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The West Greenland trawl survey for *Pandalus borealis*, 2011, with reference to earlier results.

by

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Abstract

Stratified random bottom trawl surveys have been carried out since 1988 in NAFO Subarea 1 and a small part of NAFO Division 0A (east of 60°30'W) as a contribution to the assessment of the stock of the Northern Shrimp (*Pandalus borealis*) in West Greenland waters.

The area over which the stock is distributed has decreased a little more compared with 2010, and it remains concentrated in few survey strata in the centre of its range. Densities are still high in Disko Bay and Vaigat, but have decreased in the two strata to the west of Disko Bay, falling almost to nothing in the part of stratum W2 lying south of about 68°35'N as well as in strata W3 and W4 north, south, and west of Store Hellefiskebanke. Further south, densities are practically zero on the continental slope west of the banks all the way from Store Hellefiskebanke to Kap Farvel, although there are some patches of higher density in the inshore ends of the gullies between the banks.

The record high biomass value in 2003 was followed by continuous decline to about 278 500 tons in 2008–09. In 2010 the biomass estimate increased to 345 200 tons, but in 2011 has decreased again to its lowest value in the past 14 years.

Since the late 1990s the stock appears to be found in shallower water than before. Some large catches were made in shallow water in 2011, and the shallowest depth stratum, between 150 and 200 m, yielded its second highest proportion ever of the survey biomass. However, it is not clear that this is a continuing trend: a depth index for the survey biomass has been fairly stationary since 2001.

In 2011 fishable biomass (FB) decreased to about 16% below the series average, the lowest level observed since 1997, and 44 % of the record high 2003 level. In Disko Bay the FB stayed well above the average and was the fifth highest in the series.

By numbers and biomass both, the stock is heavily weighted toward the largest, female, shrimps, which compose an unprecedentedly high proportion of the total. The stock structure seems deficient in the middle length classes, so that overall the fishable biomass, as a proportion of the total, is close to average. The number of males in 2011 has decreased to a level last registered in the late 1990s. The proportion of males (pre-recruits to the FB) is the lowest registered (57%) since the survey starts in 1988. Relative to numbers in other length classes, the smallest shrimps are

abundant—shrimps up to 15 mm CPL compose nearly 20% of the males and 14% of the total—but the estimated numbers at age 2 are well below even the modest average of the foregoing 3 years.

Area-weighted mean bottom temperature in the survey area started increasing in the beginning of the 1990s and this relatively warm period continued in 2011.

Introduction

Since 1988, the Greenland Institute of Natural Resources has carried out annual trawl surveys on the West Greenland shelf between June and August to assess the biomass and recruitment of the stock of *Pandalus borealis* and to 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 2011 survey, and compares them with revised series from previous surveys.

Material and Methods

Survey design and area coverage

The offshore survey area for the Northern shrimp, *Pandalus borealis*, covers waters on the West Greenland continental shelf from Kap Farvel in the south to latitude 72°30'N, comprising NAFO Sub area 1 and, where the shelf bulges into the Canadian EEZ, a small area in the eastern part of NAFO Div. 0A. In the late 1980s when the survey was initiated, *P. borealis* was fished in waters between about 150 m and 550 m deep, and the shrimp survey has always been restricted to depths from 150 m to 600 m. Since 1991 he survey has included the inshore areas of Disko Bay and Vaigat in NAFO Div. 1A, but along most of the coast, the survey does not cover areas closer to shore than 3 miles offshore of the fishery baseline. In some coastal areas fishable concentrations of *P. borealis* exist closer to shore than this, including areas that extend up into some fjords (see e.g. Fig. 4a of Hammeken and Kingsley 2010).

The survey area is divided into primary and secondary strata. The primary strata correspond to geographical areas identified by Carlsson *et al*. (2000) on the basis of logbook information on the distribution of the fishery. They are sub-stratified into four secondary depth strata at 150-200 m, 200-300 m, 300-400 m, and 400-600 m. When the survey was initiated, bathymetric information in Disko Bay, as well as offshore north of 69°30'N, did not support this depth stratification, and these regions were therefore originally divided into geographical strata not based on depth. Depth data logged by the survey and by other investigations eventually allowed these waters to be stratified on depth and new geographical strata with depth sub-strata were introduced in 2004 (Wieland and Kanneworff, 2004). At the same time, the geographical strata in the Canadian zone, formerly two, were merged into one.

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 biomass variances have been high in previous years in order to improve the precision of the overall biomass estimate (Kingsley *et al*., 1999). An exponential smoothing of previous years' stratum variances was applied in the allocation procedure, giving higher influence to the more recent years. In recent years, in addition to variance data for Northern shrimp, past variance data for Atlantic cod and Greenland halibut has been made available to the allocation procedure, which is now set to minimise a weighted combination of the expected survey precision for the three species.

Generally the station layout is based on a division of the survey area into elements about 2 nautical miles square. Until 1998, trawl locations were selected by an adjusted random procedure, in which stations were randomly and independently positioned, but manually adjusted afterwards if too close to one another. Since 1999 survey stations have been positioned using 'buffered random' sampling, in which stations are placed randomly with the constraint that a minimum distance between them, which depends on station density within the stratum, must be observed (Kingsley *et al*., 2004).

From 1988 through 1998, survey designs were independent from year to year, stations being placed anew in the strata. Since 1999 about 50% of the stations included in the preceding year's design have been repeated as fixed stations in the following year, the others being placed, as before, using the buffered sampling rules. Catches are correlated from year to year by position, and fixing stations improves the ability of the survey to indicate year-to-year changes in stock size; i.e. it induces some serial correlation in survey error (Kingsley, 2001a). However, this serial correlation has not been quantitatively estimated nor taken into account in analysing the data or in drawing inferences from the results.

In 2011, 282 stations were planned at depths between 50 and 600 m in the survey area. Of these 249 were allocated to depths between 150 and 600 m; i.e. constituted the design of the shrimp survey proper; 270 of them provided data acceptable for the shrimp survey. The others were allocated to shallower strata with a view to investigating the distribution and abundance of Atlantic cod. In addition, 11 stations were planned in waters between 600 and 800 m in NAFO Div 1B to monitor the offshore stock of Greenland halibut.

In the course of the survey, 26 CTD casts were made along standard transects in the offshore and the Disko Bay/Vaigat area; data was transferred to oceanographic laboratories. This report presents fishing results from the shrimp-survey stations.

Survey period and daily sampling period

The trawl survey has been carried out every year between mid-June and the end of August to minimise the effect of seasonal cycles in the biology of the species. Trawling is carried out between 0800 and 2000 UTC; it appears that the daily vertical migration of the Northern shrimp is quite abrupt at sunrise and sunset and a shorter trawling day is not necessary.

Tow duration

From 1988 to 1997 all tows in the shrimp survey lasted 60 min. Various studies of the effect of shortening tow duration, including operating the survey itself with mixtures of durations (Carlsson *et al*., 2000; Kingsley, 2001b; Kingsley *et al.*, 2002; Wieland and Storr-Paulsen, 2006; Ziemer and Siegstad, 2009), concluded that shorter tows gave just as accurate results. Since 2005 the survey has been operated with 15-minute tows alone. It has not been considered necessary to adjust earlier data as a consequence of shortening the standard tow.

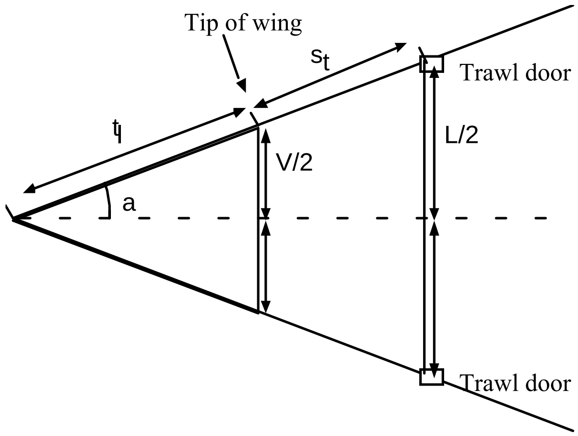
Fishing practices

The surveys have been conducted with the research trawler *Paamiut* (722 GRT) since 1991; similar vessels were used in 1988–1990. Initially, a 3000/20-mesh *Skjervøy* bottom trawl with a twin cod-end, and equipped with a heavy steel-bobbin footrope, was used. A 20-mm (stretched-mesh) liner was added to the 44-mm-mesh cod-end in 1993. From 1988 to 1991 estimates of trawl geometry—door spread and height of head-rope—were based on results from tank experiments at the Danish Institute for Fisheries Technology and Aquaculture. Since 1991 *Scanmar* acoustic sensors have been mounted on the trawl doors, and a *Furuno* trawl-eye on the head rope. The reading from the trawl-eye is used to judge when the trawl has settled and the tow can be deemed started, and door-spread readings are recorded during the tow.

From 1988 through 2003 *Greenland Perfect* trawl doors were used, measuring 9.25 m^2 and weighing 2420 kg. They were replaced in 2004 by *Injector International* 7.5 m^2 trawl doors weighing 2800 kg to facilitate a change of survey trawl in 2005. In 2005 the *Skjervøy* 3000 trawl was replaced by a *Cosmos* 2000 trawl with 'rock-hopper' ground gear comprising steel bobbins and rubber disks. Towing speeds have been about 2.5 knots in all surveys.

Swept area calculation

Nominal swept area for each tow was calculated as the straight-line distance between its GPS start and end positions multiplied by the wingspread. The distance between the trawl doors was recorded 3 or 5 times during each tow; provided it was recorded at least once, wingspread for a tow was calculated from the mean doorspread and the geometry of the trawl. For both trawls the wingspread (i.e. the width of the swept area) V has been calculated as follows: the trawl and the trawl plus bridles are assumed to form two similar triangles, bridles and wings making a straight line:



and the lengths of the bridles (s) and the trawl wings (t) are known. The wingspread V is then calculated as:

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

where L is the distance between the doors (doorspread).

The length of the *Skjervøy* trawl is 67.15 m and the length of the *Cosmos* trawl is 71.8 m, both measures excluding the cod ends. Since 2004 the bridle length, i.e. the total length of lines, chains and shackles between the trawl doors and the tip of the trawl wing, has been 54 m for both trawls; other bridle lengths were used in earlier years (Table 1). In the case of the *Skjervøy* trawl, 0.7 m has been added to the calculated wingspread because the *Skjervøy* trawl is a three-winged trawl and the lower 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.).

If doorspread was not recorded in the course of a tow, the unweighted mean of the calculated wingspreads for the year was used, without regard to fishing depth or wire length. If the speed of the tow calculated from its duration and its start and end positions lay outside a range of 3.0 to 6.5 km/hr, its length was recalculated from the survey average towing speed and the tow duration.

Biomass estimation

Each haul's catch was divided by its estimated swept area calculated from wingspread and track length to estimate a biomass density. Unweighted mean stratum densities were multiplied by the stratum area to compute stratum biomass, and a corresponding error variance for the stratum biomass estimate was also calculated for strata with two or more accepted hauls. For strata with only one accepted haul, an error coefficient of variation of 0.95 was assigned. Stratum biomasses and their error variances were summed to get regional and overall estimates; error variance was also presented as error coefficient of variation.

Indices of distribution and location of shrimp biomass (Kingsley, 2008)

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 and Siegstad, 2009) 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;
- three 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:

$$Spread.Index = \left(\sum_{Subdivisions} Biomass_{Subdiv.} \right)^2 \Big/ \sum_{Subdivisions} \left(Biomass_{Subdiv.} \right)^2$$

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 subdivision; low values, near 1, would show that the biomass was concentrated in only one or two subdivisions. The units of both indices are ‘subdivisions’.

Depth distribution of biomass.

The overall depth distribution of the estimated survey biomass was calculated according to available depth information. Up to 2003, such information was only available for the west-coast area W and the Canadian EEZ, and the depth distribution of the biomass was analysed only for those areas. Since 2004, the northern area and the inshore areas in Disko Bay and Vaigat have been sub-stratified depth and the depth analysis extended to those areas.

A single depth index, in metres, was calculated by assuming that the entire survey biomass in any depth stratum was concentrated at the stratum’s midpoint depth, except for the deepest stratum: the fishery takes little from water deeper than 520 m, so the central depth for the 400–600 m stratum was set at 460 m.

Sampling, weighting and “area expansion”

The composition of the stock by size and sex is based on a two-stage analysis of lengths and weights. From catch samples, 1000–2000 individual shrimps are both weighed and measured, and these measurement pairs are used to estimate a weight-length relationship. From all catches, samples are taken and the shrimps in the sample are measured and sexed. These length measurements are then supplemented with weight estimates based on the fitted weight-length curve. Aggregated, and then averaged over the stations in a stratum, these observations of sex and measurements of length and their associated estimates of weight are used to estimate the distribution of stratum biomass between sex and length classes and the numbers of shrimps in each stratum in the various sex and length classes.

