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The West Greenland trawl survey for *Pandalus borealis*, 2015, with reference to earlier results.

by

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Abstract

A trawl survey is carried 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 2015, 235 stations were fished in 42 fishing days; 186 provided data to the shrimp survey in all strata.

The 2003 peak in total survey and fishable biomasses has been followed by continuous decline, reaching in 2014 the lowest levels since 1997. Total survey biomass increased by 58% over 2014. While offshore survey biomass were 137% higher in 2015 than in 2014, and is about 85% of its previous maximum in 2010, in Disko Bay and Vaigat the survey biomass is 16% less than in 2014, 56% of its (2005) maximum, but in its range to 2007 – 2014 values. Offshore regions comprise 73% of the total survey biomass, and 27% is inshore in Disko Bay and Vaigat.

Surveyed regions showed increase in survey biomass of about 157% in U1-U3 and 128% in the West (W1-W9) compared with 2014 results. Biomass in the southern part area, W5-W9, amounted only 7% of the total estimated survey biomass in 2015 compared with the 2014 value.

The Fishable proportion of the survey biomass is below the mean of the foregoing 20 years. Female biomass is close to its 20-year median, but the proportion of the fishable biomass has, in both regions, decreased over 2014, while the biomass of fishable males significantly increased offshore but is 12% less inshore.

That the spawning stock compose a low proportion of the total survey biomass, makes the stock sensitive to fishing pressure: and long-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 20-year upper quantile when considered relative to survey biomass. Absolute numbers of age-2 shrimps increased by more than four times offshore, but remain at a comparable 2014 level inshore.

Since the late 1990s the stock is found in shallower water than before, this trend have continued since 2011, except for and increase over 2013, and in 2015 the survey biomass depth index at 266m is at a comparable level to its previous past.

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 2015.

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 2014 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 2015, 294 stations were planned at depths between 150 and 600 m in the survey area, with 82 'extra' stations mapped and available to be included if time permitted. 235 of the 294 planned stations incl. 55

‘extra’ stations were fished. 33 stations were reported as having been moved more than 2 n.mi. from the planned position, with a mean of 15.24 n.mi.; 1 of the 33 because of untrawlable bottom and 10 station were discarded owing to general trawl difficulties.
Of the 235 stations fished, 186 provided usable data to the shrimp survey. In the course of the shrimp survey, 33 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 minimize 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.

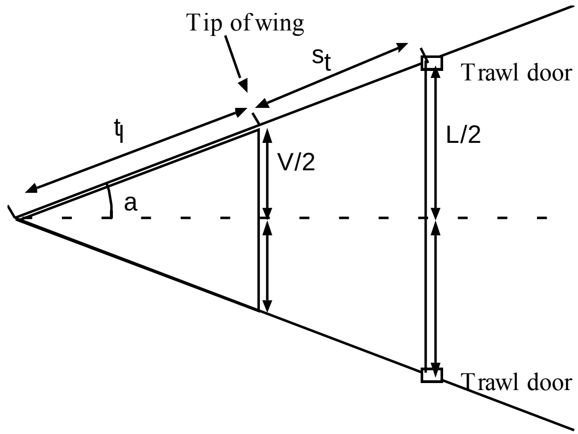
Fishing practices

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 door spread 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 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. 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.

Indices of distribution and location of shrimp biomass

Indices to summarize 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:

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

This index summarizes 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 analyzed 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 meters, 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 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, 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 Partiel Mix (Kingsley, 2014, MCSKMIX 2014 © Greenland Institute of Natural Resources), implemented in an Excel spread sheet. Partiel MIX fits numbers of shrimps at age 2 years and is estimated by decomposing the length distributions, fitting Normally distributed components.. To prevent a skweness to the plus age 3 group, analysis was only done on shrimps below ore equal to 19 mm CPL. While using this new method in 2014, all age-2 results from 2005 to 2014 was re-calculated. A more comprehensive decription of the method is found in Kingsley (2014).

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 analyzed. The analyses of sex and length distribution in the stock, and the modal analyses, were re-done in 2014 for data from 2005–2014. To simplify the modal analysis, 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 Partil MIX as a haul.

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 2015 started from Nuuk on 28 May. The first cruise occupied stations from Nuuk north to Disko Bay having occupied 65 shrimp and fish stations and 15 CTD cast in 14 days. The second cruise occupied 89 shrimp and fish stations and 18 CTD cast in 19 days in Vaigat, north to the survey limit, and west of Disko on its way back south, the northern area being less densely sampled. The third cruise started from Nuuk on 02 July to occupy 81 stations south to the southern limit of the survey and occupied 68 stations at 14 days until July the 24. No CTD cast were sampled at the third trip.

All cruise was accompanied by a crew engaged in taking photographs of the sea bottom, who used the ship at night when the survey was suspended. From all planned shrimp and fish stations, at the tree cruises, by-catch of benthic faunal invertebrates were sorted from each stations at all, identified to the lowest possible taxonomic level, and some species were preserved in 10% buffered formalin solution for later identification, and both projects amis to investigate the long-term effects of trawling on bottom ecosystems. Same procedure were done for benthic species sampled with a beam-trawl. 21 beam-trawl stations were done at the first cruise, 38 beam-trawl stations at the second cruise and 14 beam-trawl stations at the third cruise. Of the 58 planned survey strata, 1 (the Canadian zone C0) had no stations trawled caused by the ice cover. 35 stations had no catch of *P. borealis*; 7 strata, with 23 occupied stations between them, had no catches and only strata U1 – U3, I1, I2, W1, and W4 had catches *of P. borealis* at all stations. Length samples were measured from 29 stations with catches, even very small ones.

There were no exceptionally large catches and only at one station in I2-1 catches exceeded 1 ton. There were 25 catches over 200 kg, of which 13 were made in Disko Bay or Vaigat, 3 stations north from 69°30 N, 7 in strata W1-W4 and 2 in W6. Disko Bay or Vaigat. In southerly areas, strata W7-W9 yielded an average catch of 2.2kg and 24 of 36 stations had no catch of *P. borealis*.

Owing to ice cover in some substrata, the proportion coverage were less this year than usually. Proportion coverage in U1-1 were 0.75, U1-2: 0.59, U1-3: 0.26, U1-4: 0.20, U2-2: 0.80, U2-3: 0.33, U2-4: 0.30, W1: 0.98, W1-2: 0.39, W1-3: 0.26, w3-2: 0.61, W3-3: 0.64 and W3-4: 0.81.

Based on observations from the pasts surveys, it was hypothesized that density of shrimps were higher at lower longitude. Simple linear regressions of density of shrimps (kg/km$^{2)}$ as a function of longitude were performed to test this hypothesis. Overall the result in the table below, reviled that most slopes are negative, indicating that density tend to be lower with increasing longitude, however, this tendency was not significant within all substrata.

Strata	**n**	**Slope**	**b**	**Adj R^2**	**t value (slope)**	***P***
U1-1	11	-1696.76	96518	0.0059	-1.03	0.3303
U1-2	14	-336.46	20351	-0.0377	-0.73	0.4813
U1-3	16	237.59572	-12483	16	0.3	0.7688
U1-4	8	-67.37	3989.15	0.2527	-1.84	0.1162
U2-2	12	-4.87	1695.31	-0.1	-0.01	0.9914
U2-3	16	-284.58	17615	0.0503	-1.34	0.2018
U2-4	20	-108.16	6517.22	0.2959	-3	0.0077
W1-1	11	-701.197	40686	-0.0445	-0.76	0.4679
W1-2	64	-598.61	37528	0.0174	-1.47	0.1458
W1-3	36	-732.11	43945	0.1054	-2.26	0.0301
W1-4	8	9.8	-573.90	0.004	1.01	0.3498
W3-2	83	-2419.84	139272	0.2068	-4.73	0.0001
W3-3	11	1235.21	-69710	0.1859	1.81	0.1034
W3-4	21	958.84	-53044	0.4176	3.92	0.0009

Owing to the fact that the proportion coverage (fished) in 2015 of the strata, mention above, is less than normal and the findings of that shrimp density decrease with increasing longitude, it was assumed that The lower limit is the biomass we know is there, i.e. the density in the ice-free area multiplied by the ice-free area. The upper limit is the density in the ice-free area multiplied by the area of the whole stratum. These are the limits, while we based on the regressions analysis, assumed that the density in the ice-covered area would be less than that in the ice-free area.

In the present survey document we have estimated the density, biomass and other stock component as being the upper limit in the density and biomass.

As it appears from the Assessment paper (Burmeister and Kingsley, 2015) we did also estimate the lower limit of density, biomass and fishable biomass. Both approaches (upper and lower limit were run in the model for the assessment work.

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 2013 were:

Region–2013	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	54 085	29	16.1
Canadian zone (C0)*	0 412	4	76.8
West (W1–W9)	97 901	126	19.8
Disko Bay & Vaigat (I1, I2)	81 377	22	11.6
Total	233 775	181	9.9

- sub-strata C0-4Area was not surveyed in 2013 because of ice and W9-4 (400-600) due to poor bottom conditions.

and in 2014:

Region–2014	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	29 381	32	26.8
Canadian zone (C0)*	-	0	-
West (W1–W9)	57 015	131	17.2
Disko Bay & Vaigat (I1, I2)	93 461	26	11.6
Total	179 857	189	9.2

- Area C0 was not surveyed in 2014, owing to time trouble.

and in 2015:

Region–2015	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	75 394	32	26.8
Canadian zone (C0)*	-	0	-
West (W1–W9)	130 004	132	29.1
Disko Bay & Vaigat (I1, I2)	78 215	22	10.7
Total	283 613	186	14.7

- Area C0 was not surveyed in 2015, owing to ice cover.

