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The West Greenland trawl survey for *Pandalus borealis*, 2012, with reference to earlier results

by

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Abstract

A trawl survey is carried out annually in NAFO Subarea 1 and NAFO Division 0A east of 60°30’W as a contribution to the assessment of the stock of the Northern Shrimp (*Pandalus borealis*). In 2012 230 stations were fished in 42 fishing days; 193 provided data to the shrimp survey in all strata except Div. 0A, not surveyed owing to sea ice.

The 2003 peak in total survey and fishable biomasses has been followed by continuous decline, reaching in 2012 the lowest levels since 1997. However, while offshore the total biomass is at 20% of its 2003 peak and about 92% of its previous minimum, in Disko Bay and Vaigat the total biomass is still 66% of its (2005) maximum and is sixth highest in the series.

The decrease offshore is uneven. In the northern part, from the limit of the survey to the latitude of Disko Bay, total biomass has decreased in 2012 to about 55% of the (already low) 2011 value, but is still close to one third of its peak. W3 and W4, which lie round Store Hellefiskebanke, collapsed in 2011 and remain empty, and the southernmost areas collapsed already in 2004–2007. But the south-central offshore area, W5–7, lying from offshore of the Lille Hellefiskebanke south to the north side of Julianehåb Bay had an estimated biomass still about two-thirds of its 2011 value, although only about one fifth of its peak.

The overall stock structure is extreme in some respects. While the fishable proportion of the survey biomass is, in total, a little over the lower quartile of the foregoing 20 years, the female biomass is high as a proportion both of the survey and of the fishable biomasses, while the biomass of fishable males is low, the stock appearing deficient in these length classes. That the spawning stock should compose a high proportion of the total survey biomass makes the stock sensitive to fishing pressure: short-term recruitment to the spawning stock is likely to be low.

Both inshore and offshore the index of age-2 shrimps is well below its lower quartile when considered relative to survey biomass, and at its lowest value ever in absolute terms.

Since the late 1990s the stock is found in shallower water than before, and in 2012 the survey biomass depth index decreased again from its 2011 value.

Area-weighted mean bottom temperature in the survey area increased at the beginning of the 1990s, by about 1.6°C, and this relatively warm period continued in 2012.

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 2012 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 between 150 m and 600 m. Since 1991 the 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 into some fjords (see e.g. Fig. 4a of Hammeken and Kingsley 2010).

The survey area is divided into primary and secondary strata. The survey primary strata correspond to geographical areas identified on the basis of logbook information on the distribution of the fishery (Carlsson *et al*. 2000). They are subdivided 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 subdivided into geographical substrata not based on depth. Depth data logged by the survey and other investigations eventually allowed these waters to be stratified on depth and a new geographical stratification with depth sub-strata was 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. Past variance data for Atlantic cod and Greenland halibut is also 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. 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 by inducing serial correlation in survey error (Kingsley 2001a).

In 2012, 187 stations were planned at depths between 150 and 600 m in the survey area, with 58 ‘extra’ stations mapped and available to be included if time permitted. 153 of the 187 planned stations and 33 ‘extra’ stations were fished, together with 9 stations fished *ad hoc*. 31 stations were reported as having been moved more than 2 n.mi. from the planned position, with a mean of 5.7 n.mi.; 18 of the 31 because of untrawlable bottom. Of the 195 stations fished, 193 provided usable data to the shrimp survey. In the course of the shrimp survey, 40 CTD casts were made along standard transects offshore and in Disko Bay and Vaigat.

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. However, shorter tows give just as accurate results (Carlsson *et al*. 2000; Kingsley 2001b; Kingsley *et al.* 2002; Wieland and Storr-Paulsen 2006; Ziemer and Siegstad 2009) and since 2005 the survey has been operated with 15-minute tows alone.

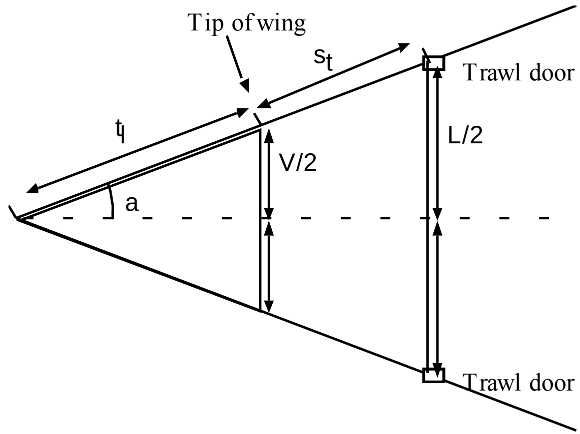
Fishing practices

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. Door-spread readings are recorded during the tow and the reading from the trawl-eye is used to judge when the trawl has settled and the tow can be deemed started.

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 should be 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 tips of the trawl wings, has been 54 m for either trawl; 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. The unweighted mean of densities in each stratum was multiplied by the stratum area to compute a 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.

Indices of distribution and location of shrimp biomass

Indices to summarise how widely the survey biomass is distributed and a measure of its central latitude were calculated (Kingsley 2008). Data from surveys executed in 1994–2012 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;
- 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.

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

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

This index summarises how widely the survey stock biomass is distributed among survey 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 each catch a sample of about 0.5 to 3 kg 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 (Allen 1959, McCrary 1971). The oblique carapace length (CL) of each shrimp in the sample was measured to the nearest 0.1 mm. 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 the stratum biomass between sex and length classes as well as the numbers of shrimps in the stratum in the various sex and length classes.

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 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 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, calculated from the weight-length function, instead of using its weighed weight. In effect, the length-measurement data is used only 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 since 2007 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.

Modal analysis is carried out using CMIX (de la Mare 1994, CMIX.EXE 1997, © Australian Antarctic Division), implemented as an Excel Add-In. CMIX fits overlapping Normal distributions to length frequency distributions by maximum-likelihood methods. It assumes that the length-density data have 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 is so variable that for each analysis it is necessary to test whether all the fitted Normal distributions should be constrained to have the same coefficient of variation, or whether variances should be fitted separately for each one.

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. 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: 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 stratum group 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

Bottom temperature was measured with a *Starmon* sensor mounted on one of the trawl doors. It records at intervals of 30 s 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 2012 started from Nuuk on 06 June. The first cruise occupied stations from Nuuk north to Disko Bay. The crew was changed at Ilulissat on 23 June having occupied 136 stations in 17 days. The second cruise occupied stations in Vaigat, north to the survey limit, and west of Disko I. on its way back south. It occupied 80 stations, the northern area being sparsely sampled and steaming times long.

The second crew change was at Nuuk on 8 July, and the Paamiut was then chartered out for a week, so the third cruise started south from Nuuk on 19 July to occupy stations south to the southern limit of the survey. It was accompanied by a crew engaged in taking photographs of the sea bottom to investigate the long-term effects of trawling on bottom ecosystems, who used the ship at night when the survey was suspended. A day was lost to weather in southern West Greenland and mechanical problems curtailed the third cruise on 29 July, so the last six shrimp stations were taken on 2 August at the start of the next (groundfish) survey.

Of 58 planned survey strata, 3 (the Canadian zone C0, 3.1% of the survey area) had no stations trawled, and 3 had only 1 each. 21 stations had no catch of *P. borealis*; all were in area W6 or further south. 2 strata, with 5 occupied stations between them, had no catches. Length samples were measured from all 172 stations with catches, even very small ones.

There were no exceptionally large catches. Two catches over 1 ton (about 33 t/sq. km) were made in Disko Bay. There were 18 catches over 200 kg, of which 13 were made in Disko Bay or Vaigat. In southerly areas, sub-strata W6-2 and W7-2 each had one biggish catch, of 830 and 550 kg, but the other 11 stations in these two sub-strata yielded an average catch of 2 kg. This is like 2011, when isolated large catches were made in this same area in this depth band.

Overall Biomass and Area Distribution.

For all strata biomass estimates have been calculated (Table 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 were:

Region—2010	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	73 206	27	11.14
Canadian zone (C0)	2 982	8	29.67
West (W1–W9)	169 666	196	25.19
Disko Bay & Vaigat (I1, I2)	99 328	27	9.97
Total	345 182	270	12.93

in 2011:

Region–2011	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	55 525	25	9.75
Canadian zone (C0)*	—	0	—
West (W1–W9)*	112 215	137	30.04
Disko Bay & Vaigat (I1, I2)	92 850	30	12.40
Total	260 590	192	13.84

- sub-stratum W1-4 (400–600 m) and area C0 were not surveyed in 2011 because of sea-ice cover.

and in 2012:

Region–2012	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	33 469	26	16.0
Canadian zone (C0)*	—	0	—
West (W1–W9)	64 360	141	18.2
Disko Bay & Vaigat (I1, I2)	92 473	26	17.4
Total	190 302	193	10.8

- area C0 was not surveyed in 2012 because of ice.

The 2010 total survey biomass had been an increase over the levels recorded in 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. Strata W3 and W4 suffered catastrophic decreases in survey biomass to about 9% of the 2010 level, or 11% of their 1988–2010 mean. Disko Bay and Vaigat together remained above their 1991–2010 mean by about 38%. In 2010 there had been some catches in W1 and the northern part of W2, but very little south of about 68° 34.5’N. The northern area comprising strata U1–U3 also showed a decrease in estimated biomass, of 24%, from 2010 to 2011.

In 2012 the biomass estimate for Disko Bay and Vaigat was little changed from 2011, but there were further large decreases in biomass in U1–U3, of 40%, and in the southern offshore area (the W areas), of 44%. The decrease in the W areas was not uniform. Areas W3 and W4—north, west and south of Store Hellefiskebanke—had fallen to nothing already in 2011, so could not fall further, and areas W8 and W9 in the extreme south had been empty since 2007. The biomass estimate for areas W1 and W2 decreased to less than half its 2011 value, but in contrast areas W5–W7 collectively were close to their 2007–2011 average. As in 2011, the biomass in W2 was concentrated in the northern part of the stratum, the southern ‘tail’ being empty.

The spread index, of how widely the survey thinks the stock biomass is distributed, showed a further decrease in 2012, while the north index remained close to the high value of the previous 4 years, with little change (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; the survey biomass depth index was stable near 350 m. In the late 1990s this situation started to change. The proportion in water 300–600 m deep decreased and that in 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 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 2012 16.5% of the survey biomass was estimated to be in 150–200 m of water, 57.5% in 200–300 m, 22.3% in 300–400 m and 3.6% deeper than 400 m.

In fact, the distribution has been reversed: 17% deeper than 400 m in the early years has been replaced by 17% shallower than 150 m now, and 55% in 300–400 m of water by 55% in 200–300 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 underwent a step increase 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.

In summary: bottom temperature increased in a stepwise fashion 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.