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 classified—juveniles and males composed one class, primiparous and multiparous females two others—based on their sexual characteristics according to Allen (1959) and McCrary (1971). The oblique carapace length (CL) of each shrimp in the sample was measured to the nearest 0.1 mm.

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. 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 are averaged. 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. Shrimp density does not vary much within a haul's distance (Kingsley et al. 2002) and so it is statistically preferable to use the unweighted mean 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

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

The stratum estimate from many stations is:

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

where the divisor K_t, 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 equals the stratum total biomass calculated from catches and swept areas. This is ensured by using, as the weight of the Length Sample, the total weight of the shrimps it comprises, each weight calculated from the weight-length function, instead of using its weighed weight. The length-measurement data is used to partition the stock biomass between sex and length classes.

Where catches were, for one reason or another, not sampled for lengths, the mean of the length frequency distributions from the available samples in that stratum, each raised by its catch and swept area, was applied to the entire stratum biomass. If it occurred that there were no length samples from the catches in an entire stratum, the length distribution estimated for the entire survey from data for the strata that did have length samples would be applied to its estimated biomass.

Results from these calculations were subsequently used to construct area-specific length frequency distributions (LFD). LFD results were used to calculate indices of numbers by sex and length, biomass by sex, an index of fishable biomass (comprising shrimps at least 17 mm CPL), and numbers of small pre-recruits ('age 2 shrimps'), which are expected to enter the fishery in coming years.

For data from 2005 the following weight-length relationship has been fitted:

$$w(l) = w_0 + a \cdot (l - l_0)^z$$

with the parameter l_0 constrained to be less than 4.5 mm. A weighted fit was used with constant coefficient of variation about the fitted line.

As there is no reliable method of aging even young shrimps, indices of numbers at age are obtained by modal analysis of length frequencies for juveniles and males, attempting to fit overlapping age-specific normal distributions to the aggregated length distributions. As growth is probably affected by temperature, the survey area is divided into 6 regions, defined from gradients in bottom temperature (Wieland, 2004) and estimated numbers in strata are pooled over regions. Length-frequency histograms are not smoothed before being analysed.

Historically, the MIX 3.1A software (MacDonald and Pitcher, 1979; MacDonald and Green, 1988; release 3.1A by Ichthus Data Systems in 1993) was used, but data since 2005 has been analysed—and, for years since 2007, re-analysed in 2011 on a consistent basis—using the 1997 version of CMIX (de la Mare, 1994), implemented as an Excel® Add-In. Like MIX, CMIX fits overlapping Normal distributions to length frequency distributions, but uses a maximum-likelihood fit and assumes that the length-density data has an Aitchison delta distribution, suitable for fitting to data from trawl surveys since it provides for the possibility that some survey hauls will catch nothing (Aitchison, 1955; Pennington, 1983). The data from the West Greenland trawl survey is so variable that for each regional analysis it is necessary to test whether all the fitted Normal distributions should be constrained to have the same coefficient of variation, or whether, on the other hand, variances should be fitted separately for each one.

The analyses of sex and length distribution in the stock, and the modal analyses, were re-done in 2011 for data from 2007–2011. To simplify the modal analysis and to get it to converge more easily, and because the main objective is to estimate the numbers at age 2, only the numbers for the 'Juveniles and Males' sex class were put through it. For this re-analysis, strata were grouped into regions: U1 to U3, I1 and I2, W1 to W4, W5 and W6, and W7 to W9. Within each group, the estimated stock numbers in each stratum were aggregated over depth substrata, and the stratum aggregate numbers presented to CMIX as a haul. E.g. for the region U1 to U3, CMIX was presented with three 'hauls', each comprising the numbers at length estimated for an entire stratum. The resulting fitted components were adjusted (by very small factors) to bring the sum of the CMIX fitted numbers into exact agreement with the demographic estimates.

Bottom temperature
Until 1994 bottom temperatures were measured with a *Seabird* CTD. Since 1994 the temperatures have been measured with a sensor (at first *Seamon*, later *Starmon*) mounted on one of the trawl doors. The sensor records at intervals of 30s with a resolution of 0.01°C. The average temperature for each haul was calculated after retrieval of the sensor. All measurements taken at greater depths than 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

Survey conduct and progress.
The survey in 2011 started from Nuuk on 11 June. The first cruise occupied stations from Nuuk north to Ilulissat, including Disko Bay. It was accompanied first by a crew engaged in taking photographs of the sea bottom in connection with an investigation of the long-term effects of trawling on bottom ecosystems, replaced on 20 June at Aasiaat by a geological crew investigating marine geology in connection with hydrocarbon explorations. These crews used the ship at night when the trawl survey is habitually suspended.

This first cruise was hindered by sea ice, which prevented it from occupying any stations in NAFO Div. 0 (survey region C0) or in the western, deepest, sub-stratum of stratum W1. These compose 3.7% of the usual survey area. The crew was changed at Ilulissat on 26 June. The second cruise occupied stations in Vaigat, west of Disko I., and north to the survey limit. The second crew change was at Nuuk on 14 July, and the third cruise occupied stations from Nuuk south to the southern limit of the survey.

The survey incurred no loss of time due to wind, weather, or mechanical problems. Of 282 planned stations in the survey, a number of stations were annulled owing to untrawlable bottoms, gear damage, or hold on the trawl. 192 stations provided usable data on biomass density in the shrimp survey area. Stations, 24 in all, were occupied on all cruises at depths outside the shrimp-survey depth range in connection with monitoring stocks of groundfish; at 10 of these, some Pandalid shrimps were caught and from 9, length samples of shrimps were taken and measured—although in one case, one single shrimp.

Of 58 planned survey strata, 4 (3.7% of the survey area) had no stations trawled, and 2 had only 1 each. 21 stations had no catch of *P. borealis*; 3 strata, with 8 occupied stations between them, had no catches. Length samples were measured from all 171 stations with catches, even very small ones.

The largest catch included in the survey data, of about 3.8 t (137 t/sq. km), was made in sub-stratum W7-2; two of the other three hauls in the sub-stratum had zero catches. (The sub-stratum accounted for 71% of the survey error variance.) Two other survey catches were over 1 t (about 33 t/sq. km). Of 25 catches over 200 kg, 19 were in Disko Bay or Vaigat, where 30 stations were occupied in all; 6 were in the rest of the survey area, where 162 stations were occupied.

In the course of the first cruise, concerned at consistent low catches and informed by trawler skippers in the neighbourhood that shrimps were being caught in unusually shallow water, the cruise leader added an unplanned station at a depth of 180 m on the northern margin of the Holsteinsborg Dyb and made an unexpectedly large catch of 1.3 t in 15 minutes. The two planned stations in the same stratum, trawled in 175 and 195 m of water, made catches of zero and 34 g of *P. borealis*. The station, being unplanned and incited by reported local concurrent fishing success, was subsequently treated as ‘cashiered’ and its result was not added to the data from the planned survey stations. A 15-min haul in 120 m of water—i.e. a ‘fish station’ outside the standard survey range—at 62.29°N, 50.77°W near the Frederikshåb Isblink made an exceptional catch of 5.8 t. (The mean catch of *P. borealis* for the other 23 fish stations was 132 g—about one sandwich.)

Overall Biomass and Area Distribution.
For all surveyed strata biomass estimates have been calculated (Table 2) on the basis of the nominal swept area. The biomass estimates for the five main regions and the entire survey area in 2010 were:

Region—2010	Biomass estimate (Kt)	Number of stations	ECV (%)
North (U1-U3)	73.2	27	11.1
Canadian zone (C0)	3.0	8	29.7
West (W1–W9)	169.7	196	25.2
Disko Bay & Vaigat (I1, I2)	99.3	27	10.0
Total	345.2	270	12.9

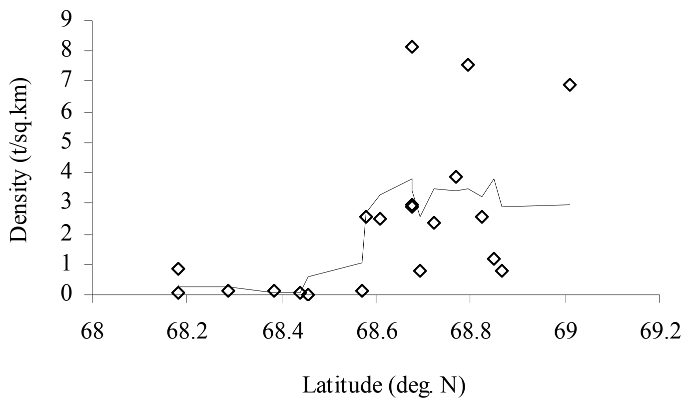
and in 2011:

Region–2011	Biomass estimate (Kt)	Number of stations	ECV (%)
North (U1-U3)	55.5	25	9.8
Canadian zone (C0)*	—	0	—
West (W1–W9)*	112.2	137	30.0
Disko Bay & Vaigat (I1, I2)	92.9	30	12.4
Total	260.6	192	13.8

* sub-stratum W1-4 (400–600 m) was not surveyed because of sea-ice cover. Area C0 was missed for the same reason.

The 2010 total survey biomass had been an increase over those of 2008 and 2009, which averaged 280 Kt, and had been close to the 2007 result. In 2011 all the surveyed regions showed decreases in survey biomass compared with the 2010 results, of about 24% in the North and about 34% in the West, but only about 6% in Disko Bay and Vaigat. The Canadian area was not surveyed, but usually contributes only a few percent of the survey biomass. In the West area, strata W3 and W4 appeared to have suffered catastrophic decreases in survey biomass to about 9% of the 2010 level, or 11% of their 1988–2010 mean. Owing to a single large catch, the next area to the south, W5–W7, recorded its biggest survey biomass since 2006, but this was still only 67% of the 1988–2010 mean. Disko Bay and Vaigat together remained above their 1991–2010 mean by about 38%.

There were almost no significant catches on the outer slope of the continental shelf from the Holsteinsborg Dyb south to the southern limit of the survey. What catches there were in this area were in the inshore ends of the gullies between the banks; some small catches were also made in Julianehåb Bugt. The two survey strata west of Disko Bay, W1 and W2, also had some fair densities; however, stratum W2 appears to divide into a northern part, north of about 68°34.5'N, in which densities averaged about 3½ t/sq.km, and a southern tail in which they were low—average about 200 Kg/sq.km—like those in W3 and W4. *Prima facie,* the areas where catches have decreased most since 2010—W3, W4, and the outer slope of the West Greenland shelf—correspond to areas where there were significant catches of cod in the 2011 survey.



Pandalus borealis in West Greenland: Density vs latitude in stratum W2, 2011, with 5-point moving average.

As is usual, Disko Bay and Vaigat had far higher survey densities than other areas, over three times as high as the next highest, strata W1 and W2 combined. Most of the hauls in Disko Bay and Vaigat showed densities over 3 t/sq.km.

Further north, the northern area comprising strata U1–U3 also showed a decrease in estimated biomass from 2010, although the inshore stratum, U3, mostly had good densities.

The spread index, of how widely the survey thinks the stock biomass is distributed (Kingsley 2008), showed a further slight decrease in 2011 to its second-lowest value since the survey coverage was stabilised in 1994, while the north index remained close to its maximum value (Fig. 4).

Depth distribution of the shrimp biomass.

During the early and mid-1990s the depth distribution of the survey biomass was stable, with a significant contribution from the 400–600 m stratum, but most of the biomass found in 300–400 m of water (Fig. 5). From 1990 to 1998 the average distribution was 1.9% in 150–200 m of water, 25.2% in 200–300m, 55.9% in 300–400 m, and 17.1% deeper than 400 m, and the survey biomass depth index was stable near 350 m. In the late 1990s this situation started to change. The contributions of the two deepest strata, in water 300–600 m deep, decreased and that of the 200–300 m stratum increased greatly. It was at this time, in the late 1990s, that the stock biomass started the sustained increase that peaked in 2003. Somewhat later, starting in the early 2000s, the shallowest stratum, which is only 50 m from its shallowest to deepest, also started to contribute a little more to the biomass than it had done. In 2001–2011 the survey biomass depth index has ranged between about 265 and 300 m, with an average near

285 m. In the 2011 survey 17.8% of the biomass was estimated to be in 150–200 m of water, 54.4% in 200–300 m, 23.2% in 300–400 m and 4.6% deeper than 400 m.