Survey biomass decreased over 2010 and the declining trend in survey biomass continued in 2012, where biomass estimate for Disko Bay and Vaigat was little changed from 2011, but were further large decline in U1–U3, of 40%, and in the southern offshore area (the W areas), of 44% (Table 2,table 3 and table 4). In 2013 total biomass increased by 19% compared with its 2012 level, but was only 39% of the 1988-2013 mean (Figure 2a and 2b). A further drop in survey biomass of 23% over 2013 was observed in 2014, caused by an almost bisection both in the North (U1-U3) and in the West (W1-W9). The increase in Disko Bay was mainly caused by a 47% increase in biomass in I2, whereas biomass showed a minor decrease of approx. 3% in I1.

The 2015 total survey biomass had been an increase over the levels recorded since 2010, in fact the total survey biomass increased over 2014 and were 57.6% higher in 2015 (Table 2, Figure 2a and 2b). All the offshore surveyed regions showed increases in survey biomass compared with the 2014 results, of about 156.5% in the North (U1-U3) recorded its biggest survey biomass since 2009, and about 128% in the total West regions. However surveyed biomass declined about 16% in Disko Bay and Vaigat, but remained above their 1988–2015 mean by about 15%. 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 a significant increases in survey biomass of 345% over 2014 and is comparable to the 2013 level, or 16% higher than their 1988–2015 mean (Table 3 and 4). Owing to three large catches (847 kg, 648 kg and 182 kg in W6-2), the next area to the south, W5–W6, increased by 73% over 2014, but is only 40% of its 1988–2015 mean. Nevertheless, biomass estimates for areas W5-W9 amounted only amounted only 7% of the total estimated survey biomass in 2015.

Densities of *P. borealis* in Disko Bay have been almost stable from 2010 to 2014, a minor increase is observed in 2015, but is still above its 1988 – 2015 mean. However, the inshore region, had far higher densities (7.85 t/km^2) than other areas (Fig 3a), over almost three times as high as the second highest, strata W1 and W2 combined (2.9 t/km^2). Lowest densities were found in the Southern areas W8-W9 (0.10 t/km^2) (Table 5). Over all mean density more than double over 2014, and was estimated to 2.27 t/km^2 in 2015, almost at the 1988–2015 means (2.33 t/km^2)(Fig. 3b).

The spread index, of how widely the survey thinks the stock biomass is distributed, showed a slight decrease in 2015 to its second-lowest value since the survey coverage was stabilized 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. 5a). 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 (Fig 5.b). 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. In the late 1990s, 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.

The 200–300 m stratum started showing biomass increases as early as the late-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 and until 2012, 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.

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 was reversed: 17% deeper than 400 m in the early years was replaced by 17% shallower than 150 m now, and 55% in 300–400 m of water by 55% in 200–300 m.

Depth distribution of survey biomass slightly changed in 2015. Almost 22% of the total surveyed biomass was observed in the shallow water (150 – 200m), mainly caused by a significant increase in the biomass in the shallow water in U3, W3 and W4 where biomass was more than 35 times the 2014 level. The proportion of biomass in 200 – 300 m and 300-400m was about 74% and comparable to 2014, while the proportion of biomass in the deep water 400-600 m show a slightly drop to 3.7% of the total surveyed biomass (Fig 5a and Fig 5b).

In 2001–2015 the survey biomass depth index has ranged between 265 and 300 m, with an average near 280 m compared to an average of 329 m in the period from 1988 to 2000 (Fig 5.c). In 2015 the depth index was estimated to approx. 267 m, a decrease of 10 m compared with 277 m in 2014.

Bottom temperature and biomass

The overall mean bottom temperature in the shrimp survey area was 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 neighborhood 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 (Figure 6 and figure 14). 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 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 2015, only 1088 shrimps were individually weighed and measured (Table below). 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. Parameter values estimated in 2015 were changed from the past years.

Table. *Pandas 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	9.753	4.5*	2.25051	2569	6.64
2012	0.08185	8.928	4.229	2.27317	2300	7.31
2013	0.12644	9.541	4.5*	2.26021	2353	6.66
2014	0.10582	9.554	4.5*	2.27123	2371	6.75
2015	0.07269	4.165	3.1	2.49521	1088	6.79

* L0 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 2012 data, when the sample is relatively large, and has a slightly larger scatter, than the other years. In 2015 also the scatter was consistent with 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
2013	0.58	2.07	4.80	8.92
2014	0.56	2.10	4.93	9.21
2015	0.59	2.08	4.90	9.28

Estimated weights at length have been consistent over years, and there is very little change from 2010–2014. Though 2015 has rather heavy shrimps at the small and large size, 10 and 25 mm.

The mean weight of both sexes has decreased steadily over the 27-year history of the survey (Fig. 8), by, on average, 61 mg/yr for females and 25 mg/yr for males. We do not know the reason for this; it might be due to a progressive reduction in the size at sex change, which would affect the mean size of both sexes. There is serial correlation in the residuals about the trend lines, 0.49* for males and 0.82** for females, indicating that there is some underlying mechanism.

Recruitment and mean length at age 2

Length-frequency plots—e.g. regions I1 – I2 and W1–W4 in 2014 (Fig. 9)—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: they 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 six years, however, estimates of the mean size at age 2 were fairly consistent (Table 9).

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 and 2012.

Since 2013 numbers of age-2 shrimps has increased and more than double (to 10.85 bn in 2015) compared to the two previous years and is considerably above the series 23-year-mean of 6.06 bn (Fig. 11 and table 10). The increase in numbers of 2-age shrimp is caused by a significant increase of age-2 shrimps in area W3W4, and numbers of age-2 shrimps is at its highest level since 2009 in North (U1-U3), while there were almost no age-2 shrimps found in W5-W9.

Disko Bay and Vaigat, which include only about 7% of the survey area, contributed 28–72% of the numbers at age 2 in 1997–2005, and more than 40% in the period from 2006 -2010 (Table 10). Whereas the contribution from Disko Bay and Vaigat was about 50 and 68% in 2013 and 2014 respectively, it is only 33% in 2015 (Table 10, Fig 11a).

In the north most region U1- U3 numbers of age 2 shrimps increased significantly to it fourth highest level and is way above the 1993–2015 mean (Table 10).

Age-2 shrimps have always been few in the southernmost region W7 to W9, and since 2004 they have also been very few in W5 and W6. In the most recent years contributions of age-2 shrimps have been low in region W1-W4/C0 (8 – 12%), but constitute about 50% of the total numbers in 2015 (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 low level compared to 2002-2006, survey biomass and fishable biomass increased considerable over 2014 to a level comparable with 2009 and 2010 (Table 2 and table 8). Spawning stock biomass—i.e. of females—accounted for more than 40% of the total survey biomass from 2010 to 2014, reached its highest level at 47.8% in 2014, but dropped over the past year to 35% in 2015 (Table 7). The biomass of females, estimated at 99 Kt in 2015, is below the 1988 – 2015 mean (106.6 Kt) (Table 6).

Compared with the length distributions in past twelve years, there are a greater proportion of the very smallest shrimps, those below about 15 mm CPL caught by this year survey in Disko Bay and Vaigat as well as in the offshore regions (Fig10). The proportion of the largest females above 23 mm CPL were comparable with the 2012 - 2014 level in Disko Bay and Vaigat, while the proportion were higher, in 2015 than observed the year before, in the offshore regions(Fig. 7 and Fig. 10). In offshore regions, length distribution is relatively adequate in the intermediate lengths. In spite of this, the fishable biomass is estimated at 87% of the survey total biomass, a proportion that is a bit lower than average, probably because of the unusually high proportion of pre-recruits. The high proportion of small shrimps is expected to enter the fishery with the next two to three years.

Female biomass in offshore regions were low in 2014, increased significantly over the previous year, but is still below the 20-yr mean, while female biomass declined over 2014 and is still at its 20-yr mean. However, it is expected the low biomass to make the stock in its present state sensitive to fishing pressure, as the fishery prefers, in general, to catch the largest shrimps; however, an adequate in intermediate sizes bodes, especially offshore, will assumable ensure long-term recruitment to the fishable and to the spawning stocks.

Bottom temperature

Area weighted bottom temperatures is given in Fig. 6. Bottom temperature have been stable at somewhat 3.1°C from 2008 to 2012, but decreased in 2015 to 2.98 °C.

Regionally the temperature in the Northern regions (U1-U3 and I1-I2) at 3°C is a suspicion more than compared to previous years. In W1-W3 temperature increased about to 3.9 °C in 2014.In the southern most areas (W5-W9) temperature is a little above the overall mean temperature, and warmest bottom temperature have been observed in the southernmost regions W7-W9 at 4.7°C. In shallow water in depth between 150-200 m the area weighted average bottom temperature is continuously rising since 2007. In conclusion the overall temperature has increased slightly since 2012.

Conclusions

Stock size

In aggregate, the stock has in 2015 stopped the steep decline it has maintained for the past 9 years, interrupted by a small increase in 2013. The overall survey biomass increased by 57.6% over 2014, mainly caused by an significant increase of 138% in the offshore region, while a minor decline of 16.4% in the survey biomass has been observed in Diso Bay & Vaigat. The offshore regions is now constitute 72% of the total surveyed biomass, compared to only 48% in 2014.

The offshore and inshore components have had very different trajectories since 2008. Inshore, in Disko Bay 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. Surveyed biomass in Disko Bay decreased by 12% over 2012, but increase with 14.9% over 2013. Despite the minor decline in survey biomass over 2014 it is still, in 2015, at 137% of its 27-year mean. 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 continued until 2014. Offshore survey biomass more than double over 2014 and is now in 2015 at 90% of its 27-year mean.

Fishable biomass increased about 119% over 2014, again caused by a significantly increase in offshore regions, but a 19% decline fishable biomass in Disko Bay. In 2015 fishable biomass constitute 87% of the total surveyed biomass. In both regions fishable biomass is at 84% of its 27-year mean offshore and 115% of its 27-year mean inshore (Disko Bay & Vaigat).

Stock distribution

The area over which the stock is distributed has decreased a little more since 2013, and it remains concentrated in Disko Bay, Vaigat and the Northern part of its range. Mean densities are high in Disko Bay and Vaigat and still above the 27-year mean. In almost all strata in the Offshore regions, densities increased over 2014; was about 2.5 times higher the Northern regions, about 5 times higher in W3-W4 north, south, and west of Store Hellefiskebanke and is at 89% of its 27-year mean. Densities are practically zero on the continental slope west of the banks all the way from Store Hellefiskebanke to Kap Farvel.

