



Serial No. N7127

NAFO SCR Doc. 20/053

NAFO/ICES PANDALUS ASSESSMENT GROUP—October 2020

The West Greenland trawl survey for *Pandalus borealis*, 2020, with reference to earlier results.

by

AnnDorte Burmeister and Frank Farsø Rigét

Greenland Institute of Natural Resources
Box 570, 3900 Nuuk, Greenland

Abstract

A trawl survey is carried out 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 2020, 247 stations were fished in 30 fishing days; 187 stations provided data to the shrimp survey in all strata, except for stratum C0 and strata W8-2 and W9-4.

In 2020, the annual trawl survey was conducted with a chartered vessel, the Icelandic trawler Helga Maria. All the standard gear from the research vessel Paamiut (such as cosmos trawl, doors, all equipment such as bridles etc. Marport sensors on doors and headlines) were used, in attempt to make the 2020 survey as identical as possible with the previous year's survey with Paamiut.

The 2003 peak in total survey and fishable biomasses was followed by a continuous decline, reaching in 2014 the lowest levels since 1997. In aggregate, the stock has shown no clear trends since 2007. In fact, at short term (10 years), there has been fluctuations in the stock with ups and downs in biomass. The overall survey biomass increased by 13% to 378 Kt in 2020, little higher than the 2019 value at 334 Kt. The total survey biomass is 143% of its past 10-year mean, 132% of its past five-year mean, and above its serial mean (297 Kt). Offshore regions comprise 82% of the total survey biomass, and 18% is inshore in Disko Bay and Vaigat. The Fishable proportion (87%) of the survey biomass is below the serial mean (92%). Both female and male biomass is above the serial means.

In offshore regions survey biomass (311 Kt) remain almost comparable to the 2019 value. Whereas biomass in W4 (Holsteinsborg Dyb) increased by 37% over 2019 and almost doubled in W6 (Fylla region), biomass declined significantly (85%) in region Toqqusaq banke (W5) and (56%) in the outer part of Disko Bay region (W3). Biomass in the southern part area, W7-W9, amounted less than 1% of the total estimated survey biomass in 2020. Inshore, Disko Bay and Vaigat, survey biomass has been fluctuated over the last 12 years, but increased by 50% over 2019 and is in 2020 almost at its past five-year mean, but below its serial mean.

In total, the age-2 shrimp index is well above its past 5-year mean and the serial mean. Offshore numbers of age-2 shrimp remain high, way above its serial mean and above past 5-year mean. Numbers of age-2 shrimp



in Disko Bay & Vaigat is despite an increase in numbers low and is far below its serial mean and only 49% of its past 5-year mean.

Since the late 1990s the stock is found in shallower water than before. This trend has continued since 2011, except for 2013, and in 2020 the survey biomass depth index was 255 m, which is lowest observed value in the time series.

Area-weighted mean bottom temperature in the survey area increased at the beginning of the 1990s, by about 1.6°C, to 3.3°C in 1999. In the successive year's bottom temperature remain stable but starts a continuous decrease from 2015 to 2.1°C in 2018, followed by a minor increase in 2019 and 2020 (2.6°C).

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 2020 survey and compares it 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 Subarea 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 based on 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 Kannevorff, 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 on 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 minimize 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 2020, 260 stations were planned at depths between 150 and 600 m in the survey area, with 60 'extra' stations mapped and available to be included if time permitted. 257 of the planned stations incl. 'extra' stations were fished. 6 stations were reported as having been moved more than 2 nautical miles from the planned position, with a mean of 3 n.mi; 6 stations were discarded, either due to untrawlable bottom or owing to general trawl difficulties.

Of the 260 stations fished, 187 provided usable data to the shrimp survey. In the course of the shrimp survey, CTD casts were made along standard transects offshore and in Disko Bay and Vaigat; and in 2020, 0 station were fished with a beam trawl for benthos monitoring, but at 83 station a video beam-sledge were used for benthos recording and at 0 station a drop camera was used.

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.

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

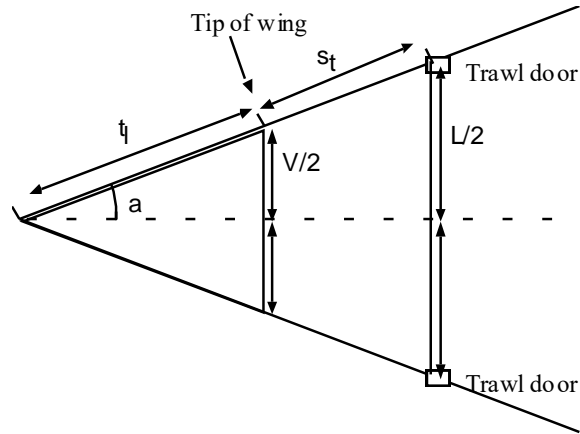
The surveys have been conducted with the research trawler *Paamiut* (722 GRT) since 1991, similar vessels were used in 1988–1990. However, in the beginning of 2018 it was decided that the old research vessel *Paamiut* must be scraped owing to increasing expenses to maintenance. Instead, the survey was conducted with a chartered fishing vessel *Sjudarberg* in 2018 and *Helga Maria* in 2019 and 2020. All fishing gear were removed from *Paamiut* and installed at the chartered vessels, both in 2018, 2019 and 2020. Fishing practice and handling of catch were exactly as used on the research ship *Paamiut* (See appendix 1).

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 m² and weighing 2420 kg. They were replaced in 2004 by *Injector International* 7.5 m² 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:

$$V = (t_t \cdot L) / (t_t + s_t)$$

where L is the distance between the doors (door spread).

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 Kannevorff, pers. com.).

If door spread was not recorded during 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 1994–2020 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 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, re-stratified 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) center 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:

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

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 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 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:

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

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 skewness to the plus age 3 group, analysis was only done on shrimps below or equal to 19 mm CPL. While using this new method in 2014, all age-2 results from 1996 to 2014 was re-calculated. A more comprehensive description 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 1996–2014. 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 Partial 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 2020 started from Nuuk June 4th. The first cruise occupied stations from Nuuk north to Disko Bay & Vaigat and the northern most regions having occupied 147 shrimp and fish stations and 40 CTD cast in 26 days. The second cruise started from Nuuk July the 2 occupied 100 shrimp and fish stations in 14 days. No CTD cast were sampled at the second trip.

In most previous years, a crew engaged in taking photographs of the sea bottom, who used the ship at night when the survey was suspended, has accompanied cruises. However, this part was not conducted on the survey in 2018 but again in 2019 and 2020. From all planned shrimp and fish stations, at the two cruises, by-catch of benthic faunal invertebrates were sorted from each stations, identified to the lowest possible taxonomic level, and some species were preserved in 10% buffered formalin solution for later identification, and both projects aims to investigate the long-term effects of trawling on bottom ecosystems. Same procedure was done for benthic species sampled with a beam-trawl.

Of the 58 planned survey strata, 1 (C0) had no stations trawled caused by lack of ship time and ice conditions. 21 stations had no catch of *P. borealis*; 6 strata (W7-4, W8-1 and W8-3), with 5 occupied stations between them had no catches and stratum U1, U3, I1, I2, W1, W2 and W3, had catches of *P. borealis* at all stations. Length samples were measured from 164 stations with catches even very small ones, and length & weight samples were measured at 79 stations.

There was one exceptionally large catch only at one station in W6-1 with a catch closed to 4 ton (3882.5 kg) and two stations in W4-1 (1120.3 kg) and in W6-2 (1111.1 kg) had a catch close to 1 ton. There were in total 4 stations situated in I2-1 and W2-2 with catches above 500 kg and 29 catches over 200 kg but less than 500 kg, of which 12 were made in Disko Bay or Vaigat, 4 stations north from 69°30 N, 11 in strata W1-W4, 1 in stratum W5, 1 in stratum W6 and none in W7- W9. In southerly areas, strata W7-W9 yielded an average catch of 1.2 kg at the 27 stations, in the southern regions.

Overall Biomass and Area Distribution.

For all strata biomass estimates have been calculated (Table 2) based on the nominal swept area. The biomass estimates (in tons) for the five main regions and the entire survey area in 2018 were:

Region– 2018	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	65 798	36	16.1
Canadian zone (C0)*	-	-	-
West (W1–W9)	154 027	124	17.3
Disko Bay & Vaigat (I1, I2)	72 231	24	10.8
Total	316 152	184	10.2

- Area W1-4 was not surveyed in 2018, owing to bottom trouble.

and in 2019:

Region–2019	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	65 080	41	15.2
Canadian zone (C0)	-	-	-
West (W1–W9)*	224 002	104	20.1
Disko Bay & Vaigat (I1, I2)	44 907	21	7.9
Total	333 989	166	13.9

A Strata C0 was not surveyed in 2019, owing to lack of ship

and in 2020:

Region–2020	Biomass estimate (t)	Number of stations	ECV (%)
North (U1-U3)	89 008	37	24.1
Canadian zone (C0)	-	-	-
West (W1–W9)*	221 959	121	28.1
Disko Bay & Vaigat (I1, I2)	67 907	27	7.0
Total	333 989	185	17.5

- Strata C0 was not surveyed in 2020, owing to ice cover and W8-2 and W9-4 due to problems with the placement of the allocated stations.

Survey biomass decreased over 2010 and the declining trend in survey biomass continued until 2014 and fluctuated with some smaller ups and down in 2015 and 2016 (Burmeister and Kingsley, 2015a; Burmeister and Kingsley, 2015; NIPAG, 2015) (Table 3, Figure 2a and 2b). In 2017 the biomass (316.2 Kt) was 49% higher than in 2016. Total survey biomass remained on a comparable level in 2018 at 292 Kt. Since biomass have been increasing, and was in 2020 (378 Kt), 13% higher than the year before, (Table 3, Figure 2a and 2b) and above its serial mean (1988 – 2020; 297 Kt).

The 2020 survey biomass value is 132% of its past 5 yr. and 143% its past 10 yr value. While offshore survey biomass (311 Kt) remained almost comparable to the 2019 value (289 Kt) considerably above both its past 5 yr and past 10 yr mean as well as the serial mean (247 Kt), survey biomass in inshore regions Disko Bay & Vaigat (67.3 Kt) increased by 50% over 2019. Inshore survey biomass is in 2020, almost at its past 5-yr. mean (99%), but below the serial mean (1988 – 2020; 73.6 Kt). Offshore biomass constitutes 82% and Disko Bay & Vaigat 18% of the total survey biomass. The Canadian area was not surveyed in 2020 due Ice cover, but was surveyed in 2017, and contributes less than 1% of total offshore survey biomass (Table 3).

In offshore survey regions, survey biomass dropped by 11% in W1-W2, 56% in W3 and 85% in W5. However, biomass in W4 (Holstsinsborg Dyb) increased by 37% and almost doubled in W6 to a record value (76.3 Kt). The survey biomass in the other strata remain comparable with the most recent years (Table 3 Figure 2b). Biomass estimates for areas W6 amounted 23 % of the total offshore survey (based on only two hauls with large catches) and the southernmost area W7-W9 comprise less than 1% of the total biomass.

Densities of *P. borealis* in Disko Bay were almost stable from 2010 to 2014. In the succeeding years, densities were continuous declining, except for 2017, to a low level considerably below the serial mean in 2019. This trend stopped in 2020, where the density increased to a comparable 2015 value. Nevertheless, the inshore region had higher densities (6.8 t/km²) than the average offshore regions (2.6 t/km²) (Figure 3a). Highest densities in offshore regions were found in W1-W2 (West of Disko Bay) and lowest densities were found in the Southern areas W8-W9 (0.01 t/km²) (Table 5). Overall mean density (2.9 t/km²) has been increasing since 2018 to a value a little above its serial means (1988–2020; 2.3 t/km²), and above both its past 5-year and 10-year mean (Fig. 3b).