The 200–300 m stratum started showing biomass increases as early as the mid-1990s, and at that time the deepest stratum also started its decline—hence the start of the change in the mean-depth index. The 150–200 and 300–400 m strata increased later, and less. After 2004, the biomass has declined in all strata, but proportionally by more in the deepest two strata.

Compared with this shift in the depth distribution of the survey biomass, a shift in the depth distribution of the commercial catches appears to have started earlier. In 1991–1994 the median catch depth was 347 m but in 1995–98 it had already decreased by about 30 m, and by 2003–2006 it was 100 m less at 247 m (Kingsley 2011). This change has stayed in place in the case of the inshore fleet, which in 2007–2010 was still taking its median catch at 255 m, but the offshore catches show slight signs of moving back to deeper water with a median catch depth of 277 m in 2007–2010. The fraction of catches taken in water shallower than the lower limit of the survey, i.e. 150 m, is however still only a few percent, so this is probably not the reason for the recent decrease in survey biomass; besides, the great increase in survey biomass between about 1997 and 2003 coincided with the first years of this shift of the biomass, and the fishery, into shallower water.

Bottom temperature and biomass

The overall mean bottom temperature in the shrimp survey area was fairly stable near 0.9 C in the early 1990s. Between the mid- and the late 1990s it abruptly increased and since the late 1990s it has been stable in the neighbourhood of 1.6 C. The increase has affected all depth strata and all areas. The depth distribution of the shrimp survey biomass appears to have shifted after, and not concurrently with, the temperature shift (Fig. 6). The latitude distribution of the stock has also shifted, but also *after* the temperature shift: it is *since* the late 1990s that the survey 'North index' has continually increased, and the mean catch latitude in the fishery also reached its decided minimum, at 64°41'N, in 1998, i.e. at the end of the 1990s.

In summary: bottom temperature increased suddenly in the mid- to late 90s, and after that the survey biomass moved north and into shallower water, and the fishery catches also moved north; but fishery catches started moving into shallower water when the temperature started to increase. On the West Greenland shrimp grounds, the warmest water tends to be deeper (e.g. Ribergaard 2011) and colder water nearer the surface, so a general warming could have brought shallower water within the temperature tolerance of *P. borealis.*

Demography and recruitment

Length-weight relationships

In 2011, 2575 shrimps were individually weighed and measured. 6 measurements were rejected as outliers, leaving 2569 measurement pairs collected at 39 stations (32.3 effective stations). A single weight-length relationship was fitted to all sex classes. The same relationship was retrospectively fitted to data from 2005–2010 to provide a consistent basis for estimating numbers of pre-recruits for those years; we have compared estimated weight at length from the weight-length relationships used in different years.

Table: *Pandalus borealis* in West Greenland: parameters of a relationship $w(l) = w_0 + a \cdot (l - l_0)^z$ fitted to weight-length data for individual shrimps.

Year	w_0 (mg)	coefficient *a* (mg)	l_0 (mm)	exponent *(z)*	sample	scatter c.v. (%)
1988–2000[1]	0	0.669	0	2.9600		
2001–02[2]	0	0.483	0	3.0576	1225[2]	
2003[3]	0	0.752	0	2.9177		
2004[3]	0	0.765	0	2.9092		
2005	31.0	1.726	1.91	2.7188	1616	6.79
2006	57.7	1.426	1.591	2.7612	1907	7.89
2007	770.0	1.789	4.5[4]	2.7822	487	6.42
2008	– 32.9	1.416	0.797	2.7501	2147	6.67
2007–08	– 121.0	0.403	-1.660	3.0527	2634	6.88
2009	18.2	2.774	2.190	2.5890	1768	6.86
2010	153.3	8.155	4.5[4]	2.3204	1096	6.66
2011	129.9	9.753	4.5[4]	2.2505	2569	6.64

[1] Carlsson and Kanneworff, 2000. [2] Wieland 2002a. [3] Ziemer and Siegstad 2010. [4] l_0 is limited to 4.5 mm.

The scatter about the fitted weight-length relationship is strikingly consistent from year to year, except that the 2007 data, when the sample was relatively small, has a slightly smaller scatter, and 2006 a scatter markedly greater, than the other years. We have not looked into this and do not know why it is so.

Table: *Pandalus borealis* in West Greenland: weights at length predicted from fitted weight-length relationships.

Year	Weight (g) at length (mm):			
	10	15	20	25
1988–2000	0.61	2.03	4.75	9.19
2001–2002	0.55	1.91	4.59	9.08
2003	0.62	2.03	4.70	9.02
2004	0.62	2.02	4.66	8.92
2005	0.54	1.91	4.56	8.82
2006	0.57	1.91	4.50	8.67
2007	0.98	2.01	4.44	8.75
2008	0.60	2.06	4.76	9.02
2007–2008	0.61	2.04	4.70	8.96
2009	0.59	2.06	4.82	9.12
2010	0.58	2.06	4.87	9.17
2011	0.58	2.07	4.79	8.86

Wieland (2002a) observed that shrimps were lighter at length in 2001–2002 than Carlsson and Kanneworff (2000) had reported for 1988–2000 and inferred a drop in condition associated with an increase in stock biomass. The longer series, above, of tabulated weights at 15, 20 and 25 mm have correlations of -0.41 to -0.49 with survey biomass (averaged over years for the first two lines of the Table). The most recent years—2008–2011—seem to have heavier shrimps in the intermediate lengths, 15 and 20 mm. This might be connected with a shift in the timing of the West Greenland survey, which since 2008 has been about a fortnight earlier than in 2007 and before.

The mean weight of both sexes has decreased steadily over the 24-year history of the survey (Fig. 8), by, on average, 92^{**} mg/yr for females and 32^{*} mg/yr for males. We do not know the reason for this. It might be because shrimps are changing sex progressively smaller. This would affect the mean size of both sexes. There is serial correlation in the residuals about the trend lines, 0.48^{*} for males and 0.77^{**} for females, implying that there is some underlying mechanism.

Recruitment and mean length at age 2

Length frequencies of juveniles and males by survey area with the fitted Gaussian components from the modal analysis are shown in Figs. 9 a–e for 2007–2011. A first component with mean carapace lengths between 7 and 8 mm can be seen in some sets of data, e.g. region W1–W4 in 2008 (Fig. 9b). It is believed that this size group consists of individuals that had hatched in the spring of the year before and settled at the bottom in that year. Catches of this first component are small owing to mesh size selection, and even the second component is not fully retained in the codend of the survey gear (Wieland, 2002b). Regional differences in mean length of the second component ('age 2') are obvious (Table 9a and 9b); year-to-year changes have been related to shifts in bottom temperature and changes in stock density (Wieland, 2005). For the most recent five years, however, fairly uniform estimates of the mean size at age 2 have been obtained (Table 10).

From 1993 to 1995, estimates of numbers at age 2 were low, in particular for the inshore area (Table 10), and included the lowest value in the series, 2.3×10^{9}. This period was followed by exceptionally high values in the offshore area in 1996 but numbers dropped again in 1997. After 1997 age-2 numbers increased steadily to a record high in 2001, followed by a steady decline to 3.4×10^{9} in 2005. The low value of 1995 was observed again in 2007. Thereafter age-2 numbers increased, but the estimate for 2011 of 3.6×10^{9} is again considerably below the series average of 6.5×10^{9} (Fig. 11).

In 1997–2002 Disko Bay and Vaigat (inshore regions I1 and I2), which comprise only about 7% of the total survey area, contributed between 28 and 45% of the total number at age 2. In more recent years, this area has contributed more than 40% of the total in all years except 2003 and 2008 , and in 2011 its contribution is about 71 %. Age-2 numbers have always been low in the southernmost region W7–W9, and in most years since 2004 have also become negligible in W5 and W6. Almost no age-2s were found in region C0 in 2007–2010 (Tab. 10).

The indices of numbers at age 2 showed significant correlations with the fishable biomass (all shrimps ≥ 17 mm CL) two, three and four years later (Fig. 12). Time lags of two to four years in the correlation between number at age 2 and fishable biomass are reasonable considering that the fishable stock comprises mostly shrimps 4 to 6 years old. The low values observed in recent years presage a decrease in the fishable biomass in the near future to a level close to the average recorded in the late 1990s. However, the large confidence and prediction intervals of the linear regression indicate that these estimates are associated with high uncertainty.

Numbers, spawning stock biomass and fishable biomass

Given that the survey biomass is down to a lower level than any seen since the late 1990s, it is expected that numbers and weights of all stock components are also lower. Spawning stock biomass—i.e. of females—is however in 2011 at 43% an unusually high proportion of the total biomass (Table 7), and female numbers at 26% are also an unusually high proportion of total numbers (Table 6).

Compared with the length distributions of the 6 foregoing years, 2005–2010, there is a greater proportion of the very smallest shrimps caught by the survey, those below about 15 mm CPL, and also a greater proportion of the largest females above 23 mm CPL (Fig. 7), which compose over 25% of the stock by number; the length distribution is relatively deficient in the intermediate lengths. In spite of this, the fishable biomass is estimated at 91.7% of the survey total biomass, a proportion which is close to average; this is probably because of the unusually high proportion of females. The high proportion of large shrimps is expected to make the stock in its present state sensitive to fishing pressure, as the fishery prefers, in general, to catch the largest shrimps; while a deficiency in intermediate sizes bodes ill for short-term recruitment to the fishable stock.

Bottom temperature

Bottom temperatures this year was around average (Fig. 12). The temperature in the southernmost areas (W5–W9) stayed at the relatively high average; in W1–W3 it is slightly higher again this year. In I1–I2 and in U1–U3 it was about the same as last year. At depths between 150 and 200 m the area-weighted average bottom temperature has risen continuously since 2007. In summary, the overall temperature was similar to the long-term average area-weighted temperature for West Greenland.

Conclusions

Stock size

The stock has not maintained the higher biomass reached in 2010, but has returned to slightly below the levels of 2008–09. It does not appear to be continuing the steep decline of 2004–08. In 2011 fishable biomass (FB) decreased to about 16% below the series mean, the lowest level since 1997 and 44 % of the record high 2003 level. In Disko Bay and Vaigat the FB stayed well above the mean and was the fifth highest in the series.

Stock distribution

The area over which the stock is distributed has decreased a little more since 2010, and it remains concentrated in few survey strata in the centre of its range. Densities are still high in Disko Bay and Vaigat, but have decreased in the two strata to the west of Disko Bay, falling almost to nothing in the part of stratum W2 lying south of about 68°35'N as well as in strata W3 and W4 north, south, and west of Store Hellefiskebanke. Further south, densities are practically zero on the continental slope west of the banks all the way from Store Hellefiskebanke to Kap Farvel, although there are some patches of higher density in the inshore ends of the gullies between the banks.

The latitude index of the survey has not changed, because the decreases in density in the W strata have been balanced by a 25% decrease in survey biomass in area U lying north of 60°30'N.

Since the late 1990s the stock appears to be found in shallower water than before. Some large catches were made in shallow water in 2011, and the shallowest depth stratum, between 150 and 200 m, yielded its second highest proportion ever of the survey biomass. However, it is not clear that this is a continuing trend: a depth index for the survey biomass has been fairly stationary since 2001.

Stock structure

By numbers and biomass both, the stock in 2011 is heavily weighted toward the largest, female, shrimps, which compose an unprecedentedly high proportion of the total. The stock structure seems deficient in the middle length classes, so that overall the fishable biomass, as a proportion of the total, is close to average. Relative to numbers in other length classes, the smallest shrimps are abundant—shrimps up to 15 mm CPL compose nearly 20% of the males and 14% of the total—but the estimated numbers at age 2 are well below even the modest average of the foregoing 3 years.

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Table 1. Vessels, trawl types and rigging parameters used in the West Greenland bottom trawl survey, 1988–2011.

	Vessel	Trawl	Bridle length (m)	Wing-spread (m)	
1988	Elias Kleist	Skjervøy	59.9	23.1	*
1989	Sisimiut	"	81.1	17.9	*
1990	Maniitsoq	"	59.9	23.1	*
1991	Paamiut	"	75.1	28.3	**
1992–2003	"	"	60.1	20.1–25.2	**
2004	"	"	54.0	25.7	**
2005–2011	"	Cosmos	54.0	27.4–28.2	**

(*: from tank experiments (Per Kanneworff, pers.com.), **: average for all valid tows calculated from measures of door spread and approximate geometry of the trawl).

Table 2. Survey estimates of total biomass 2011.

