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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), 1988-2010

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. In 2010 the biomass has increased to 345 200 tons.

The main part of the biomass is found W1-4 and in Disko (96%). 29% of the total biomass is to be found in Disko bay, the highest proportion ever measured in the time period. The shrimp biomass is still mainly found in depths between 200 and 300 m. The shrimp stock were thus mainly found in areas from 67° N and 70° 30' N. The areas in the south held very few shrimp, only a few were found in Julianehaab Deep. The spread index is 4.2, indicating the shrimp biomass being mainly in four areas. The lat. Index shows that the biomass is to be found in northward areas.

Fishable biomass is 59 % of 2003 level and is 30% higher than last yr and for inshore areas the rise is 36% compared with last yr and for offshore areas the rise is 28%.

The length density distribution in 2010 is mainly dominated by age 4 (carapace length (CL) 19.2 mm), but the age groups 4, 5 and 6 is also abundant. The abundance of age 2 is at $3.03*10^9$. The calculations of age 2 for 2008 and 2009 should result in similar results, but CMIX seems to have an problem with that. Furthermore the recruitment abundance seems to be very low since 2005, where there was a gearshift. In order to mark the gearshift and hence the apparent bad coverage of small shrimps with Cosmos gear, we suggest that recalculations is to be made preferredly in the whole timeperiod. Until these results exists we must rely on the grouping of lengths is the best figure for recruitment trends (figure 11a and 11.b). And the results imply that the assumed age 2 group has been very low in 2007 but since 2008 till 2010 that group is stable, if not increasing.

Area weighted mean bottom temperature in the survey area started increasing in the beginning of 1990s and this relatively warm period continued in 2010, and is around the series mean (1994-2010). Temperature means by various depth strata showed a weak decrease in temperatures in all depth strata except for 300-400m depth where the temperature slightly raised. There was a slight increase in temperature in the Midgreenlandic area, but rest of Greenlandic Sea 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 2010 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 2010, 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).

The allocation procedure has been combined for Shrimps, GHL and COD 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 2010, 359 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. 26 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 2011. For the Shrimp biomass calculations 270 stations were used.

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

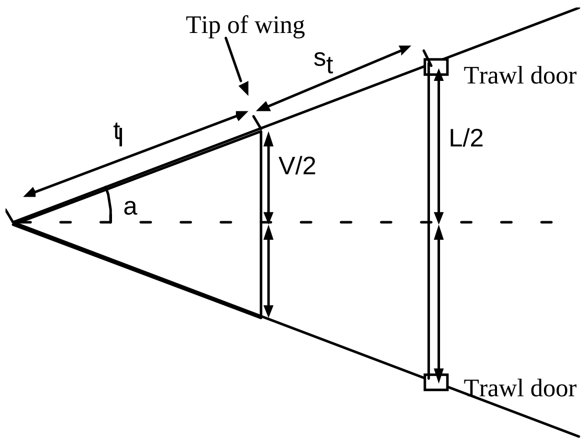
Survey tow duration has been changed through the years, from 60 min in the years 1988 to 1997, and then stepwise shortened to a mixture of 30 and 15 min tows randomly distributed in the strata in the proportion 2:1 in the years 2001 to 2003. These reductions were made in order to optimise the sampling 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 in different papers (Ziemer & Siegstad, 2009; Kingsley, 2001b; Kingsley *et al.*, 2002; Wieland and Storr-Paulsen, 2006). 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.

The descriptions of calculation methods that follow consider only one stratum. Survey strata are considered here as independent sampling problems. Survey totals are got by summing stratum results. 'Length class' can be generalized to include sex or sex-length class.

There are two methods readily available for calculating stratum biomass from station catches. From the catch and swept area at a station, the single-station estimate of stratum biomass is

$$\hat{B}_{ts} = \frac{Strat.Area_t \cdot Catch_{ts}}{Sw.Area_{ts}}$$

These single-station estimates densities can be simply averaged, or a mean weighted by swept area can be used. An unweighted analysis gives

$$\hat{B}_t = \frac{Strat.Area_t}{K_t} \sum_s \frac{Catch_{ts}}{Sw.Area_{ts}}$$

where t is the stratum and s is the station, of which there are K_t in stratum t. An estimate weighted on swept area would be:

$$\hat{B}_{ts} = Strat.Area_t \frac{\sum_s Catch_{ts}}{\sum_s Sw.Area_{ts}}$$

where the density estimate—ratio of catch to swept area—from each haul is weighted by the swept area before averaging. If density varies greatly within the span of a haul, so that longer hauls estimate an average local density more accurately, more accurate estimates of the stratum biomass are obtained by thus giving greater weight to longer hauls. Shrimp density does not vary much within a haul's distance[1] (Kingsley et al. 2002) and so it is statistically preferable to use the unweighted estimate of stratum biomass. This is what is done in the West Greenland survey.

If the number of shrimps in class l in the Length Sample, of weight $Samp.Wt_s$, from station s in stratum t is n_{lts}, the corresponding single-station estimate of the number of shrimps in the class in the stratum is

$$\hat{N}_{lts} = Strat.Area_t \frac{n_{lts}}{Samp.Wt_{ts}} \cdot \frac{Catch_{ts}}{Sw.Area_{ts}}$$

Using the unweighted analysis, the stratum estimate from many stations would be

$$\hat{N}_{lt} = \frac{Strat.Area_t}{K_t} \sum_s \left(\frac{n_{lts}}{Samp.Wt_{ts}} \cdot \frac{Catch_{ts}}{Sw.Area_{ts}} \right)$$

[1] Kingsley, M.C.S., D.M. Carlsson, P. Kanneworff, and M. Pennington. 2002. Spatial structure of the resource of *Pandalus borealis* and its implications for trawl survey design. Fisheries Research 58(2): 171–183.

where the divisor Kt, the number of stations, includes those with no catch. The coefficient $\frac{Catch_{ts}}{Samp.Wt_{ts} \cdot Sw.Area_{ts}}$ common to all length (and sex) classes counted in the Length Sample for a station can be called its 'raising factor'.

Given these estimates of numbers, and if estimates *w*(*l*) of individual weight at length are available, length-class biomass is given by

$$\hat{W}_{lt} = w(l)\frac{Strat.Area_t}{K_t}\sum_s\left(\frac{n_{lts}}{Samp.Wt_{ts}}\cdot\frac{Catch_{ts}}{Sw.Area_{ts}}\right)$$

Provided that for all Length Samples $\sum_l n_{lts} w(l) = Samp.Wt_{ts}$, i.e. the weight of every Length Sample answers exactly to the number and size of the shrimps that compose it, the sum of length-class biomasses should equal the stratum total biomass calculated from catches and swept areas. However, usually there are discrepancies between the measured and calculated Length-Sample weights. These can occur because the weight-length relationship used does not hold over the whole survey area, because there are errors in weighing the Length Samples or in recording the weights, and so on. As a result, estimated class biomasses do not sum to the total stock biomass calculated from the gross catches. In the assessment of the West Greenland shrimp stock the discrepancy is resolved by adjusting all the class biomasses by the constant factor necessary to correct their sum.

Results from these calculations were subsequently used to construct area-specific length frequencies distributions (LFD). 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.

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 2010 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 after 1994 the temperatures were measured with a *Seamon* sensor (later a Starmon sensor was used) mounted on one of the trawl doors. The 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 2010, 270 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 2010 are:

Region	Biomass estimate (t)	Number of stations	OECV (%)
North (U1-U3)	73 206	27	11,14
Canadian zone	2 982	8	29,67
West (incl. South)	169 666	196	25.19
Disko B./Vaigat (I)	99 328	27	9,97
Total	345 182	270	12,93

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 2010 it is 345 182 tons (Tab.3, Fig.3 upper panel), which is approx. 24 % higher than last year total biomass and 12 % compared to long term average.

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 rise in biomass.

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. In 2010 the OECV was 12.93, which is below long term average OECV.

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-W3, the Disko Bay and area U1-U3, as last year. These areas contributed more than 95% 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 (W4 to W7) a continuous decline since 2004.

The overall survey biomass index has decreased since 2003 in the West Greenland, but this year the biomass has increased and the concentration remains in the northward areas (Fig. 4).

The 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 still relatively low, which means that the shrimp biomass is mainly concentrated in three areas. The lat. Index shows that the biomass is to be found in northwards and inshore areas.

This year's survey results indicate a increase in fishable biomass on about 30% (tab. 8) compared to last yr. This year's total biomass is only 47 % of the biomass observed in 2003 and the fishable biomass in 2010 is 62% of that observed in 2003. Most of the shrimp biomass is concentrated in the areas U1 – U3, W1 – W3 and the Disko/Vaigat. 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 29 thousand tons compared to last year. That area contributes 29 % of the biomass in W. Greenland waters although it only covers about 7 % of the total survey area. Fishable biomass off shore increased with 28% compared to last yr. In Disko/Vaigat area was about 36% more than last year.

In conclusion 21 % of the total biomass in 2010 was found in areas U1 – U3 that covers about 38 % of the survey area. W1 – W2 contributed with 26 % of the total biomass and Disko/Vaigat 29 %. W3 – W4 contributed with 19%, W5 – W7 contributed with 4% and W8 – W9 approx. null. Hence the shrimp biomass in 2010 appeared to be concentrated in the U1 – U3, in offshore areas W1 – W4 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 for areas W1-7 and region C. The biggest proportion of the biomass is still to be found in the depth between 200-300 m, and this yr there was a 10% increase compared to last yr and it is the highest proportion measured in the time 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 73 % 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 2010 the highest off shore densities were found in the W1-2 and the W3-4 (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 2010 are very low (Table 5).

C0 had a very low shrimp density distribution this year, and the overall error of coefficient of variation (OECV) for C0 is high (30%) (See table 4).

The shrimp density distribution results have increased with 20 % overall. The overall average density is 2.538 tons/km^2 and for off shore areas it is 1.951 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 Disko/Vaigat is 9, 97 tons/km^2 and the average density is 7.03 tons/km^2 in the time period 1991-2010.

Conclusion

In conclusion the shrimp density distribution is the same for the off shore areas compared to the long term average for offshore, and the inshore areas the shrimp density is also around long term average for inshore area. The shrimp density overall is also approximately the same for long term average.

Demography and recruitment

Fig. 6 gives length density distributions for males in combined strata in the survey area in 2010, Fig. 7 gives the length frequency distribution for all shrimp sexes combined (juveniles/males, primiparous and females) in the survey area in 2010. Fig. 8 gives the overall West Greenlandic length frequency distribution in the period from 2007 till 2010.

Size distribution by area in 2010

The length density distribution in 2010 is mainly dominated by age 4 (carapace length (CL) 19.2 mm), but the age groups 4, 5 and 6 is also abundant (Fig. 6). Grouping Length frequencies in 0 – 9 mm and 9.5 – 14 and 14.5 – 16.5 mm shows an increasing trend for especially group 2, 3 and 4 (see Fig. 11.a).