The spread index, of how widely the survey reflects the stock biomass is distributed, has shown an increase from 2016 to 2018, remain stable in 2019 and 2020, indicating that the stock is more widely distributed than compared to the period from 2010 to 2014. The north index has shown declining trend over the past 5 years (Figure. 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, Fig. 5b). 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 (Fig. 5c). In the subsequent year biomass at 200 – 300 m increased significantly until 2004, so do the 150–200 and 300–400 m strata, however increased later, and less.

In the following years, biomass declined to a low value in 2012 in strata 300–400, and to a low value two years later in stratum 200–300 m. Since 2015, the biomass has continuously increased in those two depths strata. However, less abundant in those depth strata in 2020, were the biomass seems to have moved into more shallow water 150–200 m. The significant increase of biomass in that depth strata was mainly caused by three large hauls (Fig. 5a). The biomass in the deeper stratum, 400 –600 m, has remained stable since 2010, whereas the biomass in the shallow water has been fluctuated throughout the entire time series.

The proportion of the biomass in the shallow water constitute in general less than 20% of the total shrimp biomass. Some years less than 5% and some years more than 15%, but with no clear trends between years. In 2020, 33% of the biomass were found in the shallow water and this increase was mainly caused by three large catch in three hauls in the strata W4-1, W6-1 and I2-1.

In general, since the late 1990s the majority (80%) of the biomass has been found in depths from 200 to 300 m and 300 to 400 m, while little biomass is found to be at deeper waters > 400 m (Fig 5a and Fig 5b).

In 2001–2020 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 2020, the depth index was estimated to approx. 256 m, considerably lower compared to the past 20 years (280 m).

Demography and recruitment

Length-weight relationships

In 2020, 2986 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 2020 were little changed from the past years.

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

Year	w_0 (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	1.9	2.7188	1616	6.79
2006	0.05771	1.426	1.6	2.761204	1907	7.89
2007	0.7700	1.789	4.5*	2.78216	487	6.42
2008	-0.03285	1.4162	0.8	2.7501	2147	6.67
2007–08	-0.121034	0.4031	-1.7	3.052731	2634	6.88
2009	0.01823	2.774	2.2	2.58902	1768	6.86
2010	0.1533	8.155	4.5*	2.32036	1096	6.66

Year	w_0 (g)	coefficient a (mg)	l_0 (mm)	exponent z	sample	Scatter c.v. (%)
2011	0.12993	9.753	4.5*	2.25051	2569	6.64
2012	0.08185	8.928	4.2	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
2016	0.18877	8.655	4.5*	2.30198	1125	5.68
2017	0.04806	2.775	2.7	2.61194	3520	7.52
2018	0.13308	7.392	4.5*	2.34835	9732	7.48
2019	0.09774	4.820	3.5	2.45119	3256	6.92
2020	-0.02491	2.107	1.7	2.64731	2986	6.81

* L_0 must be no greater than 4.5 mm.

The scatter about the fitted weight-length relationship is consistent from year to year. Whereas the scatter in 2016 was lower than most other years, the scatter in 2020 was almost average compared to 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
2016	0.63	2.13	4.95	9.24
2017	0.55	2.00	4.80	9.27
2018	0.54	1.98	4.75	9.03
2019	0.57	2.00	4.72	8.96
2020	0.56	2.02	4.74	9.02
Mean	0.60	2.03	4.74	9.02

Estimated weights at length have been consistent over years, and there is very little change from 2010–2020. Though 2016 has rather heavy shrimps at the small medium size, 10, 15 and 20 mm, but in 2017 and 2018 the weight of small shrimps at 10 mm decreased and were little less than the most previous years. The weight at the four size groups were in 2020 almost at their serial mean.

The mean weight of both sexes has decreased steadily over the 31-year history of the survey (Fig. 8), by, on average, 34 mg/yr. for females and 22 mg/yr. for males. However, the females have since 2014 in weight been almost comparable weights observed in the mid-1990s. 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 significant serial correlation in the residuals about the trend lines, 0.54 for males and 0.87 for females, indicating that there is some underlying mechanism.

Recruitment and mean length at age 2

Length-frequency plots—e.g. regions I1 – I2 (Disko Bay & Vaigat) in 2014 and W1–W4 in (offshore) in 2014 and 2015 (Fig. 10)—show a first insignificant component with mean CPL at 7–8 mm. These shrimps had probably hatched in the spring of the year before. Age-1 shrimp haven't been observed in the most recent years nor in 2020, in inshore as well as offshore regions. 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, the smallest age 2 shrimps were found in the most northern regions whereas the largest were found in the more southern regions (Table 9). In 2019 and 2020, mean length at age 2, varied from 10.2 mm to 12.5 mm carapace length. 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 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 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 increased and more than double to 10.85 bn in 2015, considerably above the series 1988–2015 mean of 6.27 bn (Fig. 11 and Table 10). The high level of age-2 shrimps was not maintained, and numbers of age-2 shrimp was about 72% less in 2017 (3.03 bn). However, numbers of age-2 shrimp increased in 2018, and almost doubled its value in 2019 (10.55 bn). Remained relatively stable in 2020 (9.75 bn) and is 143% of its past 5 years mean (2015–2019) and above to its serial mean (6.32 bn). The relatively high numbers of 2-age shrimp are only found in the central regions (W1–W4 and at mainly one station in W6). The number of age-2 in Disko Bay & Vaigat increased, nevertheless to a value far below the serial mean and the values observed for the past 5 and 10 years. In the southernmost region W7 to W9 age-2 shrimps have always been very few.

Disko Bay and Vaigat, which include only about 7% of the survey area, has back in time contributed from 30% and up to 72% of the total numbers of age 2 shrimps (Table 10). However, over the most recent years numbers of age-2 shrimp have been declining in Disko Bay & Vaigat and accounted for less than 10% of the age-2 shrimps in 2019 and 2020 (Table 10, Fig 11a). The contribution from offshore regions has historically been lower, but as observed in 2015–2020, except 2016, the abundance of age-2 shrimps is considerably higher offshore than in Disko Bay & Vaigat (Table 10).

The age-2 index is correlated with the fishable biomass two, three and four years later (Fig. 13a); 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. These relationships are corrected for serial correlation (autocorrelation) if it is found significant, which only was the case for the correlation of age 2 shrimps and the fishable biomass with 2 years lag. The regressions of age-2 numbers and of fishable biomass with a three or four year lag have strong correlation, which indicate that shrimp enter the fishable biomass as 5 to 6 year old shrimps.

Number of pre-recruits (14–16.5 mm CL) were high from 1999 to 2005, then followed by a declining to a low value in 2014. This turned to a significant increase of pre-recruits in 2015, which was not remained in 2016.

However, the abundance of pre-recruits reaches a relatively high value in 2017, has since varied in numbers and is in 2020 considerably above the average from the past five and ten years. Numbers of pre-recruits has historically been higher in offshore regions compared to inshore Disko Bay & Vaigat, and 2020 is no exception, while 90% of the pre-recruits are found in offshore regions.

Numbers, spawning stock biomass and fishable biomass

Survey and fishable biomass peaked in 2002 to 2006 and since decreased to a very low level in 2014 (Table 3 and Table 8). In the subsequent years, survey as well as fishable biomass, have increased to 2020 values above their past 5-year and 10-year mean and of their serial means. 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). Since 2018, female's biomass constituted between 37 - 40 % of the total biomass and is in 2020 above the level for its past 5-year mean as well as its serial mean (109 Kt). Female biomass is in 2020 estimated at 141 Kt, and male biomass 237 Kt (Table 6 and table 7).

Compared with the length distributions in past years, there were a greater proportion of smaller shrimps, those below about 17 mm CPL caught by 2020 survey in the offshore regions (Fig. 10). The proportion of the largest females above 23 mm CPL are comparable with observations from the past years, however in numbers considerably higher in offshore regions compared to Disko Bay and Vaigat (Fig. 10, table 6 and table 7). Female biomass in offshore regions were low in 2014, increased significantly in 2015 remain on a comparable level in 2016. Since 2018 female biomass in offshore regions has been increasing and is above its serial mean. In Disko Bay & Vaigat, female biomass declined from 2014 to a low level in 2019, except for an increase in 2017. This trend stopped in 2020, but despite an increase, female biomass in Disko Bay & Vaigat is still at a level below its serial mean.

Numbers of males is in 2020 almost eight times higher in offshore regions compared to Disko Bay and Vaigat, and in total, both in numbers and biomass, above the serial mean (Fig. 10, table 6 and table 7). It is not unusual that males are more abundant offshore, and in 2020, the occurrence of males inshore is, despite a minor increase over 2019, still at a low level compared to the past 20 year.

Bottom temperature

Area weighted bottom temperatures is given in Fig. 6 and Fig. 14. Bottom temperature have been stable at somewhat 3.1°C from 2008 to 2012, but starting a decrease in 2015 (2.98°C) which continuing in 2018 to 2.1 °C. Nevertheless, bottom temperature increased to 2.5 °C in 2019 and remained on a comparable value in 2020 (2.65 °C). Regionally the bottom temperature in the Northern regions (U1-U3 and I1-I2) were almost stable at approximately 2.8 °C from 2000 and until 2014. This was followed by a continuous decline until 2018 (1.2°C) but has increased to 2.3°C in 2020.

In W1-W4 temperature increased about to 3.9 °C in 2014, followed by a continuous decline to 2.25°C and remained at a comparable value in 2018. However, this cooling trend stopped in 2019, and bottom temperature increased in those regions to values comparable to observations from 2017. In the more southern areas (W5-W6) temperature has decrease little since 2014, but in general bottom temperature remained “warm”. While temperature in the southernmost regions W7-W9, dropped from 4.68°C in 2014 to 3.39 °C in 2018, bottom temperature increased considerably to above 5 °C in 2019, but dropped again in 2020 to 3.7 °C (Fig. 14). In conclusion the overall bottom temperature has decreased by 1.5°C since 2014 and until 2018, but a minor increase has been observed in 2019 and remained somewhat stable in 2020.

The depth distribution of the shrimp survey biomass appears to have shifted after, and not concurrently with, the temperature shift (Fig. 6 and Fig. 14). Thus, bottom temperature has been declining since 2015 and the depth index of survey biomass remained comparable to observations for the past 16 years.

Conclusions

Stock size

In aggregate, the stock has, despite the decline from its high biomass levels in 2003 – 2006, shown no clear trends since 2007. In fact, at short term (10 year), there has been fluctuations in the stock with ups and downs in biomass. The overall survey biomass increased by 49% to 316.2 Kt in 2017, drop little to 292 Kt in 2018, but raised again in 2019 and is in 2020 to 378 Kt. This is mainly caused by a change in biomass in offshore regions in most northern regions, the central regions along the West coast (Holsteinsborg Dyb), at Fylla region and in Disko Bay & Vaigat. The total survey biomass is in 2020, 132% of its past 5-yr mean, 140% of its past 10-yr mean and above its serial mean (297 Kt). The offshore regions are now constituting 82% of the total surveyed biomass, and 18% of the biomass is situated in Disko Bay & Vaigat.

The offshore and inshore components have had very different trajectories since 2008. Inshore, in Disko Bay and Vaigat, the biomass almost doubled from 2008 to 2010 and was then gradually decreasing to a low level in 2019. In the same period, the offshore biomass has fluctuated with ups and downs. Recruitment patterns have, to some extent, shown minor different trajectories, however not so conspicuously as for the survey biomass.

Fishable biomass (329 kt) only increased little over 2019 (8%) and mainly caused by an increase of the fishable biomass in Disko Bay & Vaigat, whereas fishable biomass remained almost unchanged in offshore regions. In offshore regions and in Disko Bay & Vaigat fishable biomass is above of its serial mean and its past 5-year. Total, fishable biomass is above both its serial mean (273 kt), and well above both its past 5-year mean and 10-year mean. In 2020 fishable biomass, constitute 87% of the total surveyed biomass.