Stratum	Area (km^2)	Stations	Biomass density (t/km^2)	Biomass (Kt)	Biomass error variance	Error coefft of variation (%)
C0-2	903	0				
C0-3	2179	0				
C0-4	1154	0				
Overall C0*	4236	0				
I1-1	407	2	29.339	11.929	73.5737	71.9
I1-2	1963	6	18.602	36.517	38.6171	17.0
I1-3	2441	6	4.468	10.908	4.8806	20.3
I1-4	1499	2	1.077	1.613	0.5473	45.9
I2-1	419	3	5.550	2.327	0.7009	36.0
I2-2	815	3	21.879	17.831	8.3034	16.2
I2-3	1085	6	7.155	7.762	4.7029	27.9
I2-4	1338	2	2.961	3.962	1.2351	28.0
Overall I	9967	30	9.316	92.850	132.5608	12.4
U1-1	2486	2	1.278	3.176	0.0638	8.0
U1-2	4633	3	1.329	6.158	0.3695	9.9
U1-3	4785	2	1.012	4.842	2.0145	29.3
U1-4	5129	1[†]	0.002	0.008	0.0001	95.0
U2-2	6710	2	1.683	11.290	0.4091	5.7
U2-3	8481	2	0.655	5.554	0.0381	3.5
U2-4	7994	4	0.113	0.905	0.6174	86.8
U3-1	2012	2	2.326	4.679	13.4499	78.4
U3-2	3017	3	4.117	12.421	6.0799	19.9
U3-3	1675	2	2.855	4.781	6.2758	52.4
U3-4	2710	2	0.631	1.711	0.0106	6.0
Overall U	49631	25	1.119	55.525	29.3287	9.8
W1-1	2873	2	5.193	14.917	153.4228	83.0
W1-2	6099	12	2.845	17.353	5.7424	13.8
W1-3	7520	5	2.638	19.840	7.5444	13.8
W1-4*	816	0				
W2-1	1674	2	4.173	6.984	31.5677	80.4
W2-2	2612	11	2.608	6.810	4.7705	32.1
W2-3	1741	5	1.859	3.236	0.8446	28.4
W2-4	915	2	0.078	0.072	0.0035	82.8
W3-1	2122	3	0.143	0.303	0.0101	33.1
W3-2	4725	17	0.161	0.763	0.0883	39.0
W3-3	2085	2	0.647	1.349	0.9983	74.1
W3-4	2994	5	0.922	2.761	1.2403	40.3
W4-1	4119	2	0.001	0.002	0.0000	100.0
W4-2	1818	4	0.198	0.359	0.0284	46.9
W4-3	821	2	0.693	0.569	0.2165	81.8
W4-4	1961	2	0.018	0.035	0.0006	70.5
W5-1	3001	7	0.012	0.035	0.0006	68.7
W5-2	3648	9	0.118	0.430	0.0791	65.3
W5-3	1950	2	0.000	0.000	0.0000	
W5-4	3021	2	0.164	0.496	0.2167	93.9
W6-1	1206	2	0.002	0.003	0.0000	91.7
W6-2	2006	7	0.729	1.462	1.4303	81.8
W6-3	1585	3	0.871	1.381	0.1416	27.3
W6-4	1234	2	0.001	0.001	0.0000	100.0

Stratum	Area (km^2)	Stations	Biomass density (t/km^2)	Biomass (Kt)	Biomass error variance	Error coefft of variation (%)
W7-1	2442	3	0.000	0.000	0.0000	
W7-2	891	4	34.161	30.451	927.2503	100.0
W7-3	265	1†	0.000	0.000	0.0000	95.0
W7-4	317	2	0.002	0.001	0.0000	100.0
W8-1	424	2	4.860	2.061	4.2463	100.0
W8-2	567	2	0.001	0.001	0.0000	89.1
W8-3	405	2	0.286	0.116	0.0112	91.5
W8-4	718	2	0.591	0.425	0.1279	84.2
W9-1	1711	3	0.000	0.000	0.0000	
W9-2	938	2	0.000	0.000	0.0000	100.0
W9-3	516	2	0.001	0.001	0.0000	76.0
W9-4	430	2	0.000	0.000	0.0000	51.5
Overall W	71353*	137	1.573*	112.215	1139.9826	30.1
Survey totals	130951*	192	1.991*	260.789	1302.1093	13.8

† strata with 1 trawled station have been assigned an error coefficient of variation of 95%

* Area C0, and sub-stratum W1-4 (the westernmost, and deepest, in area W1) were not surveyed in 2011 because there was too much sea ice there; their areas have not been included in survey areas, nor in the calculation of average density.

Table 3. Biomass estimates (Kt) for survey subdivisions and standard errors for the entire survey, 1988–2011. Data for 2005–2010 was re-analysed in 2011.

Year	N1–9 / U1–3[1]	C1 & 2 / C0[1]	W1 & 2	W3 & 4	W5–7[2]	S1 & 2 / W8 & 9[1]	D1–9 / I1–2[1]	Total	SE
1988	22.6	9.5	55.1	85.5	17.7		39.2[3]	229.7	24.7[3]
1989	11.1	3.7	50.0	82.7	39.0		39.2[3]	225.7	32.3[3]
1990	11.0	9.1	78.6	53.9	23.5		39.2[3]	215.3	32.6[3]
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	5.4	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	92.2	12.5	110.7	484.0	65.1
2007	61.2	1.7	128.1	64.0	21.3	1.2	79.1	349.5	44.3
2008	91.7	16.7	61.3	40.0	20.9	0.7	50.8	282.1	28.3
2009	91.7	4.3	62.9	30.1	18.4	1.0	70.1	278.4	27.1
2010	73.1	3.0	89.6	65.3	13.5	0.9	99.3	344.7	44.6
2011	55.5	0.0[5]	69.2	6.1	34.3	2.6	92.9	260.6	36.1

[1]: In 2003 Area N was re-stratified on depth as Area U with strata U1–U3, and Area S as strata W8 and W9. In 2004 strata C1 and C2 were merged into stratum C0, and Area D was re-stratified on depth as strata I1 and I2.

[2]: Stratum W6 was added to the survey in 1990 and W7 in 1993.

[3]: Area D (Disko Bay and Vaigat) was added to the survey in 1991. Biomass estimates for 1988–90 were later set to the mean for 1991–1997 and have been included in the survey total for 1988–90; however, this area has not been included in the calculation of overall standard error for 1988–90.

[4]: Probably underestimated owing to poor coverage of the northern part of Area N.

[5]: Area C0 was not surveyed in 2011 owing to sea ice cover.

Table 4. Error coefficients of variation (%) for the biomass estimates of five main survey regions and the entire survey area, 1988–2011. Data for 2005–2010 was re-analysed in 2011.

Year	N1–9 / U1–3	C1–3 / C0	W1 & 2	W3 & 4	W5–7	S1 & 2 /W8 & 9	D1–9 / I1 & 2	Overall	Number of stations
1988	31.4	40.0	17.9	26.4	42.5	-	-	14.41	131
1989	22.2	42.8	23.9	33.2	35.0	-	-	18.60	130
1990	43.5	39.9	22.7	39.5	42.0	-	-	18.30	109
1991	40.2	27.1	21.2	30.4	30.6	-	22.9	13.37	194
1992	16.9	68.9	15.5	17.9	42.0	-	15.7	13.84	167
1993	51.6	53.3	14.6	28.0	28.5	-	19.4	11.66	157
1994	48.7	18.3	27.2	16.8	45.9	99.2	26.0	19.11	157
1995	47.1	44.7	20.0	22.6	36.3	74.0	17.7	13.93	163
1996	52.6	91.0	23.9	19.8	36.2	95.0	10.6	16.31	148
1997	37.9	61.9	15.8	20.2	43.1	14.6	14.5	15.26	167
1998	40.4	44.0	33.2	44.5	30.6	58.8	18.4	19.19	209
1999	51.1	80.0	13.1	14.8	27.7	52.1	14.2	14.08	227
2000	36.1	7.8	21.5	32.7	18.5	56.8	12.9	11.08	198
2001	26.5	44.5	24.9	45.0	25.6	22.8	18.6	11.77	224
2002	56.0	45.4	16.0	28.9	36.5	55.0	18.7	12.44	216
2003	26.8	44.4	17.5	16.0	34.9	49.9	17.5	11.21	172
2004	24.9	22.6	22.8	27.1	24.1	71.4	11.6	16.03	187
2005	17.4	97.3	22.8	38.0	50.4	48.7	34.6	16.02	194
2006	20.5	79.0	19.2	20.5	41.3	79.4	12.9	13.41	223
2007	21.9	45.1	19.8	32.6	8.8	56.8	20.8	12.43	223
2008	17.3	80.7	15.6	33.1	43.5	44.8	11.5	10.02	204
2009	22.1	59.6	12.8	18.7	39.0	53.0	15.9	9.72	247
2010	11.13	29.67	26.95	61.0	66.9	98.73	9.96	12.94	270
2011	9.75	—[1]	19.07	26.17	89.0	80.46	12.40	13.85	192
Mean 1994-2011								13.82	

[1.] Area C0 and substratum W1-4 was not surveyed in 2011 owing to sea ice.

Table 5. Estimated mean densities (t/km^2) for survey subdivisions in 1988–2011. Data for 2005–2010 was re-analysed in 2011.

Year	N1–9 / U1–3	C1–3 / C0	W1 & 2	W3 & 4	W5–7	S1 &2 / W8 & 9	D1–9 / I1 & 2
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	4.28	2.20	11.26
2007	1.21	0.40	5.24	3.12	0.99	0.21	8.04
2008	1.85	3.94	2.53	1.94	0.97	0.13	5.09
2009	1.85	1.01	2.59	1.46	0.85	0.17	7.03
2010	1.47	0.70	3.70	3.16	0.63	0.16	9.96
2011	1.12	—	2.95	0.30	1.59	0.46	9.32

Table 6. Estimated numbers (billions) by sex from length analyses 1988–2011 (mean values for Disko/Vaigat area in 1991–1997 used for 1988–1990). Data for 2005–2010 was re-analysed in 2011.

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	94.5	25.1	119.6	79.0	21.0
2006	78.3	24.6	102.9	76.1	23.9
2007	55.1	16.0	71.1	77.4	22.6
2008	42.4	11.8	54.2	78.2	21.8
2009	41.3	12.0	53.3	77.4	22.6
2010	52.9	13.5	66.3	79.7	20.3
2011[1]	36.8	13.0	49.8	74.0	26.0
Average	49.2	12.4	61.7	79.9	20.1

[1.] Area C0 and substratum W1-4 were not surveyed in 2011 owing to sea ice.

Table 7. Survey biomass estimates (Kt) by sex based on length-weight distributions 1988–2011 (1991–1997 mean values for Disko Bay and Vaigat have been used for 1988–1990). Data for 2005–2010 was re-analysed in 2011.

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	355.2	196.7	551.9	64.4	35.6
2006	297.4	188.0	485.4	61.3	38.7
2007	227.8	128.7	356.6	63.9	36.1
2008	182.6	99.5	282.1	64.7	35.3
2009	173.5	105.0	278.4	62.3	37.7
2010	222.3	122.4	344.7	64.5	35.5
2011[1]	148.5	112.0	260.6	57.0	43.0
Average	197.5	109.2	306.7	64.8	35.2

[1.] Area C0 and substratum W1-4 was not surveyed in 2011 owing to sea ice.

Table 8. Estimates of fishable biomass (≥17mm CL, Kt) in the West Greenland shrimp survey 1988–2011 (mean values for Disko/Vaigat area in 1991–1997 used for 1988–1990). Data for 2005–10 has been re-analysed in 2011.

	offshore fishable		Disko fishable		overall fishable	
	biomass	%	biomass	%	biomass	%
1988	186.2		37		223.2	
1989	171.9		37		209.0	
1990	170.0		37		207.0	
1991	104.7	98.0	41.3	95.8	146.0	97.4
1992	154.8	95.0	39.4	95.2	194.2	95.0
1993	189.4	93.5	27.1	95.8	216.5	93.8
1994	191.0	94.8	32.1	94.4	223.1	94.8
1995	144.9	95.1	38.3	98.0	183.2	95.7
1996	150.6	87.8	41.5	93.7	192.1	89.0
1997	127.7	95.7	39.4	88.9	167.1	94.0
1998	197.2	94.2	47.1	90.9	244.3	93.5
1999	195.0	93.8	42.3	80.4	237.3	91.1
2000	219.8	90.1	60.6	83.0	280.3	88.5
2001	216.8	85.2	63.7	88.3	280.5	85.9
2002	302.2	90.4	67.2	78.3	369.5	87.9
2003	454.0	92.6	94.3	87.6	548.3	91.7
2004	457.5	94.9	70.8	87.0	528.3	93.8
2005	381.8	92.6	112.3	80.4	494.2	89.5
2006	358.6	96.1	92.4	83.5	451.0	93.2
2007	264.7	97.9	71.3	90.1	336.1	96.2
2008	216.8	93.7	45.8	90.2	262.6	93.1
2009	192.2	92.3	62.8	89.6	255.1	91.6
2010	229.8	93.6	88.9	89.5	318.7	92.5
2011[1]	155.9	93.0	83.1	89.5	239.0	91.7
Series mean		93.3	57.2	89.1		92.4

[1.] Area C0 and substratum W1-4 were not surveyed in 2011 owing to sea ice.

