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# A Provisional Assessment of the Shrimp Stock off West Greenland in 2016

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## Summary

The West Greenland Stock of *Pandalus borealis* was assessed from indices of biomass density based on catch and effort data from fishing fleets, biomass and stock-composition information from a research trawl survey, catch data, and information on the distribution of the stock as revealed by fishery logbooks. The assessment framework incorporates a logistic stock-recruitment model, fitted by Bayesian methods, that uses CPUE and survey series as biomass indicators, and includes as removals catch data, assumed free of error, as well as a term for predation by Atlantic cod, using available series of cod biomass.

Overall, the stock biomass, distribution and composition are extreme in several respects. Survey total biomass is below average compared with the most recent 20 years. Offshore, the fishable biomass has decreased by nearly 21% over 2015, and is below the lower quantile of the most recent 20 years; areas north of the northern margin of Store Hellefiskebanke have almost three-quarters of the offshore biomass. The fishable biomass inshore, in Disko Bay and Vaigat, 17% less than in 2015, is now below the lower quantile when compared with its history. As a result of this contrast, the proportions of biomass in the offshore area and inshore are 69% and 31% respectively, lower than the 20-year mean offshore, but higher inshore.

Both inshore and offshore the number of age 2 shrimps, was lower, than in 2015, but at the 20-year median inshore and above the lower 20-year quantile offshore both in numbers and in relation to survey biomass. However, the proportion of large pre-recruits 14.5–16 mm carapace length decreased in both regions, indicating the stock appearing deficient in these length classes and poor prospects for short-term recruitment to the fishable stock. Overall, in 2016 the proportion fishable of the survey biomass is about average for the last 20 years. Were proportion of females are at a record 20-year value, fishable males are at a very few and way below the lower 20-year lower quantile. Fishing on the stock in its present state disproportionally hit the spawning stock of females and considering lower proportions of fishable males, prospects for long-term recruitment might assumable be low.

The stock composition inshore has historically been characterized by a higher proportion of young shrimps than that offshore, in 2016 numbers of age 2-shrimps were 1.4 times the numbers of offshore, but in contrast, numbers of large pre-recruits are higher offshore than inshore.

The quantitative assessment adopted by NAFO shows a stock that has been declining for a decade—albeit from levels that were probably not sustainable—has probably been fished over its MSY mortality for the most recent four years, but now appears to be comfortably above its MSY level.

## Introduction

The stock of the northern shrimp (*Pandalus borealis*) off West Greenland is distributed in NAFO Subarea 1 and the eastern margin of NAFO Div. 0A, and within this area is assessed as one unit. A Greenlandic fishery exploits the stock in Subarea 1 up to 73°30'N (Divs 1A–1F); a Canadian fishery is restricted to Div. 0A.

In 2002 a quantitative assessment framework based on a biological model of shrimp stock dynamics (Hvingel and Kingsley 2002) was adopted by STACFIS and Scientific Council. Input data series include a swept-area index of fishable biomass from an annual research trawl survey, a series of standardized indices of fishery CPUE and the series of past catches. The model was modified in 2011 to give more weight to the survey index of biomass and less to the fishery CPU (Kingsley 2011).

Up to 2014 an externally calculated index series of 'effective' biomasses of Atlantic cod —i.e. corrected for the partial overlap of its distribution with that of the shrimps—was also included. In 2014 this was replaced by the inclusion of the four biomass index series on which it had been based as well as the series of overlap indices (Kingsley 2014). The biomass indices are combined to generate a series of estimated biomasses, and this is multiplied by the overlap series to generate a series of 'effective' biomasses that are used in estimating the amount cod remove from the stock each year.

The quantitative model was fitted to the input data and short-term (1-year) and medium-term (three-year) projections of stock development were made for annual catches from 60 000 to 100 000 tons under assumptions that the cod stock, allowance made for its overlap with shrimp distribution, might be at 25 000 tons or 35 000 tons. The median estimate for 2016 was 3 100 tons. The associated risks of transgressing reference parameters—maximum sustainable yield levels of biomass ($B_{msy}$) and mortality ($Z_{msy}$)—as well as a precautionary limit set at 30% of $B_{msy}$ were estimated.

This assessment refers also, although qualitatively, to information on the distribution of the Greenland fishery derived from logbooks. Trawl time, and catches, were assigned to statistical areas covering the West Greenland shrimp grounds, and series of indices of how widely the fishery was distributed were calculated (Hammeken Arboe 2016). The assessment also refers to indices that summarize survey information on the distribution of the stock and its structure (Kingsley 2008b; Kingsley 2015; Kingsley 2016; Burmeister et al. 2016).

## Environment

The survey mean bottom temperature—weighted by area, not by shrimp stock density—increased quite abruptly from a mean of 1.83°C in 1990–96 to 3.13°C in 1997–2016. At about the same time as the mean bottom temperature increased, the shrimp stock started a more protracted shift in its distribution, into shallower water and into more northerly areas. In the mid-90s, most of the survey biomass was between 300 and 400 m, with a significant amount deeper than 400 m. Now, a majority is between 200 and 300 m, with a significant amount between 300 to 400 m (Burmeister et al. 2016). This move into shallower water looks like a continuing trend since the early 2000s.

The estimated biomass of a main predator, the Atlantic cod, was less than 10 Kt from 1991 to 2004. It increased briefly in 2006–7 to about 87 Kt[1], distributed mostly in southern West Greenland, before declining again. In 2011 there was a smaller increase, but in that year the fish appeared to be more widely distributed into northerly areas where there was a higher density of shrimps, and the 'effective' cod stock appeared to have increased significantly. In 2012–2014 the biomass of cod increased considerably, and although it is

[1] 'German survey' estimate revised in 2014.

mostly distributed in more southerly areas so its index of overlap with the shrimp stock has been less the 'effective' cod stock has been greater than at any time since the start of the 1990s (Siegstad and Kingsley 2014). In 2015 the biomass of cod increased to a record 20-year value, especially in the southern part of the West Greenland (south of 64°N), while abundance of cod remain comparable with 2014. The increase in cod biomass is due to increase growth in the population. The high cod biomass was not maintained, decrease significantly over 2015 and was in 2016 only 14% of the 2015 value. The decrease were most noticeably south of 66°N. Owing to this, the overlap with the shrimp stock was very low compared to its past previous years and so is the 'effective' cod stock.

Stocks of Atlantic cod in West Greenland continue to fluctuate and while forecasting the biomass and distribution of cod on the West Greenland shrimp ground is important in predicting the dynamics of the stock of Northern shrimp and in managing the fishery, it remains an insoluble problem. The stock-dynamic model used in the assessment allows for flexible and comprehensive consideration of possible developments of the cod stock.