Stock distribution

The area over which the stock is distributed has increased since 2013, and it remains concentrated in Disko Bay, Vaigat and the Northern part of its range (north of 66°N). Densities are almost three times higher in Disko Bay and Vaigat compared to offshore regions. While densities in offshore regions are above to its serial means, it is almost at its serial mean in Disko Bay and Vaigat. In the northernmost regions (U areas) and Holsteinsborg Dyb (W4) in the offshore regions, densities shown some minor increases over 2019 and at value higher than observed for the past 10 years. Densities are practically zero on in the southern most regions.

The latitude index of the survey has declined from 2010 – 2013, followed by a continuous increase to 2018 and remained almost unchanged in 2019 and 2020. The North index remain stable from 2009 to 2015 owing to high proportion of biomass in the Northern regions and in Disko Bay & Vaigat, and lower proportion of biomass in the W- regions. However, for the past 3 years, there have been a declining trend in the North index. Survey biomass from the northern (above 66°N) and Disko Bay & Vaigat regions constitute in 2020 almost 79% of the total survey biomass. Over the past three years, and on average 20% of biomass have been available south of 66°N and down to 64°N.

Since the late 1990s, the stock appears to be found in shallower water than before. Nevertheless, the proportion of the biomass in the shallow water (100-200 m) constitute in general less than 20% of the total shrimp biomass. However, in 2020 more biomass (33%) were found in shallow waters mainly caused by three large catches in that depth strata. Since the late 1990s the majority (80%) of the biomass has been found in depths from 200 to 300 m and 300 to 400 m, while little biomass is found to be at deeper waters > 400 m.

Survey biomass depth index has ranged between 265 and 300 m since 2001, with an average near 281.5 m compared to an average of 329 m in the period from 1988 to 2000 (Fig 5.c). In 2020, the depth index was estimated to approx. 255 m, lower than compared with the past 5 year (281 m).

Stock composition

By numbers and biomass, the stock is heavily weighted toward males, but the females still composed a high proportion of the total fishable (43%) and surveyed biomass (approx. 37%). Fishable biomass is above at the average for the serial mean and as a proportion of the total survey biomass but compose to a relatively high degree of males.

Numbers at age-2 shrimp are overall, well above the serial mean but considerably below inshore in Disko Bay and Vaigat. The number of pre-recruits (14-16,5 mm CL) in total are close to an average level both in numbers and relative to the survey biomass; average in absolute numbers and relative to their biomass in offshore regions, but far below mean in Disko Bay & Vaigat.

References

- ALLEN, J.A. 1959. On the biology of *Pandalus borealis* Kroger, with reference to a population off the Northumberland coast. *J. Mar. Biol. Assoc. U.K.*, **38**: 189-220.
- AITCHISON, J. 1955. On the distribution of a positive random variable having a discrete probability mass at the origin. *J. Am. Stat. Assoc.* 50: 901-908
- BURMEISTER, AD. AND KINGSLEY, M.C.S. 2015. The west Greenland trawl survey for *Pandalus borealis*, 2015, with reference to earlier results. *NAFO SCR Doc.*, No. 15/043, Serial No. N6478.
- BURMEISTER, AD. AND KINGSLEY, M.C.S. 2015. A provisional Assessment of the Shrimp Stock off West Greenland in 2015. *NAFO SCR Doc.*, No. 15/044, Serial No. N6479.
- CARLSSON, D.M. and P. KANNEWORFF. 2000. Stratified-random trawl survey for shrimp (*Pandalus borealis*) in NAFO Sub area 0+1, in 2000. *NAFO SCR Doc.*, No. 78, Serial No. N4335.
- CARLSSON, D., O. FOLMER, P. KANNEWORFF, M.C.S. KINGSLEY and M. PENNINGTON. 2000. Improving the West Greenland Trawl Survey for shrimp (*Pandalus borealis*). *J. North. Atl. Fish. Sci.*, **27**: 151-160.
- KINGSLEY, M.C.S. 2014. Numbers of Age-2 Shrimps in West Greenland—again. *NAFO SCR Doc.*, No. 14/058, Serial No. N6360.
- KINGSLEY, M.C.S. 2001a. Effects in 2001 of recent modifications to the design of the West Greenland Shrimp Survey. *NAFO SCR Doc.*, No. 176, Serial No. N4565.
- KINGSLEY, M.C.S. 2001b. Studies in 2001 on the end effect of the Skjervøy 3000 trawl in the West Greenland shrimp survey. *NAFO SCR Doc.*, No. 177, Serial No. N4566.
- KINGSLEY, M.C.S., P. KANNEWORFF and D.M. CARLSSON. 1999. Modifications to the design of the trawl survey for *Pandalus borealis* in West Greenland waters: effects on bias and precision. *NAFO SCR Doc.*, No. 105, Serial No. N4184.
- KINGSLEY, M.C.S., D.M. CARLSSON, P. KANNEWORFF and M. PENNINGTON. 2002. Spatial structure of the resource of *Pandalus borealis* and some implications for trawl survey. *Fish. Res.* **58**: 171-183.
- KINGSLEY, M.C.S., P. KANNEWORFF and D.M. CARLSSON. 2004. Buffered random sampling: a sequential inhibited spatial point process applied to sampling in a trawl survey for Northern shrimp *Pandalus borealis* in West Greenland waters. *ICES J. Mar. Sci.*, **61**: 12-24.
- KINGSLEY, M.C.S. 2008. Indices of distribution and location of shrimp biomass for the West Greenland research trawl survey. *NAFO SCR Doc.*, No 78, Serial No. N5610.

- MCCRARY, J.A. 1971. Sternal spines as a characteristic for differentiating between females of some Pandalidae. *J. Fish. Res. Board Can.*, **28**: 98-100.
- NAFO/ICES 2015. NAFO/ICES *Pandalus* Assessment Group Meeting, 9-16 September 2015, Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, Canada. *NAFO SCS Doc.* 15/13 Serial No. N6497, ICES CM 2015/ACOM:14
- PENNINGTON, M. 1983. Efficient estimators of abundance for fish and plankton surveys. *Biometrics* 39: 281-286
- WIELAND, K. 2002a. A new length-weight relationship for Northern shrimp (*Pandalus borealis*) off West Greenland (NAFO Subareas 0+1). *NAFO SCR Doc.*, No. 144, Serial No. N4773.
- WIELAND, K. 2002b. The use of fine-meshed bags for sampling juvenile Northern shrimp (*Pandalus borealis*) in the West Greenland Bottom Trawl Survey. *NAFO SCR Doc.*, No. 145, Serial No. N4774.
- WIELAND, K. 2004. Abundance, mean size at age and growth of Northern shrimp (*Pandalus borealis*) juveniles and males off West Greenland in 1993–2004. *NAFO SCR Doc.*, No. 04/73, Serial No. N5043.
- WIELAND, K. 2005. Changes in recruitment, growth and stock size of Northern shrimp (*Pandalus borealis*) at West Greenland: temperature and density-dependent effects at released predation pressure. *ICES J. Mar. Sci.* **62**: 1454-1462.
- WIELAND, K. and D.M. CARLSSON. 2001. Geographical distribution and mean size of different life stages of Northern shrimp (*Pandalus borealis*) off West Greenland. *NAFO SCR Doc.*, No. 01/178, Serial No. N4567.
- WIELAND, K. and P. KANNEWORFF. 2004. Revision of depth contours and stratification of the West Greenland Bottom Trawl Survey for Northern shrimp. Technical report No. 56, Greenland Institute of Natural Resources (http://www.natur.gl/publikationer/tekniske_rapporter).
- WIELAND, K. and M. STORR-PAULSEN. 2006. Effect of tow duration on catch rates and mean length of Northern shrimp (*Pandalus borealis*) and Greenland halibut (*Reinhardtius hippoglossoides*) in the West Greenland Bottom Trawl Survey. *Fish. Res.* **78**: 276-285.

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, 1988–2020

	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	**
2005–2017	"	Cosmos	54.0	27.4–29.3	**
2018	Sjurdarberg	Cosmos	54.0	30.2	**
2019	Helga Maria	Cosmos	54.0	31.3	**
2020	Helga Maria	Cosmos	54.0	32.6	**

(*: from tank experiments (Per Kannevorff, 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 2020.

Stratum	Area (km ²)	Stations	Biomass density (t/km ²)	Biomass (Kt)	Biomass error variance	Error coefft of variation (%)
C0-2	903	0	-	-	-	0.0
C0-3	2179	0	-	-	-	0.0
C0-4	1154	0	-	-	-	0.0
Overall C0	4236	0	-	-	-	-
I1-1	407	2	7.603	3.091	0.7581	28.2
I1-2	1963	3	9.992	19.614	8.4769	14.8
I1-3	2441	5	7.591	18.531	5.8005	13.0
I1-4	1499	4	2.635	3.948	2.1359	37.0
I2-1	419	4	21.602	9.058	1.7096	14.4
I2-2	815	3	7.832	6.383	0.1542	6.2
I2-3	1085	3	4.602	4.993	2.3552	30.7
I2-4	1338	3	1.265	1.693	0.7564	51.4
Overall I	9967	27	6.753	67.312	22.1468	7.0
U1-1	2486	2	4.891	12.159	116.7501	88.9
U1-2	4633	4	1.307	6.055	9.3740	50.6
U1-3	4785	4	1.760	8.423	8.2914	34.2
U1-4	5129	3	0.314	1.608	0.6521	50.2
U2-2	6710	3	3.114	20.897	266.5146	78.1
U2-3	8481	4	1.545	13.105	11.8369	26.3
U2-4	7994	5	0.145	1.157	0.8113	77.8
U3-1	2012	2	0.339	0.682	0.4374	97.0
U3-2	3017	4	6.463	19.495	40.9905	32.8
U3-3	1675	3	2.794	4.679	2.7323	35.3
U3-4	2710	3	0.276	0.749	0.1411	50.2
Overall U	49631	37	1.793	89.008	458.5317	24.1
W1-1	2873	2	0.377	1.084	0.0156	11.5
W1-2	6099	7	3.901	23.792	59.7005	32.5
W1-3	7520	6	2.065	15.527	9.5629	19.9
W1-4*	816	2	0.006	0.005	0.0000	58.5
W2-1	1674	2	6.246	10.452	6.4896	24.4
W2-2	2612	6	10.780	28.151	13.9868	13.3
W2-3	1741	2	2.727	4.748	11.6809	72.0
W2-4	915	2	4.285	3.920	1.6725	33.0
W3-1	2122	3	3.741	7.938	37.5586	77.2
W3-2	4725	11	0.929	4.388	6.1130	56.3
W3-3	2085	2	1.639	3.416	6.8203	76.4
W3-4	2994	4	1.048	3.139	3.7407	61.6
W4-1	4119	3	7.866	32.398	1005.8612	97.9
W4-2	1818	4	1.177	2.139	0.9284	45.0
W4-3	821	2	2.874	2.361	3.4355	78.5

W4-4	1961	3	0.250	0.491	0.2344	98.6
W5-1	3001	4	0.000	0.001	0.0000	70.7
W5-2	3648	9	1.119	4.082	16.4576	99.4
W5-3	1950	4	0.467	0.910	0.7052	92.2
W5-4	3021	4	0.483	1.460	2.1147	99.6
W6-1	1206	3	42.686	51.479	2573.4455	98.5
W6-2	2006	5	9.347	18.748	139.7671	63.1
W6-3	1585	3	0.079	0.125	0.0154	99.4
W6-4	1234	1	0.760	0.938	0.7944	95.0
W7-1	2442	7	0.000	0.001	0.0000	67.6
W7-2	891	2	0.001	0.001	0.0000	100.0
W7-3	265	3	0.000	0.000	0.0000	18.3
W7-4	317	3	0.000	0.000	0.0000	100.0
W8-1	424	1	0.000	0.000	0.0000	0.0
W8-2	567	0	-	-	-	-
W8-3	405	1	0.000	0.000	0.0000	0.0
W8-4	718	2	0.368	0.264	0.0697	99.9
W9-1	1711	5	0.000	0.001	0.0000	63.5
W9-2	938	2	0.000	0.000	0.0000	100.0
W9-3	516	1	0.000	0.000	0.0000	95.0
W9-4	430	0	-	-	-	-
Overall W	72169	121	3.076	221.959	3901.1705	28.1
Survey totals	136003	185	2.781	378.280	4381.8490	17.5

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

* Substrata C0 were not covered due to Ice cover.