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: $W=5.7881E\text{-}4*CL^{2.9941}$; n= 6737; R^2= 0.9724

All females: $W=6.3959E\text{-}4*CL^{2.9635}$; n= 3590; R^2= 0.8998

Juveniles and Males: $W=5.7735E\text{-}4*CL^{2.9934}$; 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

The total number of males and females (70.6 billion) for 2010 is 31 % higher than last yr (53.7 billion) and is 14 % higher than long term average. The abundance of males is 56.2 billion and is 35% higher than last yr and 14% higher than long term average. The abundance of females is 14.4 billion and is 17% higher than last yr and is 17% higher compared to long term average.

Abundance of shrimps at age 2 is 3.03 billion and very low compared to long time average on $7.10*10^9$ (Bergstrøm, 2007).

Estimates of total stock biomass derived from a conversion of the length frequencies to weight are listed in Table 7. The fishable biomass is 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 2010, the fishable biomass for the entire survey area amounts to about 321 100 tons, which is 13 % above the long-term average (282 700) and 30 % higher than last yr.

In 2009 the female biomass estimates was 3 % higher than long term average and in 2010 it is 13% higher than last yr and 17% higher than long term average. The female proportion is as high as in 2002. The male proportion is 11 % higher than long term average.

Recruitment and mean length at age 2(age1+)

Observed overall average length density distribution of *P. borealis* is to be seen in in Figure 6a. And regional average carapace lengths with standard errors by region are given together with fitted Gaussian components for age 1, 2, and 3 and composite expected distributions in Table 9 and Figure 6b. 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 1993-2010 together with gross recruitment rate R(t). High R(t) values were observed in 1996, 1999, 2000, and in 2001 and very low values have been observed since 2003-the lowest in 2007. The high recruitment rate values in 1996 most likely caused increasing abundance values during the period 1997-2000 and the high and increasing recruitment rate values during the period 1999-2001 probably are behind the very high abundance values (and resulting biomasses) the following couple of years. Earlier survey reports (e.g. Wieland and 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.

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. Figure 10a 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.

In 2010 the recruitment stock is very low at about 3.03×10^9 shrimp, but the results must be evaluated. Figure 10 b illustrates where the gearshift back in 2005 is marked with an arrow. There is a fall in recruitment of age 2 since the introduction of the Cosmos gear in 2005 and the numbers does never comes up near the long term level on about $7*10^9$. In 2008 Kingsley shows that the Cosmos gear cannot catch the smallest shrimps (<10 mm CL) and that the next group (the recruits 10-15 mm CL) also have an smaller catch rate with Cosmos, compared to Skervøy (Kingsley *et al.* 2008).

There is a remarkable fall of age 2 recruitments from 2005 and forth, figure 10.b. It is noted that the low recruitment trend has been a persistent low since 2005. But the CMIX programme seems to have a genuine problem with reliable calculations since two very similar yrs seems to result in very different abundances for age 2. Comparing 2008 and 2009 from figure 11.a, they seem quite similar. But runs with CMIX result in 4.91E9 in 2008 and 2.32E9 in 2009.

In order to mark the gearshift and hence the apparent bad coverage of small shrimps with Cosmos gear, we suggest that recalculations is to be made preferredly in the original program used (MIX). Until these results exists we must rely on the grouping of lengths is the best figure for recruitment trends (figure 11a and 11.b). And the results imply that the assumed age 2 group has been very low in 2007 but since 2008 till 2010 that group is stable, if not increasing.

Bottom temperature

Area weighted bottom temperatures are given in Fig. 12. Bottom temperatures this year was around average.

Regionally the temperature decrease in southern most areas (W5-W9). In Canadian zone and W1-W4 it is slightly higher again this yr. In Disko and in U1-U3 it was approx. the same as last year.

In depths between 300-400 m the area weighted average bottom temperature is continuously rising since 2007. In conclusion the overall temperature was the same as the long term area weighted average temperature for West Greenland.

Conclusions

The conclusion for 2009 was that the recruitment levels observed the last years did not get up to level with long term recruitment levels. Thus a continued decrease of the biomass and fishable biomass in coming years was expected. However total biomass for 2010 did increase with 24 % compared to last yr and 12 % compared to long term average.

The contributions to total biomass came mainly from area W1-W4, the Disko Bay and area U1-U3. These areas contributed more than 95% 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 (W5 to W7) a continuous decline since 2004.

The female biomass estimates was 13% higher than last yr and 17% higher than long term average. The female proportion is as high as in 2002. The male proportion is 11 % higher than long term average. The fishable biomass was in 2003 at the record high level of 548 000 tons for the entire survey area. In 2010, the fishable biomass for the entire survey area amounts to about 321 100 tons, which is 13 % above the long-term average (282 700) and 30 % higher than last yr.

The overall survey biomass index has decreased since 2003 in the West Greenland, but this year the biomass has increased and the spread index is still relatively low, which means that the shrimp biomass is mainly concentrated in three areas. The lat. Index shows that the biomass is to be found in northwards and inshore areas.

There seems to be a problem with calculating the age 2 abundance since 2008. Comparing 2008 and 2009 from figure 11.a, they seem quite similar. But runs with CMIX result in 4.91E9 in 2008 and 2.32E9 in 2009. Therefore it is recommended that recalculations in the whole timeperiod should be done. Results from grouping lengths imply that the assumed age 2 group has been very low in 2007 but since 2008 till 2010 that group is stable, if not increasing.

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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 - 2010	Paamiut	Cosmos	54.0	27.4 - 28.2	**

Tab. 2. Basics for all strata.

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
W1-1	150-200	2873	2218.28	2	705	31.8
W1-2	200-300	6099	30440.91	24	20108	66
W1-3	300-400	7520	14488.21	10	14633	101
W1-4	400-600	816	0	2	0	-
W2-1	150-200	1674	3864.38	2	3116	81
W2-2	200-300	2612	33011.38	13	38516	117
W2-3	300-400	1741	4270.45	6	3355	79
W2-4	400-600	916	1365.73	1	.	-
W3-1	150-200	2122	6.23	4	9	139
W3-2	200-300	4725	47295.84	21	178882	378
W3-3	300-400	2085	5683.43	2	7322	129
W3-4	400-600	2994	5537.69	5	7876	142
W4-1	150-200	4119	302.47	2	303	100
W4-2	200-300	1818	1167.99	6	2416	207
W4-3	300-400	821	5255.56	5	9552	182
W4-4	400-600	1961	15.07	2	12	80
W5-1	150-200	3001	63.31	8	107	168
W5-2	200-300	3648	4276.46	13	10857	254
W5-3	300-400	1950	3.44	2	3	74
W5-4	400-600	3021	95.02	3	160	168
W6-1	150-200	1206	0.68	4	1	116
W6-2	200-300	2006	8618.86	10	26976	313
W6-3	300-400	1585	30.45	3	53	173
W6-4	400-600	1234	453.21	2	641	141
W7-1	150-200	2442	0	6	0	-
W7-2	200-300	891	0.08	8	0	162
W7-3	300-400	265	0	3	0	-
W7-4	400-600	317	0	2	0	-
W8-1	150-200	424	0	2	0	-
W8-2	200-300	567	0.58	2	0	34
W8-3	300-400	405	10.72	3	18	172
W8-4	400-600	718	1189.38	3	2060	173
W9-1	150-200	1711	0	5	0	-
W9-2	200-300	938	0.07	5	0	137
W9-3	300-400	516	0	3	0	-
W9-4	400-600	430	0.04	2	0	141
Total		72170	169666	196		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
U1-1	150-200	2486	178.5	2	66	37
U1-2	200-300	4633	9154.5	3	5811	64
U1-3	300-400	4785	12792.2	5	6763	53
U1-4	400-600	5129	276.8	1	.	-
U2-2	200-300	6710	16664.49	3	6432	38
U2-3	300-400	8481	7494.22	4	7423	100
U2-4	400-600	7994	2482.45	5	2873	116
U3-1	150-200	2012	36.21	2	32	88
U3-2	200-300	3017	16897.86	7	8455	50
U3-3	300-400	1676	5653.9	3	4396	78
U3-4	400-600	2710	1575.01	2	603	38
Total		49632	73206	37		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
C0-2	200-300	903	735.91	4	791	108
C0-3	300-400	2179	2240.02	5	1770	79
C0-4	400-600	1154	6.52	1	.	-
Total		4236	2982	10		

Stratum	Depth	Area (km²)	Biomass	Hauls	STD	CV (%)
I1-1	150-200	407	5020.06	1	.	-
I1-2	200-300	1963	34480.88	4	13196	38
I1-3	300-400	2441	20265.7	6	8753	43
I1-4	400-600	1499	1250.4	2	661	53
I2-1	150-200	419	3612.75	4	2254	62
I2-2	200-300	815	22017.96	3	6478	29
I2-3	300-400	1085	9245.5	3	5260	57
I2-4	400-600	1338	3434.4	4	3372	98
Total		9967	99328	27		

Overall Total		136005	345182	270

Tab. 3. Biomass estimates (in ‘000 tons) for combined strata and standard errors for the entire survey area 1988-2010.

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
2010		73.2		3.0	89.7	65.3	13.5		1.2		99.3	345.2	44.6

1: New stratification introduced in 2003 (regions N and S) and in 2004 (regions U, C and D)
2: Areas W6 and W7 were sampled from 1990 and 1993, respectively
3: D1-D9 1988-90 not sampled, but set to mean of 1991-1997.
4: Standard error calculated excluding D1-D9 in 1988-1990
5: Probably underestimated due to poor coverage of the northern part of the area 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 1988-2010.

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	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
2010	11.1	29.7	25.4	99.1	10.0	12.93	270
				avg.'94-'10:		13.89	

Table 5. Estimated mean densities (t/km^2) for combined strata in 1988-2010.

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
2010	1.48	0.70	3.70	3.16	0.63	0.21	9.97

Table 6. Abundance estimates (billions) for males and females from overall length distributions for the total survey area 1988-2010 (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
2010	56.2	14.4	70.6	79.6	20.4
Average	49.5	12.3	61.8	80.2	19.8

Table 7. Biomass estimates for males and females ('000 tons) in the total survey area based on length-weight distributions 1988-2010 (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	166.5	111.7	278.2	59.8	40.2
2010	219.3	125.9	345.2	63.5	36.5
Average	198.2	108.0	306.2	64.9	35.1

Table 8. Estimates of fishable biomass (<=17mm CL, ´000 tons) in the offshore, the Disko/Vaigat and the total survey area 1988-2010 (mean values for Disko/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
2008	215.1	47.2	262.4
2009	184.5	62.3	246.9
2010	236.6	84.5	321.2
Average	228.7	56.1	284.0

Table 9. Mean carapace length (mm) for Northern shrimp at “age 2” off West Greenland 1993-2010 and corresponding SD and COEV 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	150-600 m	150-300 m	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 (?)	-
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
2010	12.8	11.9	13.0	14.5	-	-	-

Table 9 - continued. Mean carapace length (mm) for Northern shrimp at “age 2” off West Greenland 1993-2010 and corresponding SD and COEV from modal analysis (- : not present, (): fixed in the final MIX run).