Demography and recruitment

Length-weight relationships

In 2012, a single weight-length relationship was fitted to measurements of 2300 shrimps of all sex classes (Table.) Parameter values were little changed from 2011.

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 (g)	coefficient *a* (mg)	l_0 (mm)	exponent *z*	sample	scatter c.v. (%)
1988–2000	0	0.669	0	2.96		
2001–02	0	0.483	0	3.0576		
2003	0	0.752	0	2.9177		
2004	0	0.765	0	2.9092		
2005	0.03103	1.726	1.91	2.7188	1616	6.79
2006	0.05771	1.426	1.591	2.761204	1907	7.89
2007	0.7700	1.789	4.5*	2.78216	487	6.42
2008	-0.03285	1.4162	0.797398	2.7501	2147	6.67
2007–08	-0.121034	0.4031	-1.66043	3.052731	2634	6.88
2009	0.01823	2.774	2.19026	2.58902	1768	6.86
2010	0.1533	8.155	4.5*	2.32036	1096	6.66
2011	0.12993	9.75324	4.5*	2.25051	2569	6.64
2012	0.08185	8.928	4.229	2.27317	2300	7.31

* l_0 must be no greater than 4.5 mm.

The scatter about the fitted weight-length relationship is 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. In 2012 also the scatter was larger than in most other years.

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
2012	0.56	2.06	4.80	8.90

Estimated weights at length are consistent over years, and there is very little change between 2011 and 2012. In recent years—2008–2012—shrimps in the intermediate lengths—15 and 20 mm—seem to have been heavier than they were before 2008. 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 over the 24-year history of the survey (Fig. 8), by, on average, 83 mg/yr for females and 30 mg/yr for males. A reduction in the size at sex change would presumably change the mean size of both sexes without changing the overall mean size, but this has in fact decreased by 33 mg/yr. Alternatively, heavy fishing on the largest sizes or gear change—for example to smaller meshes—might reduce mean size in the standing stock. There is serial correlation in the residuals about the trend lines, presumably associated with the carry-over of a large fraction of the stock from one year to the next.

Recruitment and mean length at age 2

Some of the length-frequency plots—e.g. for regions I and W1–W4 in 2008 (Fig. 9b) and 2010 (Fig. 9d)—show a first component with mean CPL at 7–8 mm. These shrimps had probably hatched in the spring of the year before. Catches of this first component are small owing to the mesh size used in the survey; even the second component is not fully retained by the survey gear (Wieland 2002b).

Regional differences in length at age 2 are obvious: these pre-recruits tend to be larger in more southerly areas and in deeper water. Year-to-year changes in the mean length at age 2 have been related to shifts in bottom temperature and changes in stock density of shrimp (Wieland 2005). For the most recent five years, however, estimates of the mean size at age 2 were fairly consistent (Table 9b).

In 1993–1995 estimates of numbers at age 2 were low, particularly in Disko Bay and Vaigat (Table 10, Fig. 11); in 1996 they were exceptionally high, especially offshore, but dropped again in 1997. After 1997 age-2 numbers increased steadily to peak in 2001, followed by a steady decline to 2005. A series minimum observed in 1995 was reached again in 2007. A slight increase followed, but the estimate for 2011 of 3.6 bn was considerably below the series mean of 6.5 bn, and in 2012 there has been another large decrease (Fig. 11).

Disko Bay and Vaigat, which include only about 7% of the survey area, contributed 28–45% of the numbers at age 2 in 1997–2002, and in most of the recent years more than 40%. In 2011 the contribution from Disko Bay and Vaigat was about 71 %, but in 2012, although this area has a higher proportion of both the survey biomass and the total numbers than in 2011, it only has 64% of the age-2 shrimps.

Age-2 shrimps have always been few in the southernmost region W7 to W9, and in most years since 2004 they have also been very few in W5 and W6. Almost none were found in region C0 in 2007–2010 (Table 10).

The age-2 index is correlated with the fishable biomass two, three and four years later (Fig. 12); lags of two to four years in such a correlation might be reasonable considering that the main contribution to the fishable biomass comes from sizes corresponding to ages 4 to 6 years. The recent low numbers of small shrimps presage a decrease of the fishable biomass in the coming years to below the average of the late 1990s. However, these estimates are uncertain: the series both of age-2 numbers and of fishable biomass have strong serial correlation, which invalidates the nominal levels of statistical significance of the simple correlations.

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 in 2012 at 39.4% still an above-average proportion of the total biomass (Table 7), and female numbers at 23.2% are also an above-average proportion of total numbers (Table 6).

Compared with the length distributions of the 7 foregoing years, 2005–2011, 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 23% 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 and to the spawning stocks.

Bottom temperature

Area weighted bottom temperatures are given in Fig. 12. Bottom temperatures this year were close to average. In the southern-most areas—W5–W9—the temperature stayed close to the relatively high average. In W1–W3 it was slightly higher again in 2012. In Disko Bay and in the northern strata U1–U3 it was approximately the same as last year. In the shallowest water—between 150 and 200 m in depth—the area-weighted average bottom temperature has been rising continuously since 2007.

Conclusions

Stock size

In aggregate, the stock has continued the steep decline it has maintained, interrupted by a small increase in 2008–10, since its 2003 peak. However, the offshore and inshore components have had very different trajectories since 2008. Inshore, in Disko B. and Vaigat, the 2008–10 increase constituted almost a doubling of the survey biomass, which in the succeeding two years has stayed close to the level reached in 2010; now in 2012 it is at 130% of its 20-year median. Offshore—and in aggregate, the subdivisions having had somewhat different trajectories—there was almost no increase from 2008–10; and since 2010 the rapid decline offshore has continued, so now the offshore survey biomass is at 55% of its 20-year median.

Stock distribution

The area over which the stock is distributed has decreased a little more since 2011, and it remains concentrated in few survey strata in the centre of its range. Mean densities are high in Disko Bay and Vaigat—little changed since 2010—but have decreased again 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 survey data show some patches of higher density in the inshore ends of the gullies between the banks. The inshore area, Disko Bay and Vaigat, has an extraordinarily high fraction of the biomass. The latitude index of the survey has not changed, the decreases in density in the W strata having been balanced by a further 40% 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. 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 is heavily weighted toward the largest, female, shrimps. But at the same time, it seems deficient in large males. As a result, while the fishable biomass is close to average as a proportion of the total, it is composed to an exceptionally high degree of females. Numbers at age 2 are, overall, at their lowest level ever and even relative to survey biomass are below their lower quartile.

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Table 1. *Pandalus borealis* in West Greenland: vessels, trawl types and rigging parameters used in the West Greenland Bottom Trawl Survey for shrimp and fish, 1988–2012

	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	**
2005–2012	"	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. *Pandalus borealis* in West Greenland: survey estimates of total biomass 2012

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					
I1-1	407	3	30.517	12.408	14.2023	30.4
I1-2	1963	4	19.812	38.893	224.8569	38.6
I1-3	2441	6	6.729	16.428	10.7661	20.0
I1-4	1499	3	1.004	1.504	0.1705	27.5
I2-1	419	3	7.732	3.242	6.8736	80.9
I2-2	815	2	18.766	15.294	1.2208	7.2
I2-3	1085	3	2.317	2.514	0.1432	15.1
I2-4	1338	2	1.636	2.189	0.0068	3.8
Overall I	9967	26	9.278	92.473	258.2401	17.4
U1-1	2486	2	0.163	0.405	0.0620	61.5
U1-2	4633	2	0.928	4.298	8.0656	66.1
U1-3	4785	2	0.552	2.642	1.0971	39.6
U1-4	5129	2	0.028	0.146	0.0196	96.0
U2-2	6710	2	1.157	7.764	1.0021	12.9
U2-3	8481	2	0.713	6.044	0.9824	16.4
U2-4	7994	3	0.009	0.070	0.0012	49.2
U3-1	2012	3	0.471	0.948	0.6430	84.5
U3-2	3017	4	2.483	7.490	12.8364	47.8
U3-3	1675	2	1.604	2.685	3.7778	72.4
U3-4	2710	2	0.361	0.977	0.1362	37.8
Overall U	49631	26	0.674	33.469	28.6235	16.0
W1-1	2873	2	0.442	1.269	0.0553	18.5
W1-2	6099	13	2.207	13.459	5.4321	17.3
W1-3	7520	8	1.333	10.025	8.9815	29.9
W1-4	816	2	0.003	0.002	0.0000	77.7
W2-1	1674	2	0.446	0.747	0.0201	19.0
W2-2	2612	9	2.479	6.474	6.1392	38.3
W2-3	1741	4	1.039	1.808	2.1969	82.0
W2-4	915	2	0.067	0.061	0.0008	46.1
W3-1	2122	3	0.453	0.961	0.9043	99.0
W3-2	4725	13	0.651	3.074	1.5707	40.8
W3-3	2085	2	0.028	0.058	0.0001	15.8
W3-4	2994	4	0.356	1.066	0.1018	29.9
W4-1	4119	2	0.105	0.431	0.0010	7.4

Stratum	Area (km^2)	Stations	Biomass density (t/km^2)	Biomass (Kt)	Biomass error variance	Error coefft of variation (%)†
W4-2	1818	6	0.485	0.881	0.1077	37.2
W4-3	821	4	0.156	0.128	0.0132	89.7
W4-4	1961	2	0.210	0.412	0.1104	80.6
W5-1	3001	6	2.056	6.171	16.9592	66.7
W5-2	3648	7	0.176	0.641	0.2408	76.6
W5-3	1950	2	0.011	0.022	0.0002	69.3
W5-4	3021	2	0.004	0.011	0.0001	90.4
W6-1	1206	2	4.073	4.912	24.1230	100.0
W6-2	2006	8	3.976	7.975	59.9502	97.1
W6-3	1585	7	0.083	0.132	0.0091	72.5
W6-4	1234	2	0.003	0.004	0.0000	100.0
W7-1	2442	3	0.000	0.000	0.0000	0.0
W7-2	891	5	3.635	3.241	10.5012	100.0
W7-3	265	1	0.002	0.000	0.0000	95.0
W7-4	317	2	0.001	0.000	0.0000	100.0
W8-1	424	2	0.000	0.000	0.0000	100.0
W8-2	567	2	0.003	0.002	0.0000	59.3
W8-3	405	1	0.129	0.052	0.0025	95.0
W8-4	718	2	0.475	0.341	0.1105	97.4
W9-1	1711	3	0.000	0.000	0.0000	0.0
W9-2	938	3	0.000	0.000	0.0000	100.0
W9-3	516	2	0.000	0.000	0.0000	100.0
W9-4	430	1	0.000	0.000	0.0000	95.0
Overall W	72169	141	0.892	64.360	137.5318	18.2
Survey totals	136003	193	1.399	190.302	424.3954	10.8

† strata with 1 trawled station have been assigned an error coefficient of variation of 95%
* area C0 was not surveyed in 2012 because there was too much sea ice there; its area has not been included in survey areas, nor in the calculation of average density.

