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A Provisional Assessment of the Shrimp Stock off West Greenland in 2017

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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 'safe' in several respects. In its history survey biomass have been fluctuated with ups and downs, and in some years biomass increased by more than 45% (1998, 2003 and 2015). In 2017, survey total biomass is above its median compared with the most recent 20 years. In total, fishable biomass increased by 41% over 2016, offshore; the fishable biomass has increased by nearly 56%, and 27% inshore. In both regions, fishable biomass is above the median of the most recent 20 years. Areas north of the northern margin of Store Hellefiskebanke have almost three-quarters of the offshore biomass. As a result of this, the proportions of biomass in the offshore area and inshore are 74% and 26% respectively, at their 20-year mean in both regions.

Both inshore and offshore the number of age 2 shrimps, was decline over 2016, below or at 20-year lower quartile inshore and offshore both in numbers and in relation to survey biomass. However, the proportion of large pre-recruits 14.5–16 mm carapace length increased in both regions, indicating the good prospects for short-term recruitment to the fishable stock. Overall, in 2017 the proportion fishable of the survey biomass is below the lower quartile for the last 20 years, owing to larger proportion of pre-recruits in the stock. Where proportion of females are close to a record 20-year value, fishable males are 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, but in 2017 numbers of pre-recruits shrimps offshore were 4.6 times the numbers of inshore, and numbers of age-2 shrimps 1.5 times 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 from 2011 to 2014, 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 100 000 to 135 000 tons under assumptions that the cod stock, allowance made for its overlap with shrimp distribution, might be at 25 000 tons. The median estimate for 2017 was 21 400 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 2017). 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; Burmeister and Rigét 2017).

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 3.5°C in 1997–2014. Since 2015 temperature have continuously declined to2.5°C in 2017. 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 and Rigét 2017). 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

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

have increased significantly. In 2012–2014 the biomass of cod increased considerably, and although it is 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 cod biomass increase in 2017, but was still considerably lower than compared to values from 2012 – 2015. 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. 6). Total survey biomass increased by 60% from 2014 – 2015, but was not maintained and survey biomass overall decreased by 25% over 2015. Nevertheless, in 2017 survey biomass overall, increased by 47% over 2016, is above its 20-year median and 93% of the temporary maximum of 2010. In 2017, the number and biomass of females are both respectively 31% and 35% higher than in 2016 values and whereas female biomass is above the 20-year upper quartile, female in numbers is above it 20-year median. Male biomass and fishable biomass both increase by 37.8% and 41.4% respectively, and in 2017 male biomass is above its 20-year median, but fishable biomass below.

Survey Measures of Stock Size

	Biomass (Kt)					Number (bn)		
	Survey							
	Disko B. & Vaigat	Offshore	Total	Fishable	Female	Male	Female	Age 2
2017 value[1]	80.9	239.1	319.9	284.6	136.7	48.2	14.2	3.06
20-year[2] upper quartile	93.2	291.7	372.5	344.4	127.1	66.4	15.2	7.7
20-year median	80.2	222.6	287.1	259.1	104.4	47.7	11.9	5.1
20-year lower quartile	68.7	169.6	253.9	232.5	98.2	36.1	10.6	4.1
2017 rank	10.8	11.6	12.3	4.3	6.9	7.7	14.6	3.3
2016 value	64.8	153.4	218.2	201.3	101.3	28.4	10.8	4.3

[1] survey estimates of stock size for 2011, 2012, 2014, 2015, 2016 and 2017 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 2017 rank, are referred to the 20 preceding years, i.e. 1997–2016.
[3] value recalculated in 2014

In the inshore area, comprising Disko Bay and Vaigat, the estimated survey biomass increased by 20% from 2016 to a 2017 value close to its 20-year median. The offshore biomass collectively, in 2014 close to its lowest for 20 years, increased in 2015, dropped in 2016, but increased over 2016 by 55.8% to a 2017 value above its 20-year median. Relative to stock size, last year' values indicated no sign of an incoming recruitment pulse. Nevertheless, numbers of fishable male increase over 2016 and were 2015 pre-recruits were not shown up in the fishable biomass in 2016, those 2015 pre-recruits might have caused the increase in both male fishable biomass and in numbers. Absolute number at age 2, declined over 2016 and is below its 20-year lower quartile (Fig. 2a).

Survey Measures of Stock Composition

Overall	Number ('000/survey ton)		Biomass (%)			
	Age 2[3]	14–16.5 mm[2]	Fishable, of survey	Fishable males, of survey	Females, of survey	Females, of fishable
2017 value	9.6	41.1	89.0	46.3	42.7	48.0
Upper quartile[1]	25.3	27.7	93.2	57.2	38.9	42.1
Median[1]	18.1	24.8	92.0	54.6	35.8	39.7
Lower quartile[1]	11.1	22.0	90.7	52.4	34.9	38.0
2017 rank[1]	3.6/20	11.8/12	4.5/20	2.1/20	16.9/20	18.1/20
2016 value	19.9	22.5	92.3	45.9	46.4	50.3

[1] quartiles and 2017 rank generally referred to 20 preceding years 1997–2016;
[2] quartiles and 2017 rank referred to 12 preceding years 2005–2016 (for which data is available);
[3] value recalculated in 2014

The overall stock composition in 2017 is marked, by a high proportion of females, both in the survey and in the fishable biomass, way above its upper 20-year quantile; males compose a considerable lower proportion of the fishable biomass in 2017 than in the previous years, but close to 2016 value. Relative to stock size the number of age-2 shrimps is below its 20-yr lower quartile, but the relative number of large pre-recruits is way above its 12-year upper quartile and close to a record value, so prospects for short-term recruitment are assumed good.