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
2010	1.1	1..1	1.07	1.3	-	-	-

Table 9 - continued. Mean carapace length (mm) for Northern shrimp at "age 2" off West Greenland 1993-2010 and corresponding SD and COEV from modal analysis (- : not present, (): fixed in the final MIX run).

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
2010	0.09	0.09	0.08	0.09	-	-	-

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). In 2005 there was a change in Gear from Skervøy to Cosmos 2000 and the abundance of age 2 was onwards quite low.

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
2010	3.03	70.6	0.04	0.0835
Average	9.03	68.90	0.11	0.03

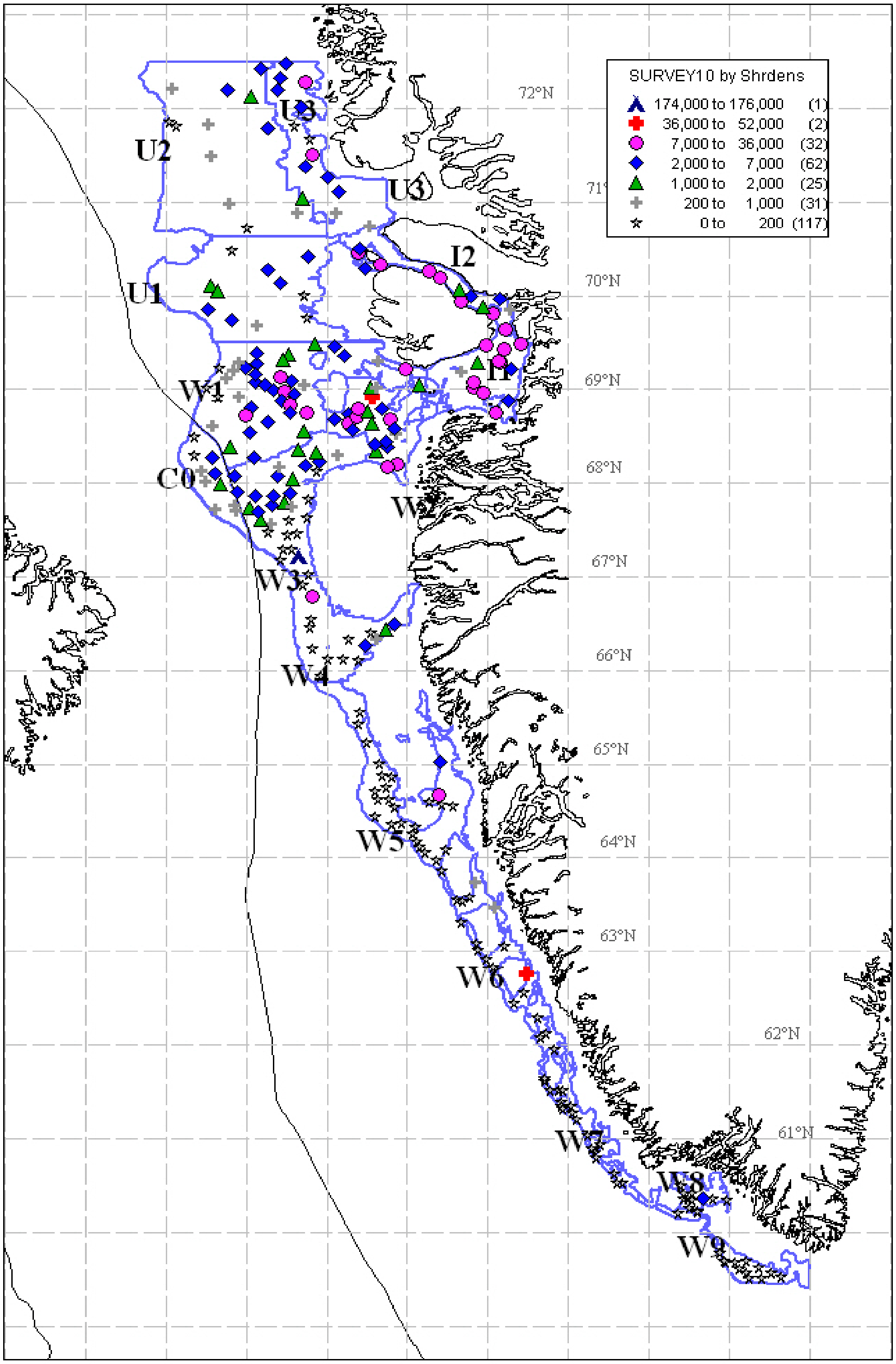


Fig.1.Survey stratification and shrimp density in W. Greenland 2010.

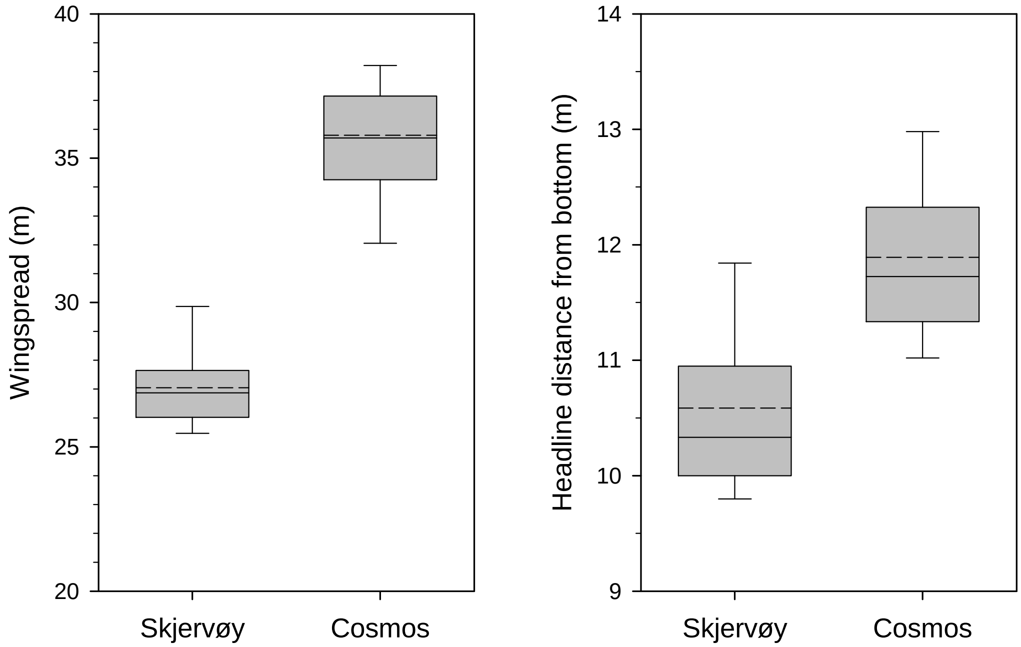
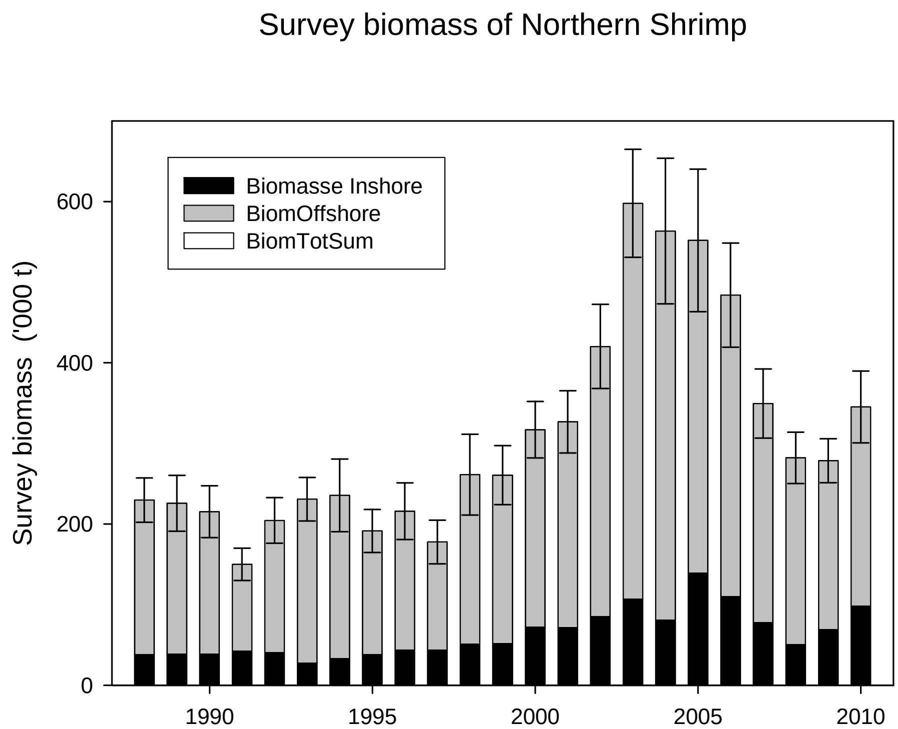


Fig. 2. Box whisker plots showing arithmetic means (stippled line) and medians (solid lines) of wingspread and headline distance to bottom for the two trawl types (*Skjervøy* 3000 and *Cosmos* 2000) with 95% confidence interval (upper and lower borders of grey box) and lower and upper quartiles (error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



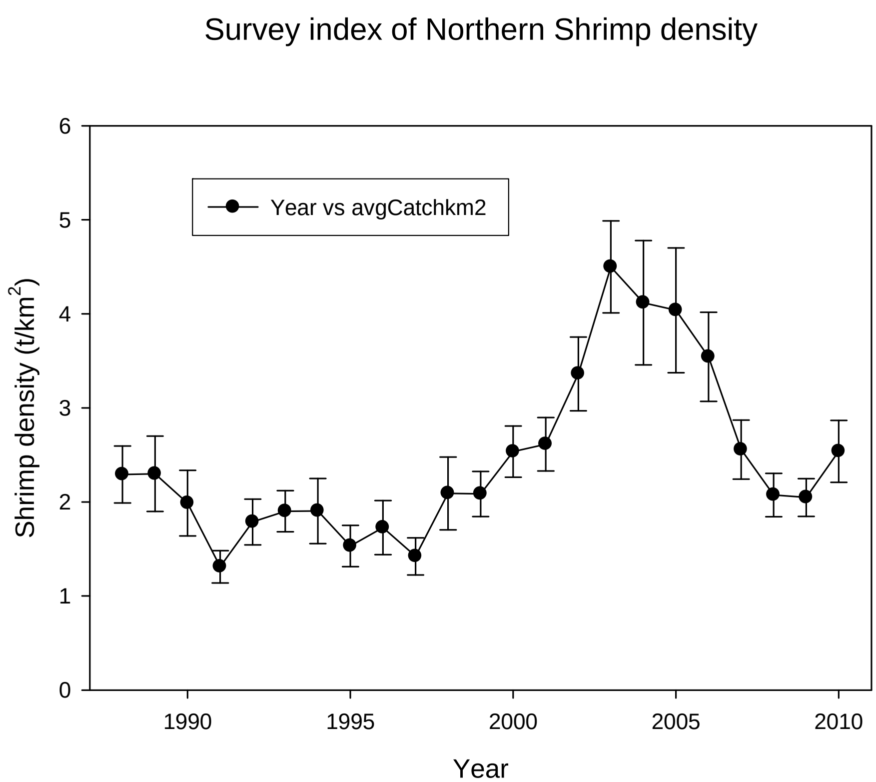


Fig. 3. Estimated total survey biomass and average survey biomass density of Northern shrimp with standard errors 1988-2008 (Average biomass estimate for inshore areas 1991-1997 are used for 1988-1990 to facilitate between-year comparisons, see tab. 3 for details).