The latitude index of the survey has declined from 2010 – 2015, irrupted by a slightly increase in 2014. The North index remain stable owing to high proportion of biomass in Disko Bay 34.8 – 52% from 2012 – 2014, an significant increase in survey biomass over 2014 in the North, and low proportion of biomass in the W – regions, despite an increase in biomass in regions W1 to W6. Survey biomass from the northern (above 66°N) and inshore regions constitute 93% of the total offshore survey biomass.

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, 2012 and 2014 but the150–200m stratum yielded its highest proportion of biomass in 2006. Proportions, of the survey biomass has slightly decreased over the past 5 years in the central depths from 201 to 400m and the depth index for the survey biomass decreased about 10 meter to 266m over 2014.

Stock composition

By numbers and biomass both, the stock is heavily weighted toward the males, which composed a high proportion of the total fishable and surveyed biomass. Aggregate offshore regions has for the first time since 2010 more smaller shrimps than Inshore Disko Bay and Vaigat, actually the number of shrimps smaller than 16.5 mm CL is at its second highest level for the past 10 years. Offshore and inshore regions have had higher proportion of females in the fishable biomass. However, this tendency seems to reverse in 2015, while females compose a lower proportion of both the inshore (45%) as well as the offshore (38%) fishable biomass.

Numbers at age 2 are offshore at a high level and well above the 24-year mean. In 2015 numbers of age-2 shrimps remain stable in Disko Bay & Vaigat and is also above the 24-year mean. Pre-recruits of 14-16.5 mm CPL are high in numbers in inshore as well as offshore regions.

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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, 1988–2015

	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	**
2005–2015	“	Cosmos	54.0	27.4–28.8	**

(*: 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 2015.

Stratum	Area (km²)	Stations	Biomass density (t/km²)	Biomass (Kt)	Biomass error variance	Error coefft of variation (%)
C0-2	903	0	0.000	0.000	0.0000	0.0
C0-3	2179	0	0.000	0.000	0.0000	0.0
C0-4	1154	0				
Overall C0	4236	0	0.000	0.000	0.0000	0.0
I1-1	407	2	26.567	10.802	3.0113	16.1
I1-2	1963	4	12.334	24.214	14.3808	15.7
I1-3	2441	4	6.618	16.156	15.8593	24.6
I1-4	1499	2	1.407	2.109	1.0737	49.1
I2-1	419	3	20.272	8.500	21.7607	54.9
I2-2	815	3	14.937	12.173	9.4125	25.2
I2-3	1085	2	1.920	2.083	2.4009	74.4
I2-4	1338	2	1.628	2.179	1.7944	61.5
Overall I	9967	22	7.847	78.215	69.6936	10.7
U1-1	2486	2	0.020	0.049	0.0009	60.1
U1-2	4633	3	0.714	3.306	1.8763	41.4
U1-3	4785	2	1.877	8.981	8.6748	32.8
U1-4	5129	2	0.017	0.085	0.0046	79.8
U2-2	6710	2	1.036	6.953	31.4907	80.7
U2-3	8481	4	2.584	21.917	80.2000	40.9
U2-4	7994	2	0.208	1.662	2.3092	91.4
U3-1	2012	3	0.550	1.107	0.0103	9.2
U3-2	3017	7	9.374	28.277	106.7594	36.5
U3-3	1675	2	1.319	2.209	2.9292	77.5
U3-4	2710	3	0.313	0.847	0.0466	25.5
Overall U	49631	32	1.519	75.394	234.3020	20.3
W1-1	2873	2	0.445	1.279	1.5505	97.3
W1-2	6099	7	3.694	22.532	67.3748	36.4

W1-3	7520	3	1.579	11.877	28.4342	44.9
W1-4*	816	0	0.000	0.000	0.0000	0.0
W2-1	1674	2	0.465	0.779	0.1277	45.9
W2-2	2612	9	5.570	14.545	43.7451	45.5
W2-3	1741	4	0.202	0.351	0.0130	32.4
W2-4	915	2	0.105	0.096	0.0092	100.0
W3-1	2122	2	1.423	3.019	0.9692	32.6
W3-2	4725	10	2.184	10.321	26.3099	49.7
W3-3	2085	4	1.497	3.122	5.6156	75.9
W3-4	2994	4	0.762	2.283	3.4940	81.9
W4-1	4119	2	8.564	35.271	1174.2149	97.2
W4-2	1818	4	1.270	2.309	1.1342	46.1
W4-3	821	3	4.214	3.461	11.0242	95.9
W4-4	1961	2	0.076	0.149	0.0130	76.8
W5-1	3001	5	0.213	0.641	0.1369	57.8
W5-2	3648	9	0.486	1.773	1.8699	77.1
W5-3	1950	2	0.084	0.163	0.0238	94.7
W5-4	3021	2	0.002	0.007	0.0001	100.0
W6-1	1206	3	0.000	0.000	0.0000	0.0
W6-2	2006	8	7.134	14.309	64.8270	56.3
W6-3	1585	5	0.393	0.622	0.1992	71.7
W6-4	1234	2	0.429	0.529	0.2778	99.6
W7-1	2442	4	0.000	0.000	0.0000	0.0
W7-2	891	5	0.000	0.000	0.0000	0.0
W7-3	265	3	0.000	0.000	0.0000	100.0
W7-4	317	2	0.000	0.000	0.0000	0.0
W8-1	424	2	0.000	0.000	0.0000	0.0
W8-2	567	2	0.058	0.033	0.0010	97.4
W8-3	405	3	0.018	0.007	0.0000	72.1
W8-4	718	3	0.733	0.526	0.0849	55.4
W9-1	1711	4	0.000	0.000	0.0000	0.0
W9-2	938	3	0.000	0.000	0.0000	0.0
W9-3	516	3	0.000	0.000	0.0000	100.0
W9-4	430	2	0.001	0.000	0.0000	41.3
Overall W	72169	132	1.801	130.004	1431.4502	29.1
Survey totals	136003	186	2.085	283.613	1735.4458	14.7

† strata with 1 trawled station have been assigned an error coefficient of variation of 95%
* area C0 was not surveyed in 2015 owing to ice cover.

Table 3. *Pandalus borealis* in West Greenland: biomass estimates (Kt) for survey subdivisions and standard errors for the entire survey in 1988–2015.

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 [3,1]	Total	SE[4]
1988	22.6	9.5	55.1	85.5	17.7		39.2	229.7	24.7
1989	11.1	3.7	50.0	82.7	39.0		39.2	225.7	32.3
1990	11.0	9.1	78.6	53.9	23.5		39.2	215.3	32.6
1991	5.1	4.2	26.8	47.4	23.3		43.1	149.9	23.0
1992	18.1	22.2	46.2	30.6	45.8		41.4	204.4	32.5
1993	6.9	2.9	93.8	36.7	62.2		28.3	230.8	30.9
1994	6.6	6.0	95.0	44.5	32.6	16.7	34.0	235.4	51.7
1995	6.8	3.9	39.0	52.4	48.7	1.6	39.1	191.4	30.6
1996	8.8	1.5	46.4	31.5	80.0	3.3	44.3	215.9	40.4
1997	5.7	0.2	34.7	13.1	57.9	21.8	44.3	177.7	31.1
1998	7.0	0.4	37.8	100.6	45.1	18.6	51.8	261.2	57.6
1999	17.6	10.5	50.1	23.2	50.5	56.0	52.6	260.6	42.1
2000	8.4	10.7	62.1	69.8	71.0	21.8	73.0	316.9	40.3
2001	34.1	3.7	74.3	47.6	58.5	36.3	72.1	326.7	44.2
2002	17.4	5.4	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	356.6	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	-(1)	69.2	6.1	34.3	2.6	92.9	260.6	36.1
2012	33.5	-(1)	33.8	7.0	23.1	0.4	92.5	190.3	20.6
2013	54.1	0.4	51.6	37.4	8.6	0.2	81.4	233.8	23.2
2014	29.4	-(1)	34.5	12.1	10.4	0.0	93.5	179.9	16.6
2015	75.4	-(1)	51.5	59.9	18.0	0.6	78.2	283.6	41.7

[1]: New stratification introduced in 2003 (regions N and S) and in 2004 (regions U, C and D)
[2]: Areas W6 and W7 were sampled from 1990 and 1993, respectively
[3]: D1-D9 1988-90 not sampled, but set to mean of 1991-1997.

[4]: Standard error calculated excluding D1-D9 in 1988-1990
[5]: Probably underestimated due to poor coverage of the northern part of the area N
[6]: Canada(C) in 2011, 2012 and 2015 was not sampled due to icecondition

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 1988–2015.

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
2013	16.1	76.8	21.1	41.8	55.6	78.6	11.6	9.93	181
2014	26.8	-(1)	19.6	43.2	34.7	65.0	11.6	9.23	189
2015	20.3	-(1)	33.2	58.3	45.5	51.8	10.7	14.69	186
Mean 1994-2015								13.28	

1: C (Canada) in 2011 - 2015, except 2014 was not sampled

Table 5. *Pandalus borealis* in West Greenland: estimated mean densities (t/km^2) for survey subdivisions in 1988-2015.

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	1.10	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
2013	1.09	0.13	2.13	1.81	0.40	0.05	8.16
2014	0.59	0.00	1.42	0.59	0.48	0.00	9.38
2015	1.52	-	2.20	2.90	0.84	0.10	7.85

Table 6. *Pandalus borealis* in West Greenland: estimated numbers (billions) by sex in 1988–2015.

Year	Males	Females	Total	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
2013	31.1	12.0	43.1	72.2	27.8
2014	22.8	9.2	32	71.3	28.8
2015	51.3	10.6	61.9	82.9	17.1
Average	47.0	12.1	59.1	79.3	20.7

[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; and in 2014 due to time trouble; no correction has been made.
[3] Sub-strata C0-4 was not surveyed in 2013 and 2015 owing to sea ice; and sub-strata W9-4 due to poor bottom conditions.