## Stock Size, Composition and Distribution

Survey biomass increased by 130% in 1999–2003, subsequently decreasing continuously to reach at nearly its lowest level in 2014 (Fig. 1). Biomass increased by 60% from 2014 – 2015, but was not maintained and survey biomass overall decreased by 25% over 2015, and is now below its 20-year lower quantile In 2016, the number and biomass of females are almost equal to 2015 values, and are near to their 20-year median, whereas male biomass and fishable biomass both decreased by 38.6% and 35% respectively and is way below above their 20-year lower quantile (Burmeister et al 2016).

*Survey Measures of Stock Size*

| | Biomass (Kt) | | | | | Number (bn) | | |
|---|---|---|---|---|---|---|---|---|
| | Survey | | | | | | | |
| | Disko B. & Vaigat | Offshore | Total | Fishable | Female | Male | Female | Age 2 |
| 2016 value[1] | 64.8 | 153.4 | 218.2 | 201.3 | 101.3 | 28.4 | 10.8 | 4.3 |
| 20-year[2] upper quartile | 93.0 | 291.7 | 372.5 | 344.4 | 127.1 | 66.4 | 15,2 | 10.1 |
| 20-year median | 80.2 | 222.6 | 287.1 | 259.1 | 104.4 | 47.7 | 11.9 | 5.4 |
| 20-year lower quartile | 65.7 | 174.1 | 253.9 | 232.5 | 93.2 | 38.1 | 9.9 | 4.1 |
| 2016 rank | 5.7 | 4.0 | 4.1 | 4.3 | 6.9 | 2.6 | 6.9 | 7.0 |
| 2015 value | 78.2 | 214.0 | 292.2 | 255.5 | 101.8 | 52.9 | 10.9 | 11.2[3] |

[1] survey estimates of stock size for 2011, 2012, 2014, 2015 and 2016 were adjusted for incomplete coverage of the offshore strata by applying the mean offshore density to the survey strata not covered, and adding the corrected offshore estimate to that for Disko Bay and Vaigat

[2] 20-year percentiles, and 2015 rank, are referred to the 20 preceding years, i.e. 1996–2015.

[3] value recalculated in 2014

In the inshore area, comprising Disko Bay and Vaigat, the estimated survey biomass decreased by 17% from 2015 to a 2016 value just below its 20-year lower quantile. The offshore biomass collectively, in 2014 close to its lowest for 20 years, increased in 2015, but dropped by 28% in 2016 to a value below its 20-year lower quartile. Relative to stock size, last years' values indicated an incoming recruitment pulse, and offshore male fishable biomass was three times higher than in 2014. Nevertheless, numbers of fishable male decline over 2015 and last year pre-recruits were not shown up in the fishable biomass in 2016. Also, absolute number at age 2, is 61% less in 2016 than in 2015, and is below its 20-year median (Fig. 2a).

*Survey Measures of Stock Composition*

| Overall | Number ('000/survey ton) | | Biomass (%) | | | |
|---|---|---|---|---|---|---|
| | Age 2 | 14–16.5 mm[2] | Fishable, of survey | Fishable males, of survey | Females, of survey | Females, of fishable |
| 2016 value | 19.9 | 22,5 | 92.3 | 45.9 | 46.4 | 50.3 |
| Upper quartile[1] | 29.6 | 29.0 | 93.2 | 576 | 38.0 | 41.3 |
| Median[1] | 18.1 | 25.2 | 91.7 | 55.7 | 35.6 | 39.1 |
| Lower quartile[1] | 11.1 | 21.8 | 89.4 | 52.7 | 34.8 | 37.8 |
| 2016 rank[1] | 11.9/20 | 4.1/11 | 11.7/20 | 1.2/20 | 19.6/20 | 19.7/20 |
| 2015 value | 38.2[3] | 35.0 | 87.5 | 52.6 | 34.9 | 39.9 |

[1] quartiles and 2016 rank generally referred to 20 preceding years 1996–2015;
[2] quartiles and 2016 rank referred to 11 preceding years 2005–2015 (for which data is available);
[3] value recalculated in 2014

The overall stock composition in 2016 is marked as in 2014, by a high proportion of females, both in the survey and in the fishable biomass, way above its upper 20-year quantile close to a record value; males compose a considerable lower proportion of the fishable biomass in 2016 than in the previous years, but close to 2014 value. Relative to stock size the number of age-2 shrimps is above its 20-yr median. The relative number of large pre-recruits is below its ten-year median, so prospects for short-term recruitment are poor.

| Disko Bay and Vaigat | Number ('000/survey ton) | | Biomass (%) | | | |
|---|---|---|---|---|---|---|
| | Age 2 | 14–16.5 mm | Fishable, of survey | Fishable males, of survey | Females, of survey | Females, of fishable |
| 2016 value | 38.7 | 25.6 | 89.9 | 43.2 | 46.7 | 52,0 |
| Upper quartile[1] | 42.8 | 33.8 | 90.4 | 56.1 | 40.4 | 45.4 |
| Median[1] | 29.2 | 31.8 | 89.2 | 50.7 | 34.3 | 39.5 |
| Lower quartile[1] | 24.3 | 29.2 | 86.1 | 48.7 | 32.1 | 37.9 |
| 2016 rank[1] | 14.5/20 | 1.2/11 | 13.5/20 | 0/11 | 11.8/11 | 12.0/11 |
| 2015 value | 46.3 | 33.7 | 88.6 | 49.0 | 39.5 | 44.6 |

| Offshore | Number ('000/survey ton) | | Biomass (%) | | | |
|---|---|---|---|---|---|---|
| | Age 2 | 14–16.5 mm | Fishable, of survey | Fishable males, of survey | Females, of survey | Females, of fishable |
| 2016 value | 11.9 | 21.1 | 93.3 | 47.0 | 46.3 | 49,6 |
| Upper quartile[1] | 24.2 | 27.3 | 94.3 | 56.6 | 44.1 | 47.7 |
| Median[1] | 14.1 | 21.0 | 93.3 | 53.9 | 39.1 | 42.3 |
| Lower quartile[1] | 8.1 | 18.5 | 91.2 | 49.0 | 36.4 | 38.5 |
| 2016 rank[1] | 8.4/20 | 6.0/11 | 10.5/20 | 1.9/11 | 10.2/11 | 10.2/11 |
| 2015 value | 35.2 | 35.4 | 87.1 | 53.9 | 33.1 | 38.1 |

Differences between the stock compositions offshore and inshore—in Disko Bay and Vaigat—have tended to be maintained over time. The inshore averages higher proportions of smaller shrimps. For the age-2 index, relative to survey biomass, the inshore quartile points have about twice the values of the offshore. Quartiles of the relative number of 14–16.5-mm shrimps are higher inshore than offshore, and inshore 2016 value are above and offshore below the 20-year median. Consistently with previous years, except for 2015, offshore regions have less number of pre-recruits, and where fishable-male proportions of the survey biomass are averaged a bit larger offshore, the female proportion of fishable biomass are lower offshore and at above its upper quartile. In fact, female proportions of fishable biomass in Disko Bay is a record value. Throughout the size distribution, the offshore stock has been biased toward larger shrimps, while the Disko component has had higher proportions of smaller and younger shrimps.