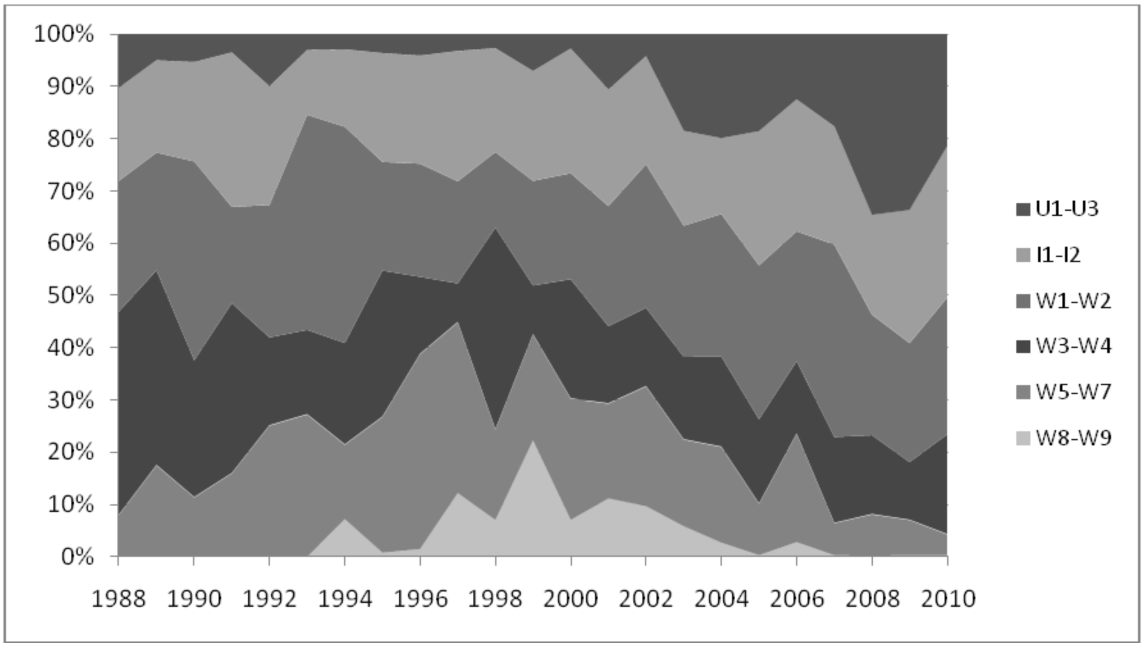


Fig. 4a. Biomass contributions from different primary survey regions 1988-2010 (area names are given in brackets, see fig. 1 for location).

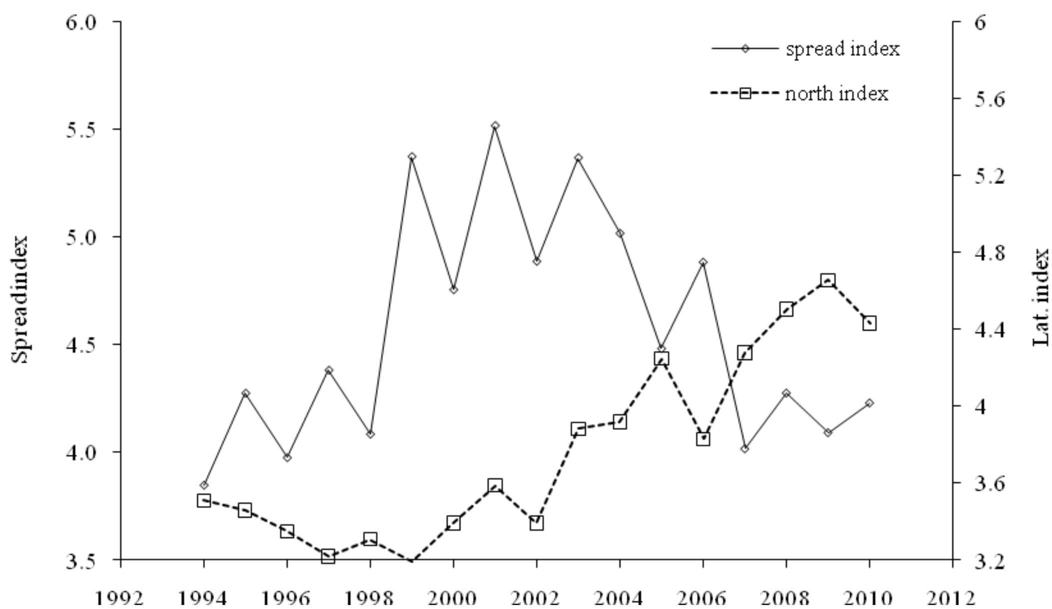


Fig. 4b. Indices of distribution and location of shrimp biomass for the West Greenlandic trawl survey 1993-2010.

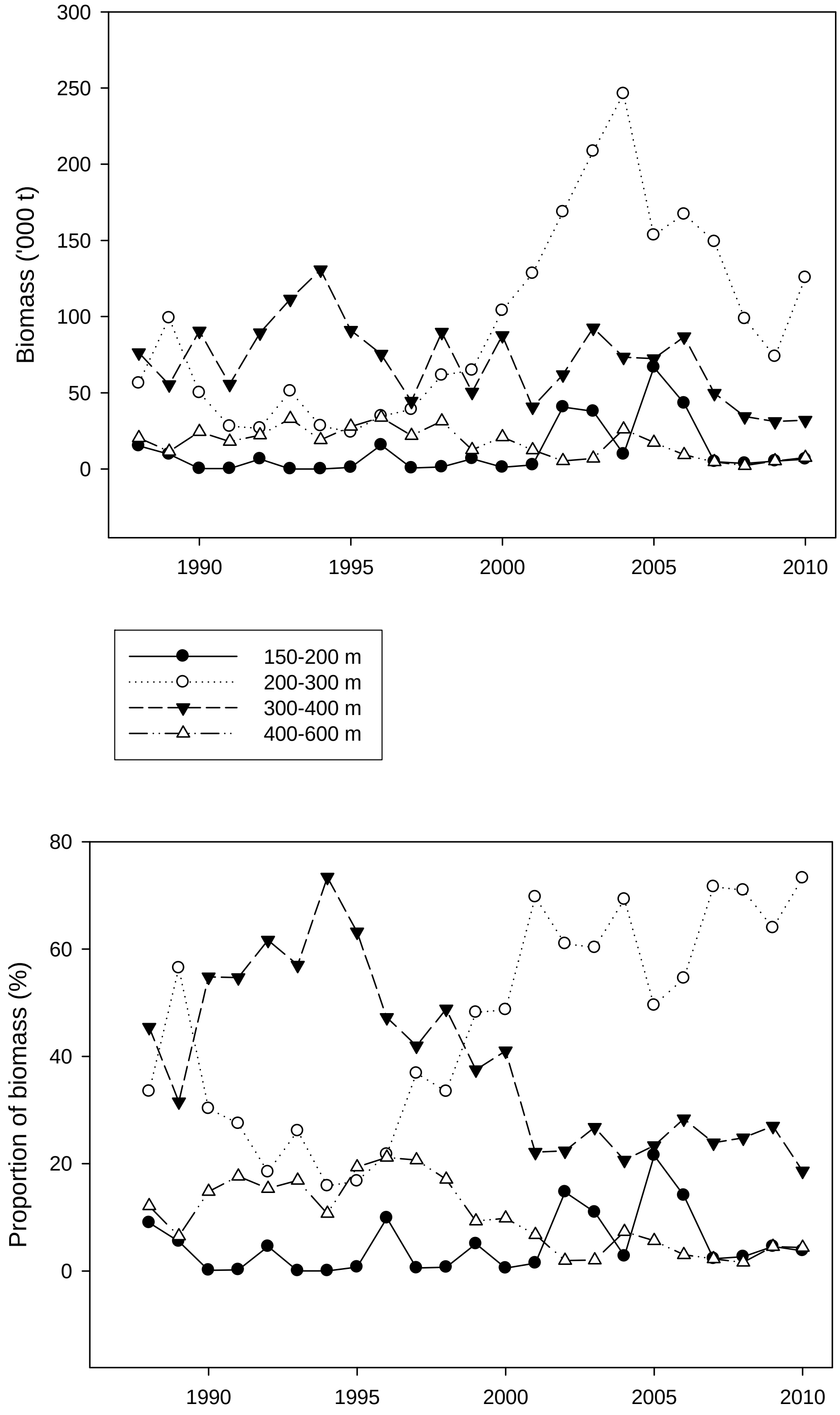


Fig. 5. Biomass distribution in the four depth strata in areas C and W1-W9 1988-2010.

