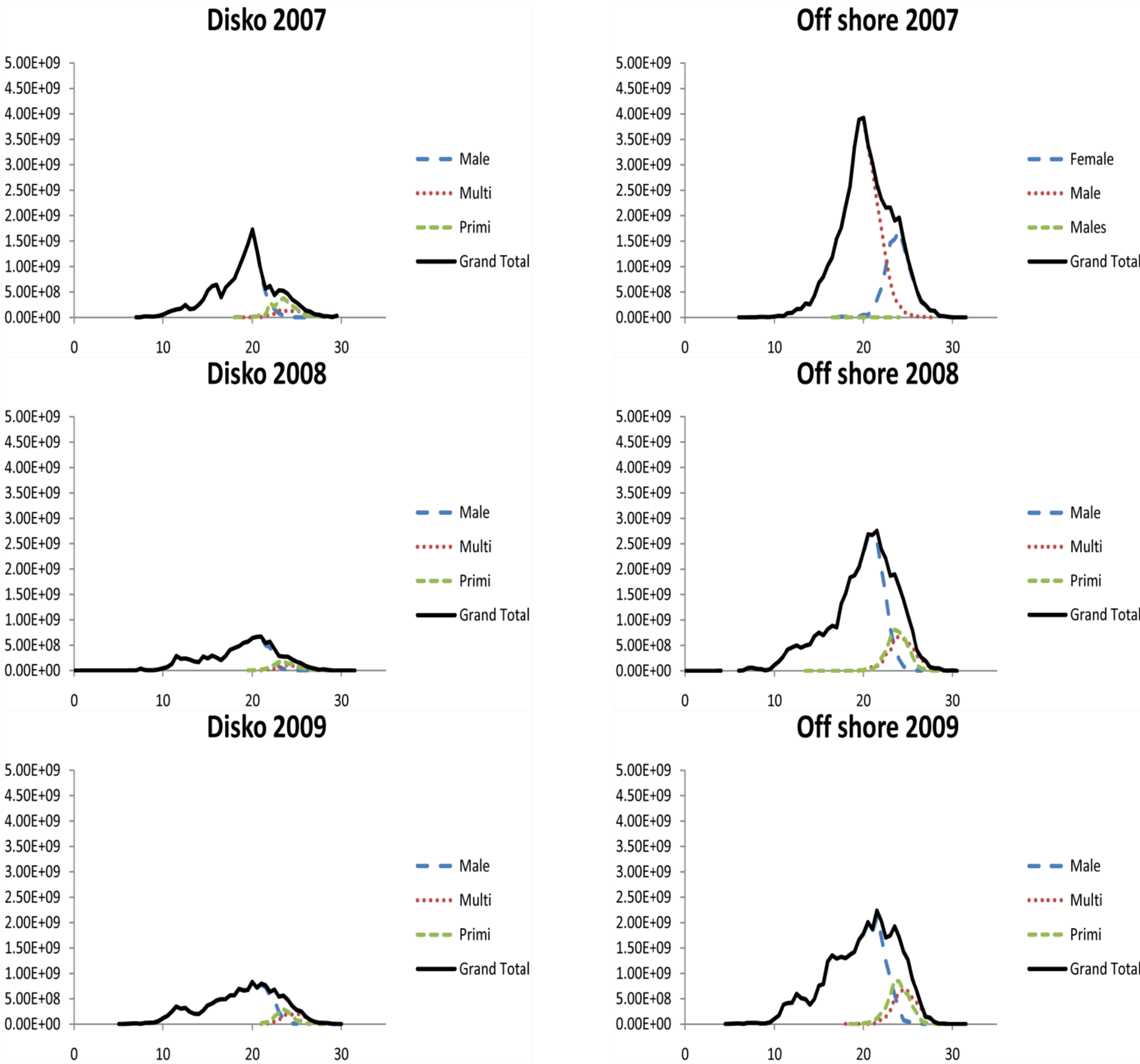


Fig. 7e. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2007 – 2009.