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 1988–2015.

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	148.5	112.0	260.6	57.0	43.0
2012	115.4	74.9	190.3	60.7	39.3
2013	129.9	103.9	233.8	55.6	44.4
2014	93.8	86	179.8	52.2	47.8
2015	184.6	99	283.6	65.1	34.9
Average	188.0	106.6	294.6	63.6	36.4

[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 1988–2015.

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%
2013	143.6	94%	74.6	92%	218.1	93%
2014	81.7	95%	85.5	91%	167.2	93%
2015	178.8	87%	69.3	89%	248.1	87%
Average	211.7	93%	60.2	89%	271.9	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, 2012, 2015 nor substratum W1-4 in 2011, owing to sea ice; 2014 due to time trouble.

Table 9. *Pandalus borealis* in West Greenland: mean carapace length (mm) at age 2 in 2005–2015, with standard deviations and coefficients of variation (- : not present, ( ): fixed in the final MIX run, na: no data).

			Region / Strata			
	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
2005	11.1	11.5	-	12.5	-	-
2006	11.5	11.4	-	12.3	12.5	-
2007	-	11.5	-	-	12.5	-
2008	13.4	12.6	-	12.4	11.5	-
2009	12.2	11.8	-	12.3	12.2	-
2010	10.8	11.9	-	13.1	-	-
2011	-	11.2	na	11.3	-	-
2012	11.7	11.0	na	-	11.7	-
2013	11.2	13.1	-	13.5	13.0	-
2014	12.3	13.5	na	13.1	-	-
2015	11.5	13.4	na	*12.1*	12.0	-

Standard deviation:

			Region / Strata			
	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
2005	0.9	1.5	-	1.3	-	-
2006	1	1.1	-	1.36	1.26	-
2007	-	1.37	-	-	1.32	-
2008	1.65	1.87	-	1.28	0.83	-
2009	1.36	1.39	-	1.12	1.26	-
2010	1.28	1.20	-	1.27	-	-
2011	-	1.00	na	1.17	-	-
2012	1.53	1.09	na	-	0.40	-
2013	0.96	1.32	-	1.08	1.4	-
2014	0.99	1.38	na	1.41	-	-
2015	0.88	1.51	na	1.13	0.96	-

Coefficent of variation:

Year	U1-U3 150-600 m	I1+I2 150-600 m	Region / Strata C0 200-600 m	W1-W4 150-600 m	W5+W6 150-600 m	W7-W9 150-600 m
2005	0.08	0.13	-	0.1	-	-
2006	0.09	0.09	-	0.11	0.1	-
2007	-	0.12	-	-	0.11	-
2008	0.12	0.15	-	0.10	0.07	-
2009	0.11	0.12	-	0.09	0.11	-
2010	0.12	0.10	-	0.10	-	-
2011	-	0.09	na	0.10	-	-
2012	0.13	0.10	na	-	0.03	-
2013	0.09	0.10	-	0.08	0.11	-
2014	0.08	0.1	na	0.11	-	-
2015	0.08	0.11	na	0.09	0.08	-

Table 10. *Pandalus borealis* in West Greenland: survey estimate of numbers (billions) at age 2 years, 1993–2015.

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	0.32	3.47	0.23		0.05	0.00	4.07
2006	0.33	1.86	2.12		0.78	0.00	5.09
2007	0.00	0.96	0.00	0.00	0.38	0.00	1.34
2008	2.96	1.48	0.00	0.86	0.36	0.00	5.66
2009	1.95	2.05	0.00	0.91	0.14	0.00	5.05
2010	0.95	2.23	0.00	1.13	0.00	0.00	4.31
2011	0.00	2.52	-	0.44	0.00	0.00	2.96
2012	0.30	1.20	-	0.00	0.07	0.00	1.57
2013	0.40	2.03	0.00	1.63	0.00	0.00	4.06
2014	0.17	3.30	-	1.36	-	0.00	4.83
2015	1.38	3.62	-	5.35	0.50	0.00	10.85
Average:	0.56	2.35	2.03		1.39	0.00	6.06

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1 data for 1993 to 2004 has been converted from Skervøy to Cosmos trawl;

2 for area C0 – numbers of age 2 shrimps is in general very low. Estimating the components in the mixture distribution to the data using maximum-likehood estimation for the grouped data, resulting is very poor fits.

* Numbers of age-2 shrimps from 2005 – 2014 have been recalculated in 2014.

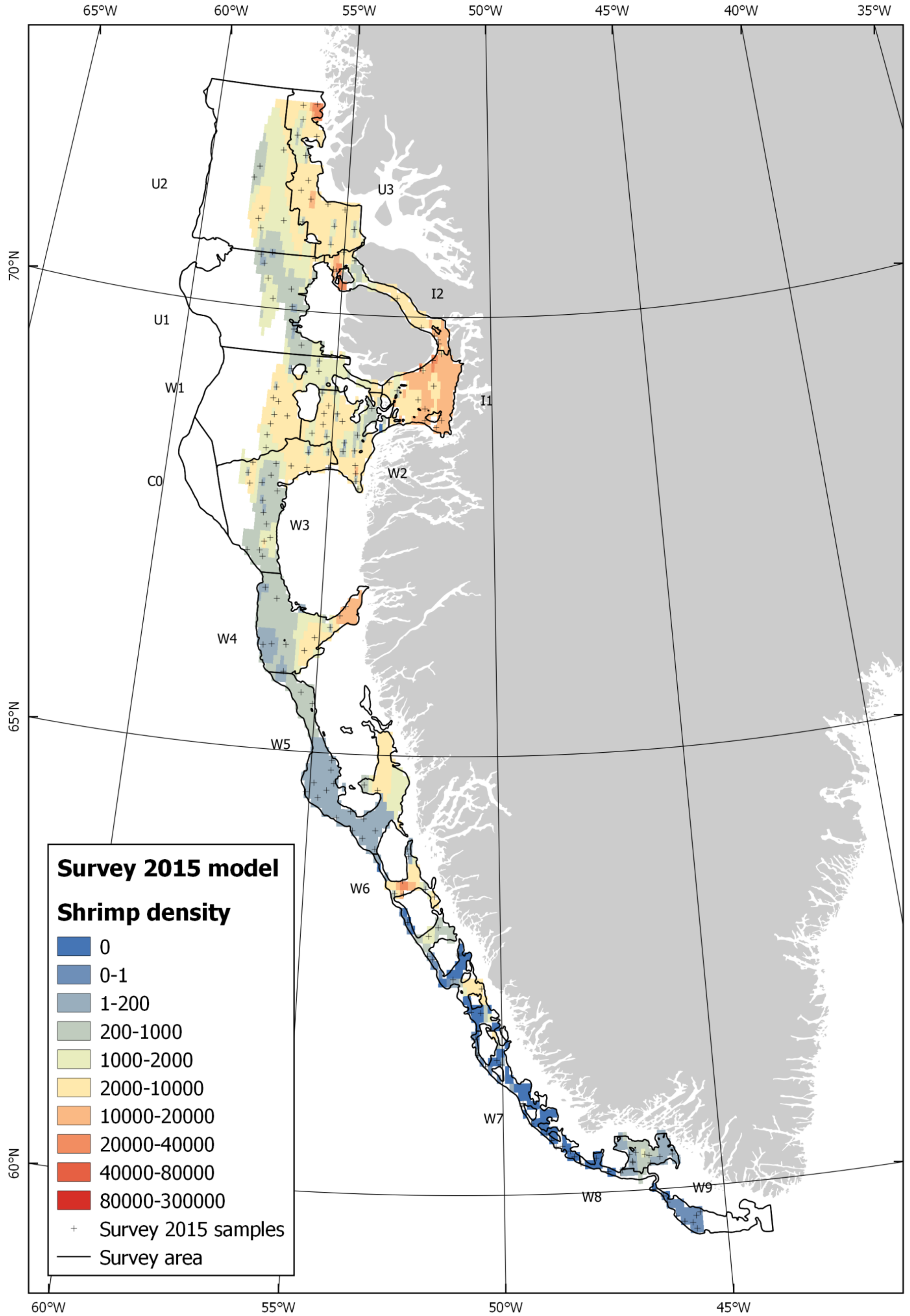

Fig. 1. *Pandalus borealis* in West Greenland: density distribution from 186 trawl-survey stations in 2015.

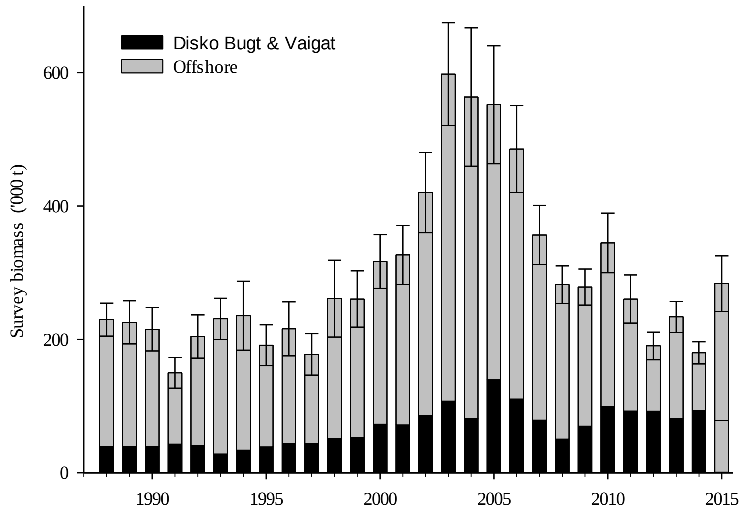

Fig. 2a. *Pandalus borealis* in West Greenland: estimated survey biomass, 1988–20145. Area C0-4 was not surveyed in 2013 and 2015 because of ice cover, in 2014 W9-4 due to poor bottom conditions and area C0 in 2014 owing to time trouble.