Table 3. *Pandalus borealis* in West Greenland: biomass estimates (Kt) for survey subdivisions and standard errors for the entire survey in 1988–2020.

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
2016	60.5	-(1)	48.0	25.5	10.3	2.8	64.8	212.0	19.1
2017	69.8	3.1	72.7	60.0	29.6	0.0	80.8	316.2	29.1
2018	65.8	-(1)	67.8	41.9	44.4	0.0	72.2	292.1	29.5
2019	65.1	-(1)	98.1	45.6	80.2	0.0	44.9	334.0	46.3
2020	89.0	-(1)	87.7	56.3	77.7	0.3	67.3	378.3	66.2
Mean 1988- 2020	44.8	7.5	73.7	50.6	45.7	10.8	67.7	297.0	41.8

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 2014, 2015, 2016, 2018 and 2020 was not sampled due to ice condition

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 1988–2020. (1) Canada(C) in 2011, 2012 and 2014, 2015, 2016, 2018 and 2020 was not sampled due to ice condition or other priorities.

Year	N1-9/ U1-3	C1-3/C0	W1-2	W3-4	W5-7	S/W8-9	D1-9/I1-2	Total survey	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
2016	12.0	-(1)	15.7	31.6	54.2	99.9	18.4	9.03	156
2017	12.4	74.2	16.2	31.0	46.3	53.8	13.2	9.20	215
2018	16.1	-(1)	14.7	27.4	47.3	63.3	10.8	10.11	184
2019	15.2	-(1)	21.2	42.6	41.4	86.1	7.7	13.86	166
2020	24.0	-(1)	14.7	27.4	47.3	63.3	10.8	17.49	187
Mean 1994- 2020	26.9	55.1	20.0	31.3	41.3	65.1	15.2	13.1	195.5

Table 5. *Pandalus borealis* in West Greenland: estimated mean densities (t/km²) for survey subdivisions in 1988–2020.

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	-	2.12	2.90	0.84	0.10	7.85
2016	1.22	-	1.98	1.24	0.48	0.49	6.50
2017	1.41	0.99	3.10	2.91	1.37	0.01	8.11
2018	1.33	-	2.89	2.03	2.06	0.01	7.25
2019	1.31	-	4.05	2.21	3.72	0.01	4.51
2020	1.79	-	3.62	2.73	3.60	0.06	6.75
Serial mean	0.93	1.91	3.00	2.50	2.42	1.73	7.26

Table 6. *Pandalus borealis* in West Greenland: estimated numbers (billions) by sex in 1988–2020.

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
2016	27.6	10.5	38.1	72.4	27.6
2017	47.7	14.2	61.9	77.1	22.9
2018	44.3	12.6	56.9	77.9	22.1
2019	53.2	14.2	67.4	78.9	21.1
2020	65.2	15.4	80.6	80.9	19.1
Average	47.1	12.3	58.7	79.0	21.1

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, 2012, 2014 – 2016, 2018 and 2020 owing to sea ice; and in 2014 due to time trouble; no correction has been made.

³ Substrata W1-4 in 2011, 2015, 2017 and 2018, W9-4 in 2015 and W9-4 were not surveyed due to trawl difficulties and 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 1988–2020. 1991–1997 mean values for Disko Bay and Vaigat have been used for 1988–1990 and included in the calculation of the average. data for 2005–2010 was re-analyzed in 2011.

Year	Males	Females	Total	Males %	Females %
1988	134.7	94.8	229.5	58.7	41.3
1989	157.1	68.6	225.7	69.6	30.4
1990	129.4	85.4	214.9	60.2	39.8
1991	100.5	49.4	149.9	67.0	33.0
1992	141.3	63.1	204.4	69.1	30.9
1993	149.2	81.9	231.1	64.6	35.4
1994	146.5	88.9	235.4	62.2	37.8
1995	124.5	66.9	191.4	65.0	35.0
1996	147.9	68.0	215.9	68.5	31.5
1997	114.7	62.9	177.7	64.6	35.4
1998	170.4	90.9	261.3	65.2	34.8
1999	166.7	93.9	260.6	64.0	36.0
2000	213.8	100.2	314.0	68.1	31.9
2001	199.1	108.3	307.4	64.8	35.2
2002	293.6	126.6	420.2	69.9	30.1
2003	389.2	208.6	597.8	65.1	34.9
2004	353.1	210.3	563.4	62.7	37.3
2005	355.2	196.7	551.9	64.4	35.6
2006	297.4	188.0	485.4	61.3	38.7
2007	227.8	128.7	356.6	63.9	36.1
2008	182.6	99.5	282.1	64.7	35.3
2009	173.5	105.0	278.4	62.3	37.7
2010	222.3	122.4	344.7	64.5	35.5
2011	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	86.0	179.8	52.2	47.8
2015	184.6	99.0	283.6	65.1	34.9
2016	113.6	98.4	212.0	53.6	46.4
2017	181.1	135.1	316.2	57.3	42.7
2018	175.8	116.3	292.1	60.2	39.8
2019	204.3	129.7	334	61.2	38.8
2020	237.1	141.2	378.3	62.7	37.3
Average	187.1	109.3	293.8	62.9	37.1

Table 8. *Pandalus borealis* in West Greenland: estimates of fishable biomass (≥ 17 mm CL; '000 t) from the West Greenland shrimp survey in 1988–2020

FB	>= 17mm CL		10^3 tons			
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%
2016	137.3	70%	58.3	90%	195.6	92%
2017	207.5	88%	73.8	91%	281.3	89%
2018	204.1	93%	66.4	92%	270.5	93%
2019	260.8	90%	41.2	92%	302.0	90%
2020	264.4	85%	65.0	97%	329.4	87%
Average	212.2	92%	60.3	90%	272.5	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 2011–2016, 2018 and 2020, except 2013 nor substratum W1–4 in 2011 and 2015, owing to sea ice; and W9–4 in 2015 and W2–4 due to trawl difficulties. Furthermore W8–2 and W9–4 were fished due to lack of time.

Table 9. *Pandalus borealis* in West Greenland: mean carapace length (mm) at age 2 in 2005–2020, with standard deviations and coefficients of variation (- : not present, (): fixed in the final MIX run, na: no data).

Mean:

Year	U1-U3	I1+I2	Region / Strata	W1-W4	W5+W6	W7-W9
	150-600 m	150-600 m	C0 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	-
2016	12.6	12.0	na	12.1	13.7	-
2017	11.5	11.8	na	11.0	11.2	-
2018	11.5	11.5	na	10.9	13.6	-
2019	10.2	12.1	na	10.9	12.2	-
2020	10.8	12.0	na	12.2	12.5	-

Standard deviation:

Year	U1-U3	I1+I2	Region / Strata	W1-W4	W5+W6	W7-W9
	150-600 m	150-600 m	C0 200-600 m	150-600 m	150-600 m	150-600 m
2005	0.9	1.5	-	1.3	-	-
2006	1.0	1.1	-	1.4	1.3	-
2007	-	1.4	-	-	1.3	-
2008	1.7	1.9	-	1.3	0.8	-
2009	1.4	1.4	-	1.1	1.26	-
2010	1.3	1.2	-	1.3	-	-
2011	-	1.0	na	1.2	-	-
2012	1.5	1.1	na	-	0.4	-
2013	1.0	1.3	-	1.1	1.4	-
2014	1.0	1.4	na	1.4	-	-
2015	0.9	1.5	na	1.1	1.0	-
2016	1.3	1.5	na	1.9	0.9	-

2017	1.3	1.2	na	1.2	0.9	-
2018	1.1	0.9	na	1.2	1.3	-
2019	0.9	1.6	na	1.3	1.4	-
2020	0.5	1.4	na	1.0	1.1	-

Coefficient of
variation:

Year	Region / Strata					
	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
2005	0.08	0.13	-	0.10	-	-
2006	0.09	0.09	-	0.11	0.10	-
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	0.10	na	0.11	-	-
2015	0.08	0.11	na	0.09	0.08	-
2016	0.08	0.10	na	0.10	0.07	-
2017	0.10	0.09	na	0.11	0.08	-
2018	0.08	0.16	na	0.11	0.04	-
2019	0.07	0.16	na	0.12	0.03	-
2020	0.07	0.09	na	0.08	0.07	-

Table 10. *Pandalus borealis* in West Greenland: survey estimate of numbers (billions) at age 2 years, 1993–2020.

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
2016	0.66	2.51	-	1.04	0.05	0.00	4.26
2017	0.24	1.18	-	1.43	0.18	0.00	3.03
2018	1.20	1.18	-	1.72	1.23	0.00	5.33
2019	0.43	0.35	-	0.35	9.42	0.00	10.55
2020	0.02	0.86	3.90		4.94	0.00	9.72
Average:	0.55	2.15	1.97		1.72	0.00	6.32

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-likelihood estimation for the grouped data, resulting is very poor fits.

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

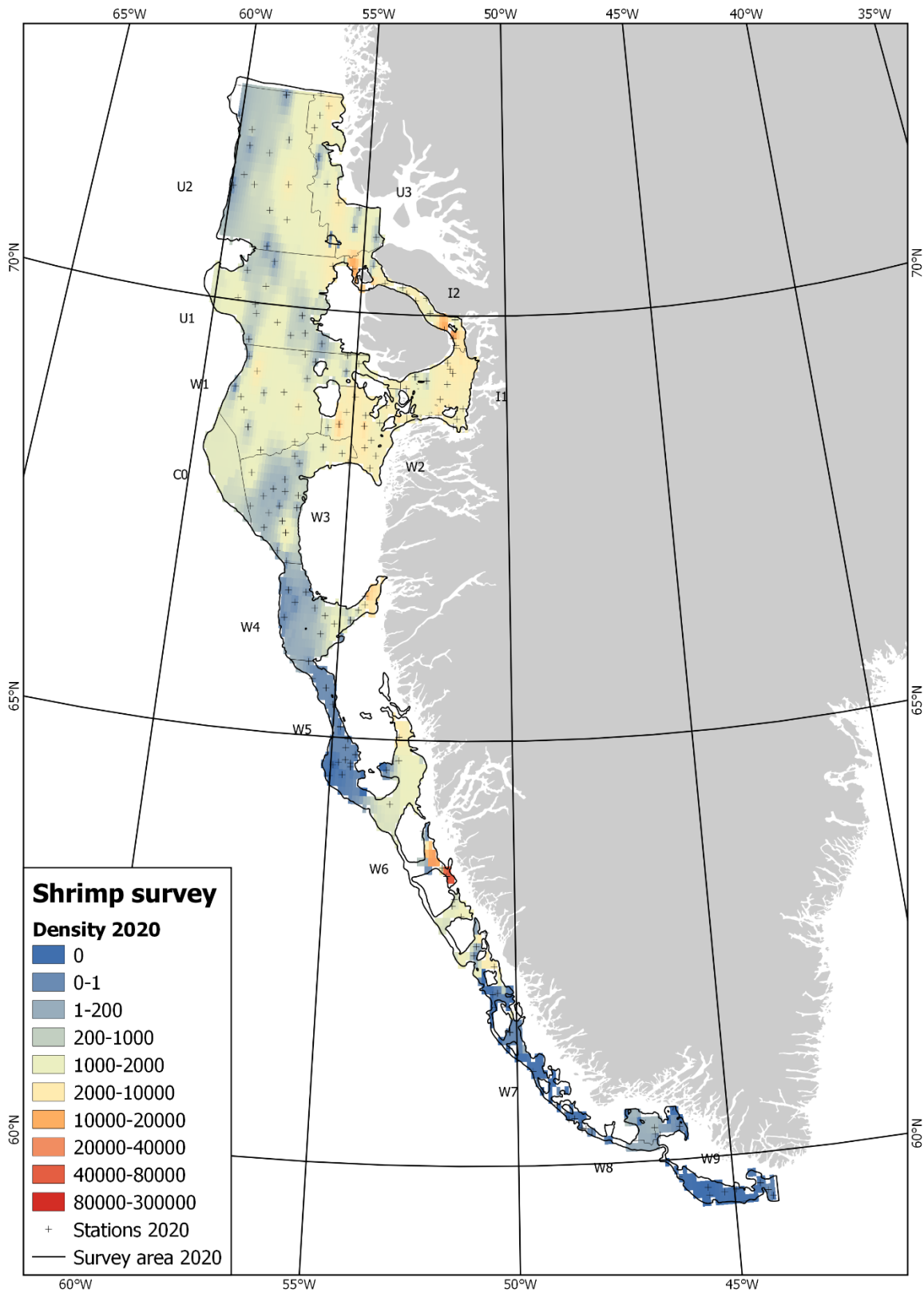


Figure 1. *Pandalus borealis* in West Greenland: density distribution from 187 trawl-survey stations in 2020.