In both regions females compose by far a high proportion of the biomass, both survey and fishable, comparable to 2014 values and fishable males very low proportion. In 2016, males constitute a low proportion of the fishable biomass, while the proportion of fishable biomass of survey biomass is high and comprise high proportions of females and like 2014, the stock in 2016 in both regions seems to be 'all females'.

It is uncertain, what are the limits for any of these stock-composition parameters to conduce to a 'healthy' stock with good potential for maintaining itself. For some of the statistics, past information is limited to 2005–14—a period characterized by a 70% decline in the offshore stock while the inshore has fluctuated. The stock seemed for the past years, except 2015, to have been at, or outside, the limits of where it has been in the past. There were few large pre-recruits; few fishable males to recruit to the spawning stock; and, concomitantly, exceptionally high proportions of spawning females in the fishable biomass. The fishable stock had in 2016 high proportion of the total, so if the fishable stock gets fished, there might assumable not be much left.

*Measures of Biomass Distribution within SA1*

| | Of offshore (%) | | | | | | Of total (%) |
|---|---|---|---|---|---|---|---|
| | North | W1–2 | W3–4 | W5–7 | W8–9 | Distribution Index | Disko B. and Vaigat |
| 2016 value | 41.1 | 32.6 | 17.4 | 7.0 | 1.9 | 3.2 | 27.9 |
| 20-year[1] upper quartile | 34.1 | 35.2 | 23.6 | 26.2 | 9.0 | 3.9 | 26.6 |
| 20-year median | 22.9 | 31.4 | 18.9 | 20.9 | 1.7 | 3.3 | 23.1 |
| 20-year lower quartile | 8.0 | 27.1 | 14.6 | 9.6 | 0.4 | 3.1 | 20.7 |
| 2016 rank | 17.8/20 | 11.5/20 | 6.7/20 | 3.7/20 | 10.9/20 | 6.8/20 | 15.6/20 |
| 2015 value | 42.5 | 25.6 | 28.9 | 3.0 | 0.0 | 3.0 | 27.9 |

[1] percentiles and 2016 rank are referred to the 20 preceding years, i.e. 1996–2015.

Compared with values for the previous 20 years, both inshore and the offshore fishable biomass is at or below their 20-year lower quantile, and proportion of total biomass inshore and offshore is consistently previous years, except extreme years in 2012 and 2014; e.i proportions is higher offshore than inshore.

Within the offshore area as a whole, the trajectories have been different and since 2000 the distribution of the survey biomass has contracted and moved northwards (Fig. 3). The southernmost area had collapsed already in 2004–2007 and W3–4, around Store Hellefiske banke, collapsed in 2011 and were empty in 2012. Whereas the North area, in 2016, continue to hold high proportion of the offshore biomass, well above the upper quartile, proportion in W1-W2, of the mouth of Disko Bay and W3-W4 almost averaged, but proportion in W5-W7 decline to a value below the lower quantile.
The proportions in W1–2, W3–4, and Disko had been relatively constant over the preceding 19 years: the inter-quartile ranges were about one quarter of the medians. The deviations in, 2015, and since, 2012 especially for Disko (downward) and the North (upward), W3–4 (upward) were, by comparison with this earlier stability, especially remarkable.

## Fishery

The trajectory of the fishery CPU agreed with that of the survey estimate of fishable biomass from 1988 until about 2002, when the survey index suddenly increased. The CPU index did not follow that jump but increased more slowly; but also did not suffered the rapid and sustained decrease of the survey index from 2003 through 2012. Instead it continued to increase, more slowly, until 2008, after which it also has continually declined. From 2007 through 2014 the CPUE index of relative biomass has remained significantly above the survey index. That CPUE can be maintained while the survey index declines might be due to shrinking of the area over which the stock, and the fishery, is distributed, although we have not been able to find a satisfactory relationship between the difference between the two indices and any measure of stock distribution.

The distribution of the fishery, like that of the survey biomass, has varied over time (Fig. 4). In the 1990s over half the catches were taken south of Holsteinsborg Dybde, but southern areas have subsequently lost their shrimp stock and the fishery in Greenland waters is now concentrated in NAFO Divisions 1A and 1B. In recent years, the offshore fishery has been extending its range northwards and recent years have seen some exploitation of grounds even north of 73° N (Hammeken Arboe and Kingsley 2013).

Between 1997 and 2003 the exploitation ratio—of catch to fishable biomass—declined from about 50% to about 25% (Fig. 1) as the catches, although steadily increasing, failed to keep up with the more rapidly increasing biomass (Fig. 6). While catches were high in 2004–2008 the ratio increased as biomass declined while catches did not, and since 2008 it has stayed above average as catches have not been brought down to match the lowness of recent biomass estimates.

## Results of the Quantitative Assessment

The median estimate of the *MSY* was 127Kt with quartiles at 96 and 158 Kt; an estimated mode is at 131 Kt. The model estimates that the stock biomass has decreased in every year from 2004 to 2013 even though catches since 1990 appear to have been sustainable. Fishable biomass at end 2016 is projected close to the 2015 value and 11% above $B_{msy}$. The low catches projected for 2016 are expected to hold total mortality in 2016 below 65% of $Z_{msy}$.

Table: *P. borealis* in West Greenland: model estimates of stock status at end of, or during, 2016.

| | |
|---|---|
| Biomass ratio *B/Bmsy* (median estimate, %) | 111.4 |
| Prob. *B<Bmsy* (%) | 35.5 |
| Prob. *B<Blim* (%) | 0.0 |
| Mortality ratio *Z/Zmsy* (median estimate, %) | 62.8 |
| Prob. *Z>Zmsy* (%) | 19.0 |

Risks associated with eight possible catch levels for 2017, with an 'effective' cod stock at 35 000 t , are estimated to be:

| 35 000 t cod | Catch option ('000 tons) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Risk of: | 60 | 70 | 75 | 80 | 85 | 90 | 95 | 100 |
| falling below Bmsy end 2017 (%) | 32.6 | 33.2 | 34.2 | 34.8 | 35.4 | 35.0 | 35.4 | 36.5 |
| falling below Blim end 2017 (%) | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| exceeding Zmsy in 2017 (%) | 15.9 | 20.1 | 23.0 | 25.8 | 28.7 | 32.0 | 35.2 | 38.9 |
| exceeding Zmsy in 2018 (%) | 16.3 | 20.1 | 22.9 | 26.1 | 28.9 | 31.9 | 36.1 | 39.7 |

If a mortality risk (i.e. that estimable mortality will exceed $Z_{msy}$) criterion of 35% is observed, catches of 90–95 Kt are predicted to be sustainable, provided that the effective cod biomass makes only moderately large gains in the coming years.

Predation by cod can be significant and have a major impact on shrimp stocks. Currently the cod stock at West Greenland is at a low level, but recent years have seen slow, but progressive, increases. A large cod stock that would significantly increase shrimp mortality could be established in two ways: either by a slow rebuilding process or by immigration of one or two large year-classes from areas around Iceland, as in the late 1980s. The question of cod predation is bedevilled by the difficulty of foreseeing the evolution of the stock and complicated by uncertainty as to the overlap between the two species.