Table 3. *Pandalus borealis* in West Greenland: biomass estimates (Kt) for survey subdivisions and standard errors for the entire survey in 1988–2012.

Year	N1–9/ U1–3[1,5]	C1–3/ C0[1,6]	W1–2	W3–4	W5–7[2]	S/W8–9[1]	D1–9/ I1–2 [1,3]	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	5.4	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	69.2	6.1	34.3	2.6	92.9	260.6	36.1
2012	33.5	0.0	33.8	7.0	23.1	0.4	92.5	190.3	20.6

[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 199, respectively

[3]: D1–D9 were not sampled before 1991, but retrospectively set for 1988–90 to the mean for 1991–1997.

[4]: Standard error calculated excluding D1–D9 in 1988–1990

[5]: Probably underestimated owing to poor coverage of the northern part of area N

[6]: Area C was not sampled in 2011 or 2012owing to ice conditions

Table 4. *Pandalus borealis* in West Greenland: error coefficients of variation (%) for the biomass estimates of five main survey regions and the entire survey area in 1988–2012.

Year	N1–9/ U1–3	C1–3/ C0	W1–2	W3–4	W5–7	S/W8–9	D1–9/ I1–2	Total suvey	Number of hauls
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	11.1	29.7	27.0	61.0	66.9	98.7	10.0	12.94	270
2011	9.8	-(1)	19.1	26.2	89.0	80.5	12.4	13.85	192
2012	16.0	-(1)	12.4	23.9	45.8	84.6	17.4	10.83	193
Mean 1994–2012								13.66	

1: C0 (Canada) was not sampled in 2011 or 2012

Table 5. *Pandalus borealis* in West Greenland: estimated mean densities (t/km^2) for survey subdivisions in 1988–2012.

Year	N1–9/ U1–3	C1–3/ C0	W1–2	W3–4	W5–7	S/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
2012	0.67	—	1.40	0.34	1.07	0.07	9.28

Table 6. *Pandalus borealis* in West Greenland: estimated numbers (billions) by sex in 1988–2012.

Year	Juv. & Males	Females	Total	Juv. & Males %	Females %
1988[1]	26.8	9.3	36.1	74.3	25.7
1989[1]	39.0	6.9	45.9	85.0	15.0
1990[1]	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[2]	36.8	13.0	49.8	74.0	26.0
2012[2]	28.8	8.7	37.4	77.0	23.2
Average	48.4	12.3	60.7	79.8	20.2

[1] mean values for Disko Bay and Vaigat in 1991–1997 have been inserted for 1988–1990, and included in the calculation of the average.
[2] area C0 was not surveyed in 2011 or 2012 owing to sea ice; no correction has been made.

Table 7. *Pandalus borealis* in West Greenland: biomass estimates ('000 t) by sex based on length-weight distributions from the West Greenland shrimp survey in 1988–2012.

Year	Juv. & Males	Females	Total	Juv. & Males %	Females %
1988[1]	134.7	94.8	229.5	58.7	41.3
1989[1]	157.1	68.6	225.7	69.6	30.4
1990[1]	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[2]	355.2	196.7	551.9	64.4	35.6
2006[2]	297.4	188.0	485.4	61.3	38.7
2007[2]	227.8	128.7	356.6	63.9	36.1
2008[2]	182.6	99.5	282.1	64.7	35.3
2009[2]	173.5	105.0	278.4	62.3	37.7
2010[2]	222.3	122.4	344.7	64.5	35.5
2011	148.5	112.0	260.6	57.0	43.0
2012	115.4	74.9	190.3	60.7	39.3
Average	194.2	107.8	302.0	64.3	35.7

[1] 1991–1997 mean values for Disko Bay and Vaigat have been used for 1988–1990, and included in the calculation of the average.
[2] data for 2005–2010 was re-analysed in 2011.

Table 8. *Pandalus borealis* in West Greenland: estimates of fishable biomass (≥17mm CL; ‘000 t) from the West Greenland shrimp survey in 1988–2012.

Year	Offshore fishable		Disko fishable		Overall fishable	
	biomass	%	biomass	%	biomass	%
1988	186.2		37.0		223.2	
1989	171.9		37.0		209.0	
1990	170.0		37.0		207.0	
1991	104.7	98%	41.3	96%	146.0	97%
1992	154.8	95%	39.4	95%	194.2	95%
1993	189.4	94%	27.1	96%	216.5	94%
1994	191.0	95%	32.1	94%	223.1	95%
1995	144.9	95%	38.3	98%	183.2	96%
1996	150.6	88%	41.5	94%	192.1	89%
1997	127.7	96%	39.4	89%	167.1	94%
1998	197.2	94%	47.1	91%	244.3	94%
1999	195.0	94%	42.3	80%	237.3	91%
2000	219.8	90%	60.6	83%	280.3	88%
2001	216.8	85%	63.7	88%	280.5	86%
2002	302.2	90%	67.2	78%	369.5	88%
2003	454.0	93%	94.3	88%	548.3	92%
2004	457.5	95%	70.8	87%	528.3	94%
2005	381.8	93%	112.3	80%	494.2	90%
2006	358.6	96%	92.4	83%	451.0	93%
2007	264.7	95%	71.3	90%	336.1	94%
2008	216.8	94%	45.8	90%	262.6	93%
2009	192.2	92%	62.8	90%	255.1	92%
2010	229.8	94%	88.9	90%	318.7	92%
2011	155.9	93%	83.1	89%	239.0	92%
2012	89.5	91%	83.9	91%	173.3	91%
Average	220.9	93%	58.3	89%	279.2	92%

[1] 1991–1997 mean values for Disko Bay and Vaigat have been used for 1988–1990, and included in the calculation of the average.
[2] data for 2005–2010 was re-analysed in 2011.
[3] area C0 was not surveyed in 2011 or 2012, nor substratum W1-4 in 2011, owing to sea ice;.

Table 9a. *Pandalus borealis* in West Greenland: mean carapace length (mm) at age 2 in 1993–2006, with standard deviations and coefficients of variation (- : not present, ( ): fixed in the final MIX.run).

	U1–U3	I1–I2	C0 & W1–W4		W5–W6		W7–W9
Depth (m)	150-600	150-600	150-300	300-600	150-300	300-600	150-600
Means							
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 deviations							
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)
Coefficents of variation:							
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. *Pandalus borealis* in West Greenland: mean carapace length (mm) at age 2 in 2007–2012, with standard deviations and coefficients of variation (- : not present, ( ): fixed in the final CMIX run, na: no data).

	U1-U3 150-600 m	I1+I2 150-600 m	C0 200-600 m	W1-W4 150-600 m	W5+W6 150-600 m	W7-W9 150-600 m
Means:						
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	-
2012	11.8	11.5	na	12.1	13.3	-
Standard deviations:						
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	-
2012	1.22	1.23	na	1.03	1.12	-
Coefficents of variation:						
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	0.10	0.10	-
2012	0.10	0.11	na	0.09	0.08	-

Table 10. *Pandalus borealis* in West Greenland: survey estimate of numbers (billions) at age 2 years, 1993–2012.

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[1]	0.01	0.21	1.51		1.20	0.00	2.92
1995[1]	0.02	0.11	0.82		1.37	0.00	2.32
1996[1]	0.11	1.25	2.45		6.20	0.00	10.01
1997[1]	0.05	1.37	0.52		1.27	0.00	3.22
1998[1]	0.04	1.79	2.01		2.60	0.00	6.44
1999[1]	0.42	5.06	2.66		3.22	0.00	11.36
2000[1]	0.33	5.54	4.92		3.50	0.01	14.29
2001[1]	1.66	5.44	7.79		1.01	0.01	15.90
2002[1]	0.02	3.98	3.41		2.97	0.04	10.42
2003[1]	0.76	1.11	1.70		2.88	0.03	6.48
2004[1]	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[2]	0.70	2.44	*0.01*	0.42	0.03	0.00	3.59
2012[2]	0.34	1.33	*0.01*	0.17	0.23	0.00	2.08
Average:	0.57	2.22	2.00		1.51	0.01	6.31

[1] data for 1993 to 2004 has been converted from Skervøy to Cosmos trawl;
[2] for area C0 in 2011 and 2012, when it was not surveyed, the average value from 2007 to 2010 has been used.