Table 9a. Mean carapace length (mm) for Northern shrimp at age 2 off West Greenland 1993–2006, and corresponding standard deviations and coefficients of variations (- : not present, ( ): fixed in the final MIX.run).

Mean:							
			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)

Standard deviation:							
	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	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)

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

Table 9b. Mean carapace length (mm) for Northern shrimp at age 2 off West Greenland 2007–2011, and corresponding standard deviations and coefficients of variations (- : not present, ( ): fixed in the final CMIX run, na: no data).

Mean:						
			Region	/ Depth		
	U1-U3	I1+I2	C0	W1-W4	W5+W6	W7-W9
Year	150-600 m	150-600 m	200-600 m	150-600 m	150-600 m	150-600 m
2007	12.7	12.0	12.7	12.5	12.8	-
2008	13.0	12.4	13.1	12.3	11.8	-
2009	12.4	12.2	-	12.5	12.5	-
2010	11.3	12.0	13.1	13.3	-	-
2011	12.2	11.5	na	12.1	13.0	-

Standard deviation:						
			Region	/ Depth		
	U1-U3	I1+I2	C0	W1-W4	W5+W6	W7-W9
Year	150-600 m	150-600 m	200-600 m	150-600 m	150-600 m	150-600 m
2007	1.44	1.25	1.05	1.35	1.02	-
2008	1.30	1.16	1.13	1.24	0.83	-
2009	1.18	1.45	-	1.14	(1.45)	-
2010	1.20	1.17	1.09	1.18	-	-
2011	1.50	1.01	na	1.24	1.30	-

Coefficent of variation:						
			Region	/ Depth		
	U1-U3	I1+I2	C0	W1-W4	W5+W6	W7-W9
Year	150-600 m	150-600 m	200-600 m	150-600 m	150-600 m	150-600 m
2007	0.11	0.10	0.08	0.11	0.08	-
2008	0.10	0.09	0.09	0.10	0.07	-
2009	0.09	0.12	-	0.09	(0.12)	-
2010	0.11	0.10	0.08	0.09	-	-
2011	0.12	0.09	na	0.09	0.10	-

Table 10. Numbers (10^9) of Northern shrimp by survey region and for the total survey area (1993 to 2004 converted from Skervøy to Cosmos trawl, C0 in 2011: average value from 2007 to 2010).

Year	U1 to U3	I1 and I2	C0 and W1 to W4		W5 and W6	W7 to W9	Total
1993	0.06	0.08	2.60		1.54	0.00	4.28
1994	0.01	0.21	1.51		1.20	0.00	2.92
1995	0.02	0.11	0.82		1.37	0.00	2.32
1996	0.11	1.25	2.45		6.20	0.00	10.01
1997	0.05	1.37	0.52		1.27	0.00	3.22
1998	0.04	1.79	2.01		2.60	0.00	6.44
1999	0.42	5.06	2.66		3.22	0.00	11.36
2000	0.33	5.54	4.92		3.50	0.01	14.29
2001	1.66	5.44	7.79		1.01	0.01	15.90
2002	0.02	3.98	3.41		2.97	0.04	10.42
2003	0.76	1.11	1.70		2.88	0.03	6.48
2004	0.64	3.39	2.24		0.47	0.01	6.75
2005	0.31	2.50	0.58		0.05	0.00	3.45
2006	0.27	1.97	1.54		0.68	0.04	4.50
2007	0.08	1.04	0.00	0.84	0.31	0.00	2.27
2008	2.61	1.60	0.04	0.76	0.40	0.00	5.41
2009	1.94	2.12	0.00	0.93	0.20	0.00	5.18
2010	1.10	2.11	0.01	2.05	0.00	0.00	5.27
2011	0.70	2.44	*0.01*	0.42	0.03	0.00	3.59
Average:	0.59	2.27	2.10		1.57	0.01	6.53

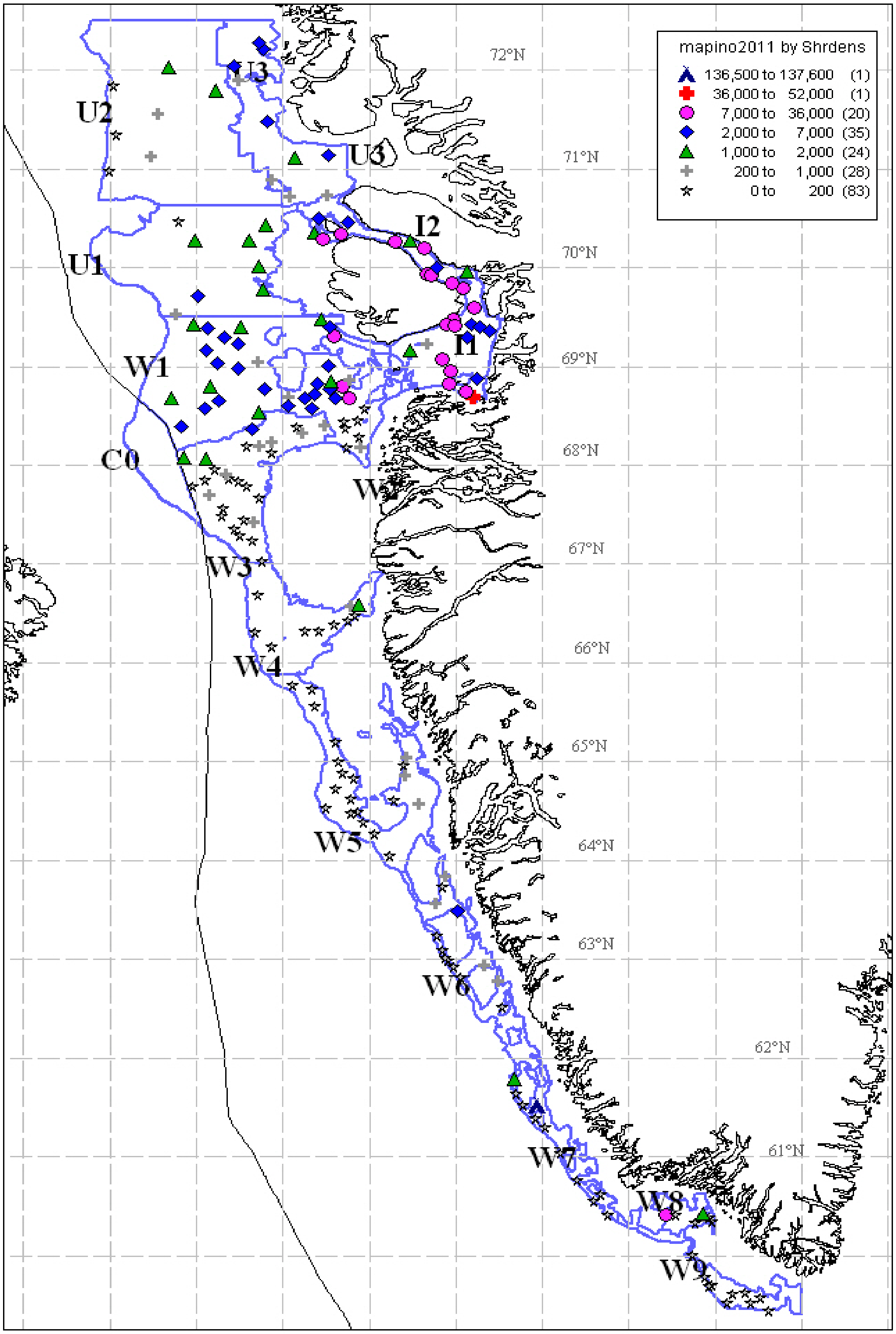
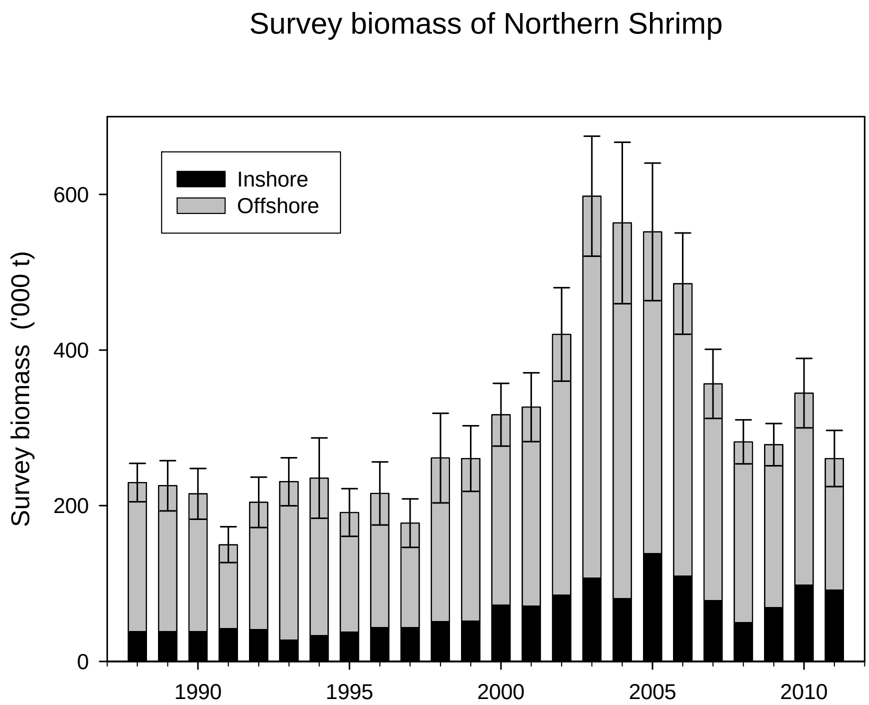


Figure 1. *P. borealis* in West Greenland: density distribution from 192 trawl-survey stations in 2011. Area C0 and sub-stratum W1-4 could not be surveyed in 2011 because there was too much sea ice there.



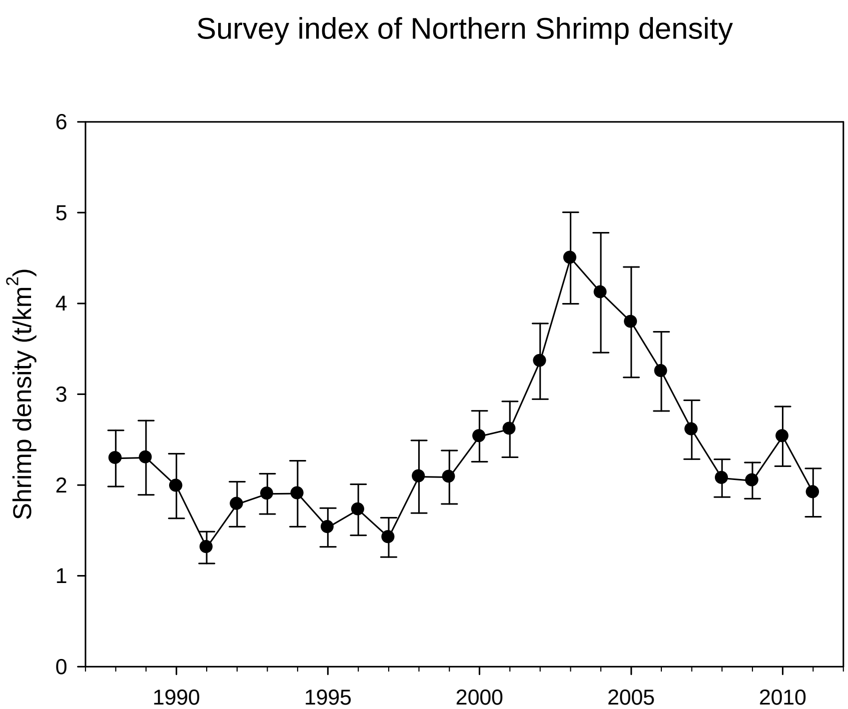


Figure 2. *P. borealis* in West Greenland: estimated total survey biomass and average survey biomass density of Northern shrimp with standard errors 1988–2011. (Area C0 and sub-stratum W1-4 could not be surveyed in 2011 because there was too much sea ice there.)