Projections of stock development were made under the assumption that the 'effective' cod stock will remain at levels consistent with recent estimates, and that parameters of the stock-dynamic and predation processes, including their uncertainties, will retain the values estimated from the 30-year data series. Eight levels of annual catch were investigated from 60 000 to 1000 000 tons (Figs 10–12, Table 4; Appendix).

## Precautionary Approach

The 'Precautionary Approach' framework developed by Scientific Council defined a limit reference point for fishing mortality, $F_{lim}$, as equal to $F_{msy}$. The limit reference point for stock size measured in units of biomass, $B_{lim}$, is a spawning stock biomass below which unknown or low recruitment is expected. Buffer reference points, $B_{buf}$ and $F_{buf}$, are also requested to provide a safety margin that will ensure a small risk of exceeding the limits.

The limit reference point for mortality in the current assessment framework is $Z_{msy}$, i.e. Z-ratio=1 and the risk of exceeding this point is given in this assessment. $B_{lim}$ was set at 30% of $B_{msy}$. The risks of transgressing $B_{lim}$ under scenarios of different future catches have been estimated (Table 4) and are low.

## Conclusions

The stock is predicted to remain well above its *MSY* level at end 2016. Given the uncertainty of both stock status and stock-dynamic parameters, the risk of exceeding $Z_{msy}$ should probably not exceed 35%. A quantitative assessment indicates that catches below 90 Kt would keep the risk of exceeding $Z_{msy}$ below 35%, assuming certain limits on the evolution of the biomass of Atlantic cod.

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**Table 1.** *Pandalus borealis* in West Greenland: input data series 1986–2016 for stock-dynamic assessment model.

| | Effective cod biomass[1] (Kt) | Catch (Kt) | Provisional catch (Kt) | Survey index of fishable biomass (Kt) | Predation estimate[2] (Kt) | Cod-stock estimate[2] (Kt) | ln CPUE (1990=0) |
|---|---|---|---|---|---|---|---|
| 1987 | 301.40 | 77.869 | | | | | 0.4266 |
| 1988 | 314.10 | 73.616 | | 223.2 | | | 0.1403 |
| 1989 | 136.70 | 80.671 | | 209 | 213.7 | 470.9 | 0.0506 |
| 1990 | 10.06 | 83.967 | | 207 | 27.8 | 184.1 | 0 |
| 1991 | 1.77 | 91.487 | | 146 | 2.7 | 19.8 | 0.0399 |
| 1992 | 0.29 | 105.487 | | 194.2 | 0.8 | 2.9 | 0.1201 |
| 1993 | 0.24 | 91.013 | | 216.5 | | | 0.1065 |
| 1994 | 0.07 | 92.805 | | 223.1 | | | 0.1028 |
| 1995 | 0.05 | 87.388 | | 183.2 | | | 0.1938 |
| 1996 | 0.08 | 84.095 | | 192.1 | | | 0.239 |
| 1997 | 0.08 | 78.128 | | 167.1 | | | 0.2183 |
| 1998 | 0.06 | 80.495 | | 244.3 | | | 0.3648 |
| 1999 | 0.09 | 92.198 | | 237.3 | | | 0.474 |
| 2000 | 0.38 | 97.968 | | 280.3 | | | 0.5717 |
| 2001 | 0.80 | 102.926 | | 280.5 | | | 0.5276 |
| 2002 | 0.70 | 135.172 | | 369.5 | | | 0.7066 |
| 2003 | 0.91 | 130.173 | | 548.3 | | | 0.7786 |
| 2004 | 1.36 | 149.332 | | 528.3 | | | 0.8774 |
| 2005 | 2.71 | 156.899 | 140.5 | 494.2 | | | 0.9155 |
| 2006 | 21.98 | 157.315 | 140.2 | 451 | | | 0.8999 |
| 2007 | 14.95 | 144.19 | 135.2 | 336.1 | | | 0.9489 |
| 2008 | 8.31 | 153.707 | 131.6 | 262.6 | | | 0.9866 |
| 2009 | 2.52 | 135.369 | 108.8 | 255.1 | | | 0.8728 |
| 2010 | 5.40 | 133.985 | 138.5 | 318.7 | | | 0.8485 |
| 2011 | 23.75 | 123.853 | 126 | 245.7 | | | 0.8831 |
| 2012 | 39.49 | 115.943 | 110 | 176.4 | | | 0.7983 |
| 2013 | 37.48 | 95.288 | 100 | 218.1 | | | 0.6672 |
| 2014 | 58.60 | 87.358 | 90 | 170 | | | 0.7623 |
| 2015 | 52.26 | 70.65 | 65 | 255.5 | | | 0.7963 |
| 2016 | 3.12 | — | 82 | 201.3 | | | 0.7846 |

[1] 'effective cod biomass' was not an input data series in 2016; instead, four series of cod survey biomass indices were input and used to estimate a cod biomass series which was multiplied by an input overlap series to generate an 'effective cod' series; tabulated are the median resulting estimates (see Kingsley 2014).
[2] Grunwald (1998).
[3] survey estimates of fishable biomass for 2011, 2012, and 2014–16 were adjusted for incomplete coverage of offshore strata.

**Table 2.** *Pandalus borealis* in West Greenland: summary of estimates of selected parameters from Bayesian fitting of a surplus production model, 2016.

| | Mean | S.D. | 25% | Median | 75% | Est. mode | Median (2015) |
|---|---|---|---|---|---|---|---|
| *Max. sustainable yield (Kt)* | 134.7 | 77.7 | 96.4 | 126.7 | 158.1 | 110.7 | 140.2 |
| *$B/B_{msy}$, end current yr (proj.)* | 114.8 | 33.3 | 91.0 | 111.4 | 134.8 | 104.6 | 123.0 |
| *Biom. risk, end current yr (%)* | 35.5 | 47.9 | – | – | – | – | – |
| *$Z/Z_{msy}$, current yr (proj.)* | – | – | 43.3 | 62.8 | 88.8 | – | 58.6 |
| *Carrying capacity* | 3734 | 3313 | 1868 | 2818 | 4449 | 986 | 3365 |
| *M.S.Y. ratio (%)* | 10.6 | 7.0 | 5.2 | 9.7 | 14.6 | 8.0 | 9.2 |
| *Survey catchability (%)* | 19.4 | 14.8 | 8.8 | 15.3 | 25.7 | 7.1 | 12.3 |
| *CPUE catchability* | 1.3 | 1.0 | 0.6 | 1.0 | 1.7 | 0.5 | 0.8 |
| *Effective cod biomass 2016 (Kt)* | 4.1 | 4.1 | 2.0 | 3.1 | 4.6 | 1.2 | 55.9 |
| *$P_{50\%}$* | 4.3 | 7.7 | 0.2 | 1.3 | 4.9 | -4.6 | 1.1 |
| *$V_{max}$* | 1.7 | 2.1 | 0.3 | 0.8 | 2.3 | -1.2 | 0.6 |
| *CV of process (%)* | 14.6 | 3.8 | 11.8 | 14.0 | 16.7 | 13.0 | 13.7 |
| *CV of survey fit (%)* | 16.7 | 1.9 | 15.5 | 16.8 | 18.0 | 17.0 | 16.5 |
| *CV of CPUE fit (%)* | 20.2 | 3.1 | 18.2 | 19.7 | 21.6 | 18.6 | 19.0 |