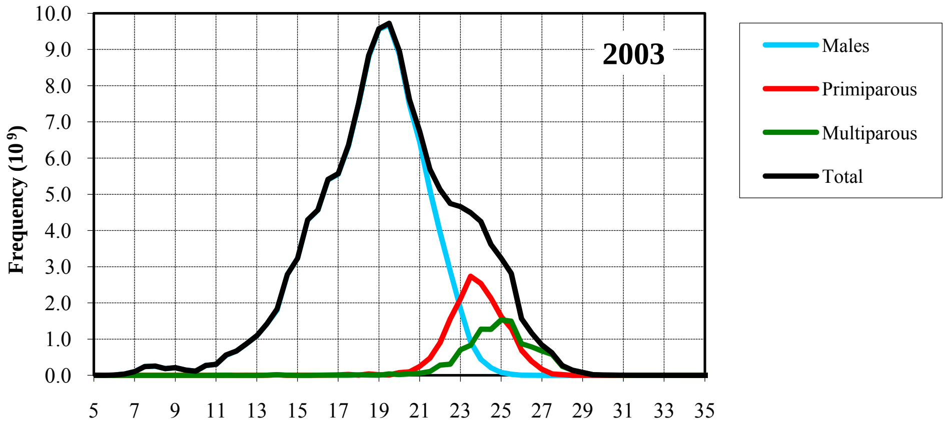


Fig. 8. Length frequencies of Northern shrimp in the total survey area (offshore and Disko/ Vaigat combined, 2004-2009).

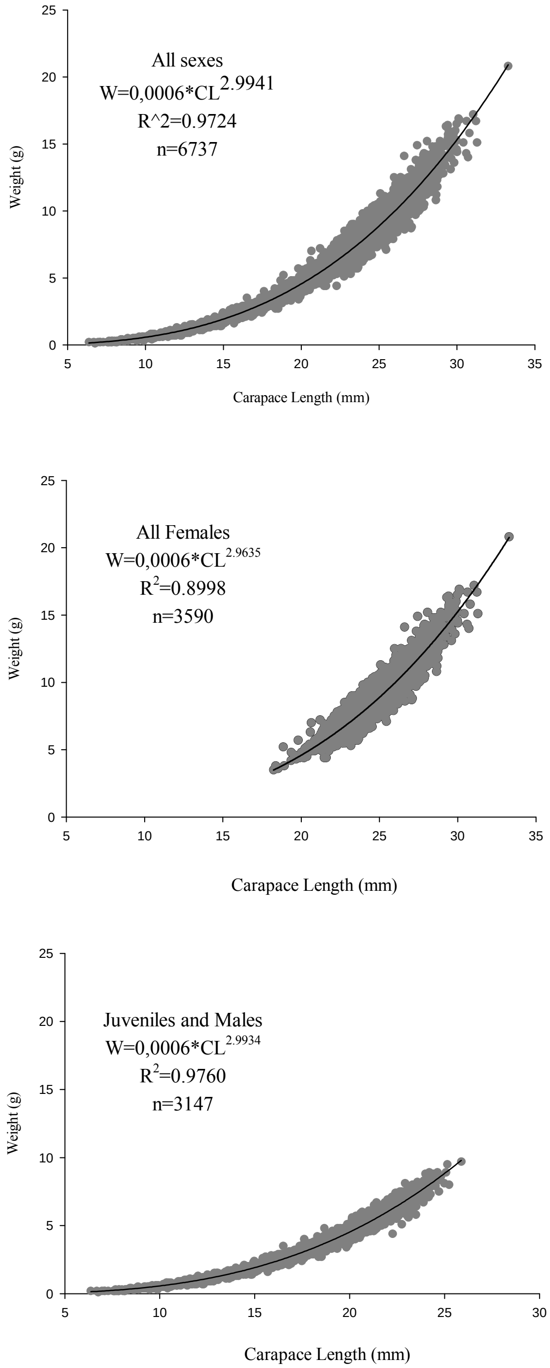


Fig. 9. Length-weight relationships of *P. borealis* off West Greenland. Data from 2001-2006.