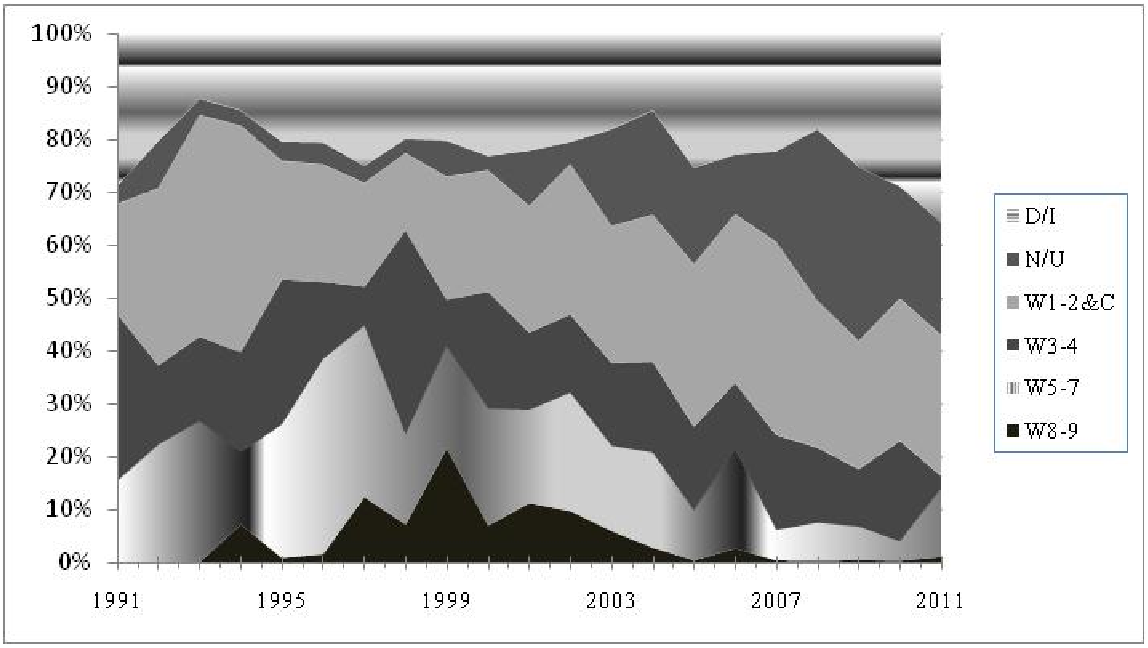


Figure 3. *P. borealis* in West Greenland: distribution of survey biomass between major survey regions, 1991–2011. Area C0 and stratum W1-4 could not be surveyed in 2011 because there was too much sea ice there.

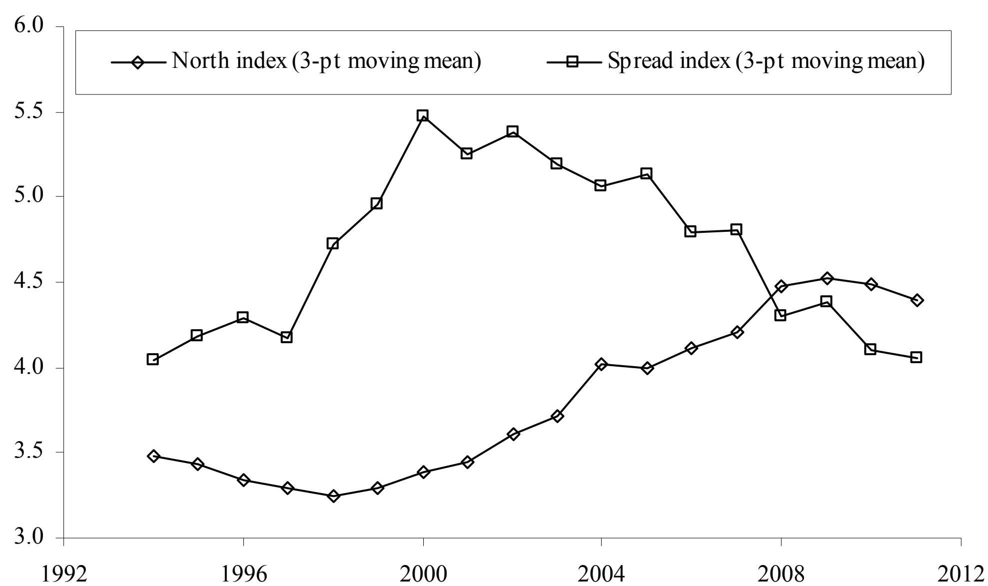


Figure 4. *P. borealis* in West Greenland: indices of distribution and location of shrimp biomass in the West Greenland trawl survey 1994–2011 (3-point moving averages).

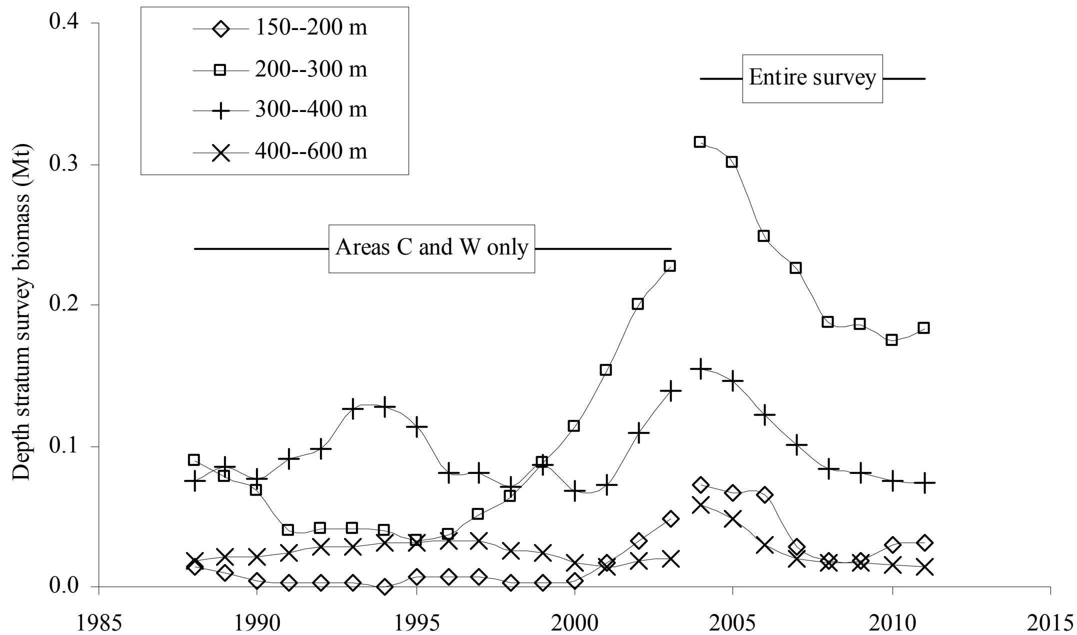


Figure 5a. *P. borealis* in West Greenland: survey biomass estimates by depth stratum, 1988–2011. (3-point moving averages.) (Up to 2003, only areas C and W were substratified by depth).

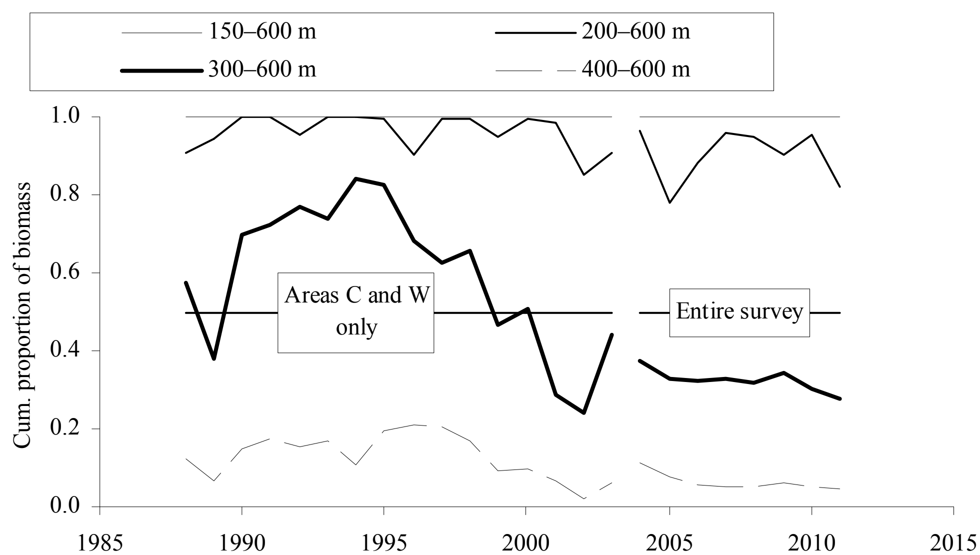


Figure 5b. *P. borealis* in West Greenland: distribution of survey biomass by depth 1988–2011 (Up to 2003, only areas C and W were sub stratified by depth).

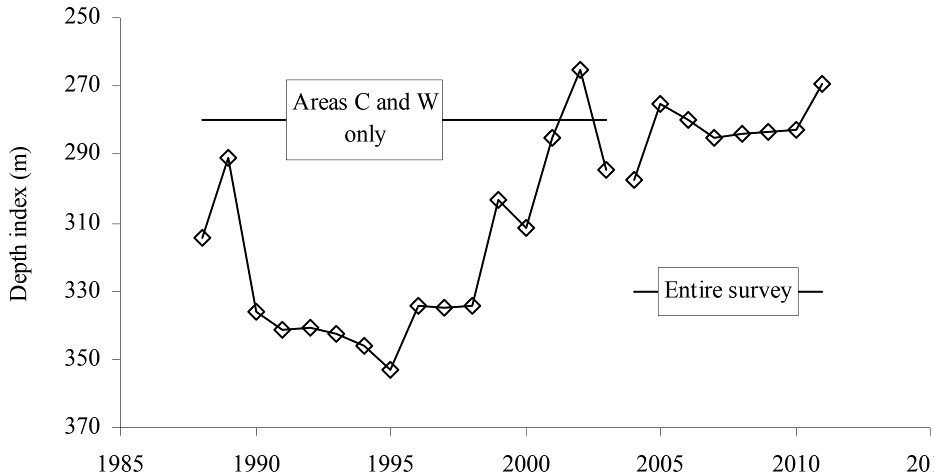


Figure 5c. *P. borealis* in West Greenland: depth index for survey biomass, 1988–2011. (Up to 2003, only areas C and W were substratified by depth).

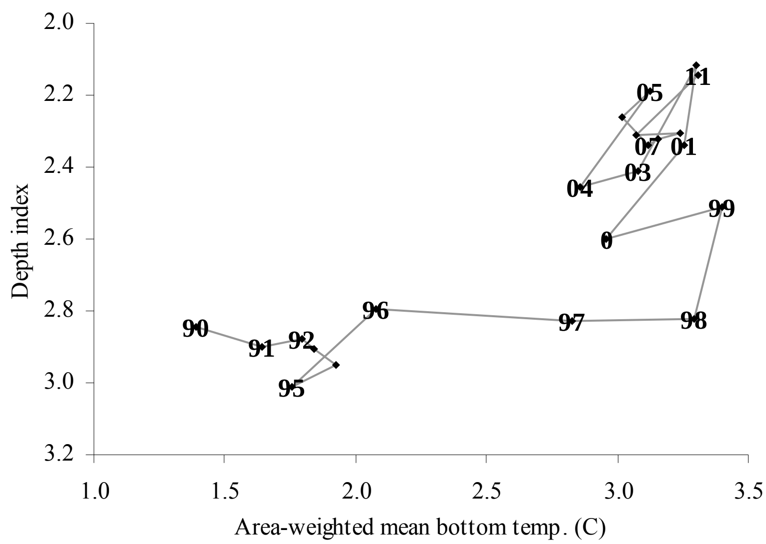


Figure. 6. *P. borealis* in West Greenland: depth index of survey biomass vs.area-weighted mean bottom temperature from survey trawl-door measurements, 1990–2011.