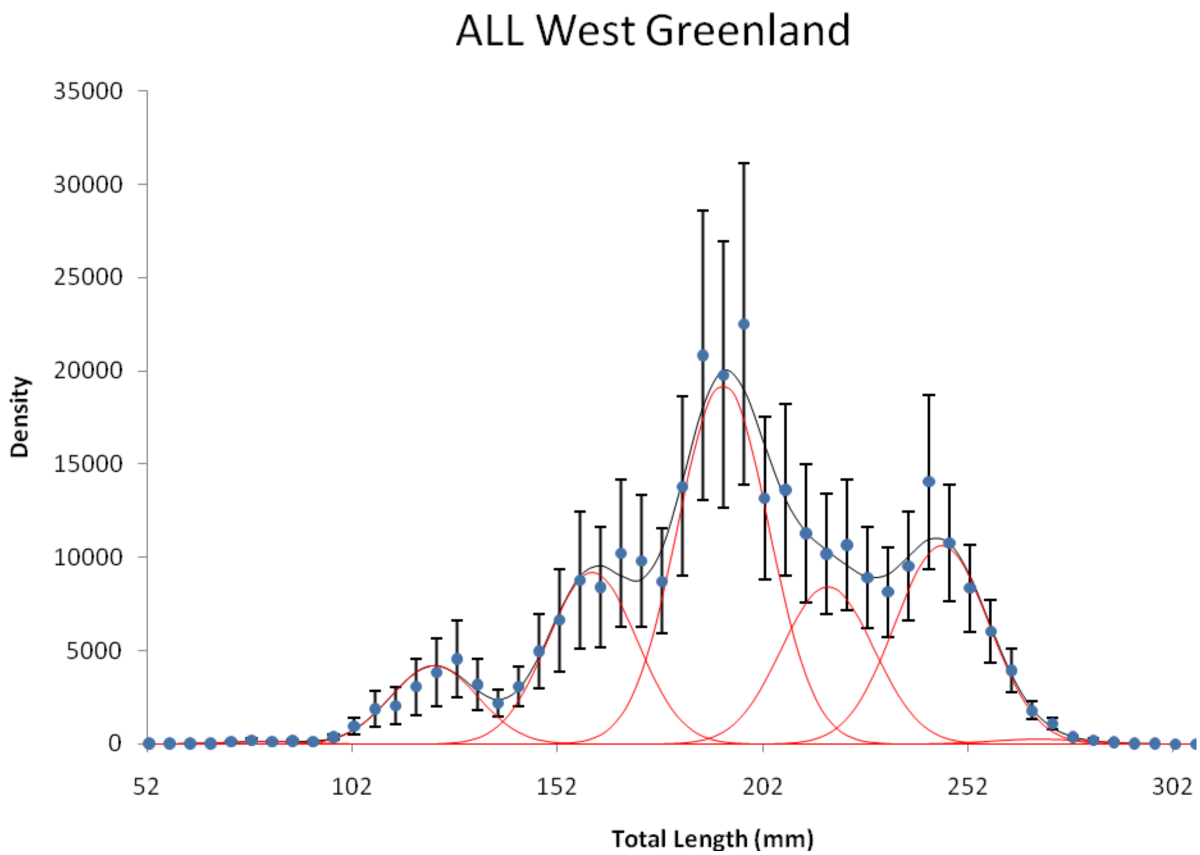
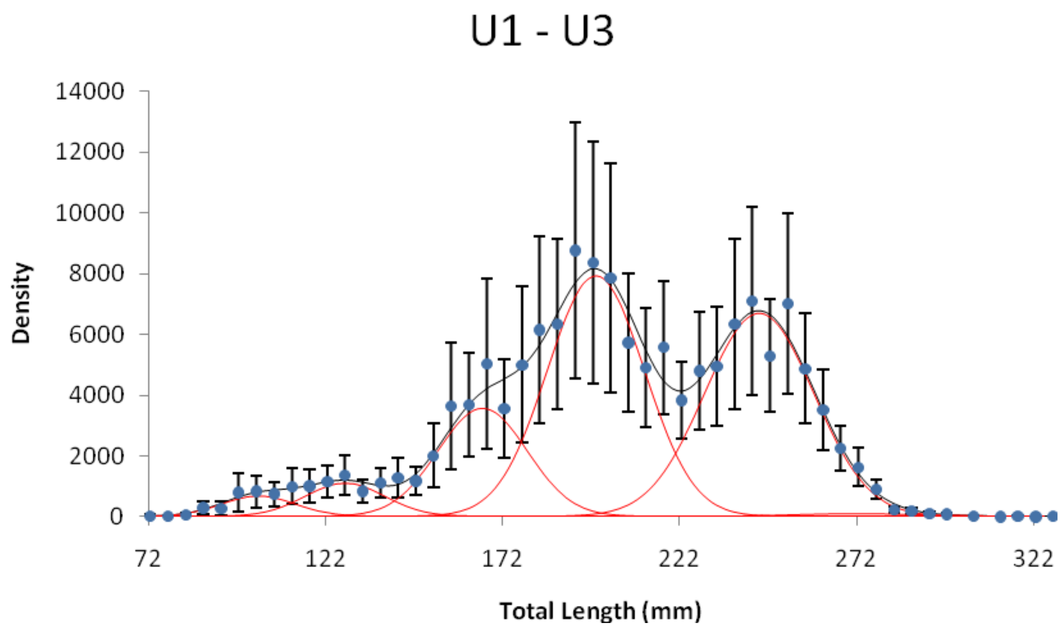


Figure 6a. Length density distributions (LDD) for West Greenland.



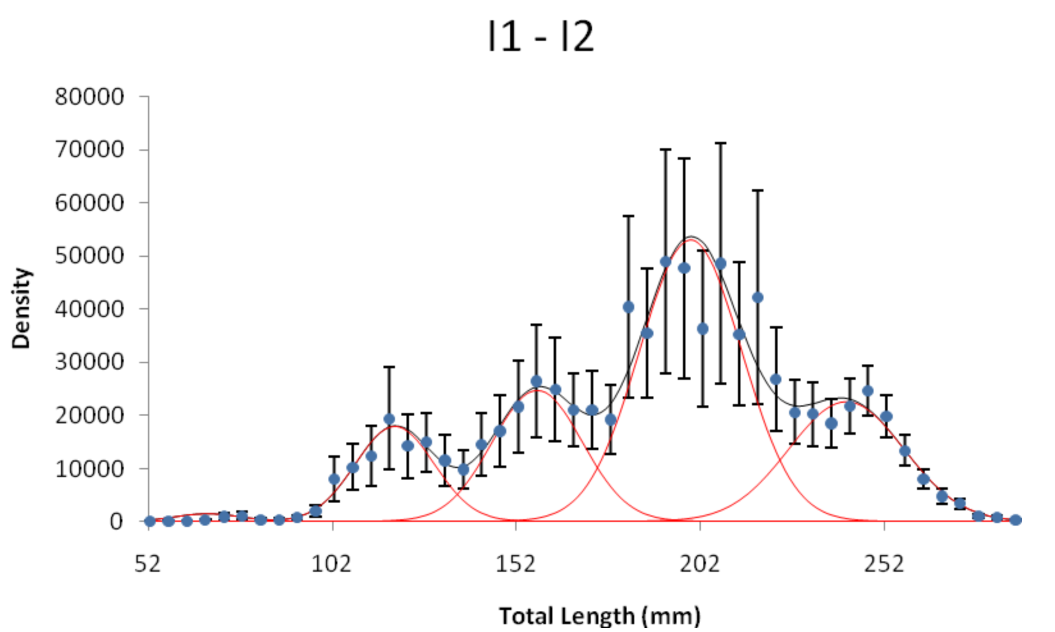
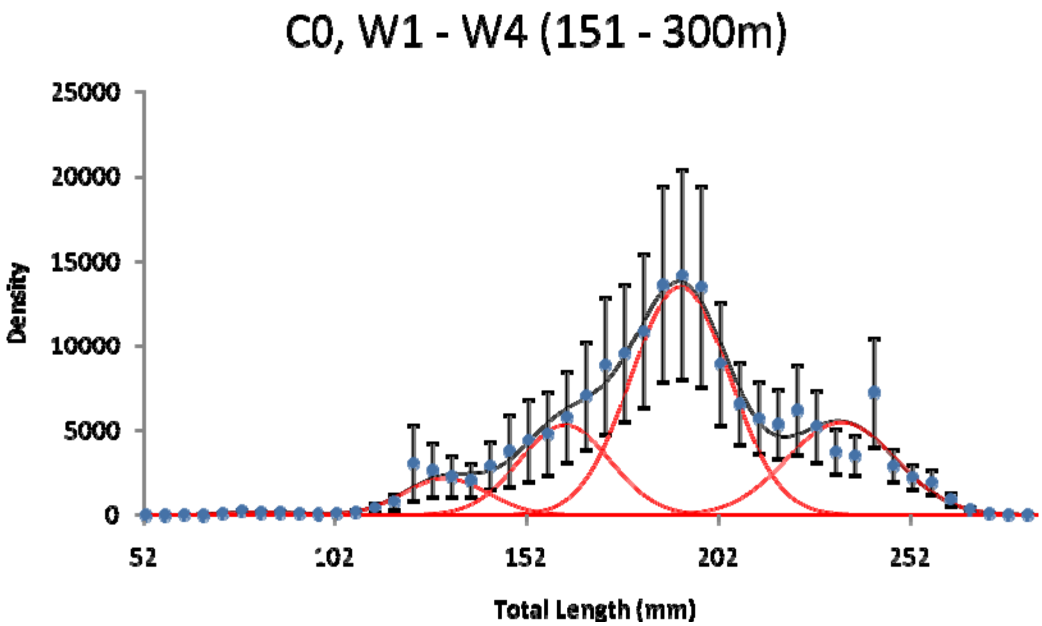


Figure 6b Length density distributions (LDD) in areas Northern areas U1-3, Disko (Inshore), Midwest Greenland (Canadian areas + W1-W4) and the southern areas had very little biomass, thus the LDD could not be produced for areas W5 to W9.



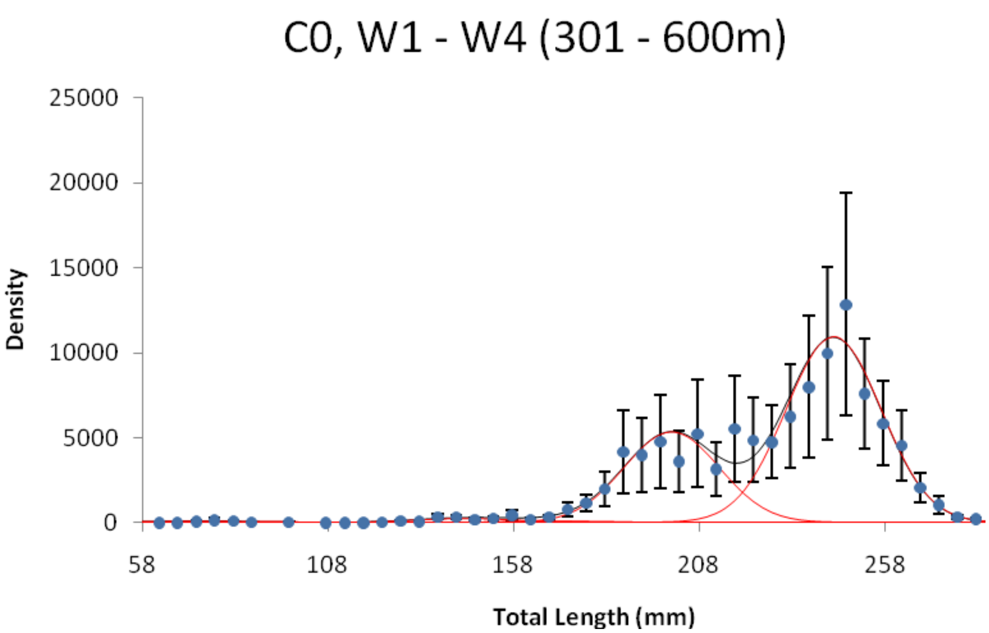


Figure 6b - continued. Length density distributions (LDD) in areas Northern areas U1-3, Disko (Inshore), Midwest Greenland (Canadian areas + W1-W4) and the southern areas had very little biomass, thus the LDD could not be produced for areas W5 to W9.