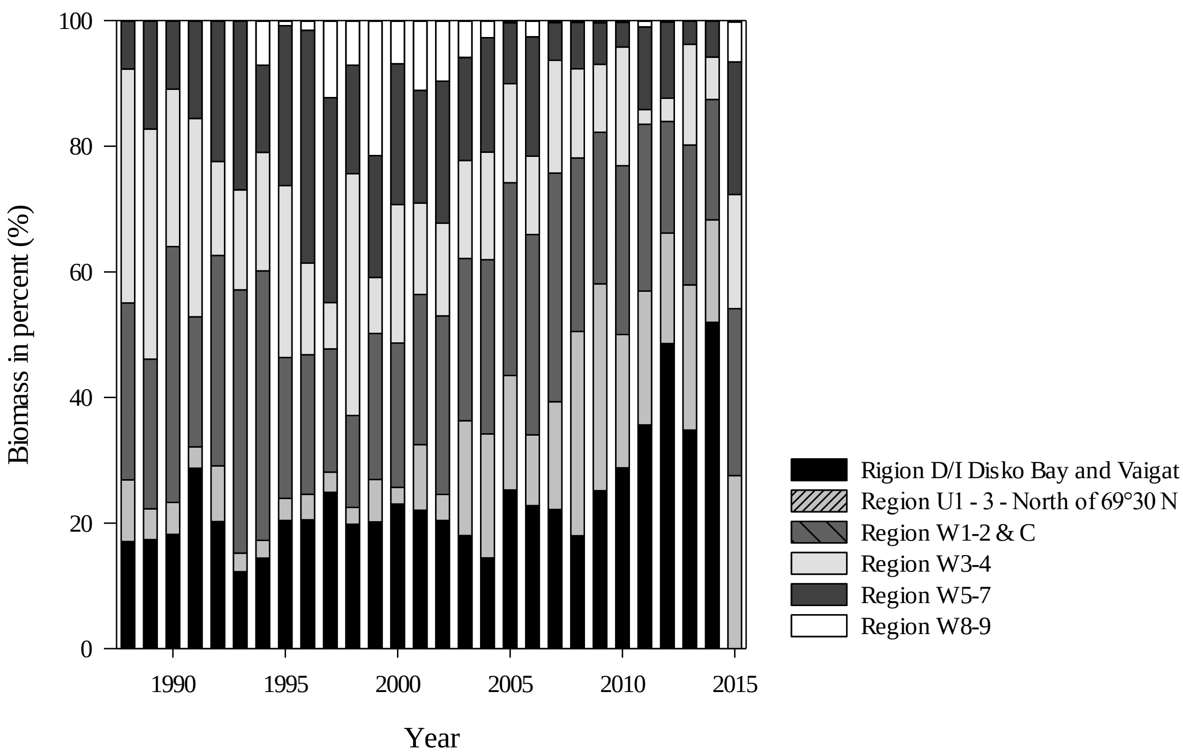

Fig. 2b. *Pandalus borealis* in West Greenland: distribution of survey biomass between major survey regions, 1991 – 2015. Area C0 could not be surveyed in 2011, 2012 and 2015 do to ice cover in the strata and area C0 in 2014 owing to time trouble.

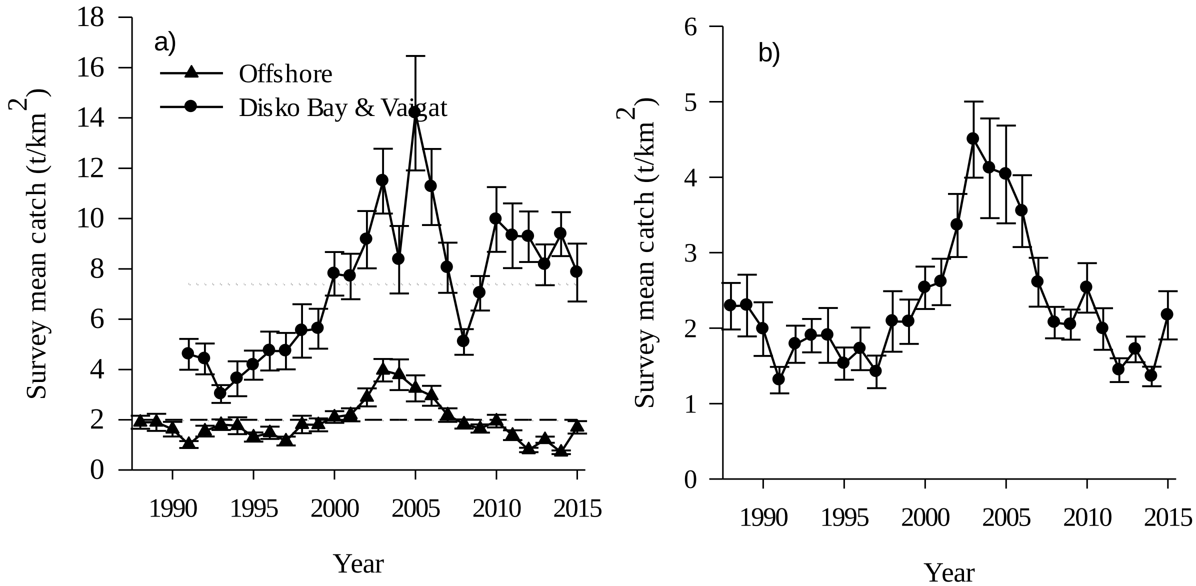

Fig. 3. *Pandalus borealis* in West Greenland: mean survey density of Northern shrimp in a) -●- Disko Bay and Vaigat (since 1991 7–8% of the survey area), -▲-offshore (92–93%) and b) total surveyed regions.

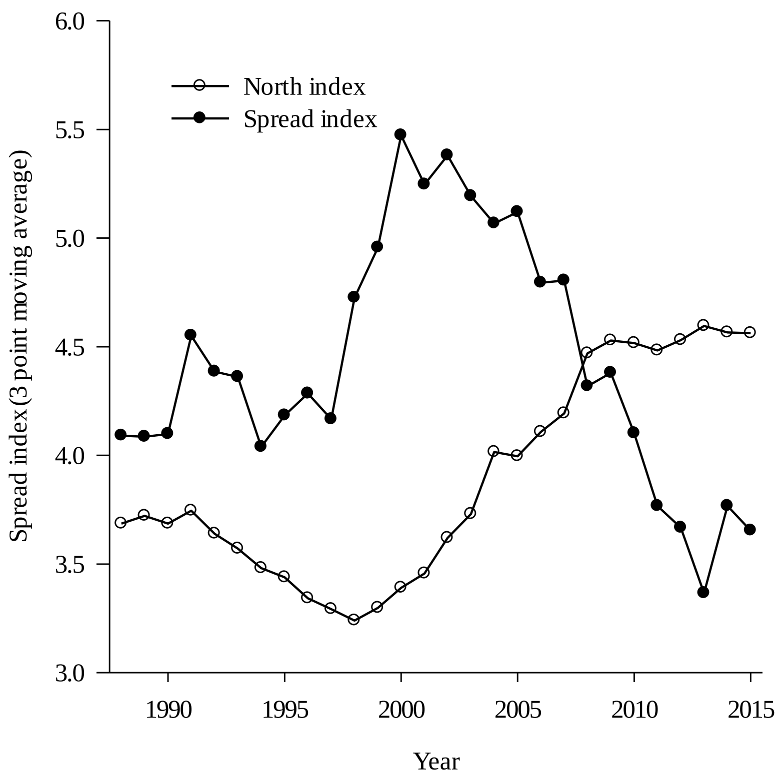

Fig. 4. *Pandalus borealis* in West Greenland: indices of distribution and location of shrimp biomass in the West Greenland trawl survey 1994–2015 (3-point moving averages). -□-: North index (3-pt moving average) and - ■-; Spread index (3-pt moving average).

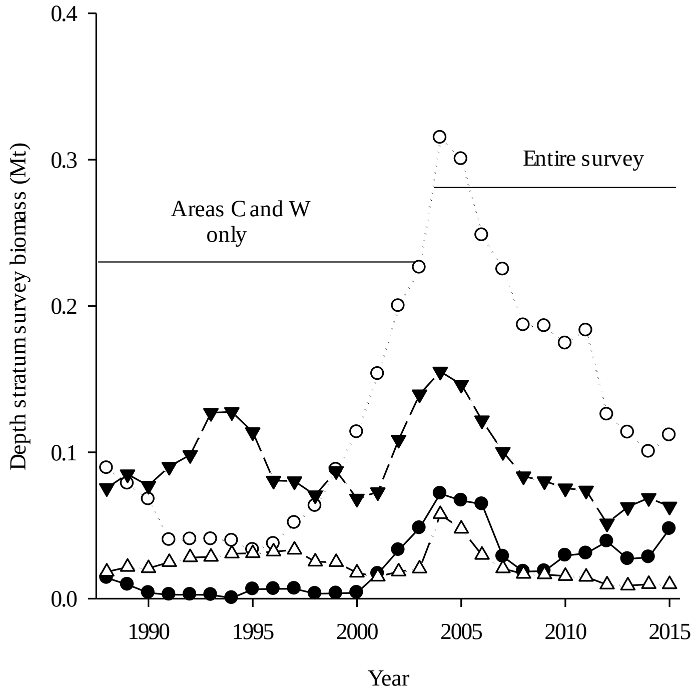

Fig. 5a. *Pandalus borealis* in West Greenland: survey biomass estimates by depth stratum, 1988–2015. 3-point moving averages.; Until 2003, only areas C and W were substratified by depth. -●-: 150 – 200m, -○-: 200-300m, -▼-: 300-400 and –Δ- : 400-600m.