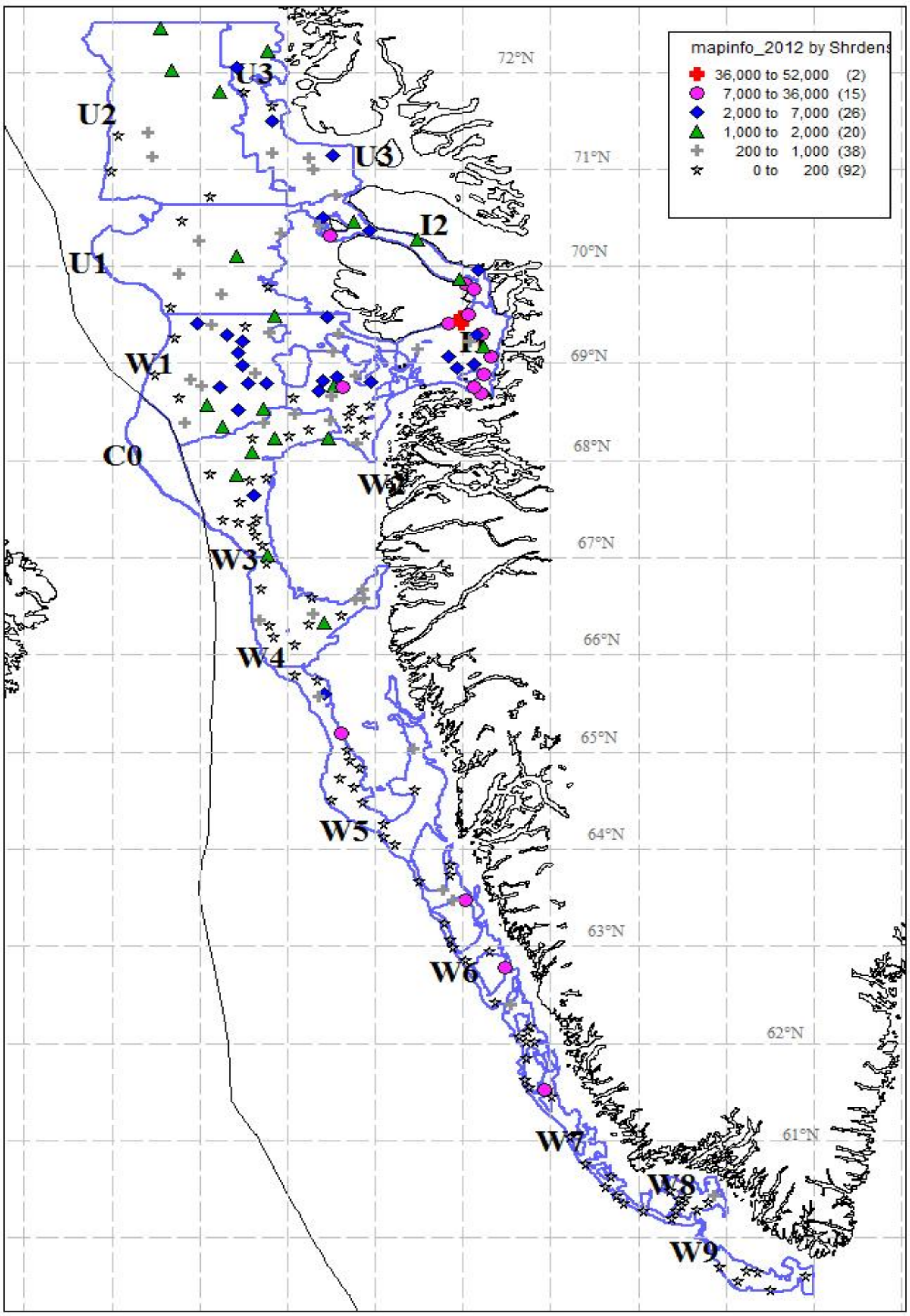
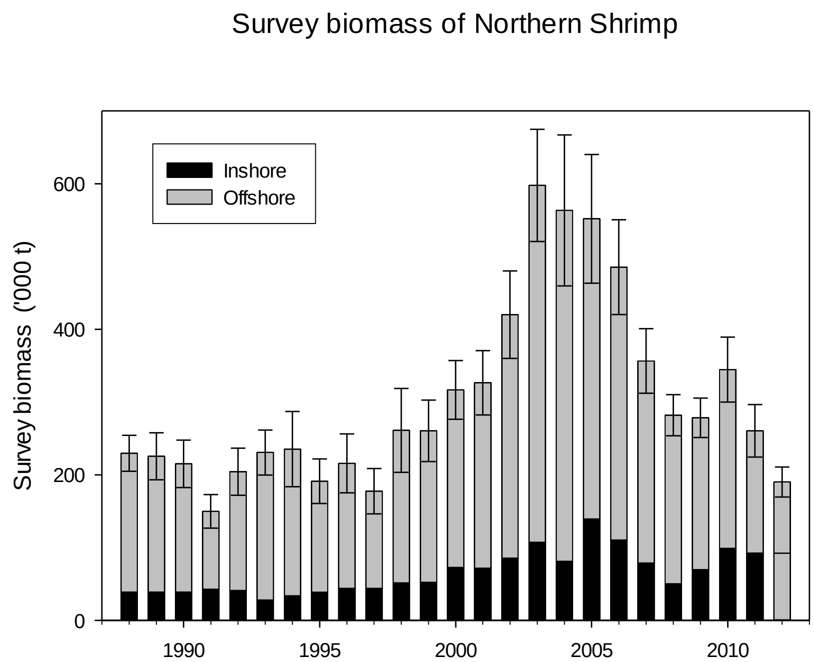


Figure 1. *Pandalus borealis* in West Greenland: density distribution from 193 trawl-survey stations in 2012. Area C0 could not be surveyed in 2012 because there was too much sea ice there.



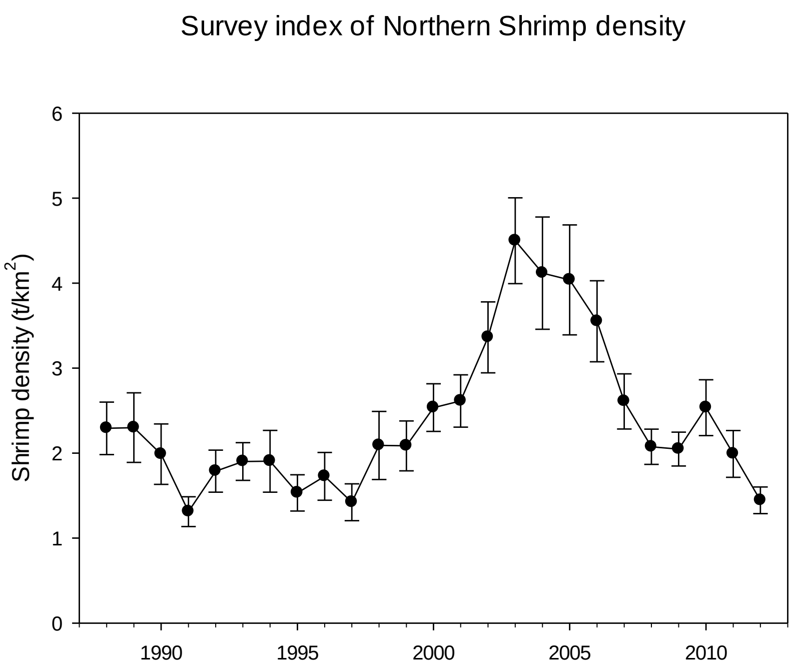


Figure 2a. *Pandalus borealis* in West Greenland: estimated survey biomass and survey mean density, 1988–2012. Area C0 was not surveyed in 2011 or 2012, nor sub-stratum W1-4 in 2011, because of sea ice.

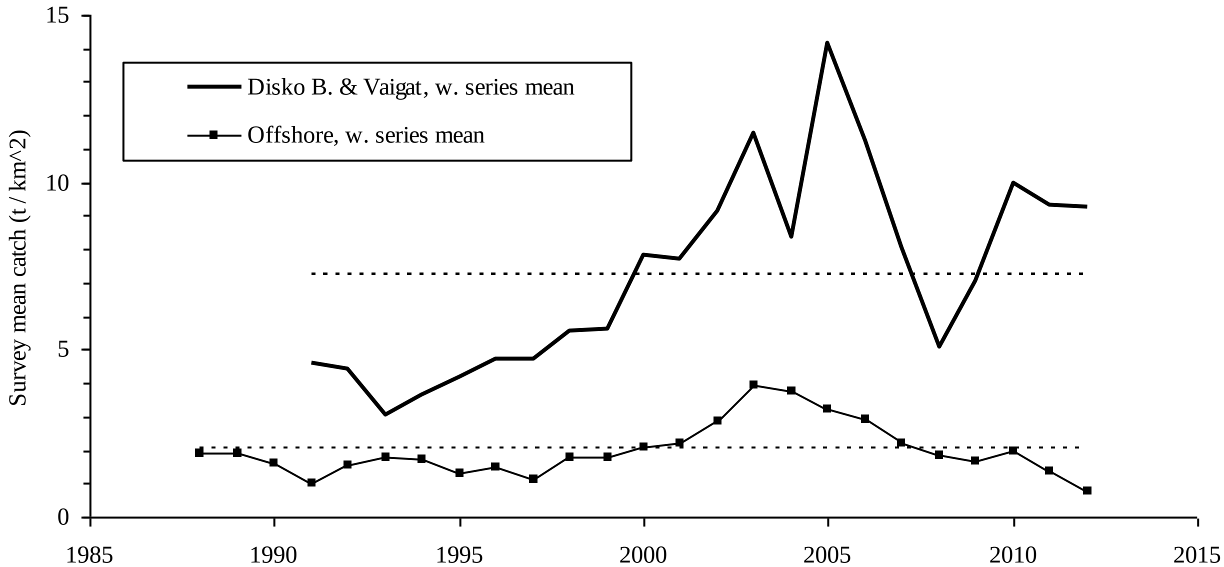


Figure 2b. *Pandalus borealis* in West Greenland: mean survey density of Northern shrimp in Disko Bay and Vaigat (since 1991 7–8% of the survey area) and offshore (92–93%).

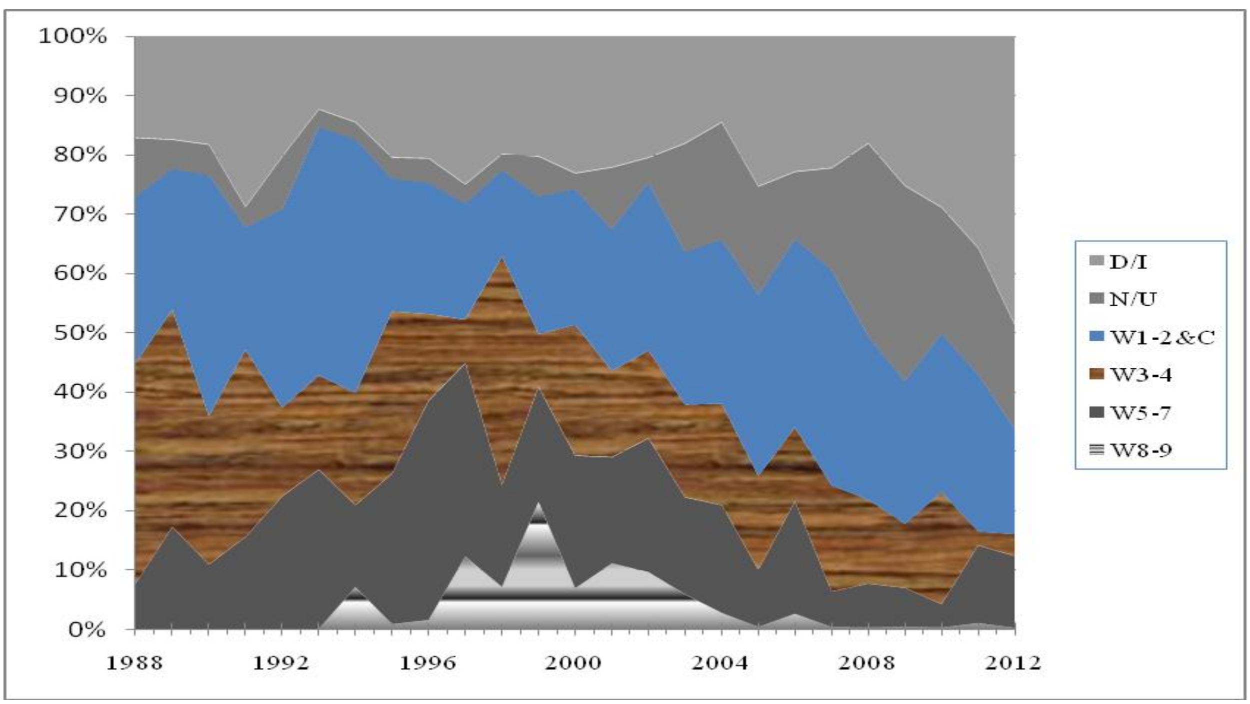


Figure 3. *Pandalus borealis* in West Greenland: distribution of survey biomass between major survey regions, 1991–2012. Area C0 could not be surveyed in 2011 or 2012 because there was too much sea ice there.