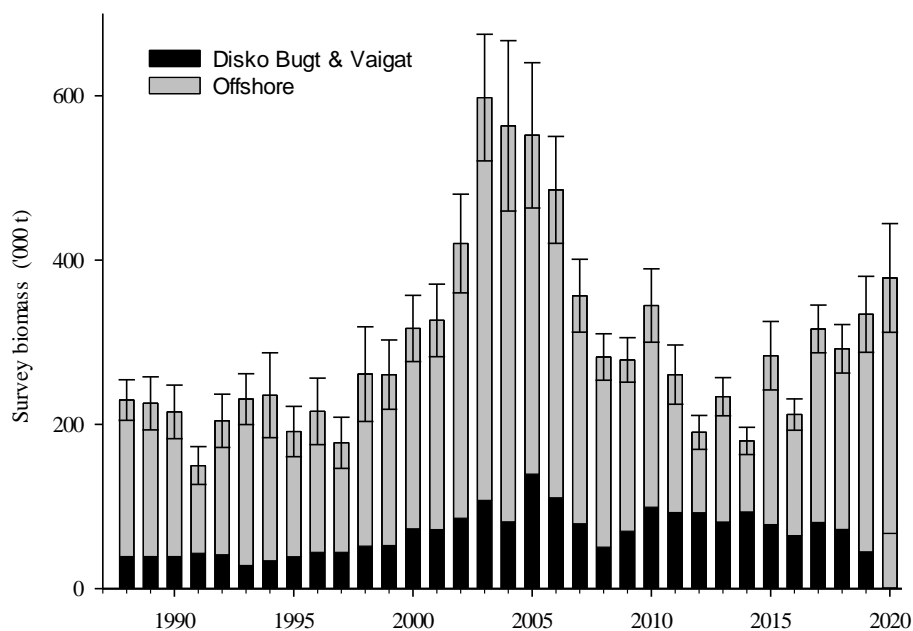


Figure 2a. *Pandalus borealis* in West Greenland: estimated survey biomass, 1988–2020. Area C0-4 was not surveyed in 2011 – 2016 and 2020, except 2013 because of ice cover, in 2014 W9-4 due to poor bottom conditions, area C0 in 2011, 2012, 2014–2016, 2018, 2020 due to ice cover and 2019 owing to lack of ship time.

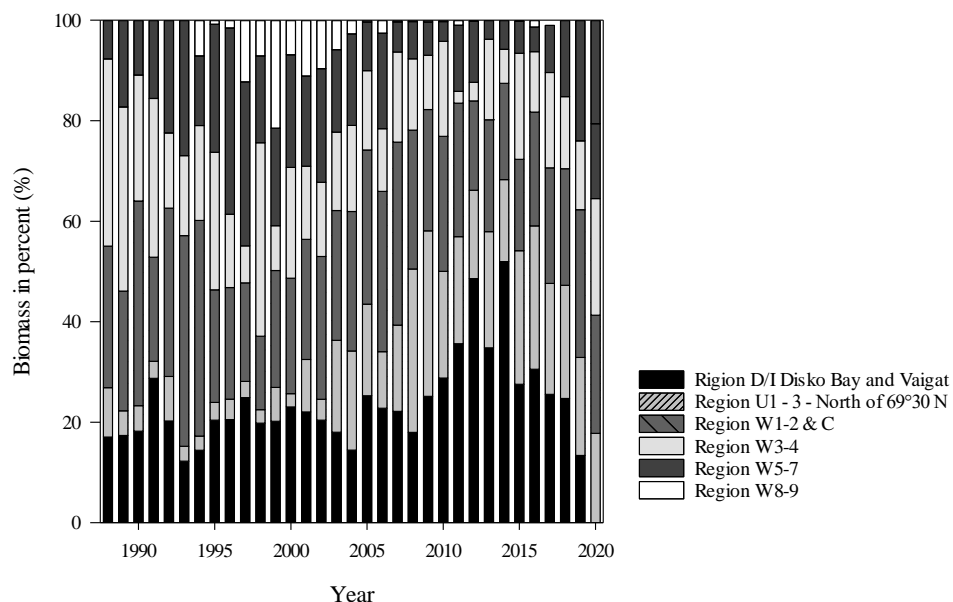


Figure 2b. *Pandalus borealis* in West Greenland: distribution of survey biomass between major survey regions, 1991 – 2020. Area C0-4 was not surveyed in 2011 – 2016 and 2020, except 2013 because of ice cover, in 2014 W9-4 due to poor bottom conditions, area C0 in 2011, 2012, 2014–2016, 2018 and 2019 owing to lack of ship time.

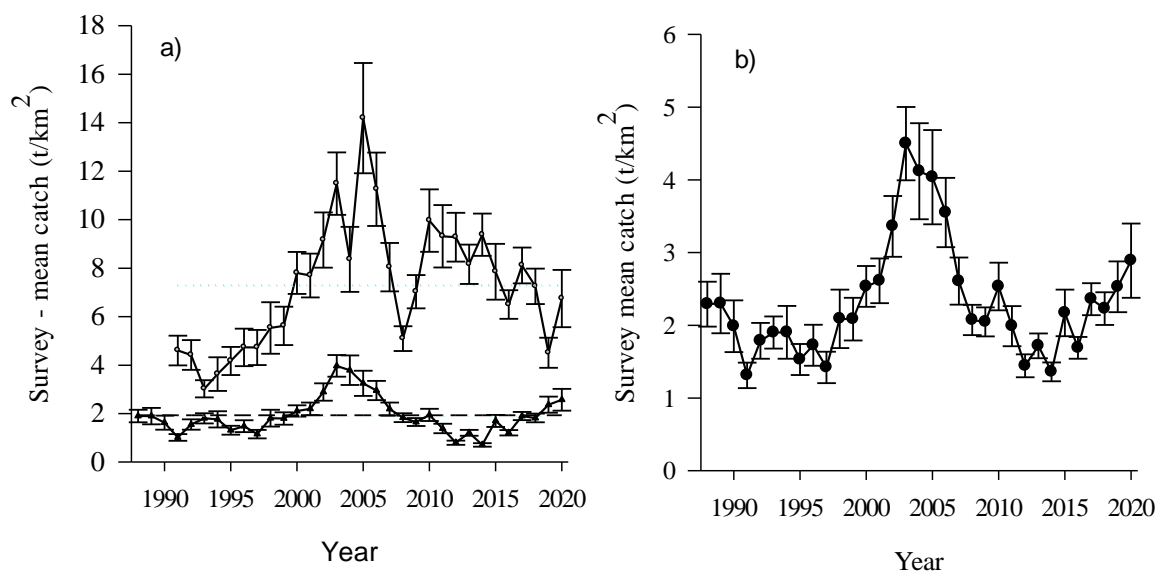


Figure 3. *Pandalus borealis* in West Greenland 1988 - 2020: mean survey density of Northern shrimp in a) -○- Disko Bay and Vaigat (since 1991 cover 7–8% of the survey area), -▲- offshore (92–93%) and b) total surveyed regions.

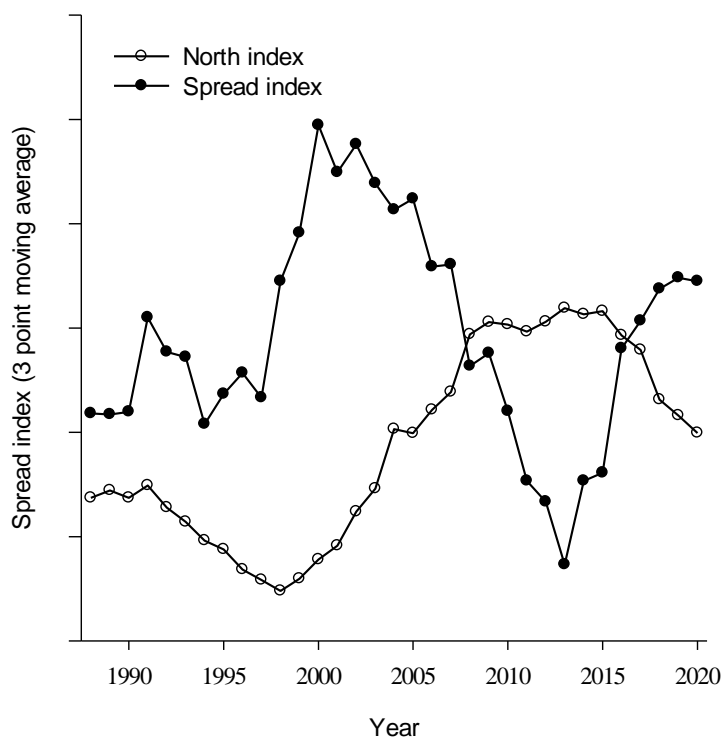


Figure 4. *Pandalus borealis* in West Greenland: indices of distribution and location of shrimp biomass in the West Greenland trawl survey 1994–2020 (3-point moving averages). -○-: North index (3-pt moving average) and -■-; Spread index (3-pt moving average).

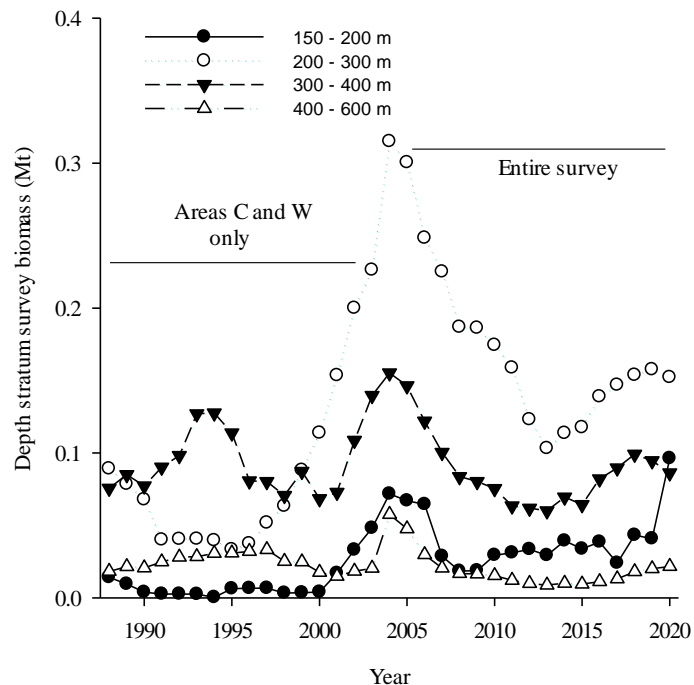


Figure 5a. *Pandalus borealis* in West Greenland: survey biomass estimates by depth stratum, 1988–2020. 3-point moving averages.; Until 2003, only areas C and W were substratified by depth. -●-: 150 – 200m, -○-: 200-300m, -▼-: 300-400 and -Δ- : 400-600m.