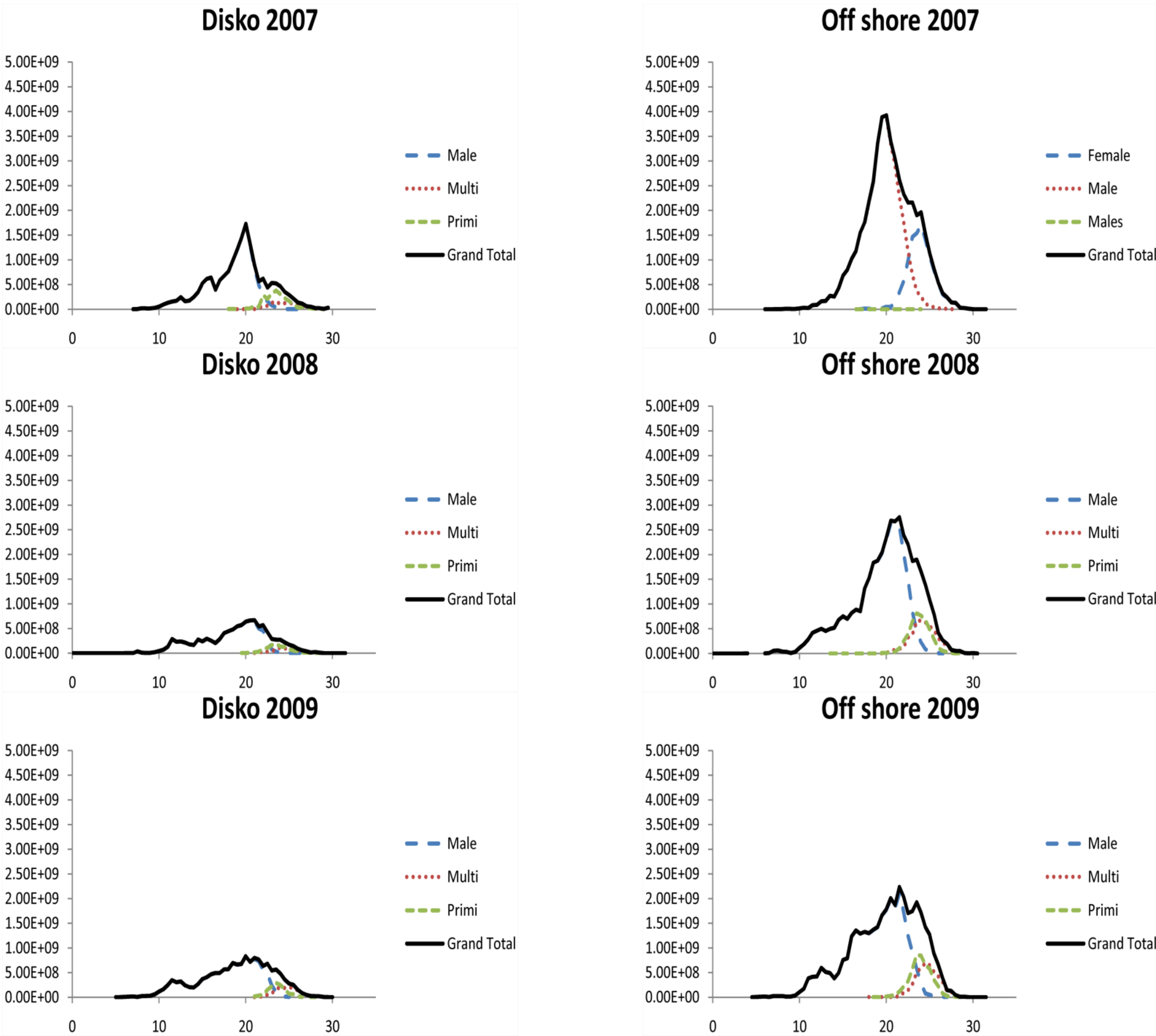


Fig. 7. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2007 – 2010.

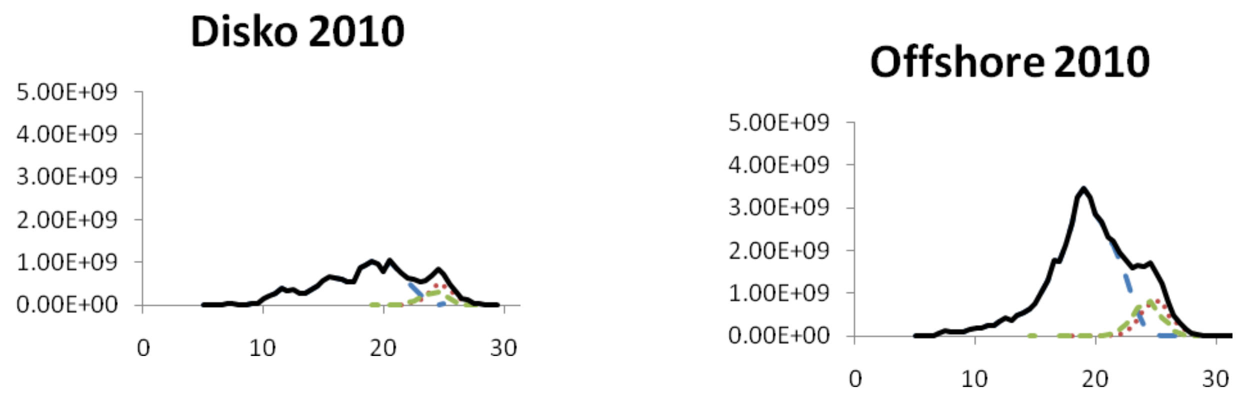


Fig. 7, continued. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2007 – 2010.

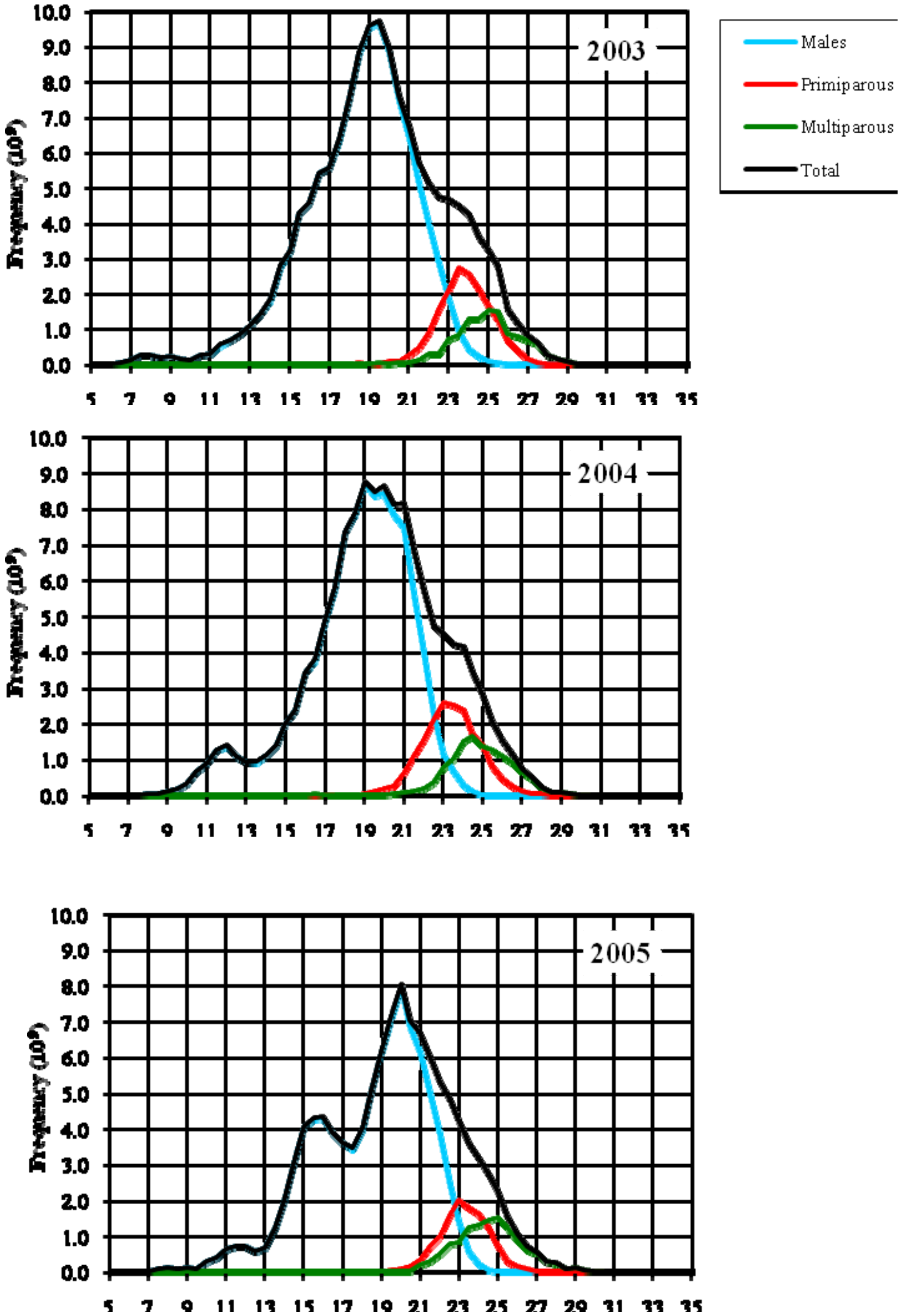


Fig. 8a. Length frequencies of Northern shrimp in the total survey area (offshore and Disko/ Vaigat combined, 2003-2005).