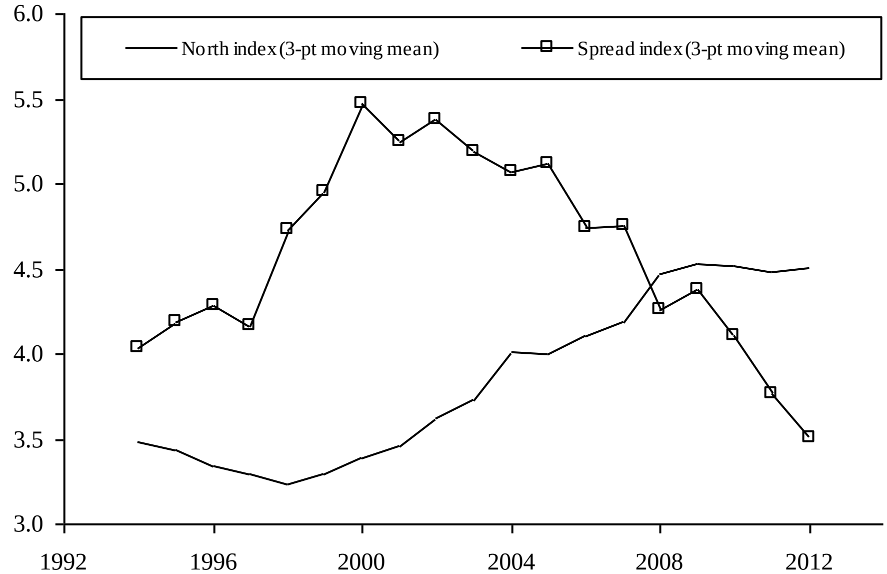


Figure 4. *Pandalus borealis* in West Greenland: indices of distribution and location of shrimp biomass in the West Greenland trawl survey 1994–2012 (3-point moving averages).

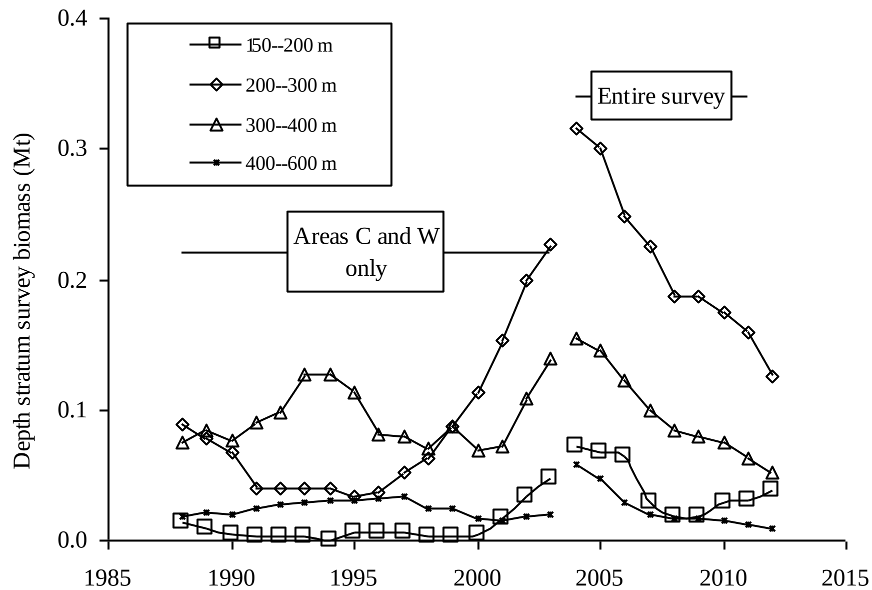


Figure 5a. *Pandalus borealis* in West Greenland: survey biomass estimates by depth stratum, 1988–2012. 3-point moving averages.; until 2003, only areas C and W were substratified by depth.

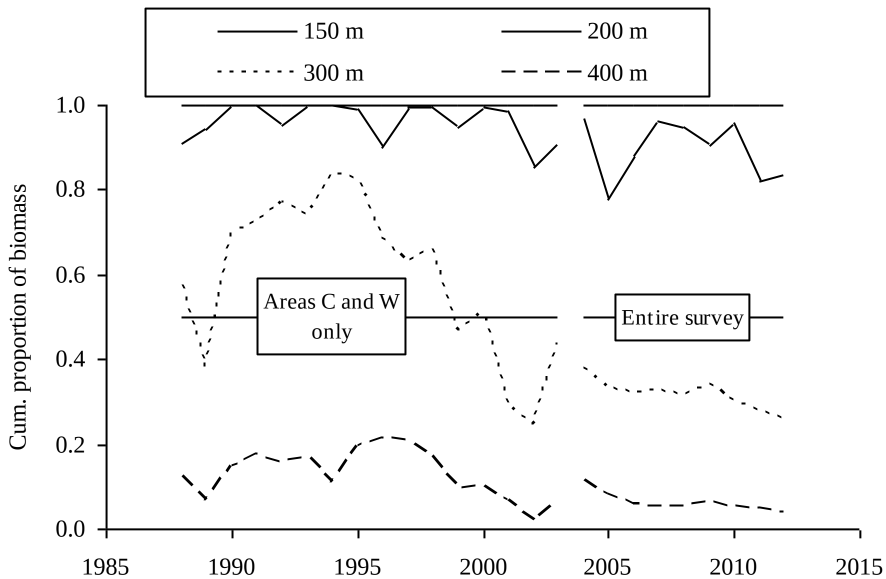


Fig. 5b. *Pandalus borealis* in West Greenland: distribution of survey biomass between 150 and 600 m by depth, 1988–2012. Until 2003, only areas C and W were substratified by depth.

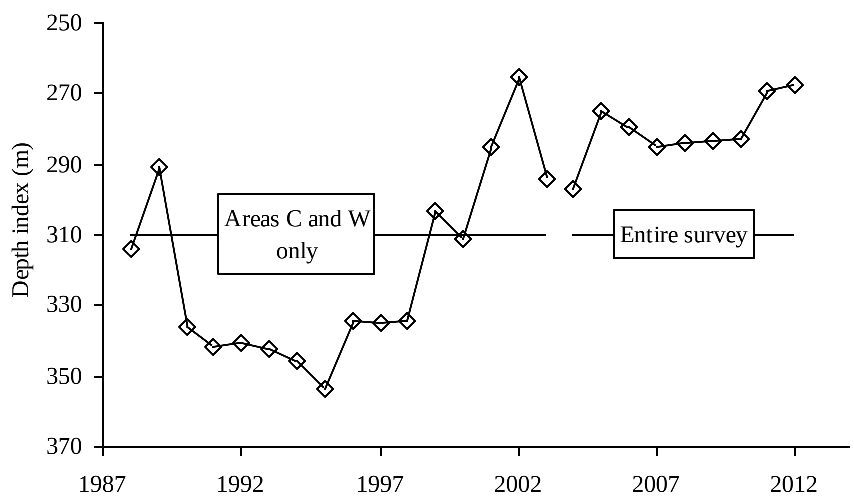


Figure 5c. *Pandalus borealis* in West Greenland: depth index for survey biomass, 1988–2012. Until 2003, only areas C and W were substratified by depth.

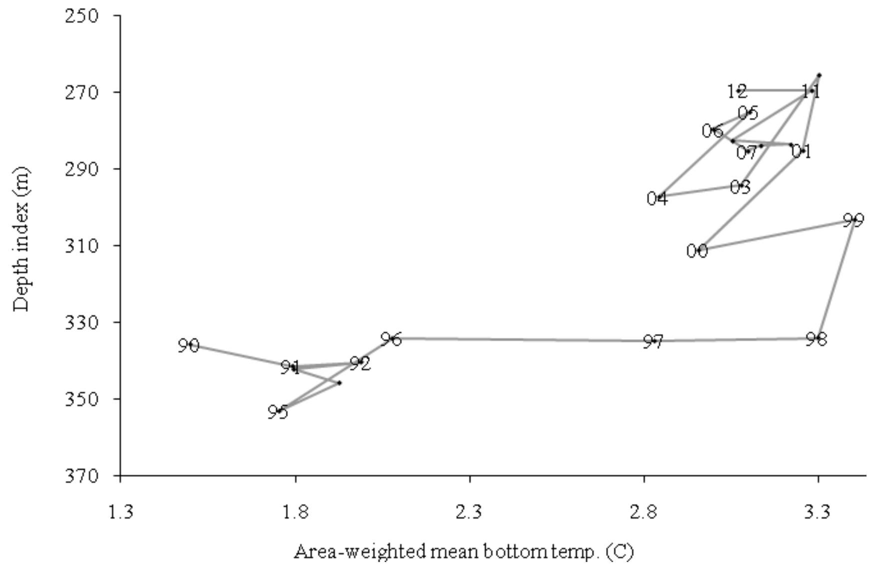
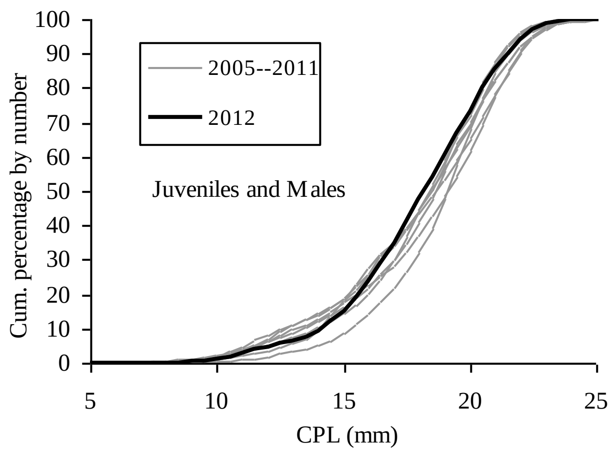


Figure 6. *Pandalus borealis* in West Greenland: depth index of survey biomass vs. area-weighted mean bottom temperature from survey trawl-door measurements, 1990–2012.



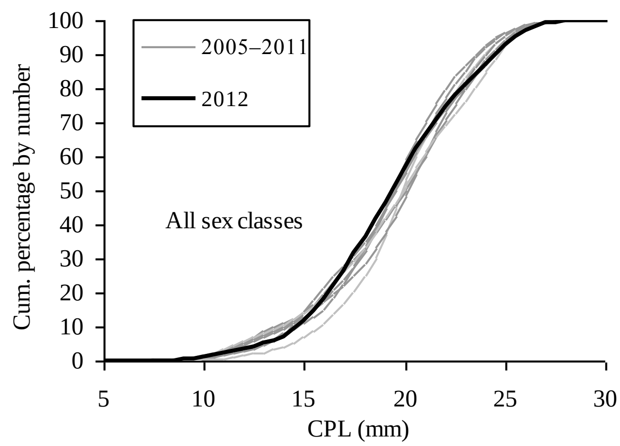


Figure 7: *Pandalus borealis* in West Greenland: distribution of lengths from survey length analyses in 2005–2011 and in 2012.