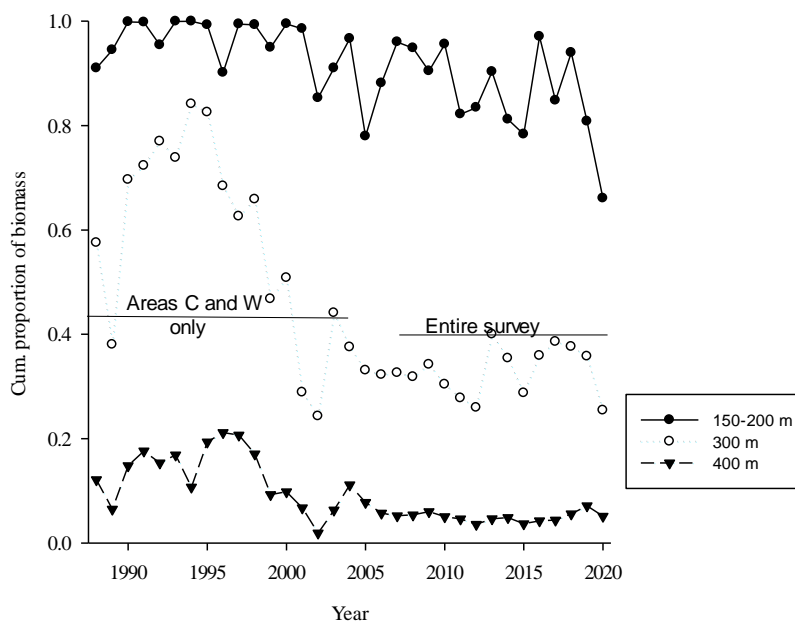


Figure 5b. *Pandalus borealis* in West Greenland: distribution of survey biomass between 150 and 600 m by depth, 1988–2020. Until 2003, only areas C and W were substratified by depth. -●-: 150 – 200 m, -○-: 300 m and -▼-400 m

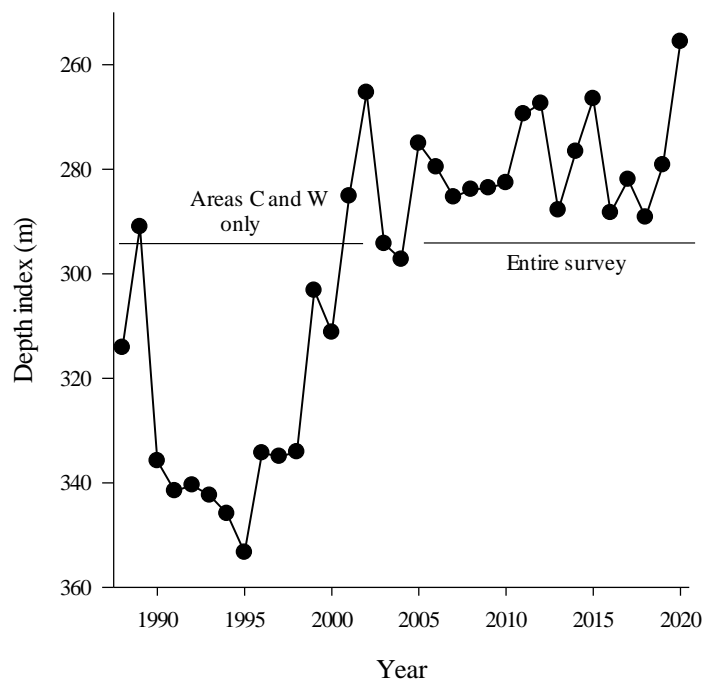


Figure 5c. *Pandalus borealis* in West Greenland: depth index for survey biomass, 1988–2020. Until 2003, only areas C and W were substratified by depth.

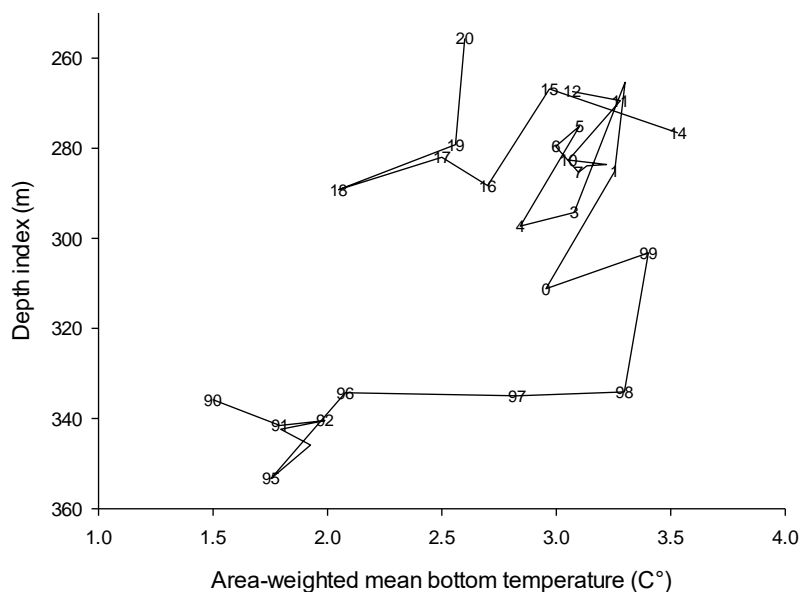


Figure 6. *Pandalus borealis* in West Greenland: depth index of survey biomass vs. area-weighted mean bottom temperature from survey trawl-door measurements, 1990–2020.

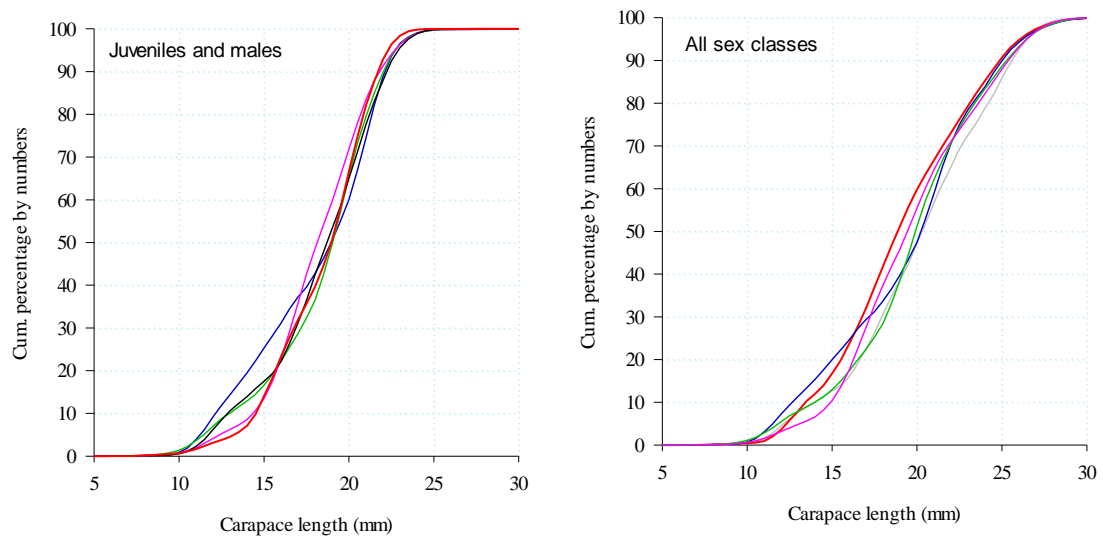


Figure 7. *Pandalus borealis* in West Greenland: distribution of lengths from survey length analyses in 2016 (gray line), 2017 (pink line), 2018 (green line), 2019 (blue line) and 2020 (red line).

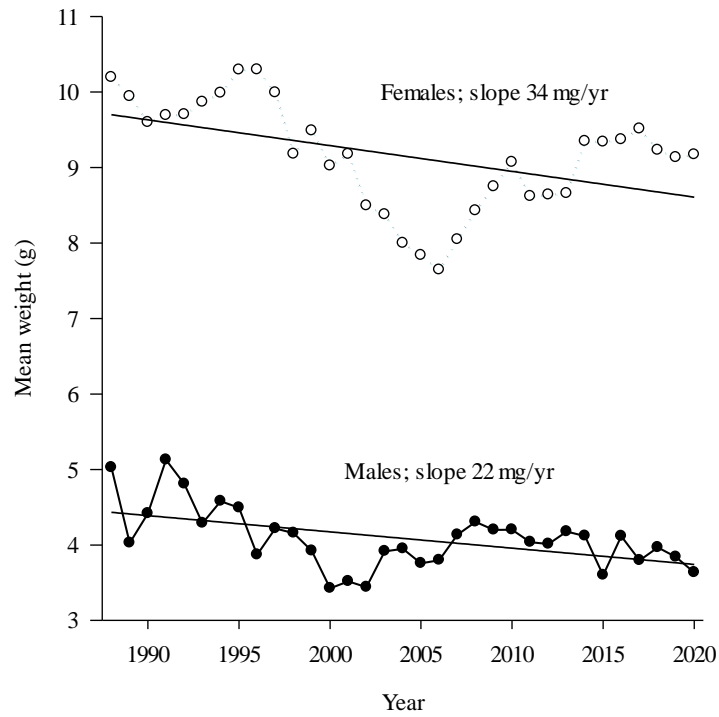


Figure 8. *Pandalus borealis* in West Greenland: mean weight by sex, from survey data, 1988–2020.