**Table 3.** *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2016.

| | *Start biom. ratio* | *CV cpu* | *CV s* | *CV proc* | *Vmax* | *P50%* | *Qc* | *Qs* | *MSY ratio* | *K* |
|---|---|---|---|---|---|---|---|---|---|---|
| *Max. sustainable yield* | | | | | | | -10 | -10 | 32 | 19 |
| *Carrying capacity* | 9 | | | | -7 | | -56 | -56 | -54 | 100 |
| *Max. sustainable yield ratio (%)* | -17 | | | | 12 | | 81 | 81 | 100 | |
| *Survey catchability (%)* | -31 | | | -8 | 15 | -6 | 100 | 100 | | |
| *CPUE catchability* | -31 | | | -8 | 15 | -6 | 100 | | | |
| *P50%* | 13 | | | | 74 | 100 | | | | |
| *Vmax* | -7 | | | | 100 | | | | | |
| *CV of process (%)* | 15 | 19 | -16 | 100 | | | | | | |
| *CV of survey fit (%)* | | | 100 | | | | | | | |
| *CV of CPUE fit (%)* | | 100 | | | | | | | | |

[1] those over 5%

**Table 4.** *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2017 and of falling below $B_{msy}$ or limit* biomass at the end of 2017 assuming effective cod biomass 35 Kt.

| Catch (Kt/yr) | Prob. biomass < $B_{msy}$ (%) | Prob. biomass<$B_{lim}$ (%) | Prob. mort > $Z_{msy}$ (%) |
|---|---|---|---|
| 60 | 32.6 | 0.1 | 15.9 |
| 70 | 33.2 | 0.0 | 20.1 |
| 75 | 34.2 | 0.0 | 23.0 |
| 80 | 34.8 | 0.1 | 25.8 |
| 85 | 35.4 | 0.0 | 28.7 |
| 90 | 35.0 | 0.0 | 32.0 |
| 95 | 35.4 | 0.0 | 35.2 |
| 100 | 36.5 | 0.0 | 38.9 |