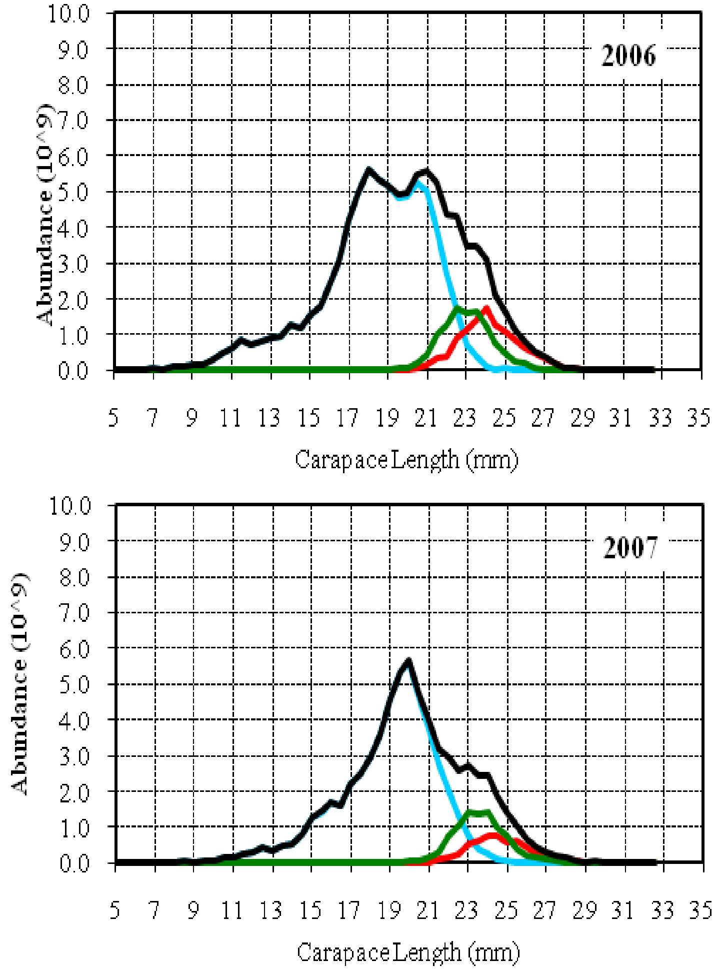


Fig. 8b. Length frequencies of Northern shrimp in the total survey area (offshore and Disko/ Vaigat combined, 2006-2010)

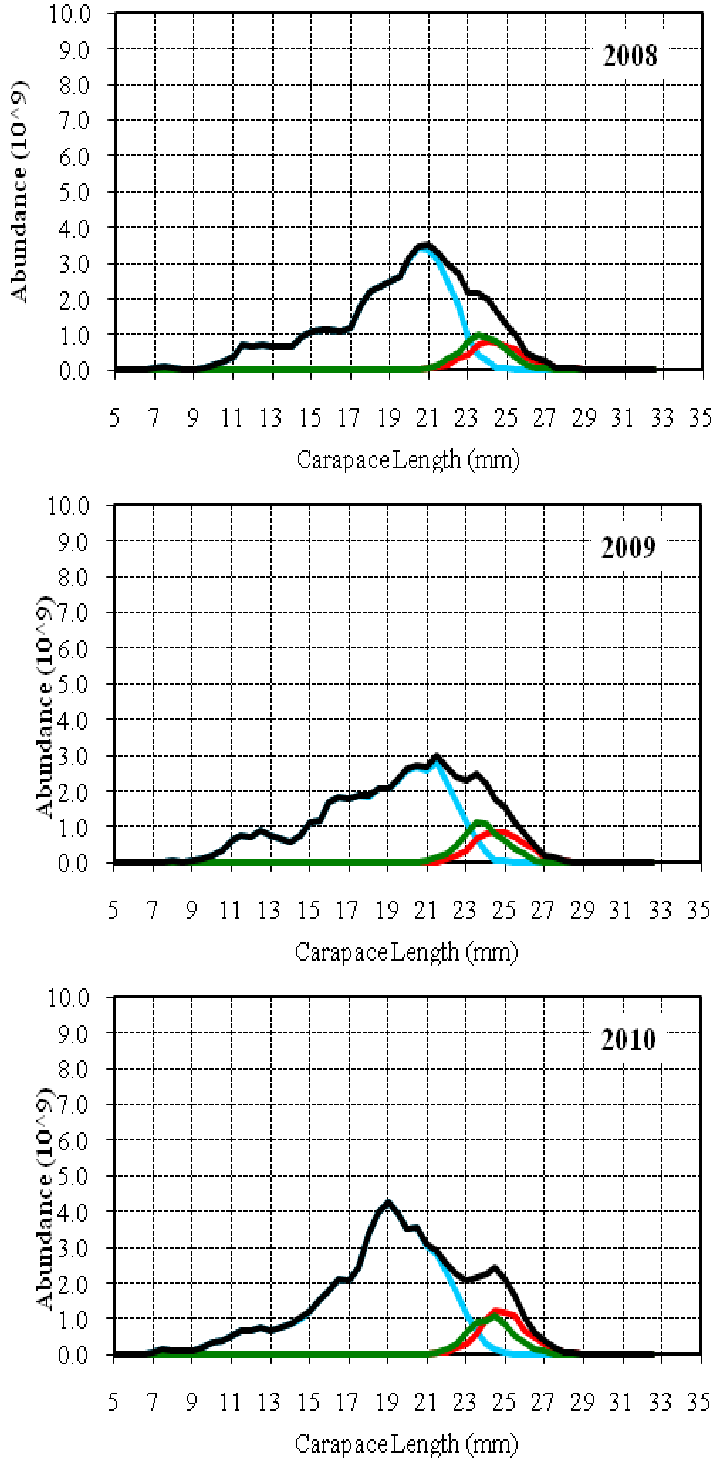


Fig. 8b continued. Length frequencies of Northern shrimp in the total survey area (offshore and Disko/ Vaigat combined, 2006-2010).

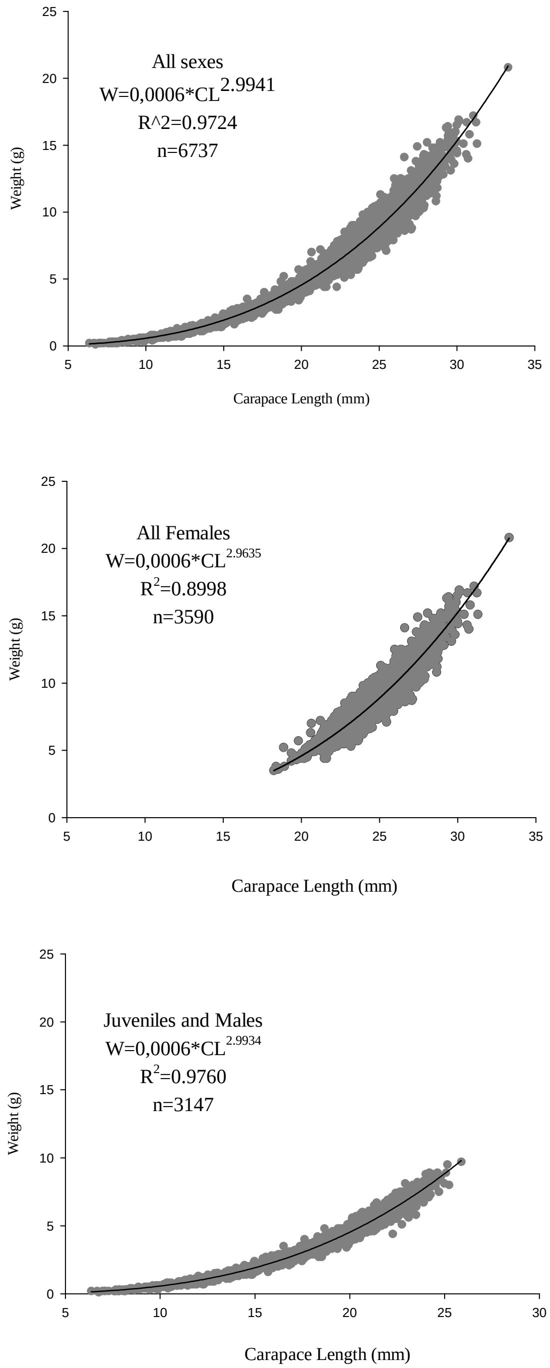


Fig. 9. Length-weight relationships of *P. borealis* off West Greenland. Data from 2001-2006.

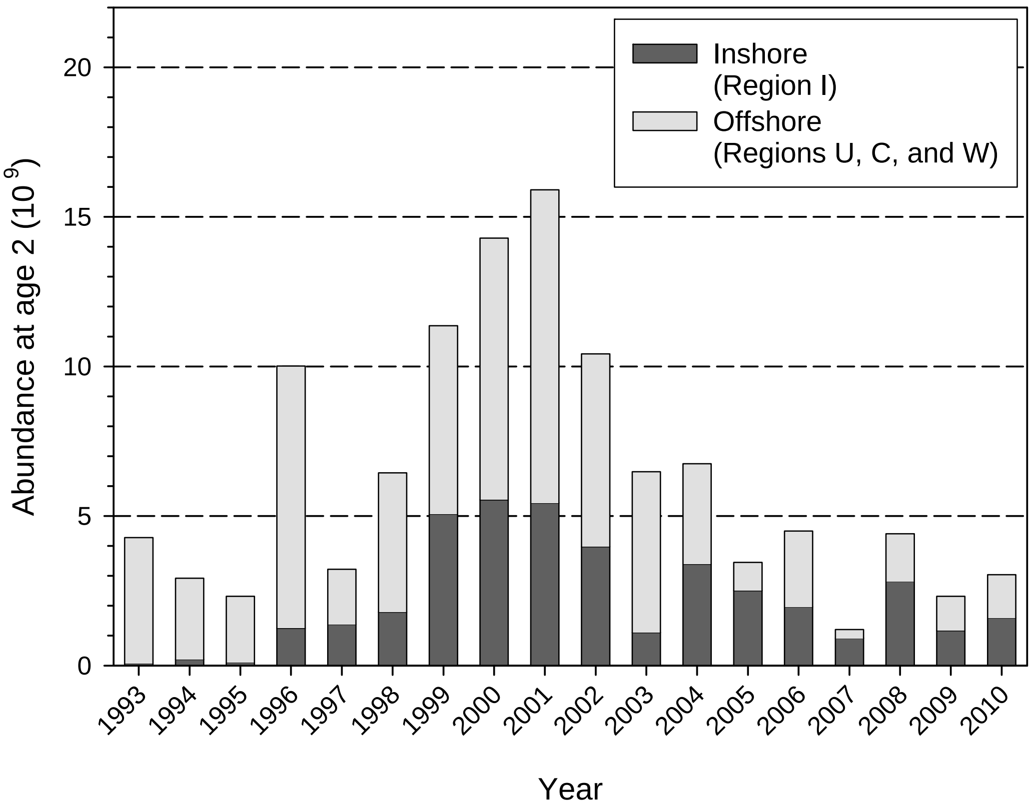


Fig. 10a. Abundance indices for Northern shrimp at age 2 off West Greenland, 1993-2010.