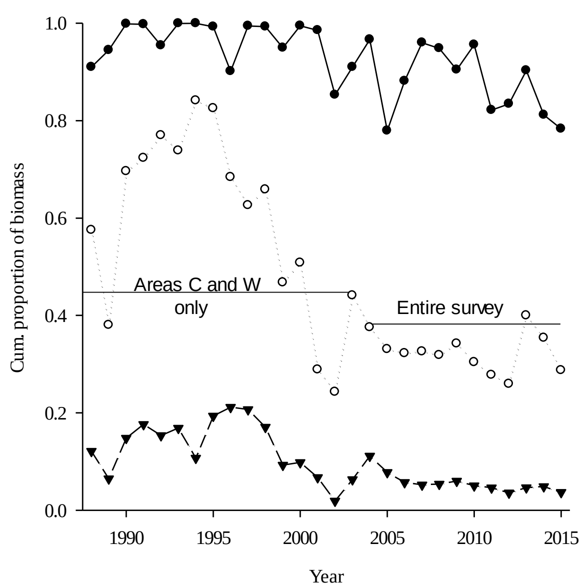

Fig. 5b. *Pandalus borealis* in West Greenland: distribution of survey biomass between 150 and 600 m by depth, 1988–2015. Until 2003, only areas C and W were substratified by depth. -●-: 150 – 200 m, - ○-: 300 m and -▼-400 m

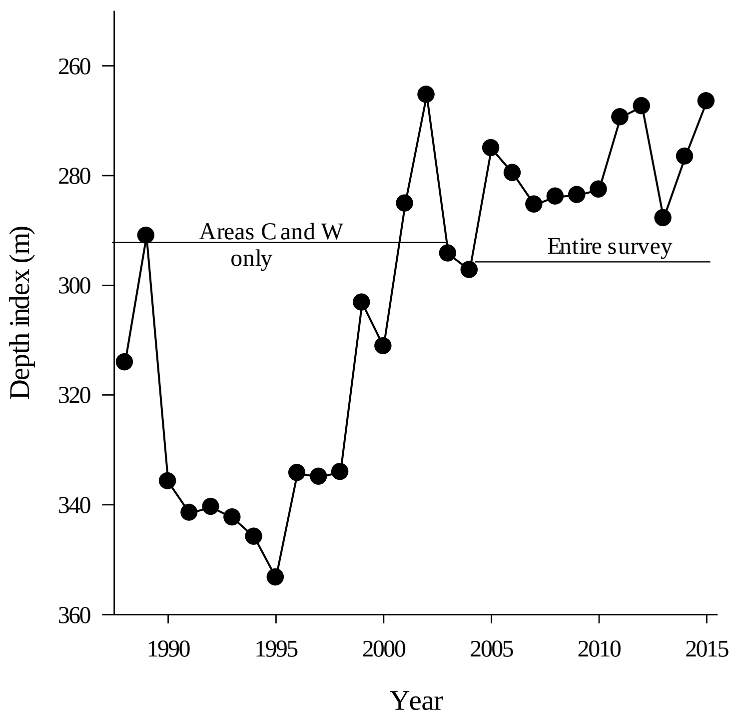

Fig. 5c. *Pandalus borealis* in West Greenland: depth index for survey biomass, 1988–2015. Until 2003, only areas C and W were substratified by depth.

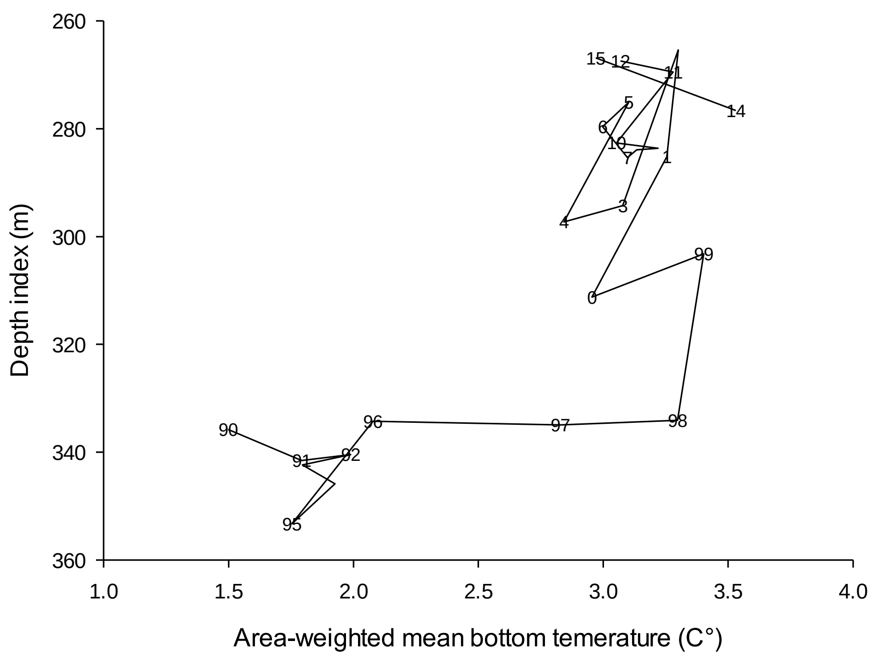

Fig. 6. *Pandalus borealis* in West Greenland: depth index of survey biomass vs. area-weighted mean bottom temperature from survey trawl-door measurements, 1990–2015.

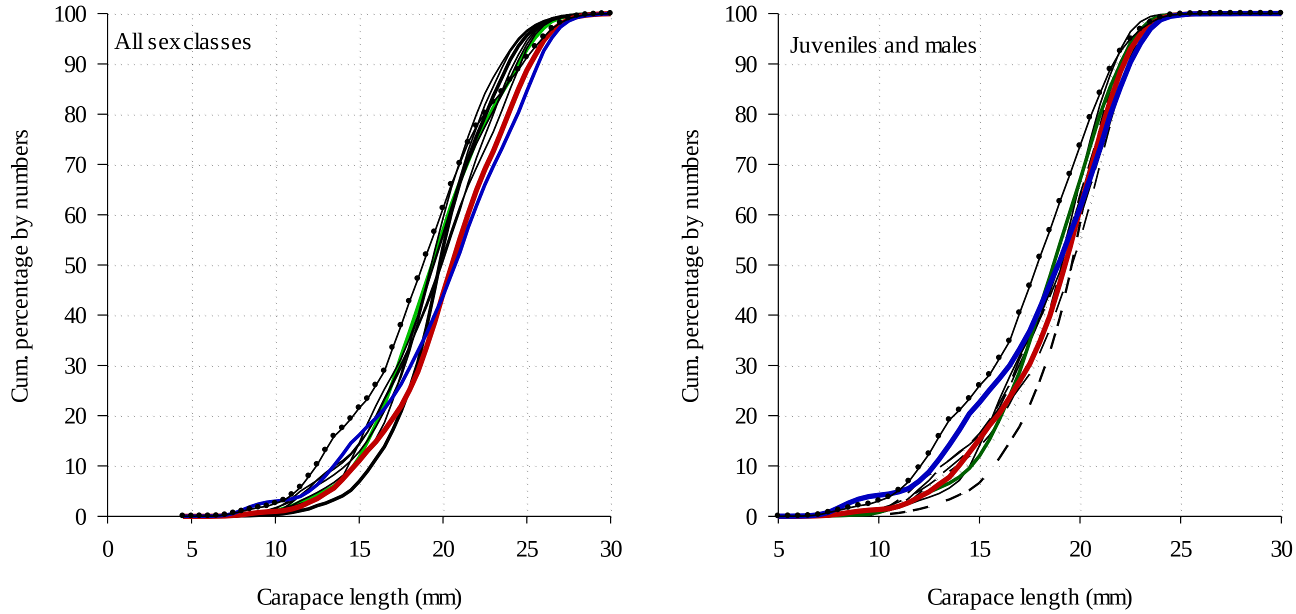

Fig. 7. *Pandalus borealis* in West Greenland: distribution of lengths from survey length analyses in 2005–2011(black lines) and in 2012 (green line), 2013 (red line), 2014 (blue line) and 2015 (black dotted lined).

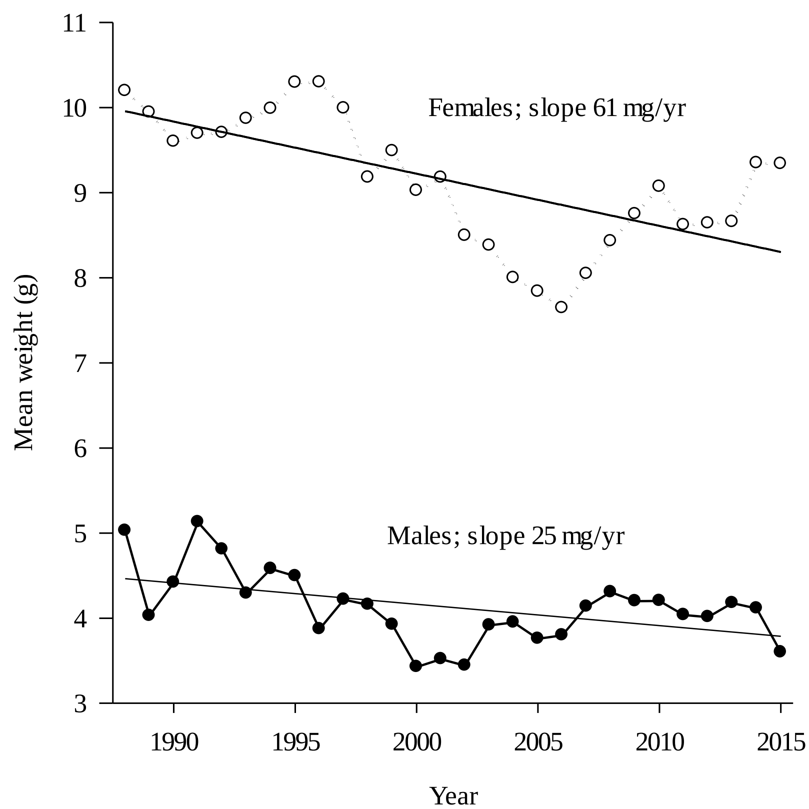

Fig. 8. *Pandalus borealis* in West Greenland: mean weight, by sex, from survey data, 1988–2015.