* limit biomass is 30% of $B_{msy}$

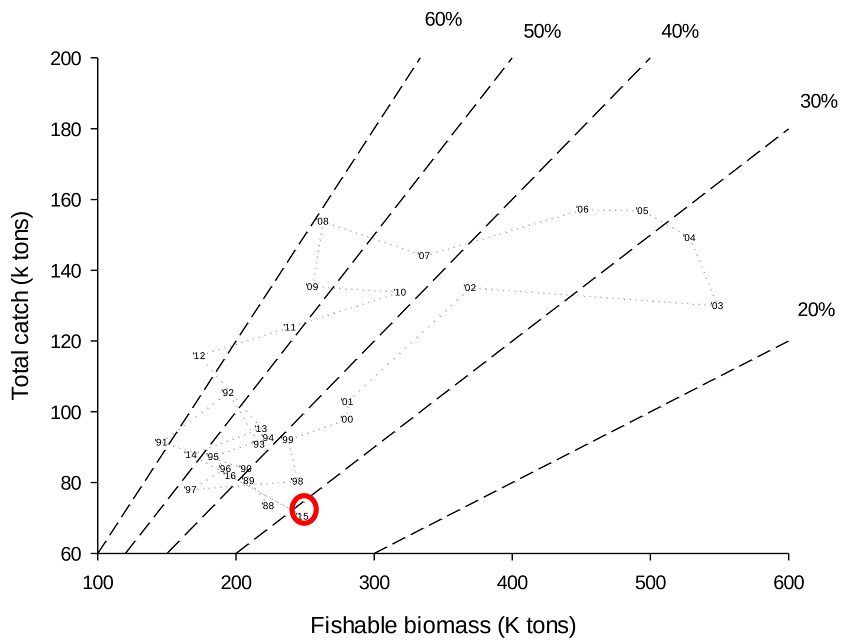



**Fig. 1.** *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1988–2016 (2016 catch is provisional).


**Fig. 2a.** *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1994–2016.

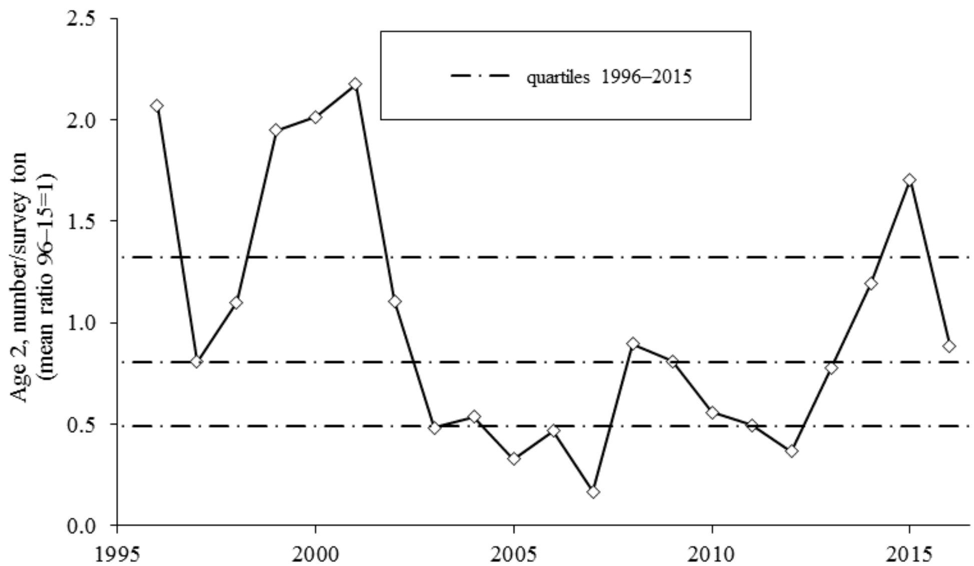



**Fig. 2b.** *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1994–2016.

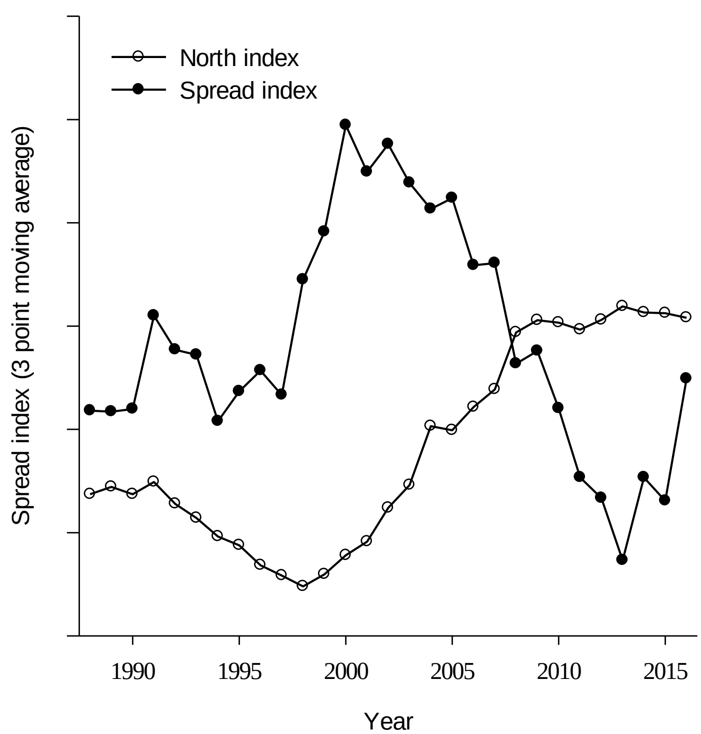



**Fig. 3.** *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2016 (3-point moving means.)

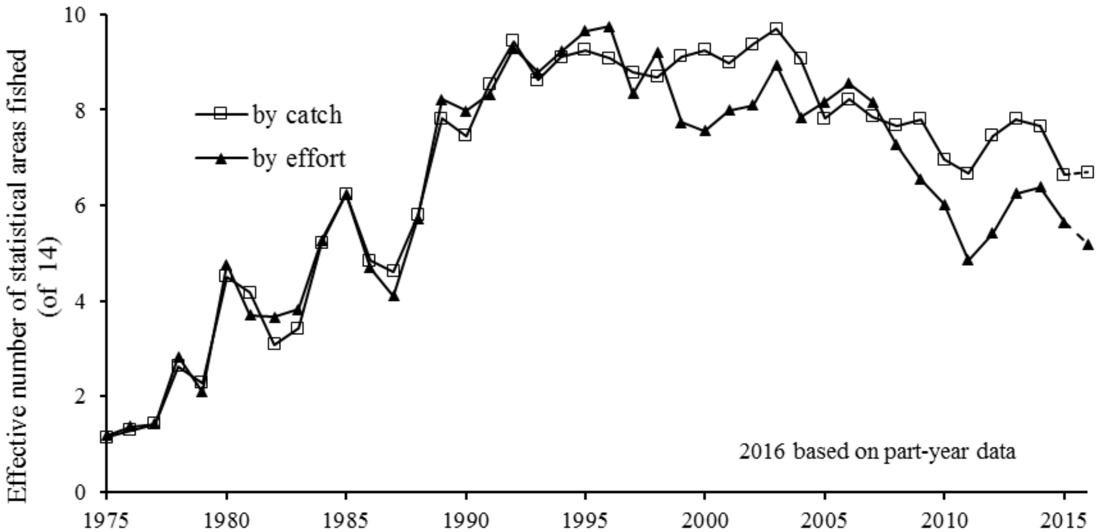



**Fig. 4.** *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 14 statistical areas, from logbook records, 1975–2016.