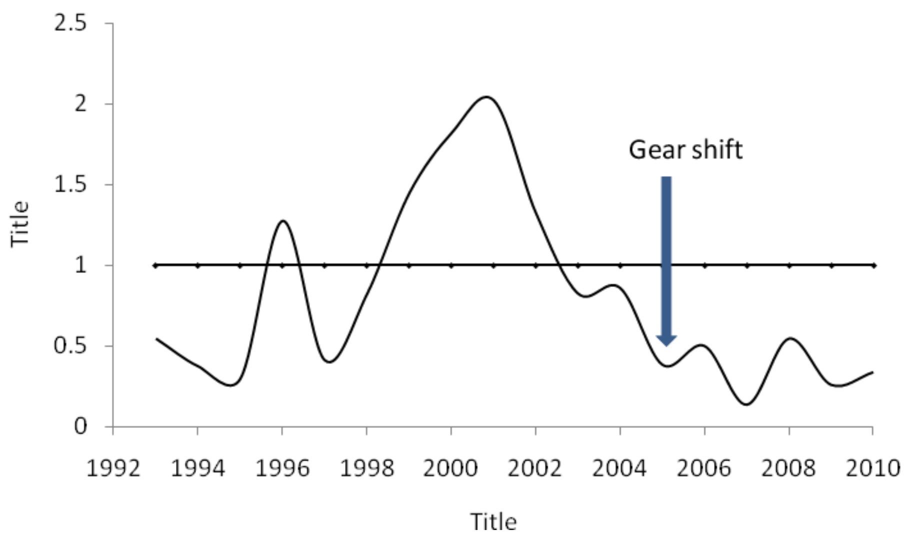


Fig. 10b. Abundance indices for Northern shrimp at age 2 off West Greenland, 1993-2010.

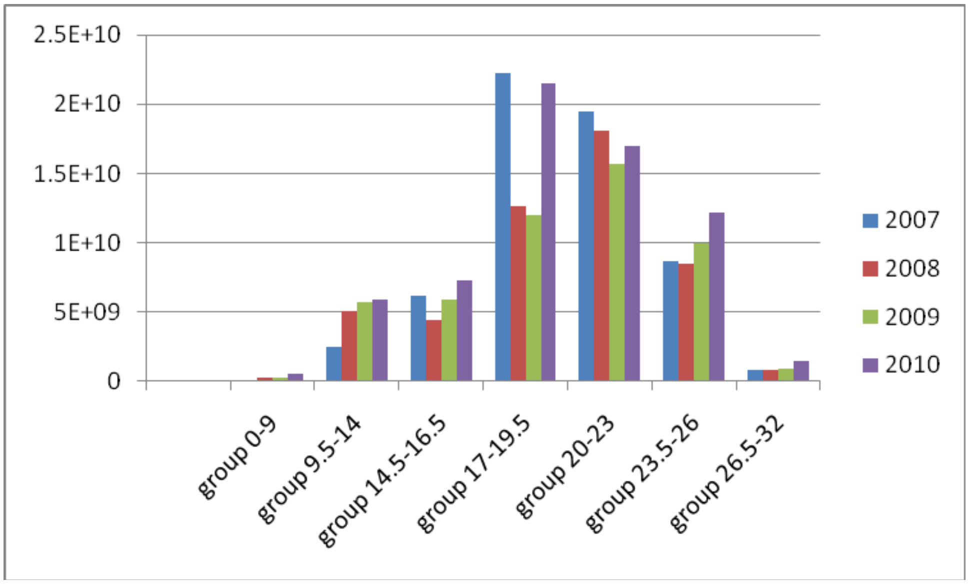
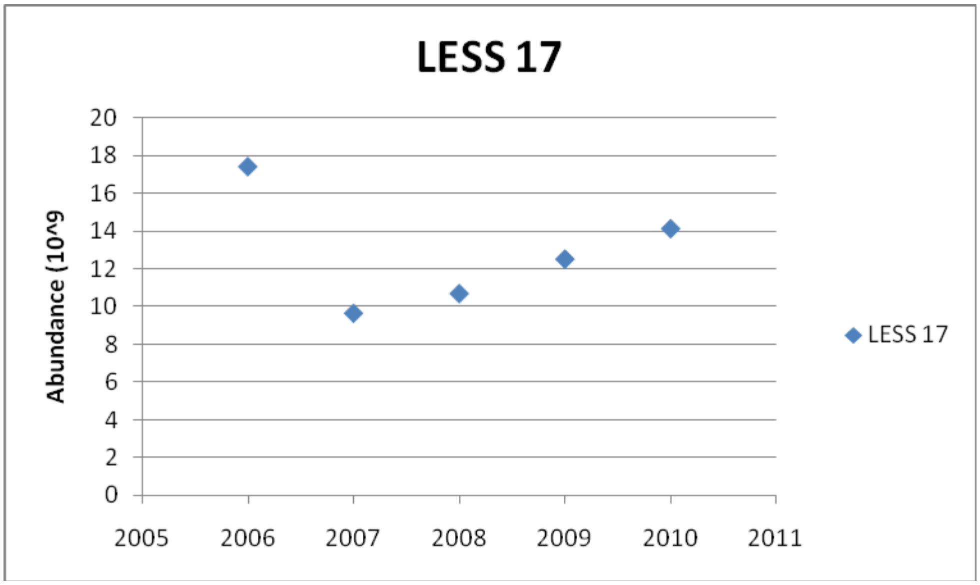


Figure 11a. Length groups in order to show the progression over 2007 – 2010.



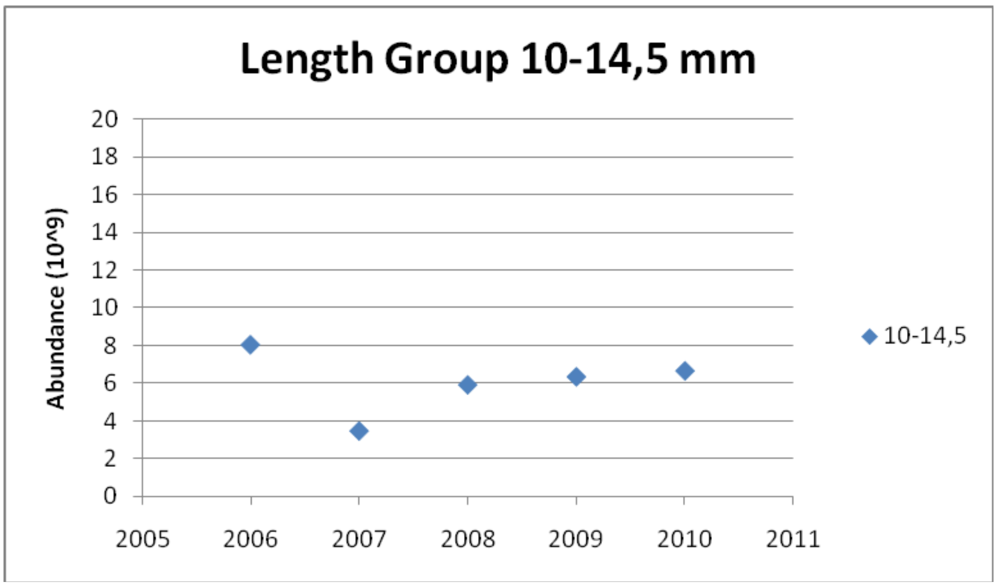


Figure 11b. Length groups in order to show the progression over 2007 – 2010. Above figure is total abundance of length groups below 17 mm CL. Below figure is total abundance of the assumed age 2 group.

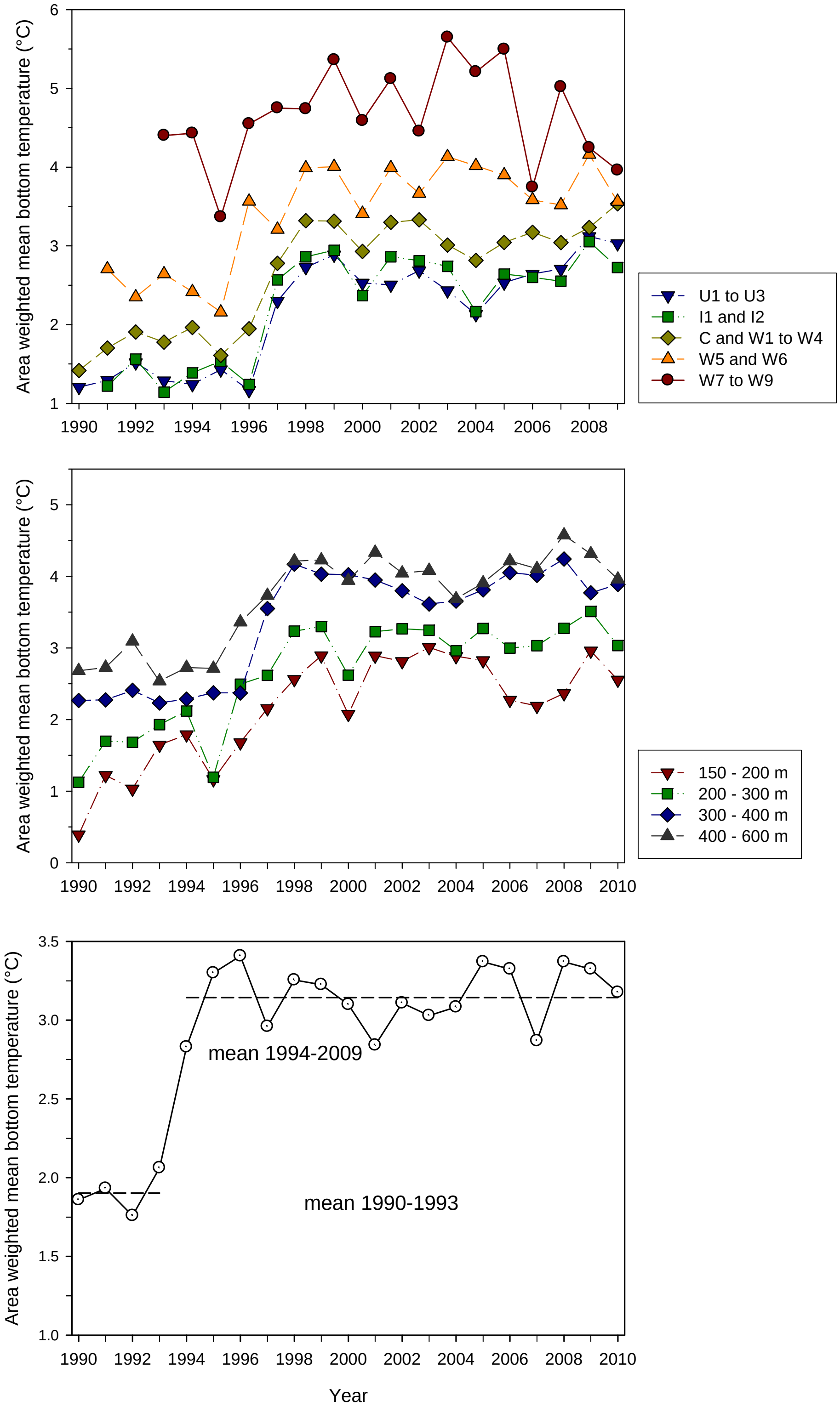


Fig. 12. Area weighted mean bottom temperature for the different survey regions (see Fig. 1 for locations), the various depth strata in offshore areas C and W1-W7 and the entire survey area in 1990 to 2010.