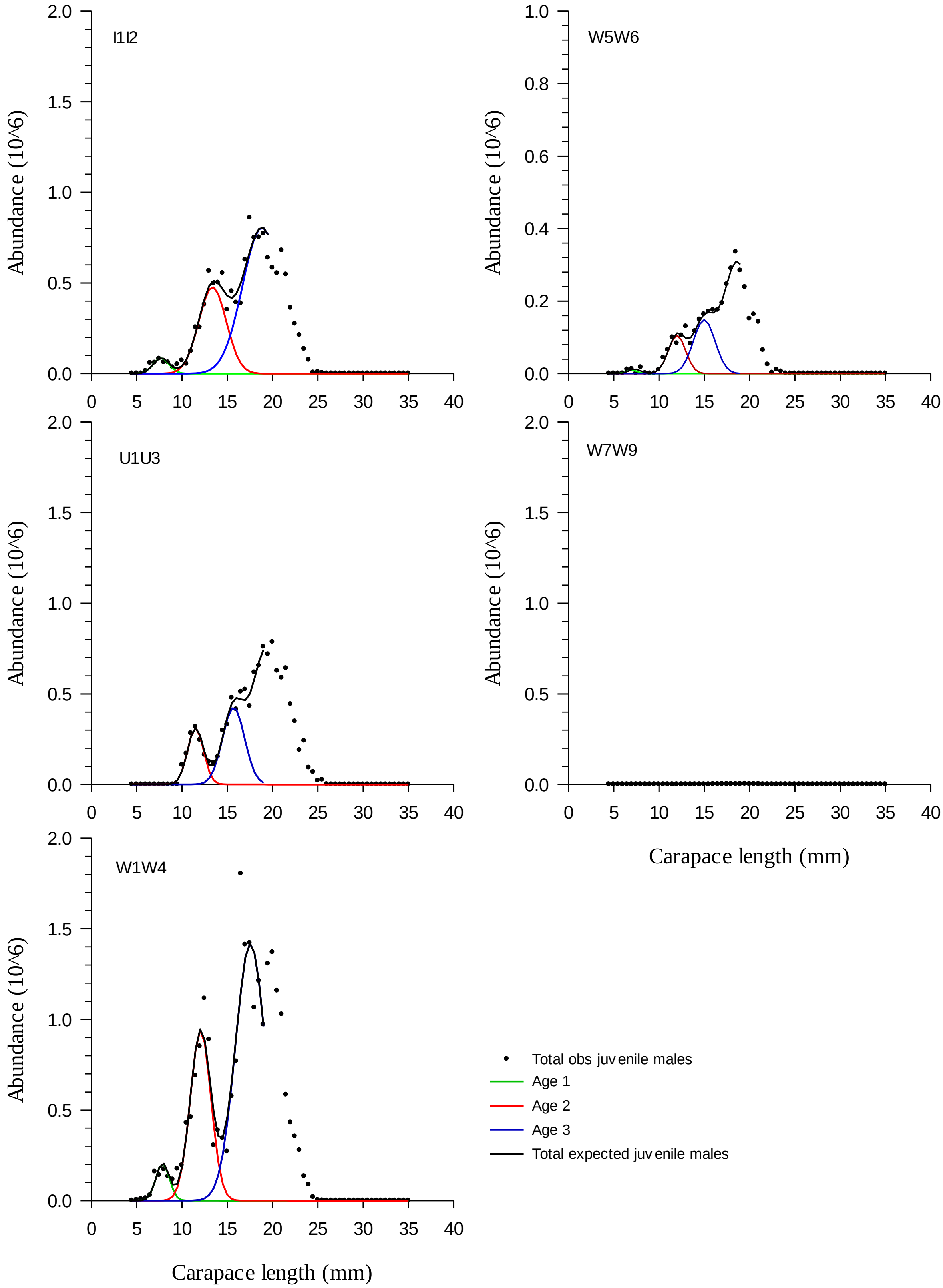

Fig. 9. *Pandalus borealis* in West Greenland: regional length frequencies in 2015.

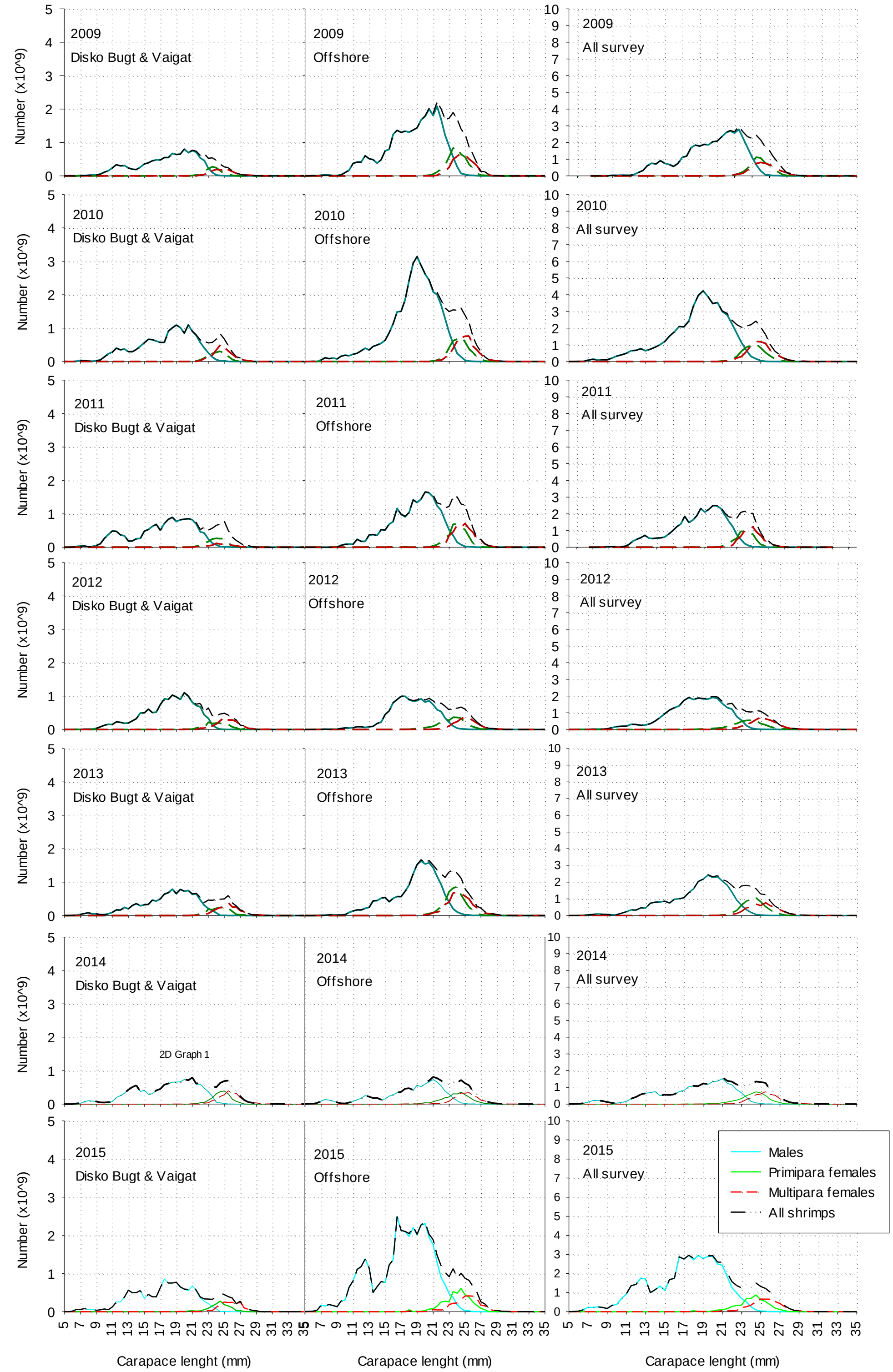

Fig 10. *Pandalus borealis* in West Greenland: length frequencies offshore, in Disko Bay and Vaigat, and overall, 2007–2015.

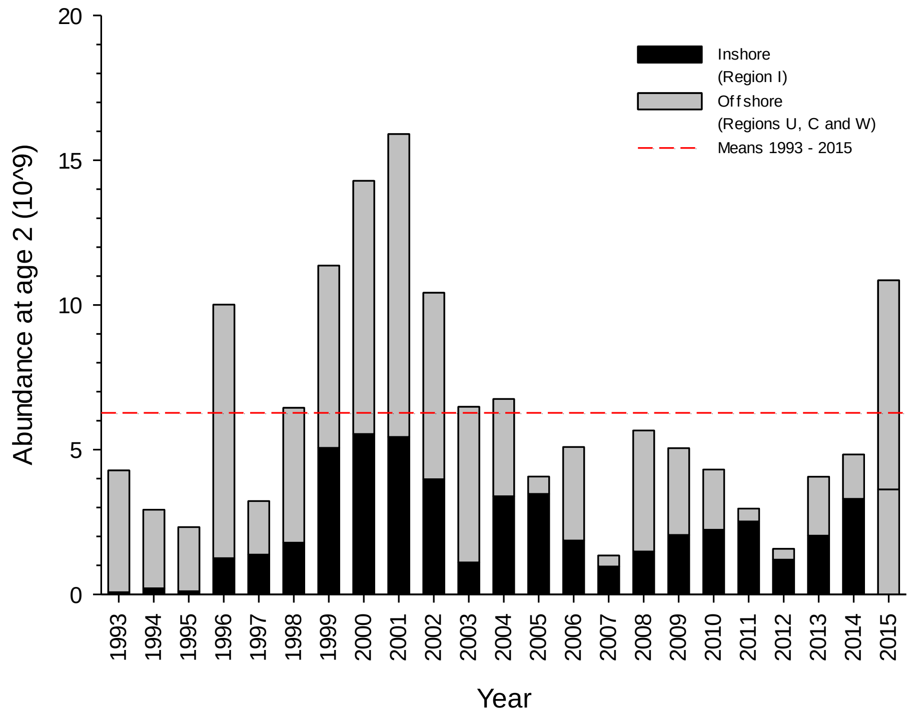

Fig. 11a. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2015.