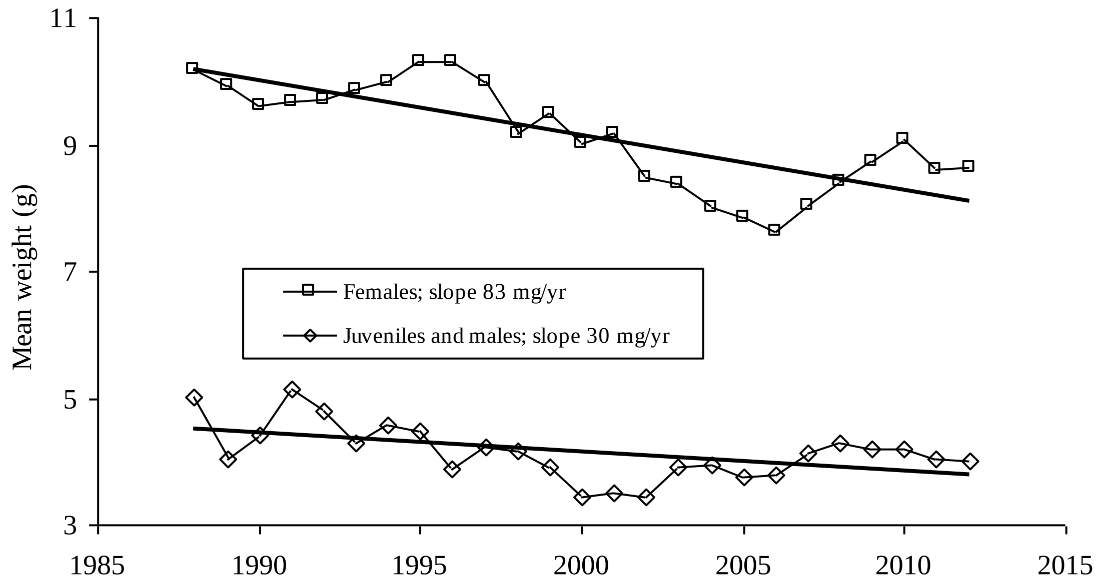


Figure 8: *Pandalus borealis* in West Greenland: mean weight, by sex, from survey data, 1988–2012.

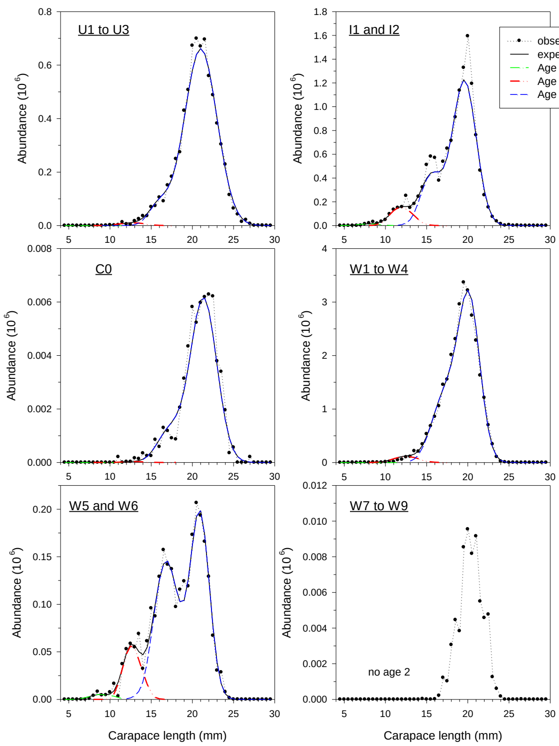


Figure 9a. *Pandalus borealis* in West Greenland: regional length frequencies in 2007

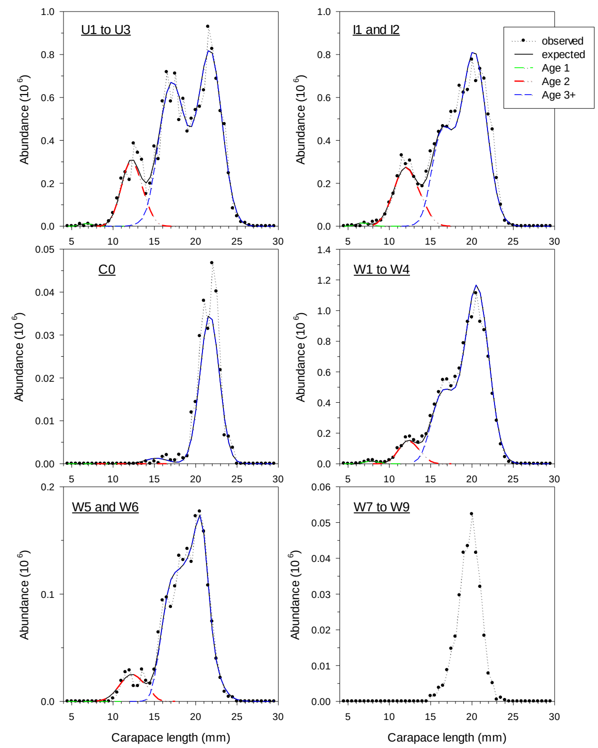


Figure 9c. *Pandalus borealis* in West Greenland: regional length frequencies in 2009.

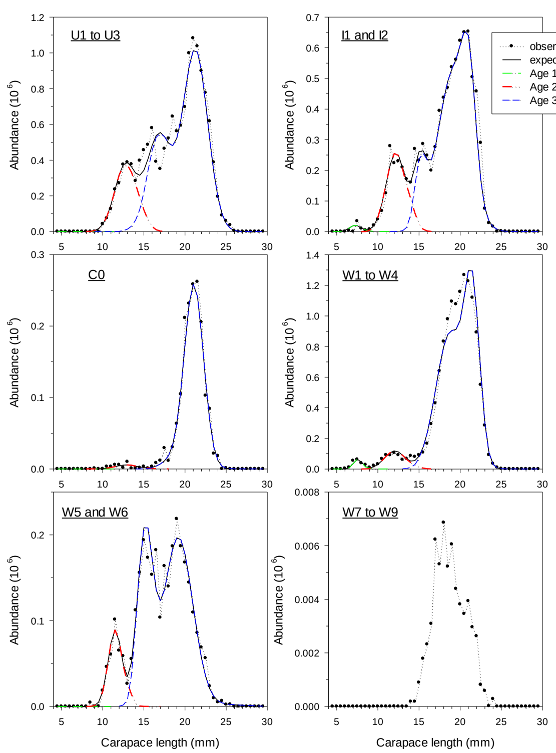


Figure 9b. *Pandalus borealis* in West Greenland: regional length frequencies in 2008.

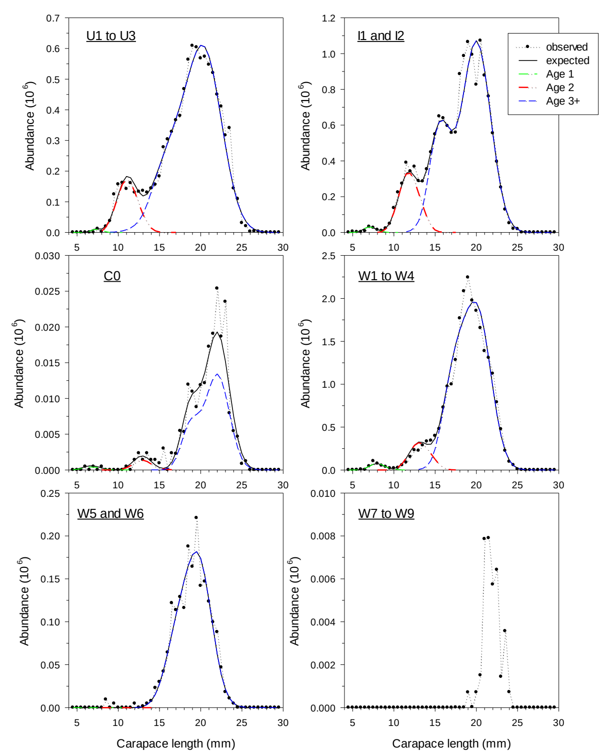


Figure 9d. *Pandalus borealis* in West Greenland: regional length frequencies in 2010.

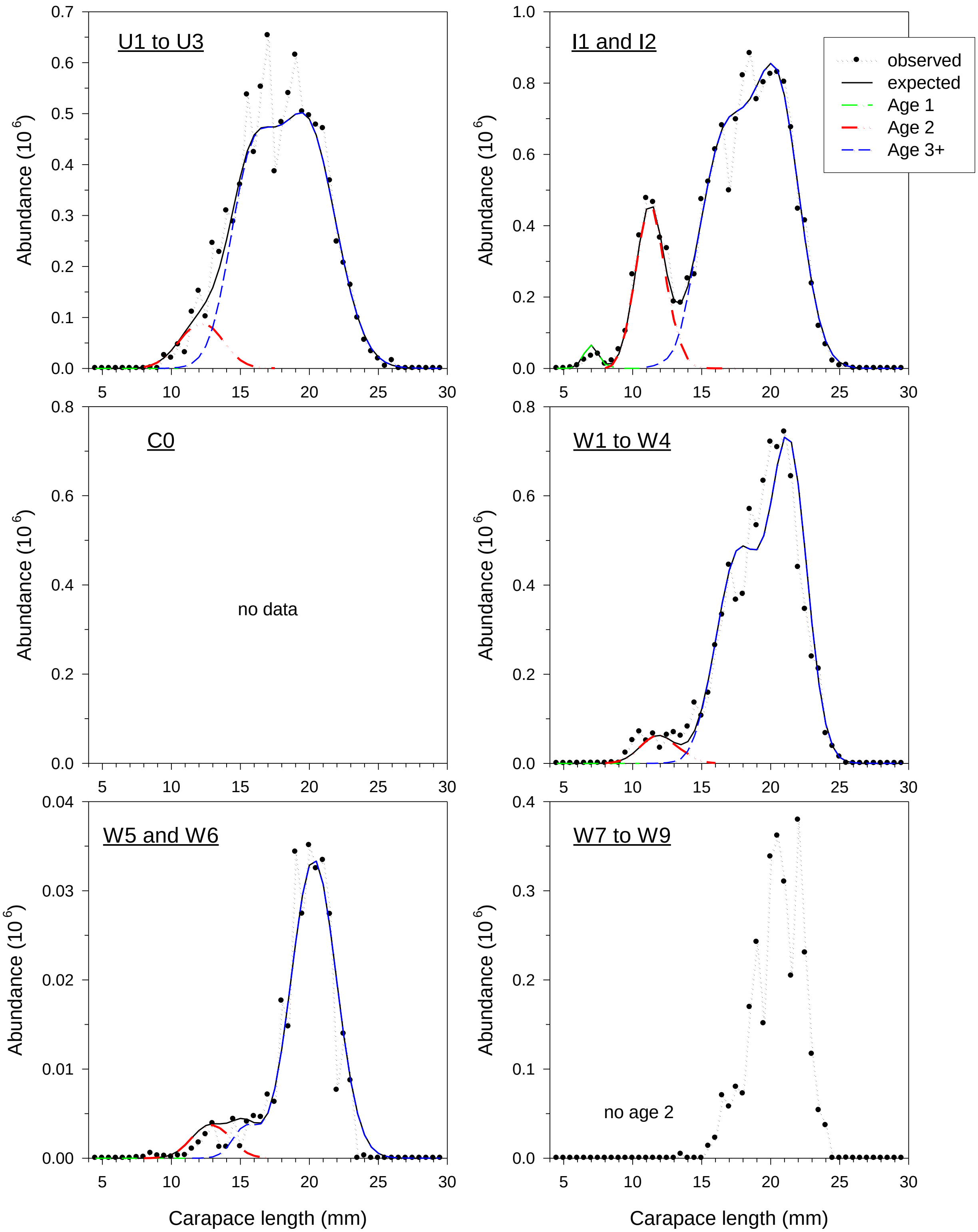


Figure 9e. *Pandalus borealis* in West Greenland: regional length frequencies in 2011. (Area C0 was not surveyed owing to ice).