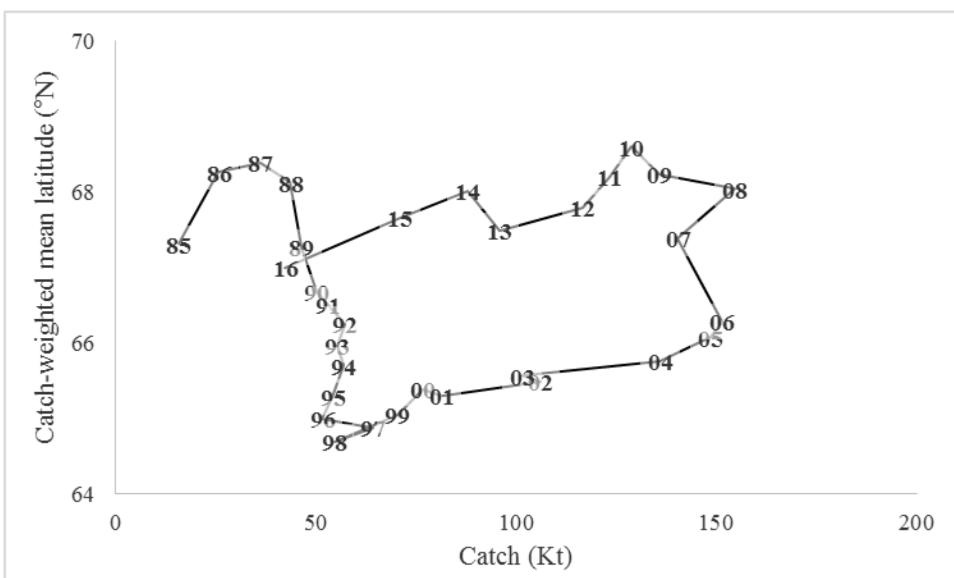



**Fig. 5.** *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1984–2016.

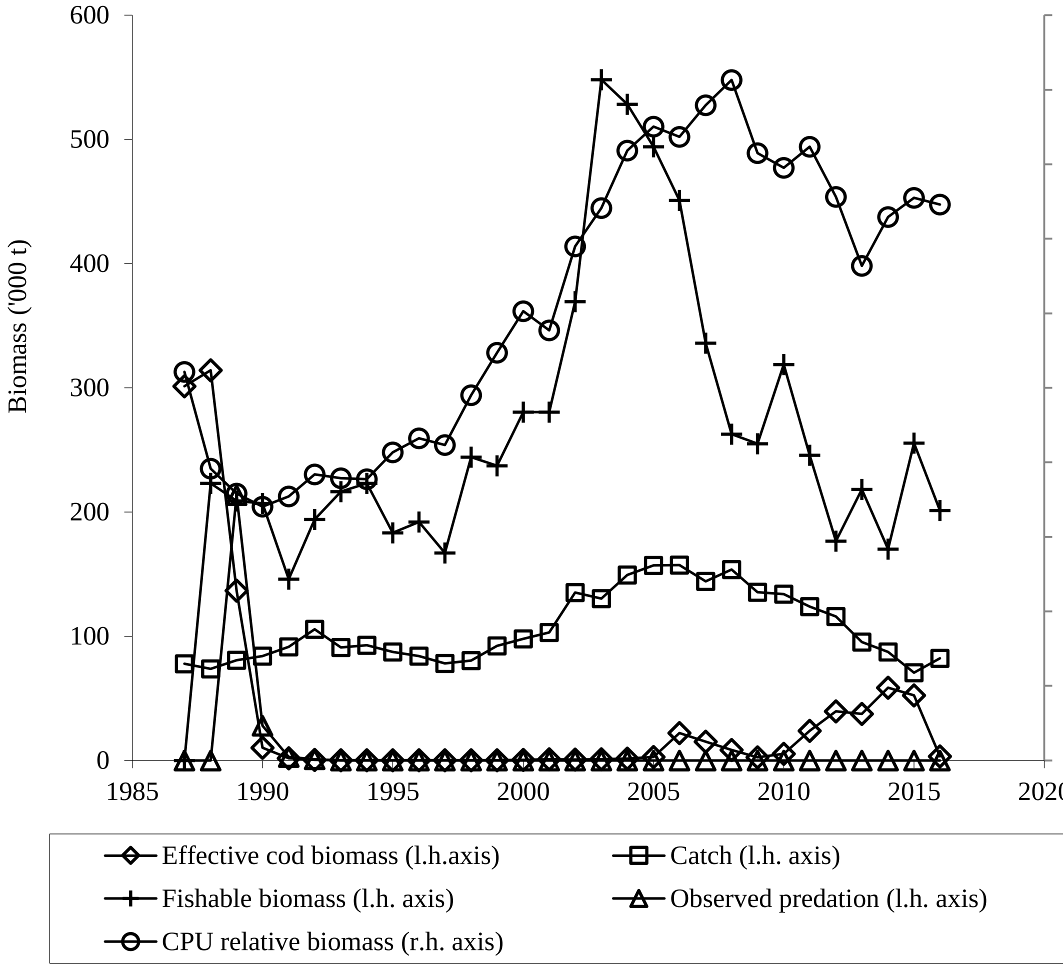



**Fig. 6.** *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2016 catch is projected; effective cod biomass is synthesised from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

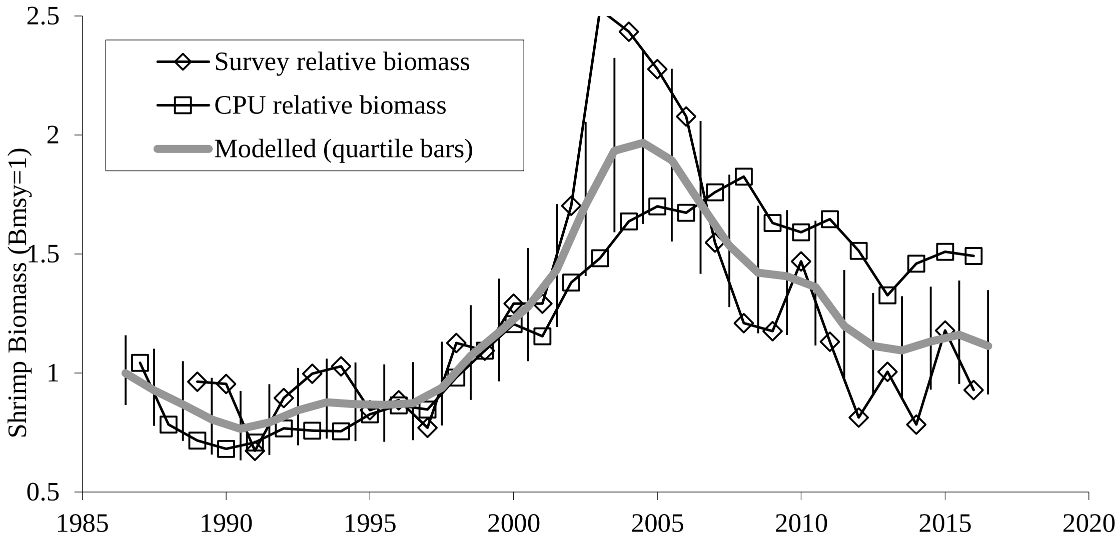



**Fig. 7.** *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1986–2016.

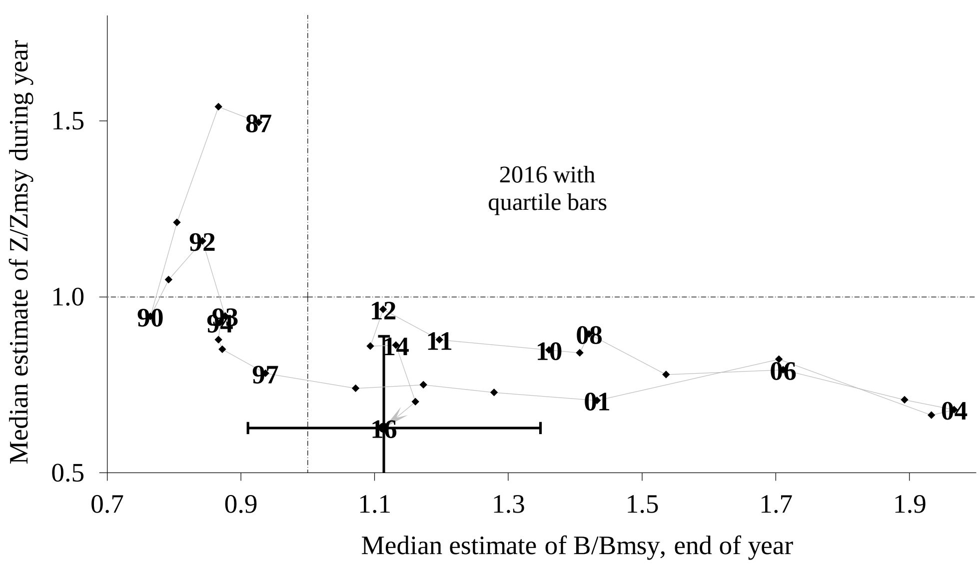



**Fig. 8.** *Pandalus borealis* in West Greenland: median estimates of biomass ratio ($B/B_{msy}$) and mortality ratio ($Z/Z_{msy}$) 1986–2016.

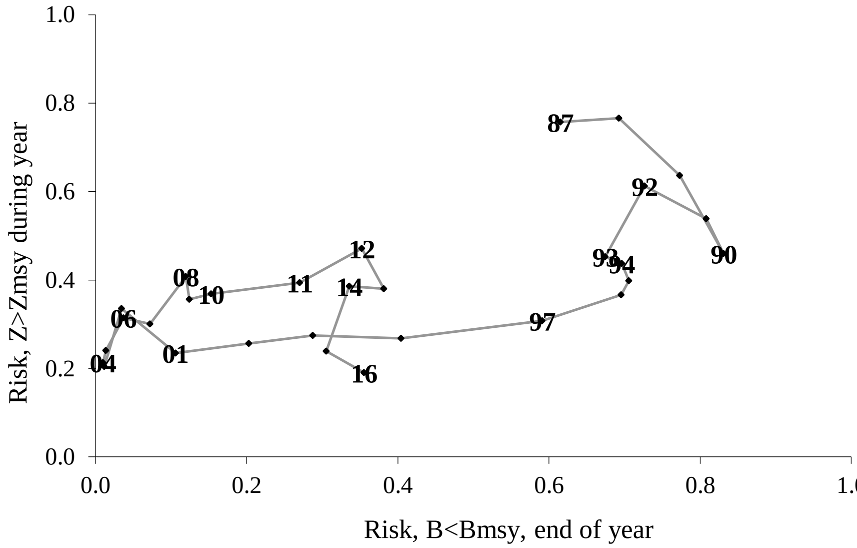



**Fig. 9.** *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below $B_{msy}$ and that mortality caused by fishing and cod predation has been above $Z_{msy}$ 1985–2016.