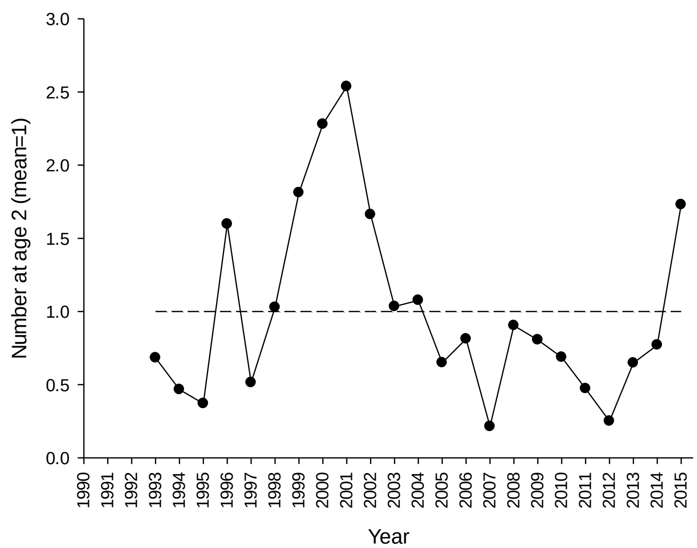

Fig. 11b. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2015.

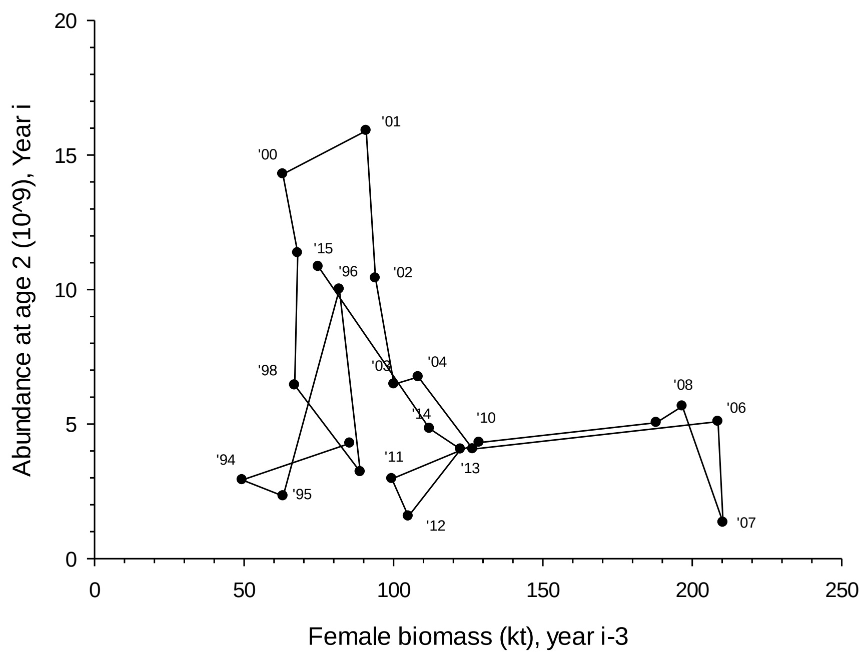

Fig. 12. *Pandalus borealis* in West Greenland: survey estimates of numbers at age 2 in 1993–2015 against female biomass 3 years earlier (labels denote years in which age-2 numbers were estimated).

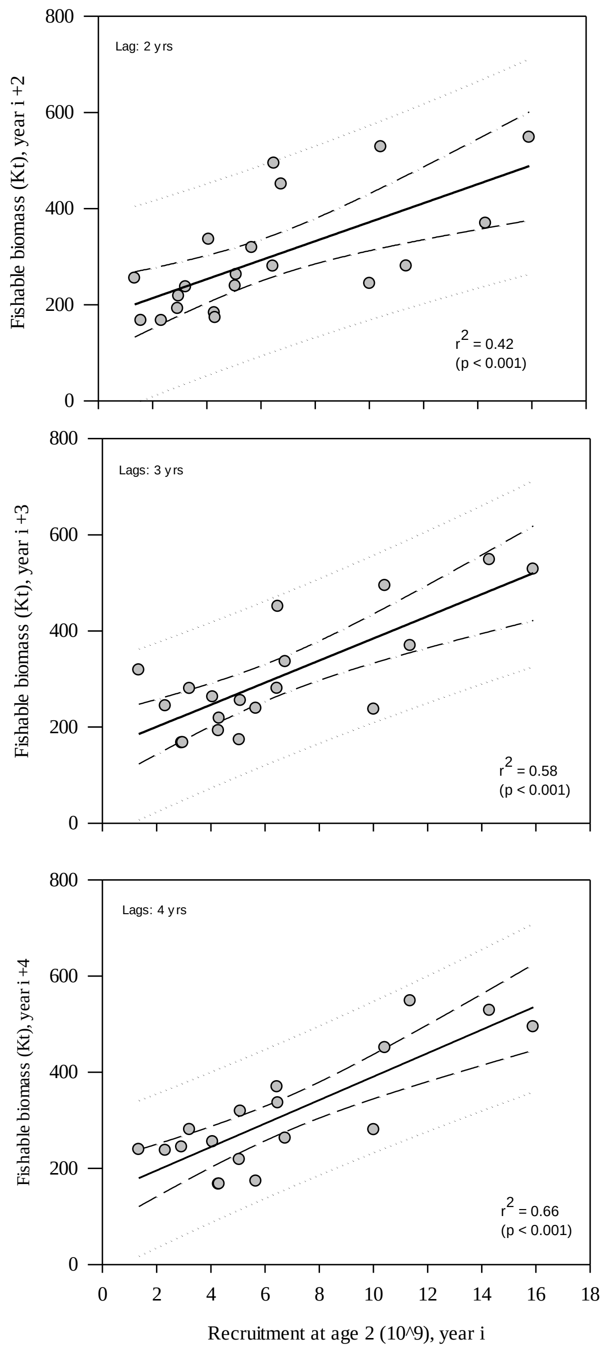

Fig. 13. *Pandalus borealis* in West Greenland: lagged fishable biomass vs. survey estimates of numbers at age 2 from 1993 to 2014 (linear regressions with 95% confidence and prediction intervals).

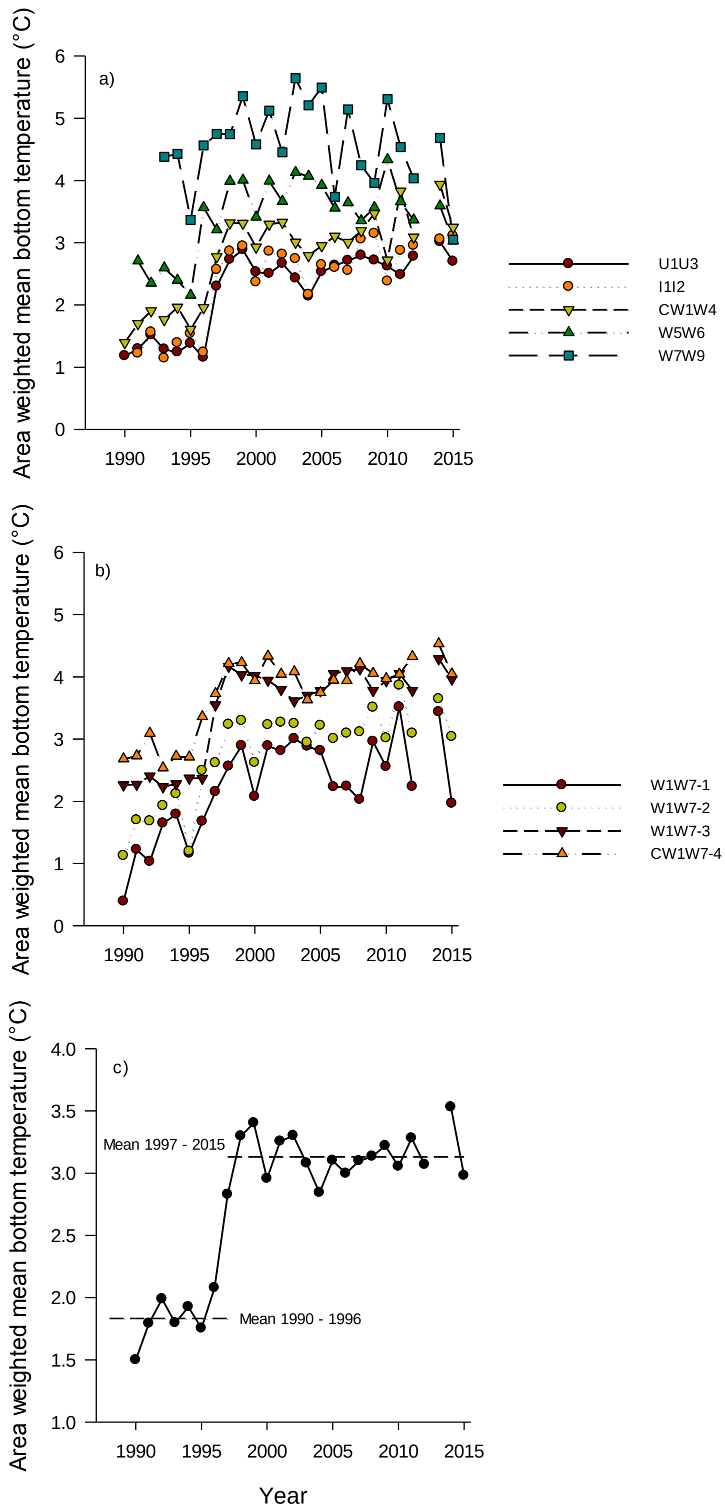

Fig. 14. *Pandalus borealis* in West Greenland: area-weighted mean bottom temperature for survey regions (see Fig. 1 for locations), depth strata in offshore areas C and W1–W7, and the entire survey area in 1990-2014.