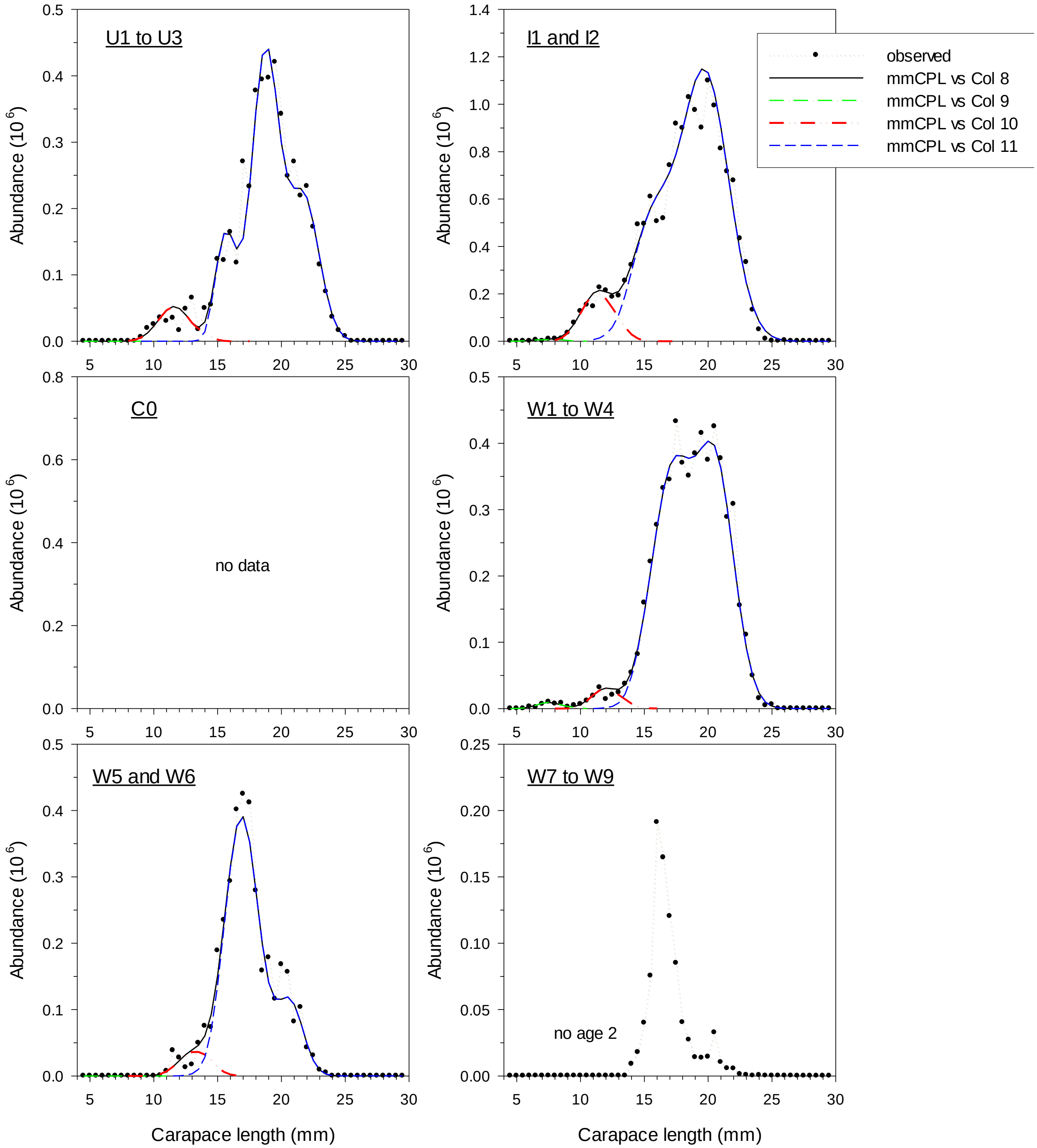


Figure 9f. *Pandalus borealis* in West Greenland: regional length frequencies in 2012. (Area C0 was not surveyed owing to ice).

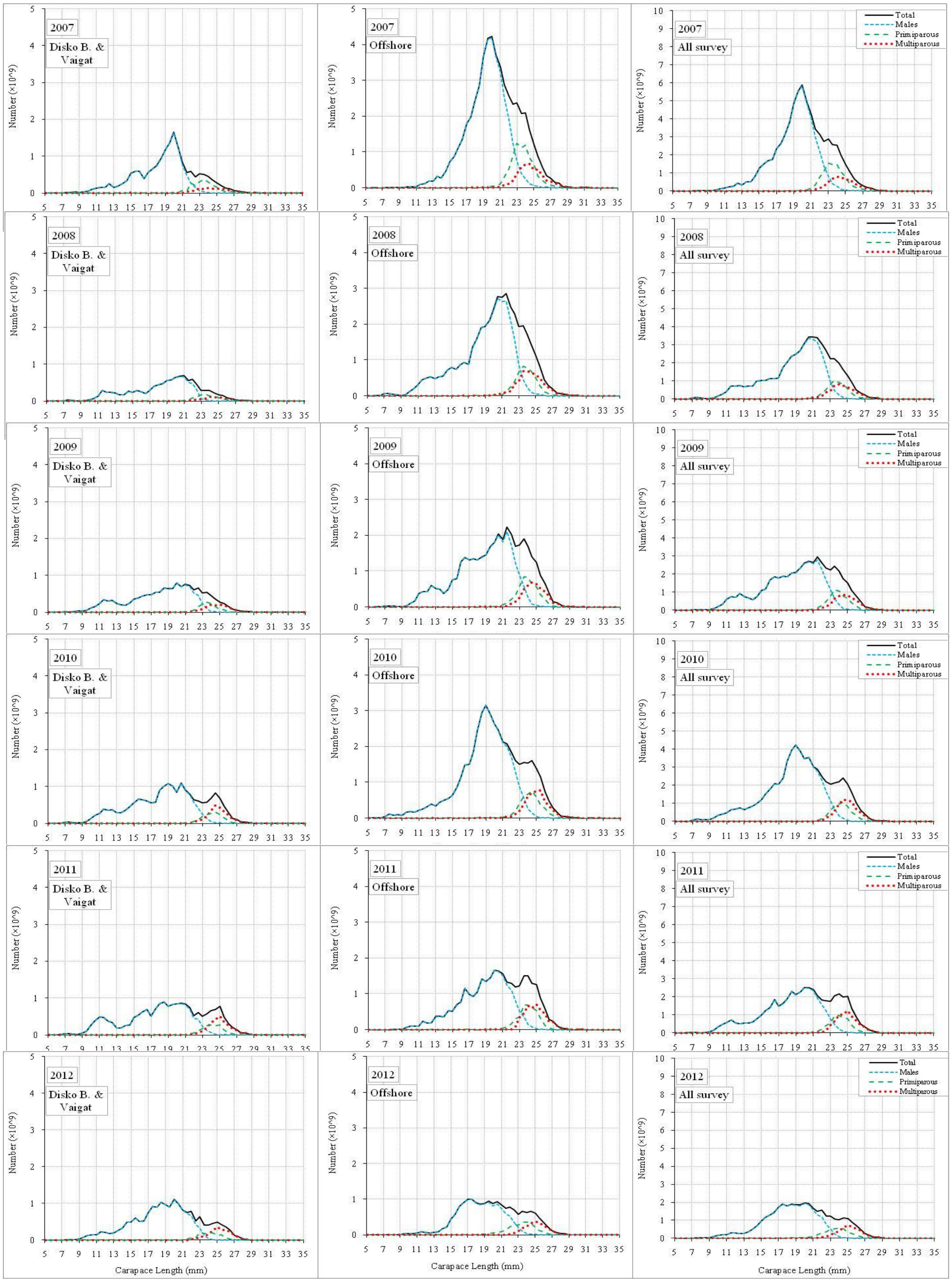


Figure 10. *Pandalus borealis* in West Greenland: length frequencies offshore, in Disko Bay and Vaigat, and overall, 2007–2012.

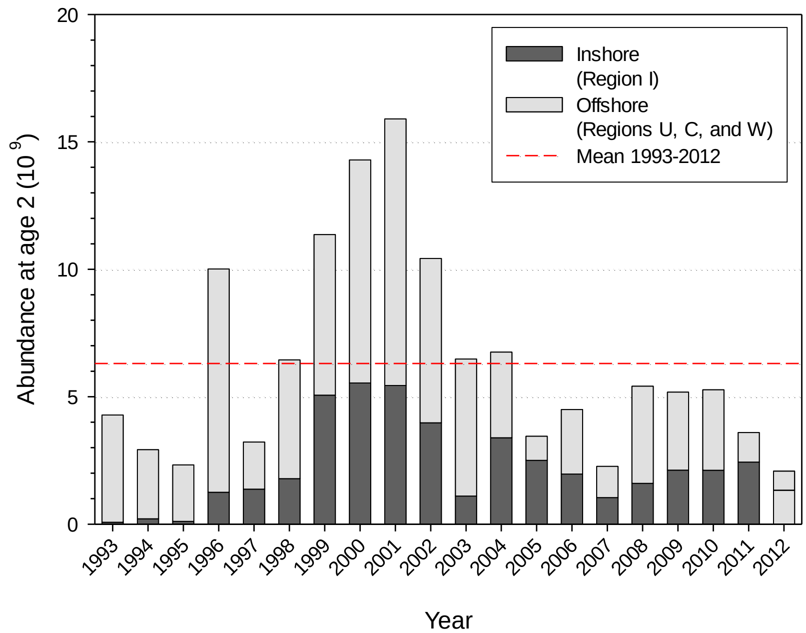


Figure 11a. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2012.