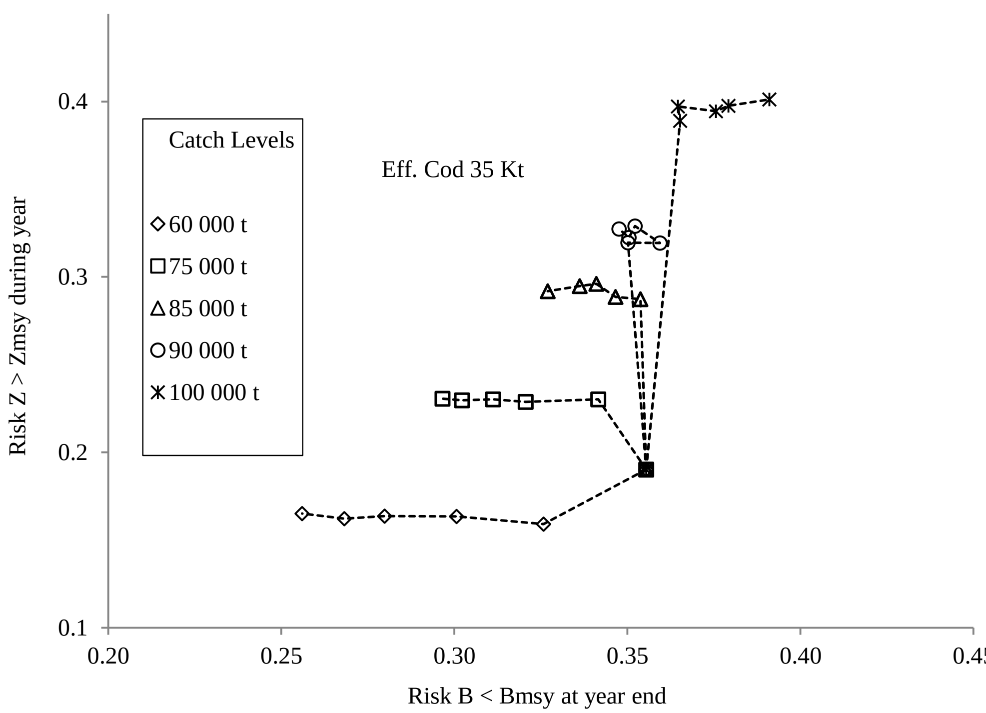
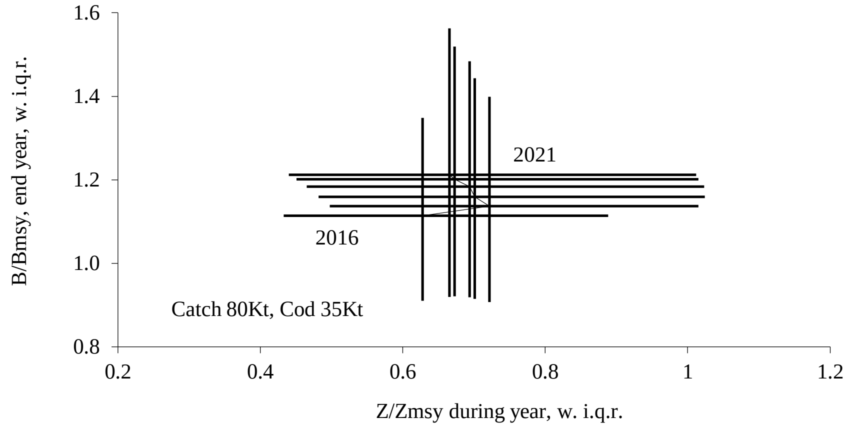
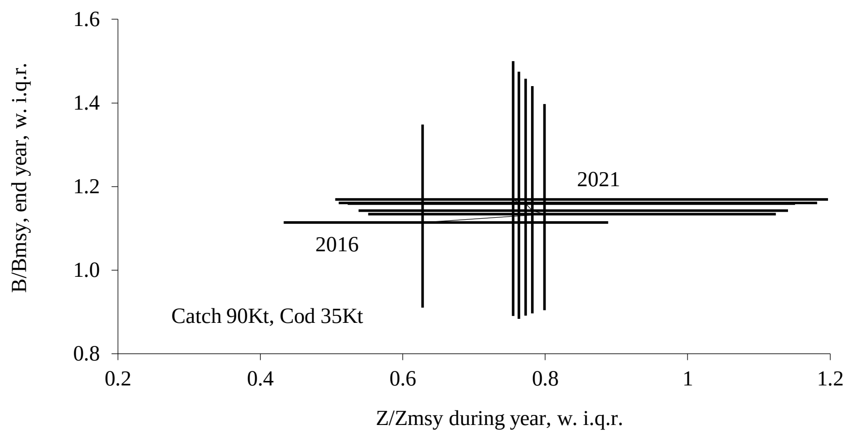



**Fig. 10.** *Pandalus borealis* in West Greenland: joint 5-year plot 2017–21 of the risks of transgressing $B_{msy}$ and $Z_{msy}$ at catch levels 60–100 Kt/yr; with effective cod biomass 35 Kt.



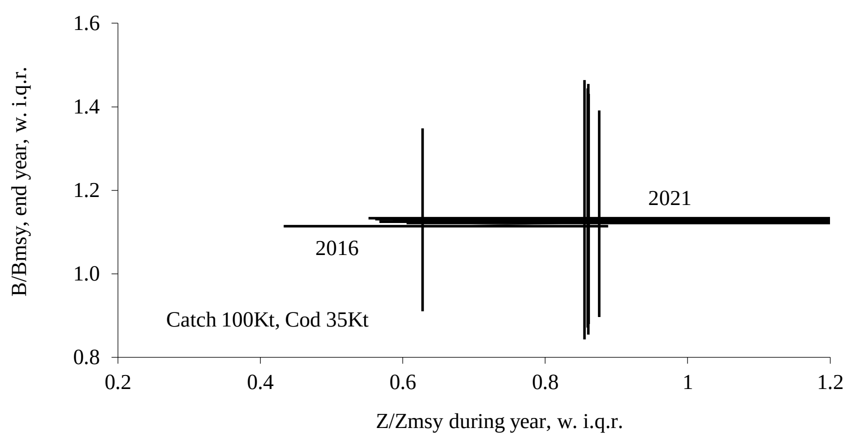




**Fig. 11a.** *Pandalus borealis* in West Greenland: projections of stock development for 2016–2021 with effective cod biomass assumed at 35 000 t: median estimates with quartile error bars.