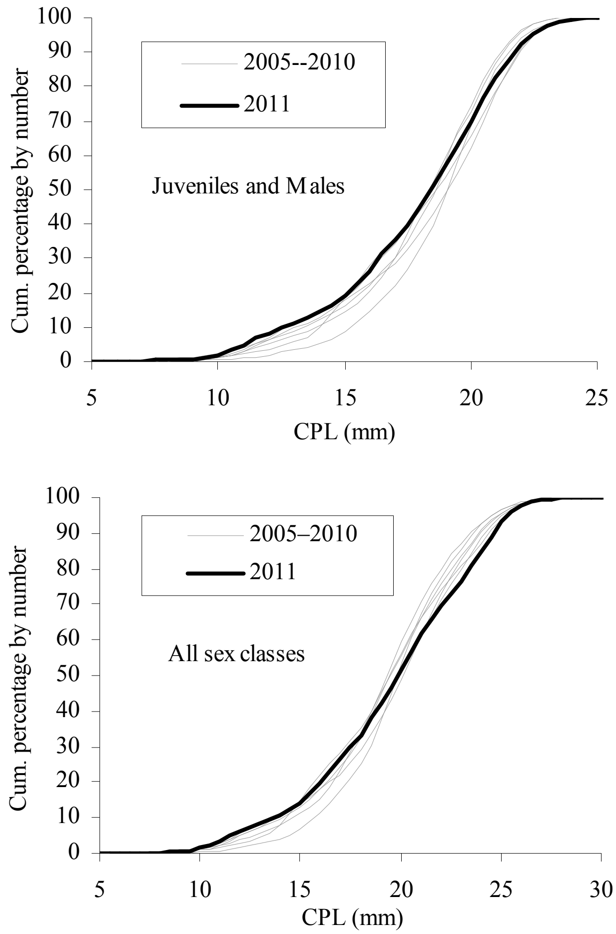


Figure 7. *Pandalus borealis* in West Greenland: distribution of lengths from survey length analyses in 2005–2010 and in 2011.

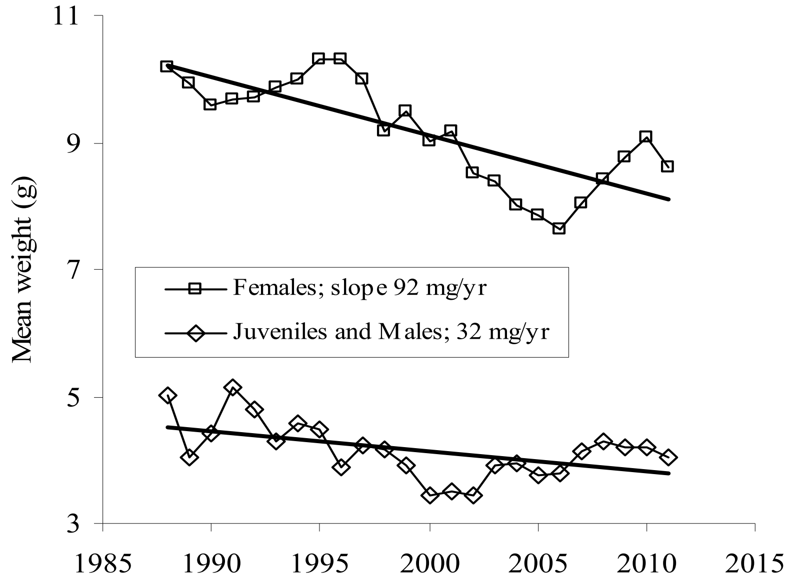


Figure 8: *Pandalus borealis* in West Greenland: mean weight, by sex, from survey data, 1988–2011.

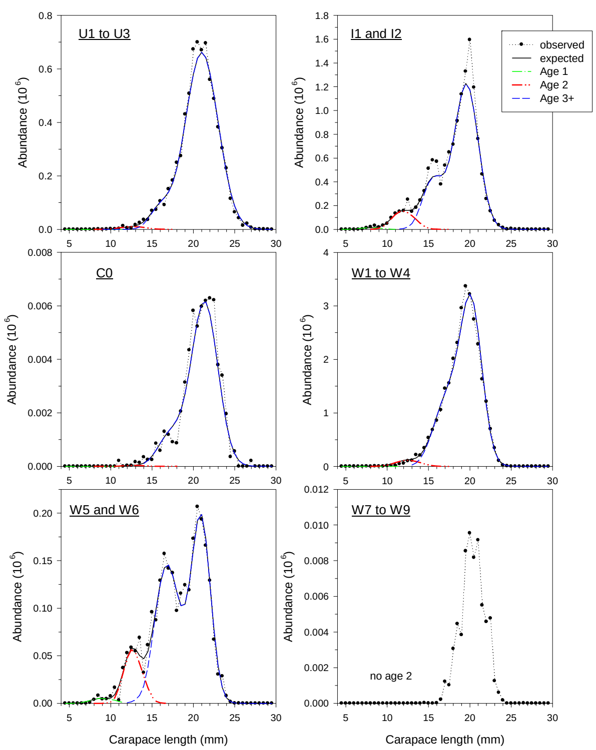


Figure 9a. Regional length frequencies of Northern shrimp in 2007.

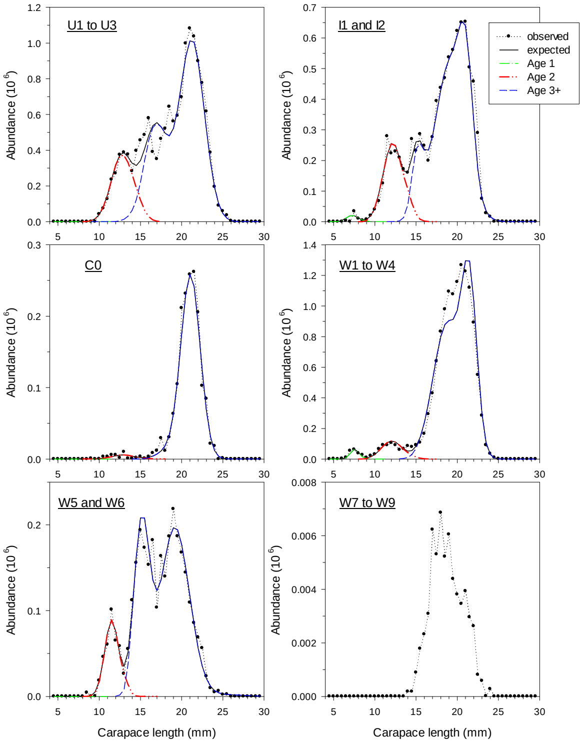


Figure 9b. Regional length frequencies of Northern shrimp in 2008.

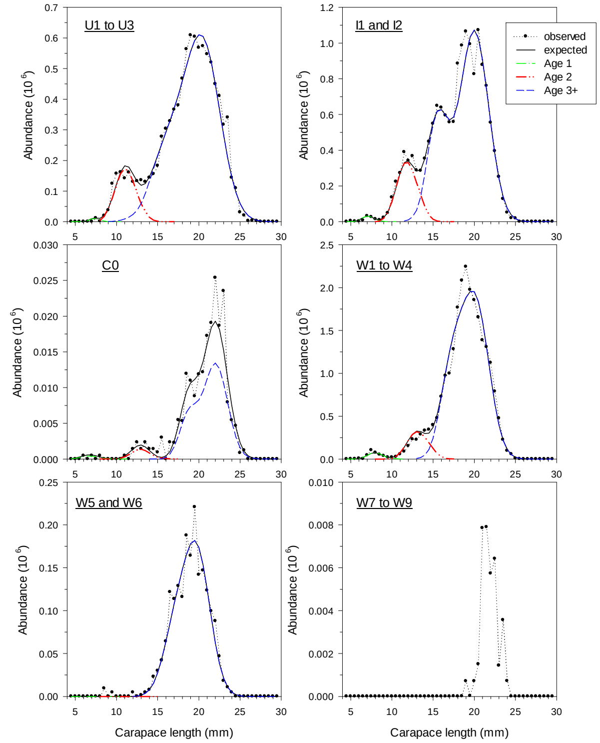


Figure 9d. Regional length frequencies of Northern shrimp in 2010.

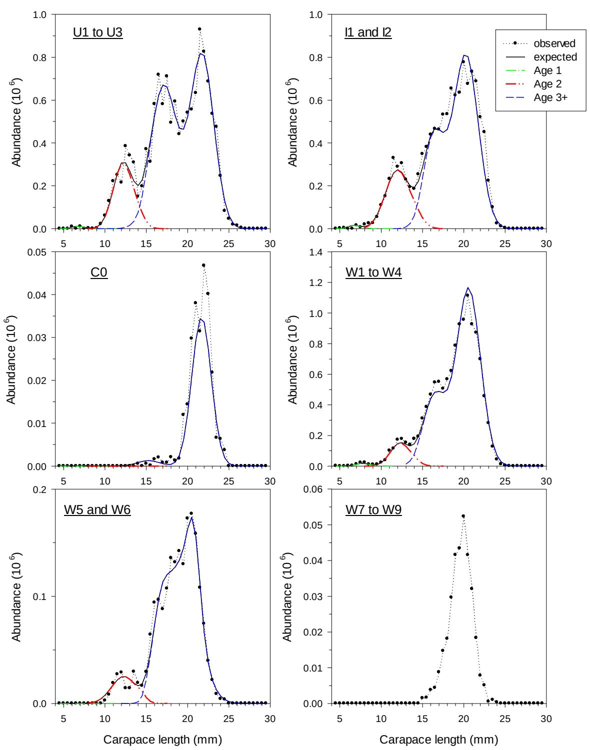


Figure 9c. Regional length frequencies of Northern shrimp in 2009.

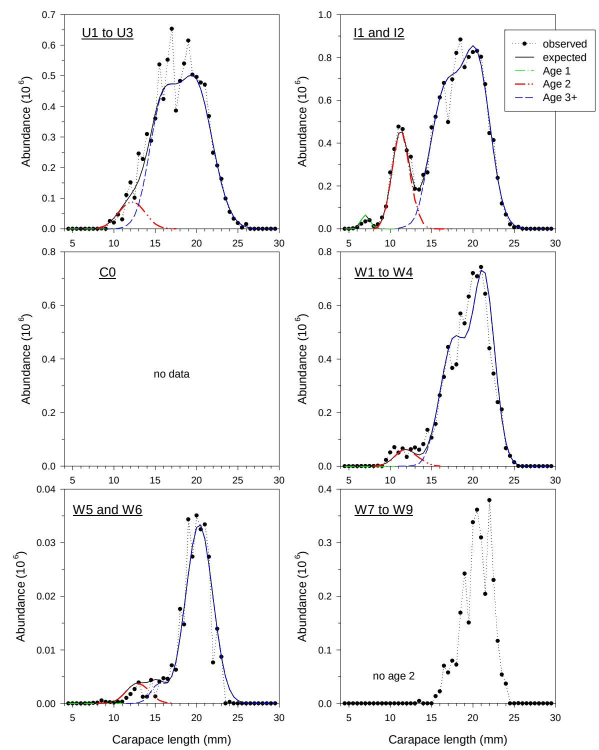


Figure 9e. Regional length frequencies of Northern shrimp in 2011.(Area CO not covered due to adverse ice conditions).