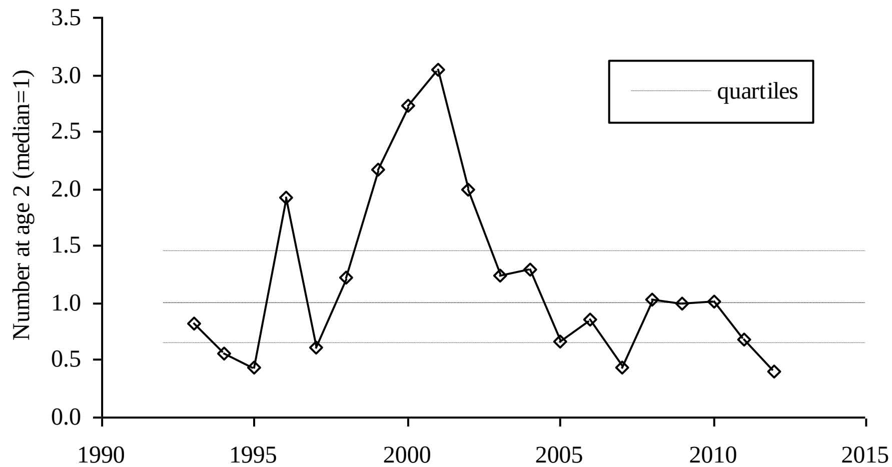


Figure 11b. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2012.

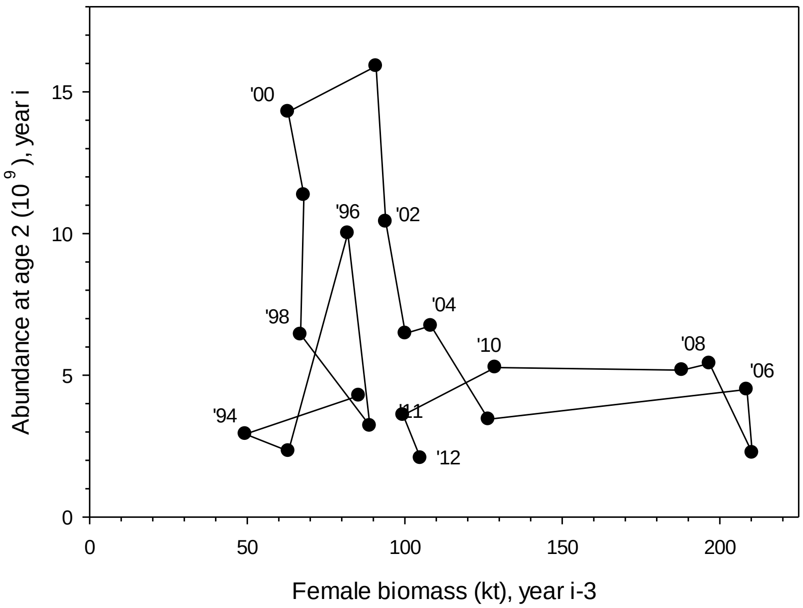


Figure 12. *Pandalus borealis* in West Greenland: survey estimates of numbers at age 2 in 1993–2012 against female biomass 3 years earlier (labels denote years in which age-2 numbers were estimated).

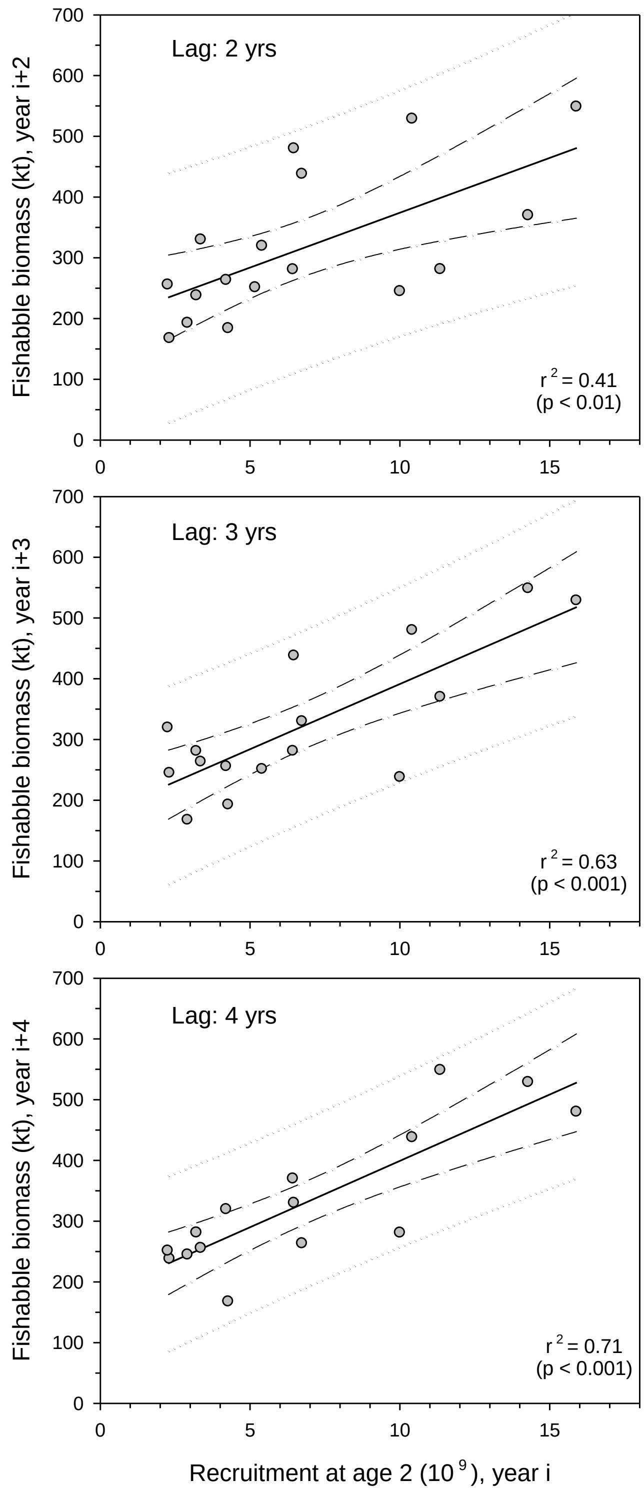


Figure 13. *Pandalus borealis* in West Greenland: lagged fishable biomass vs. survey estimates of numbers at age 2 from 1993 to 2009, 2008 or 2007 (linear regressions with 95% confidence and prediction intervals).

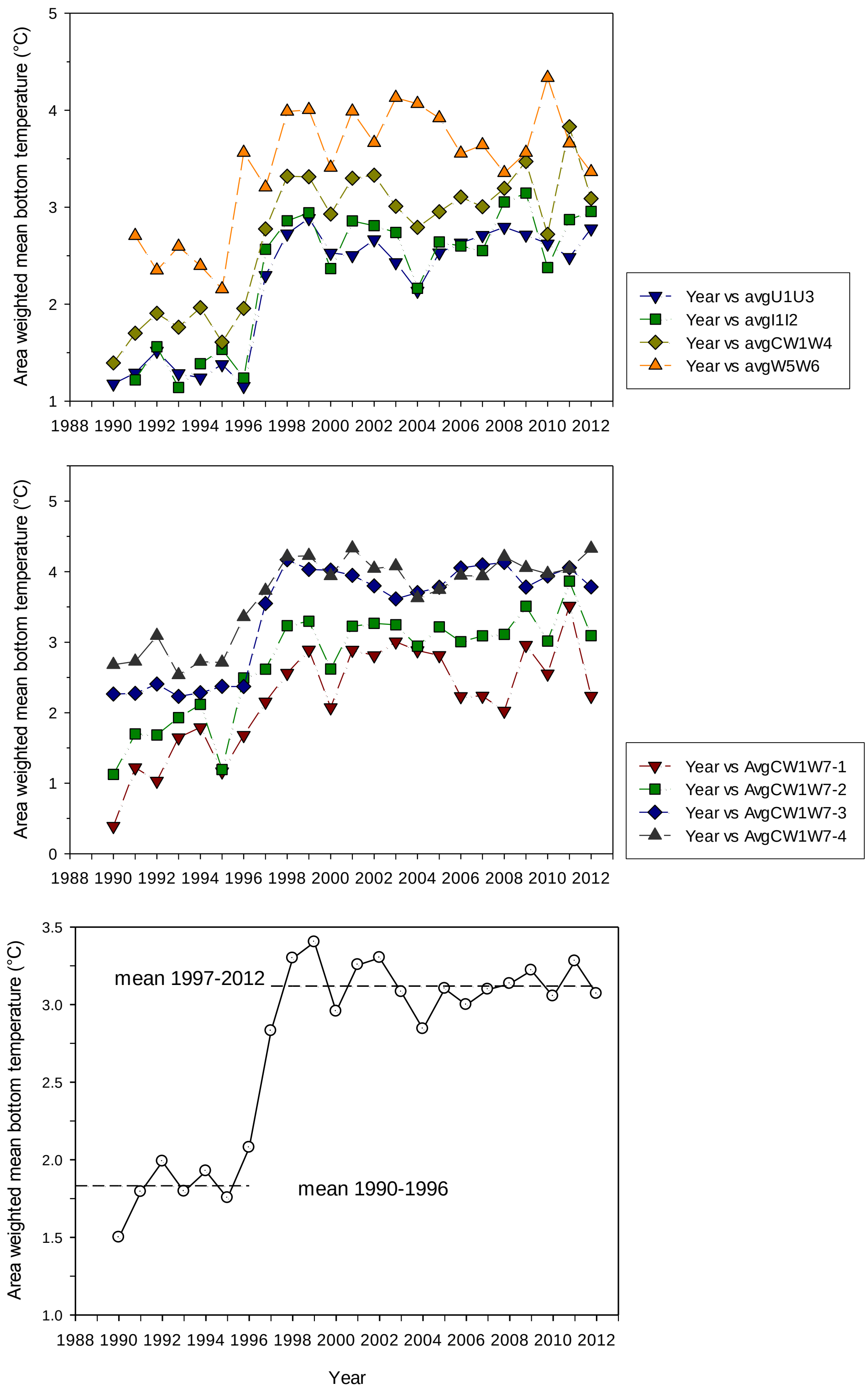


Figure 14. *Pandalus borealis* in West Greenland: area-weighted mean bottom temperature for survey regions (see Fig. 1 for locations), depth strata in offshore areas C and W1–W7, and the entire survey area in 1990–2012.