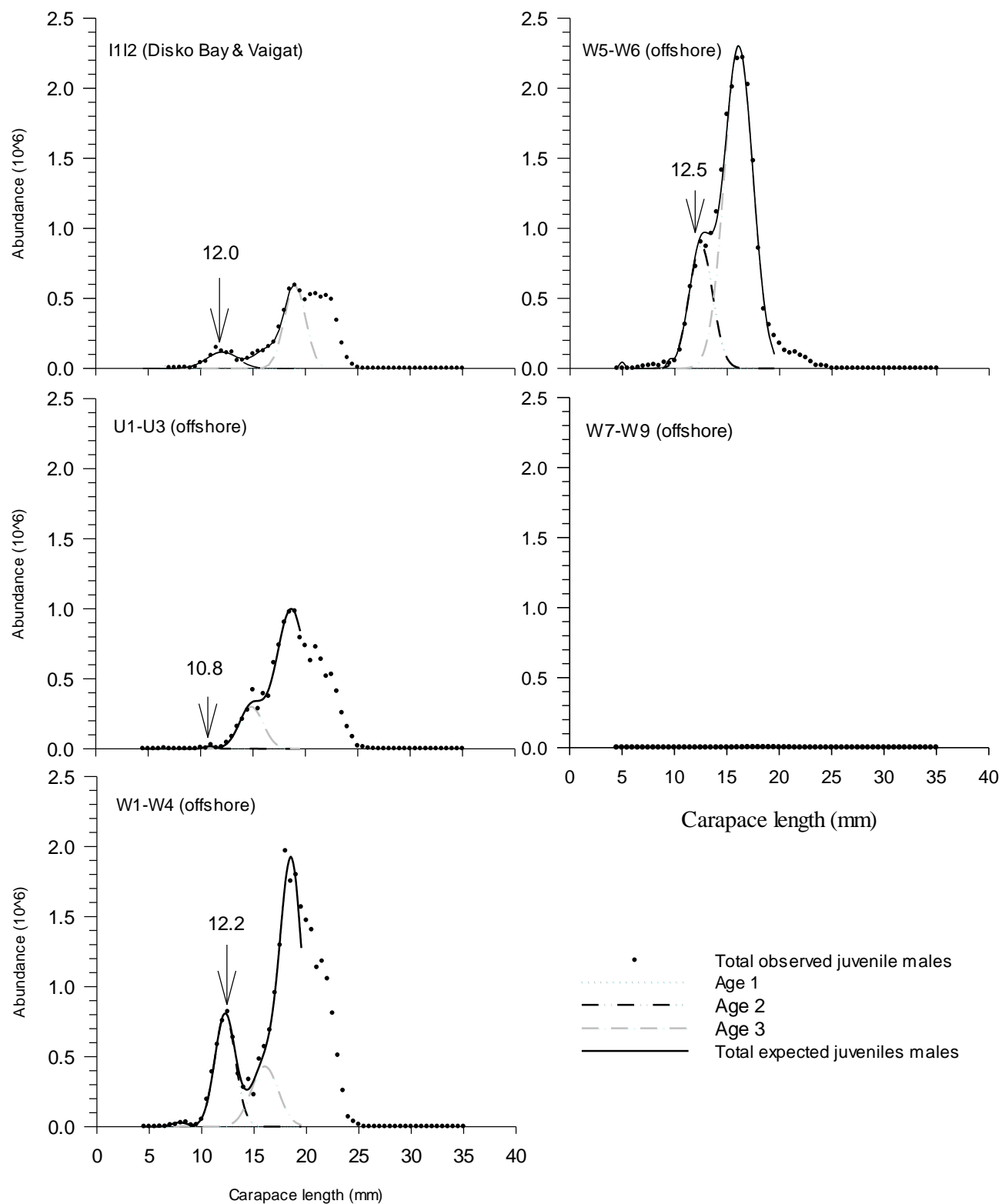


Figure 9. *Pandalus borealis* in West Greenland: regional length frequencies in 2020.

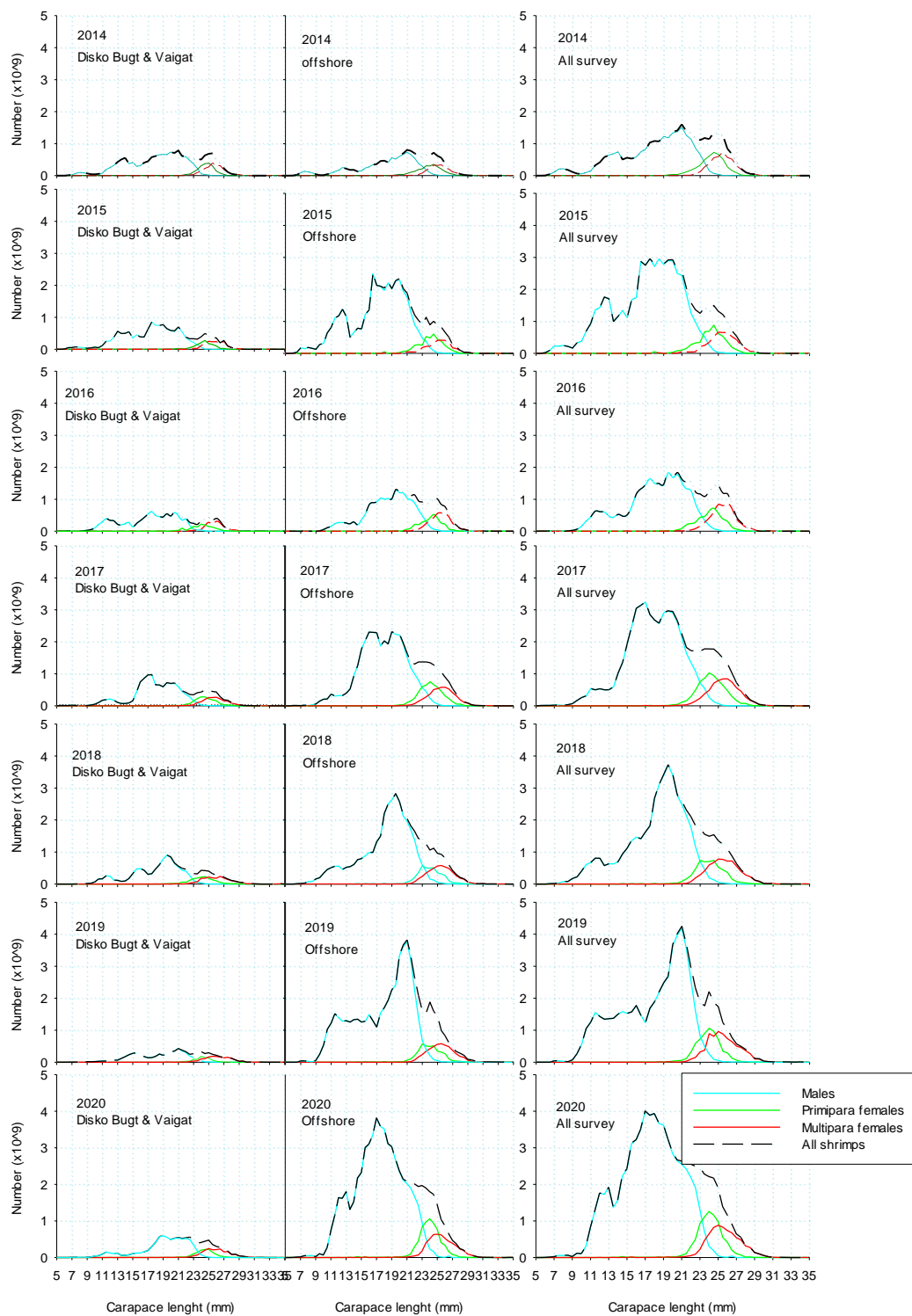


Figure 10. *Pandalus borealis* in West Greenland: length frequencies offshore, in Disko Bay and Vaigat, and overall, 2007–2020.

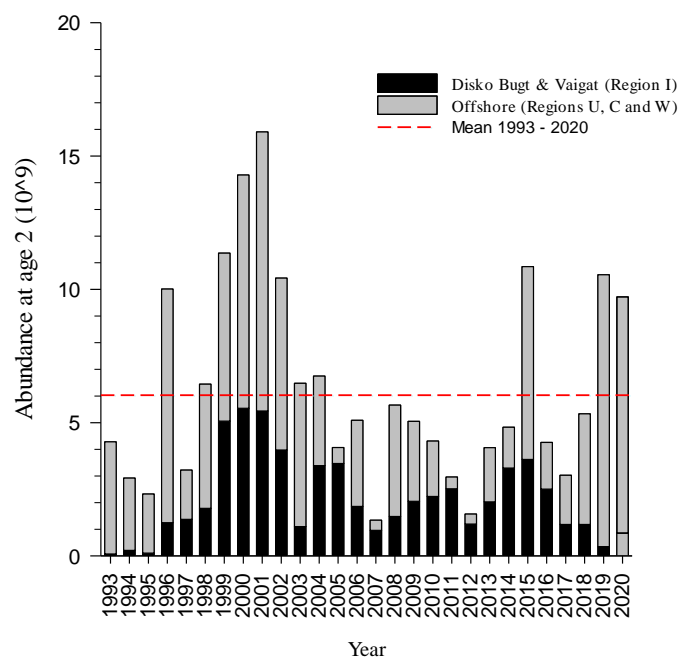


Figure 11a. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2020.

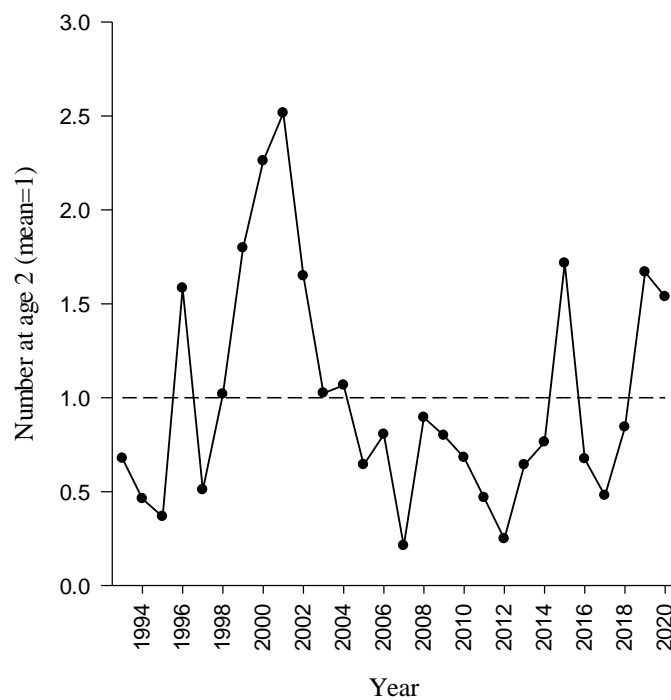


Figure 11b. *Pandalus borealis* in West Greenland: index of numbers at age 2, 1993–2020.

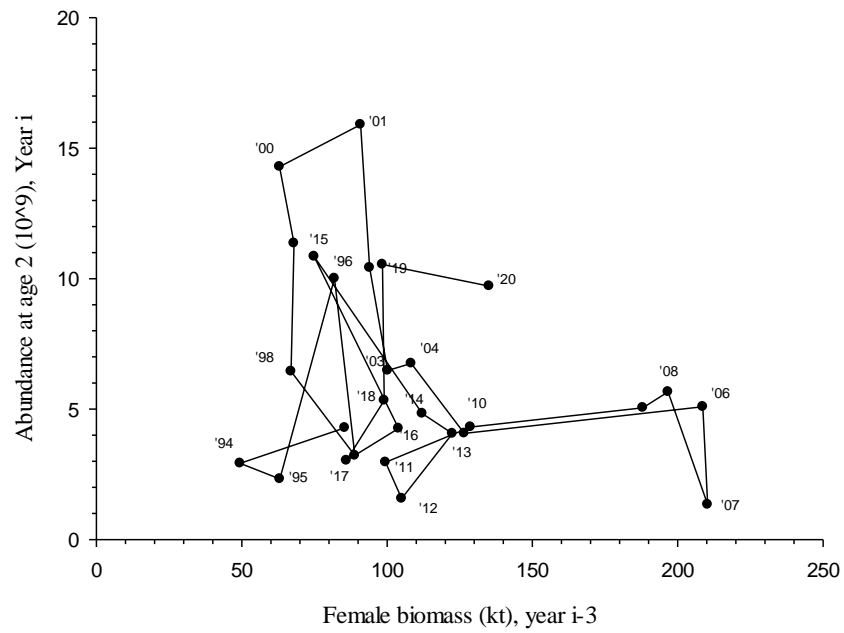


Figure 12. *Pandalus borealis* in West Greenland: survey estimates of numbers at age 2 in 1993–2020 against female biomass 3 years earlier (labels denote years in which age-2 numbers were estimated).