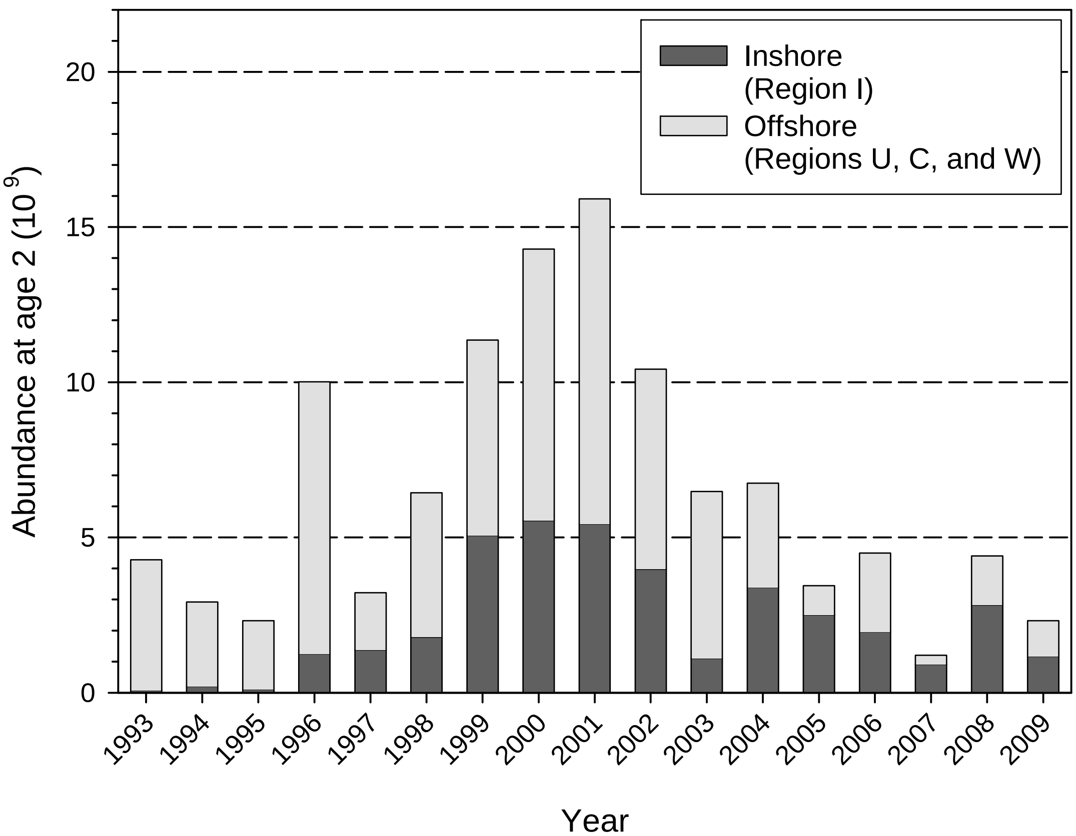


Fig. 10. Abundance indices for Northern shrimp at age 2 off West Greenland, 1993-2009.

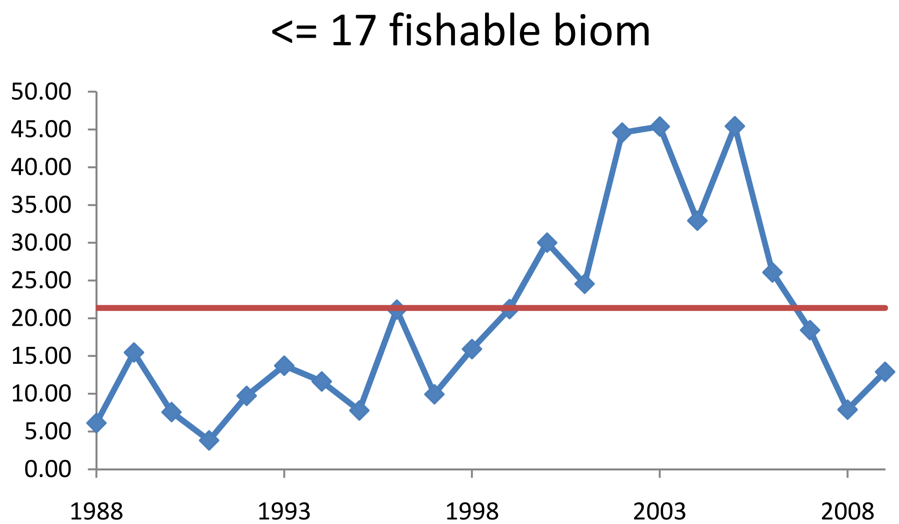


fig. 11. Total biomass of small shrimps, defined as being equal or below 17 mm CL for 1988 – 2009.