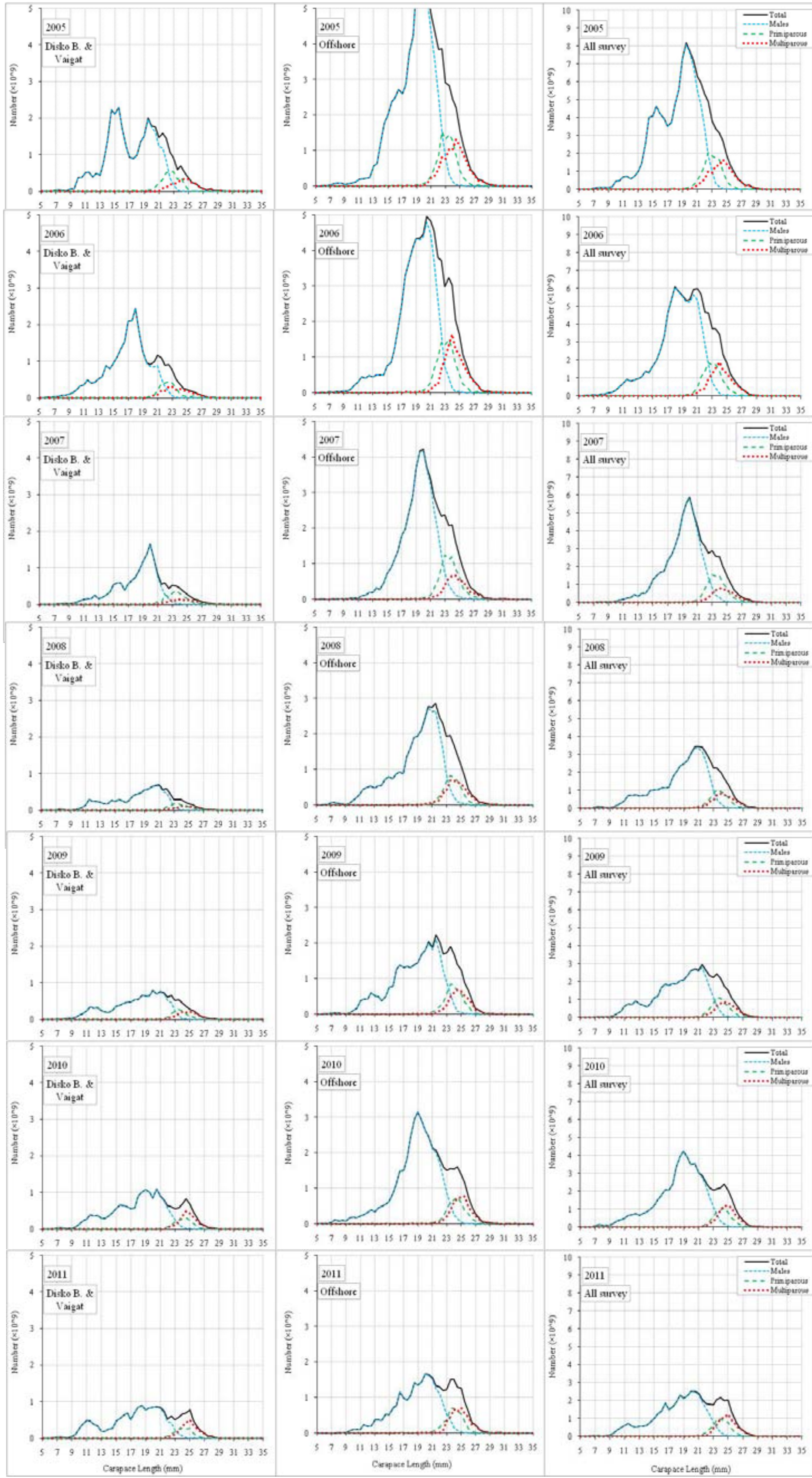


Figure 10. Length frequencies of Northern shrimp in the total offshore and the Disko Bay/Vaigat area, 2005–2011.

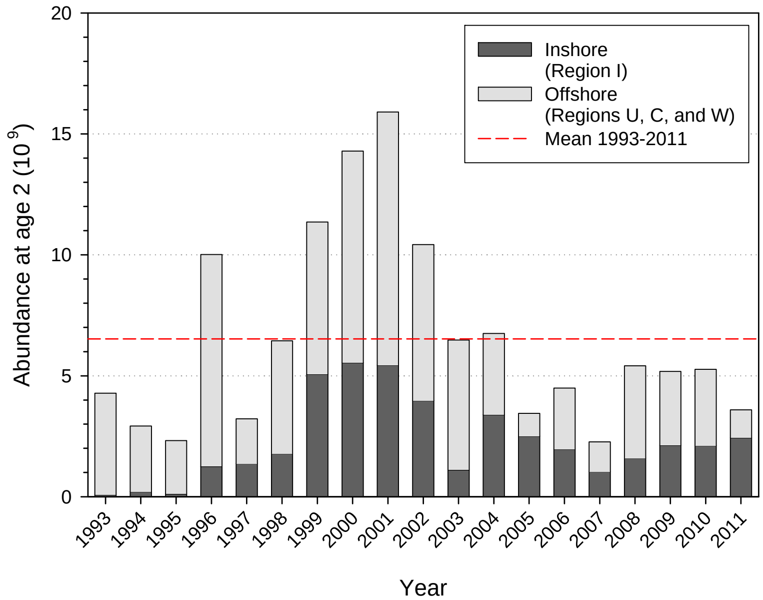


Figure 11. *P. borealis* in West Greenland: indices of numbers at age 2, 1993–2011.

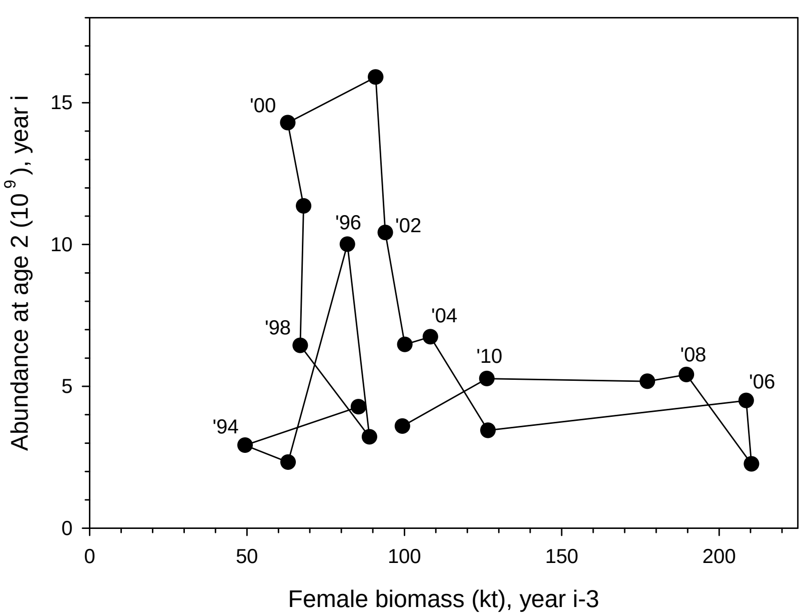


Figure 12. *P. borealis* in West Greenland: survey estimates of numbers at age 2 in 1993–2011 vs female biomass 3 years earlier (labels denote years in which age-2 numbers were estimated).

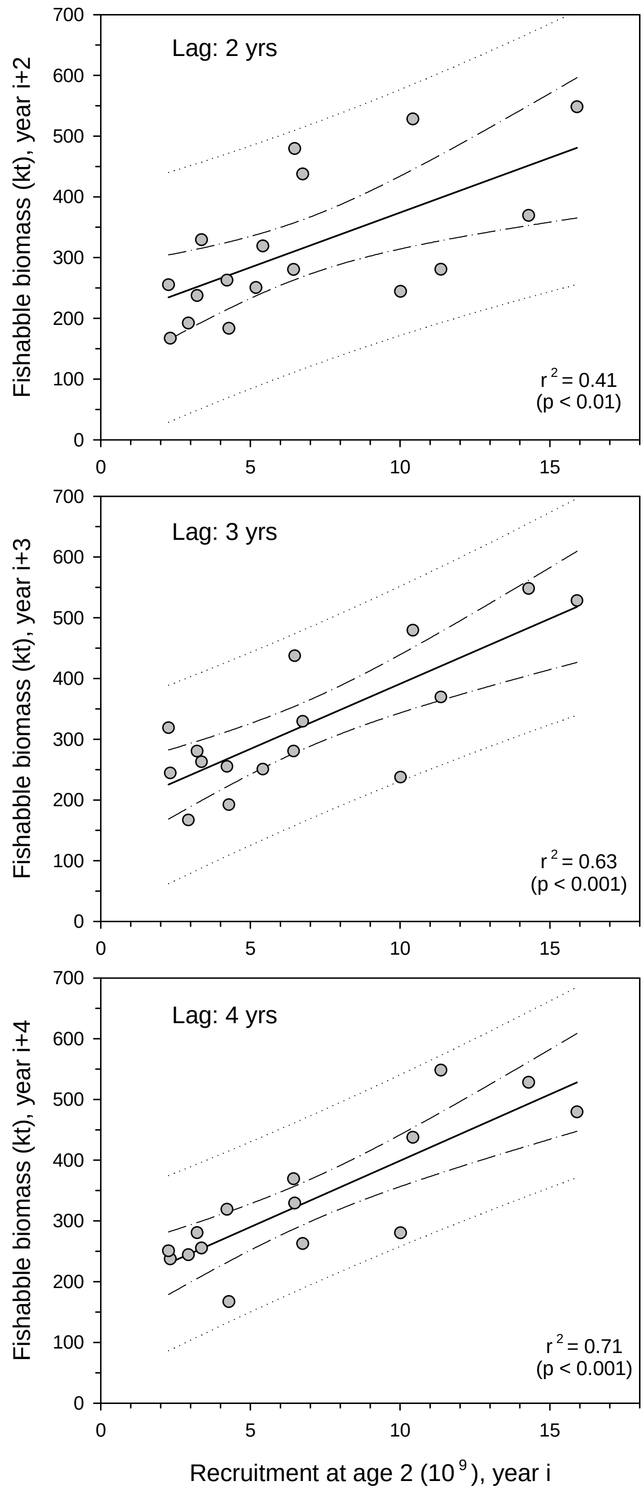


Fig.13. *P. borealis* in West Greenland: fishable biomass two, three or four years later against survey estimates of numbers at age 2 from 1993 to 2009, 2008 or 2007 (lines: linear regression with 95% confidence and prediction intervals).

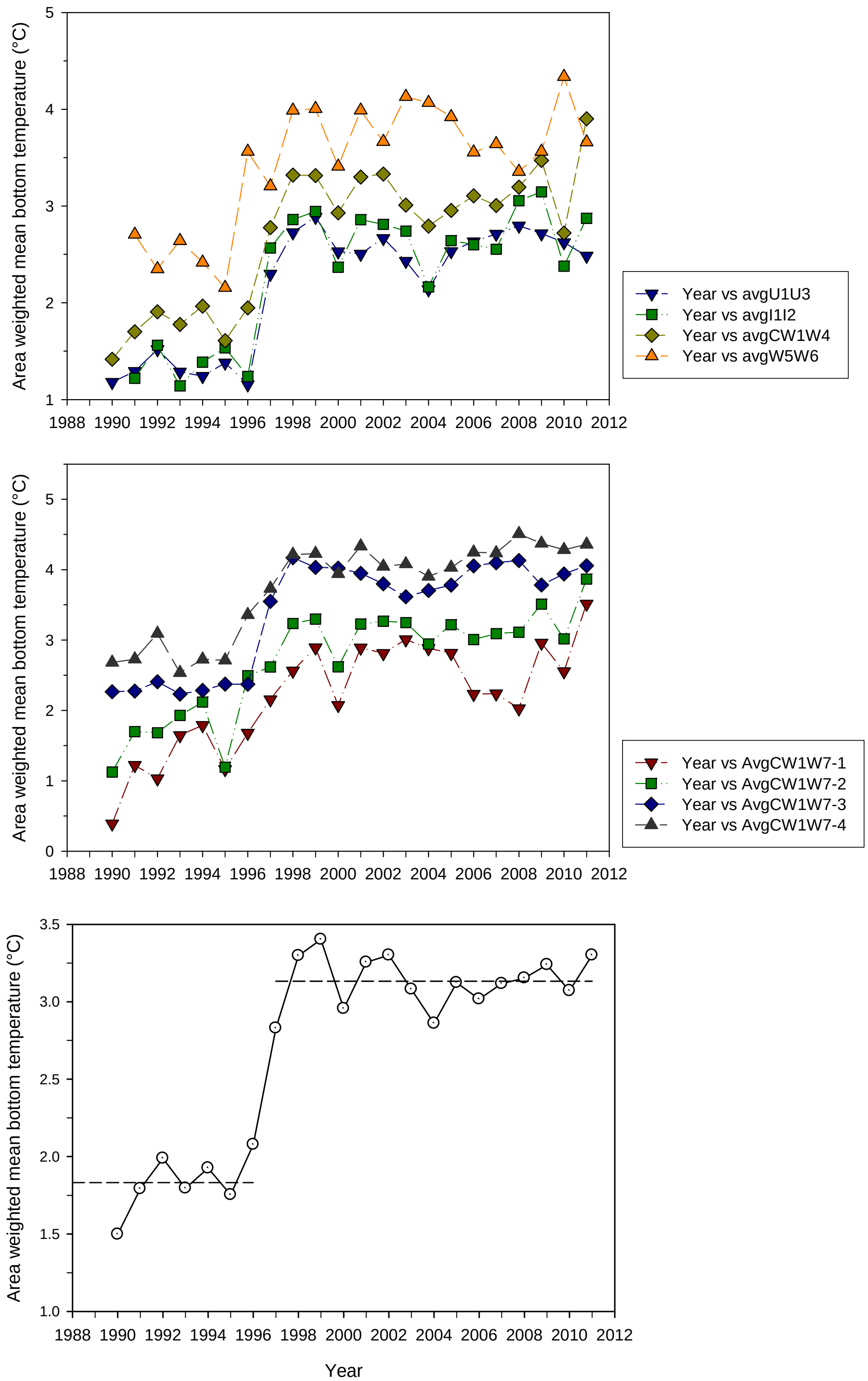


Figure 14. Area-weighted mean bottom temperature for survey regions (see Fig. 1 for locations), depth strata in offshore areas C and W1–W7, and the entire survey area in 1990–2011.