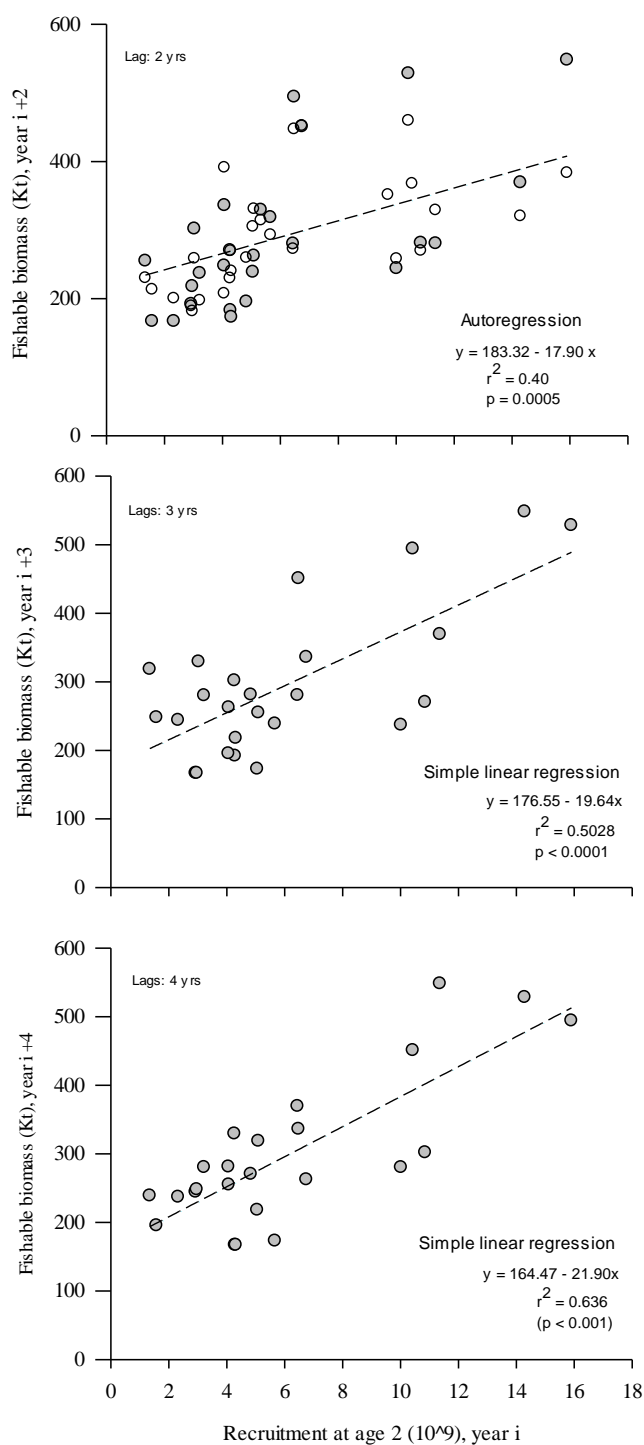


Figure 13. *Pandalus borealis* in West Greenland: lagged fishable biomass vs. survey estimates of numbers at age 2 from 1993 to 2020 (autocorrelated regressions lags: 2 years; open circles predicted values from autoregression).

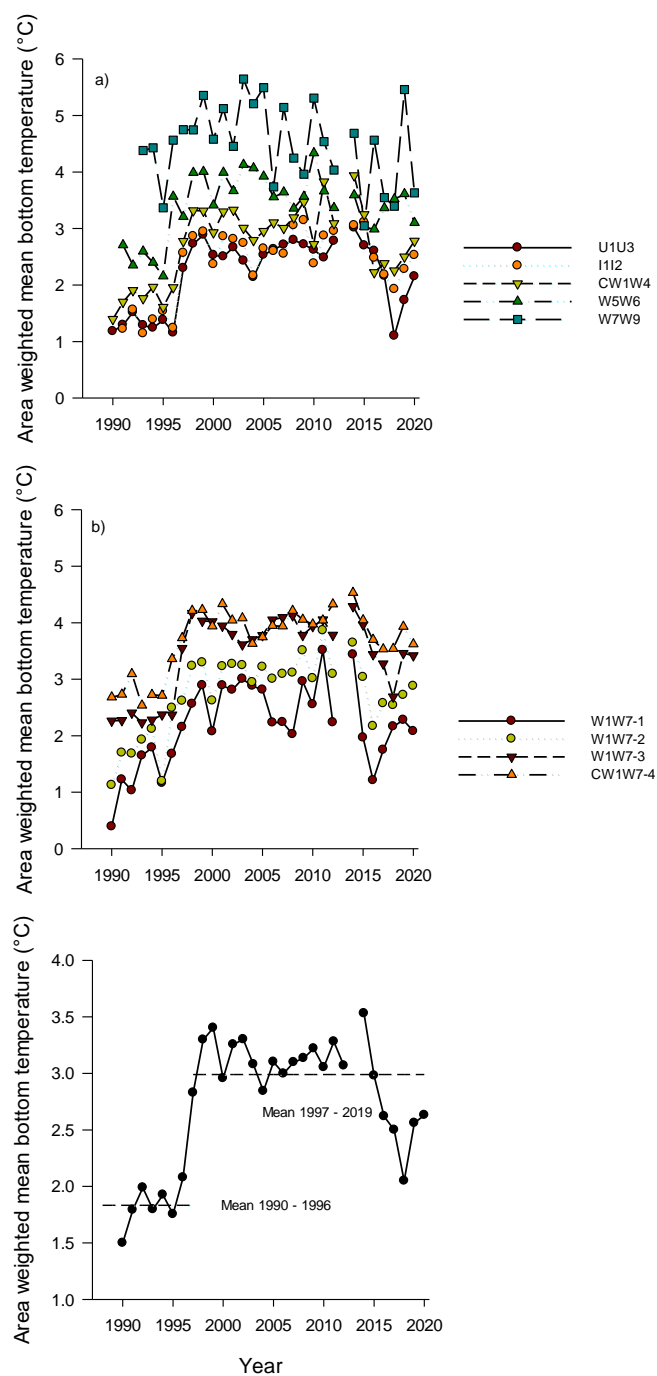


Figure 14. *Pandalus borealis* in West Greenland: area-weighted mean bottom temperature for survey regions (see Fig. 1 for locations), depth strata in offshore areas C and W1–W7, and the entire survey area in 1990–2020.

Appendix 1:

Grønlands Naturinstitut

Greenland Institute of Natural Resources
R/V Paamiut
OYZC – GR6-251
MMSI 331 102 00
engine.paamiut@gmail.com



Statement regarding using M/Tr Sjúrdarberg to carry out the same surveys as R/V Paamiut

In November 2017 R/V Paamiut failed to comply with DNVGL standards for working in Arctic waters. The management of Greenland Institute of Natural Resources (GN) decided not to spend more money on the vessel, but to go for building a new ship.

For the 2018-season, GN decided to charter Sjúrdarberg, a Faroese trawler of almost same dimensions as Paamiut, doing the normal surveys on the Greenland west coast.

To make the surveys as identical as possible this equipment was used from R/V Paamiut:

- Cosmos trawls
- All other equipment, such as bridles etc.
- Doors
- Marport sensors on doors and headline

Other steps taken ensuring the validity of received data:

- The wires/warps on Sjúrdarberg were same dimension (26mm) as used on Paamiut
- The distance between the hanging blocks was the same
- The Marport equipment on the bridge was set up and calibrated as on Paamiut
- All data from the tows were logged as normal procedure on Paamiut
- Skipper on Paamiut (Birgir Sivertsen) was on the bridge as supervisor, taking care of that all of the trawling was carried out as on Paamiut
- Chief Engineer from Paamiut was on board ensuring that all technical equipment performed as normal
- Crew from Paamiut worked together with the rest of the crew, ensuring that all maintenance of trawls etc. were carried out exactly as normal

To my best conviction regarding comparism, the surveys were executed in the best possible way, and I have absolutely no thoughts that this could be done otherwise or better.

Best regards

Kári Hansen, Chief Engineer

Grønlands Naturinstitut

Greenland Institute of Natural Resources

R/V Paamiut

OYZC – GR6-251 MMSI 331 102 00 engine.paamiut@gmail.com

Statement regarding using M/Tr Helga Maria to carry out the same surveys as R/V Paamiut for 2019

In November 2017 R/V Paamiut failed to comply with DNVGL standards for working in Arctic waters. The management of Greenland Institute of Natural Resources (GN) decided not to spend more money on the vessel, but to go for building a new ship.

For the 2019-season, GN decided to charter Helga Maria, a Icelandic trawler of almost same dimensions as Paamiut, doing the normal surveys on the Greenland west coast and Canada east coast.

To make the surveys as identical as possible this equipment was used from R/V Paamiut:

Alfredo trawls with 96 mtr bridles, as with R/V Paamiut

Cosmos trawls with 48 mtr bridles, as with R/V Paamiut

- All other equipment, such as bridles ,gear etc.
- Doors
- Marport sensors on doors and headline

Other steps taken ensuring the validity of received data:

- The wires/warps on Helga Maria were same dimension (26mm) as used on Paamiut
- The distance between the hanging blocks was the same
- The Marport equipment on the bridge was set up and calibrated as on Paamiut
- All data from the tows were logged as normal procedure on Paamiut
- Skipper on Paamiut (Jakup G.Mikkelsen) and Chief Engineer Kari Hansen was on Island ,used 14 days onboard Helga Maria, before departure to Greenland, to prepare and make the right arrangement on deck and factory for trawl equipment, and what else the Scientifics need, to make the surveys as similar as possible compare with R/V Paamiut. Skipper Jakup G.Mikkelsen also was onboard for one month, working on the bridge and deck as supervisor, taking care of that all of the trawling and equipment was carried out as on Paamiut
- Crew from Paamiut worked together with the rest of the crew, ensuring that all maintenance of trawls etc. were carried out exactly as normal

To our best conviction regarding comparison, the surveys were executed in the best possible way, and we have absolutely no thoughts that this could be done otherwise or better.

Best regards

Jakup G Mikkelsen Kari Hansen
Captajn Chief Engineer 1

Grønlands Naturinstitut

Greenland Institute of Natural Resources

R/V Paamiut

OYZC – GR6-251 MMSI 331 102 00 engine.paamiut@gmail.com

**Statement regarding using M/Tr Helga Maria to carry out the same surveys as R/V Paamiut for 2020**

In November 2017 R/V Paamiut failed to comply with DNVGL standards for working in Arctic waters. The management of Greenland Institute of Natural Resources (GN) decided not to spend more money on the vessel but decided instead to build a new ship.

For the 2020-season, GN decided to charter Helga Maria, a Icelandic trawler of almost the same dimensions as Paamiut, doing the normal surveys on the Greenland west and east coast.

M/V Helga Maria was also chartered for the 2019-season by GN to great satisfaction for good work.

To make the surveys as identical as possible this equipment was used from R/V Paamiut:

Cosmos trawls with 48 mtr bridles, as with R/V Paamiut

- All other equipment, such as bridles, gear etc.
- Doors
- Marport sensors on doors and headline

Other steps taken to ensure the validity of received data:

- The wires/warps on Helga Maria were the same dimension (26mm) as used on Paamiut
- The distance between the hanging blocks was the same
- The Marport equipment on the bridge was set up and calibrated as on Paamiut
- All data from the tows were logged as normal procedure on Paamiut
- Skipper on Paamiut (Jakup G. Mikkelsen) and Chief Engineer Kari Hansen were on Iceland. They spent 10 days onboard Helga Maria, before departure to Greenland, to prepare and make the right arrangement on deck and factory for trawl equipment, and what else the Scientists need, to make the surveys as similar as possible compare with R/V Paamiut.

The trawl bass Boas Augustussen, former deck hand from Paamiut, was onboard the whole journey, taking care of all of the trawl and equipment. He worked together with the rest of the crew, ensuring that all maintenance of trawls etc. were carried out exactly as onboard Paamiut.

The same captain onboard Helga Maria from the 2019 survey, was also onboard the 2020 survey. He also took care of all of the trawling and equipment. This was carried out as on board Paamiut.

To our best conviction regarding comparison, the surveys were executed in the best possible way, and we have absolutely no thoughts that this could be done otherwise or better.

Best regards

Jakup G Mikkelsen

Captain

Kari Hansen

Chief Engineer