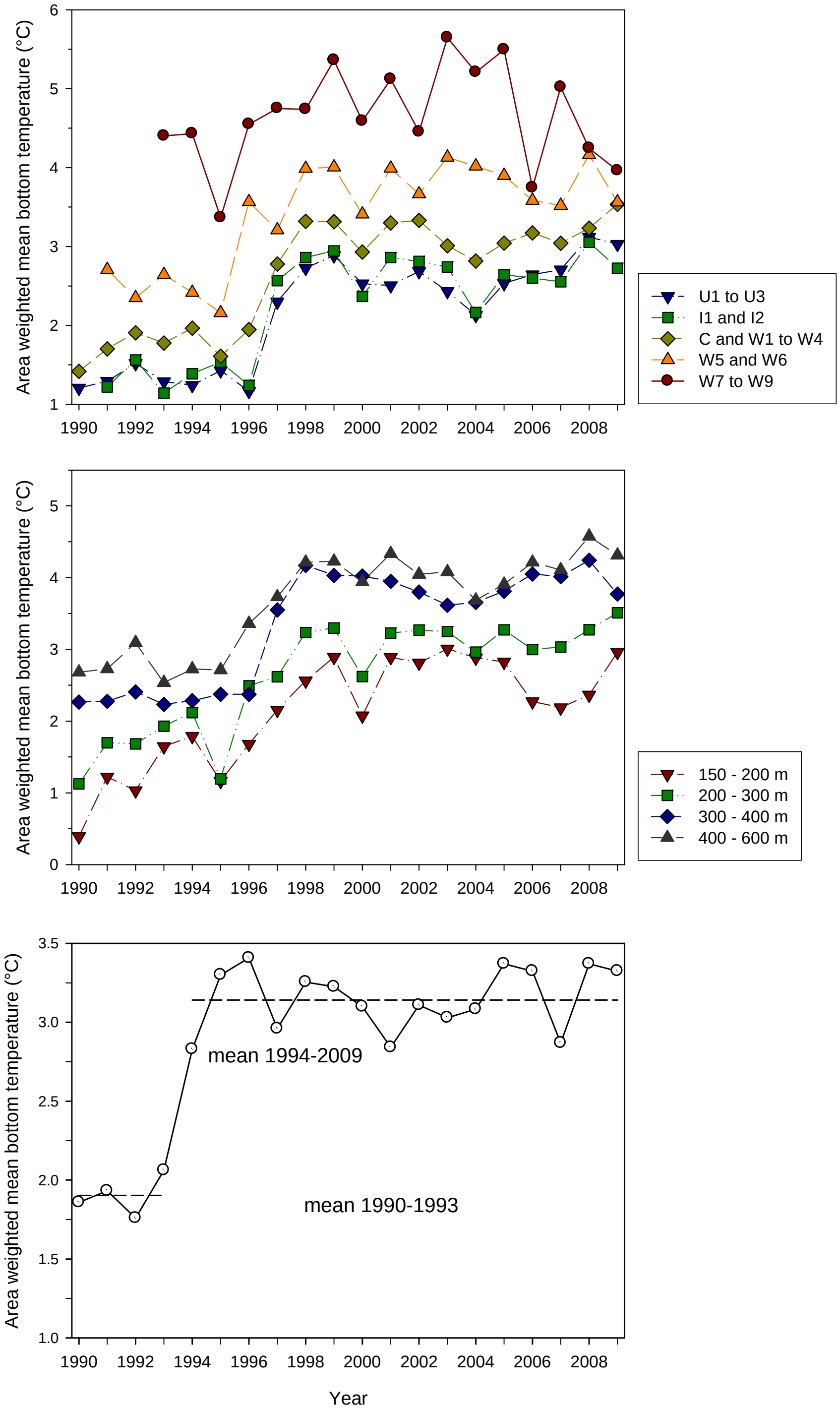


Fig. 12. Area weighted mean bottom temperature for the different survey regions (see Fig. 1 for locations), the various depth strata in offshore areas C and W1-W7 and the entire survey area in 1990 to 2009.