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
2017 value	14.6	29.1	91.3	45.6	45.6	50,0
Upper quartile[1]	42.8	33.8	90.2	56.0	41.7	46.3
Median[1]	30.1	31.2	89.2	49.9	36.2	41.0
Lower quartile[1]	24.3	27.9	86.1	48.6	33.2	38.0
2017 rank[1]	3.4/20	4.4/11	18.6/20	1.7/12	11.3/12	11.3/12
2016 value	38.7	25.6	89.9	43.2	46.7	52.0

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
2017 value	7.9	45.1	88.2	46.5	41.7	47.3
Upper quartile[1]	20.0	25.8	94.3	56.1	44.4	48.1
Median[1]	13.6	21.1	93.5	53.5	39.8	42.4
Lower quartile[1]	8.1	19.1	92.0	48.5	36.5	38.6
2017 rank[1]	5.6/20	13.0/12	10.5/20	1.8/12	7.3/12	8.0/12
2016 value	11.9	21.1	93.3	47.0	46.3	49.6

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, but 2017 value offshore is way above 20-year upper quartile, while inshore below 20-median. Inconsistently with previous years, except for 2015, offshore regions have by far higher 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 is lower offshore but close to its upper quartile. In fact, female proportions of fishable biomass in Disko Bay is close to a record value. Throughout the size distribution, the offshore stock has been biased toward larger shrimps, while the Disko Bay & Vaigat component has had higher proportions of smaller and younger shrimps.

Despite a minor drop over 2016 in both regions, females compose a high proportion of the biomass, both survey and fishable. In 2017, males constitute a low proportion of the fishable biomass. Compared with values for the previous 20 years, both inshore and the offshore fishable biomass is above their 20-year median quartile. While proportion of fishable biomass of survey biomass is unusually high inshore, it's low offshore. Like in most recent years, except 2015, the stock in 2017 in both regions, especially inshore, 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. There are high numbers of large pre-recruits offshore which are assumed to enter the fishery within the next two year; few fishable males to recruit to the spawning stock; and, concomitantly, high proportions of spawning females in the fishable biomass, so if the fishable stock gets fished, there won't 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
2017 value	30.1	31.3	25.9	12.7	0.0	3.7	25.8
20-year[1] upper quartile	34.1	35.8	23.9	24.6	9.1	3.9	28.5.
20-year median	23.2	31.9	19.0	20.4	1.5	3.4	25.0
20-year lower quartile	11.3	27.6	14.4	9.4	0.4	3.2	20.9
2017 rank	12.0/20	9.4/20	16.5/20	8.6/20	2.1/20	13.6/20	13.0/20
2016 value	41.1	32.6	17.4	7.0	1.9	3.2	27.9

[1] percentiles and 2017 rank are referred to the 20 preceding years, i.e. 1997–2016.

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 2017, continue to hold high proportion of the offshore biomass, well above the 20-year median quartile, proportion in W1-W2, of the mouth of Disko Bay almost averaged, but proportion in W3-W4 is above it 20-yearupper quartile. The proportion of biomass in W5-W7 increased over 2016, but is still below the median and in W8-W9 shrimp is almost absent.

The proportions in W1–2 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, 2012, and in 2015 especially for Disko (downward) and the North (upward), W3–4 (fluctuation) 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 2017 the CPUE index of relative biomass has remained significantly above the survey index, in fact CPUE index has been continuously increasing since 2014. 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 2017).

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 from 2008 to 2016, except in 2015, it has stayed above average as catches were not been brought down to match the lowness of biomass estimates.

Results of the Quantitative Assessment

The median estimate of the *MSY* was 137.4 Kt with quartiles at 108 and 180 Kt; an estimated mode is at 106 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 2017 is projected close to the 2015 value and 39% above B_{msy}. The catches projected for 2017 are expected to hold total mortality in 2017 below 65% of Z_{msy}.

Table: *P. borealis* in West Greenland: model estimates of stock status at end of, or during, 2017.

Biomass ratio *B/Bmsy* (median estimate, %)	138.8
Prob. *B<Bmsy* (%)	12.0
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	58.3
Prob. *Z>Zmsy* (%)	15.5

Risks associated with eight possible catch levels for 2018, with an ‘effective’ cod stock at 25 000 t, are estimated to be:

25 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2018 (%)	13.3	14.7	14.6	15.0	15.0	15.4	16.3	16.5
falling below Blim end 2018 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2018 (%)	18.0	20.5	22.7	25.0	27.6	30.5	32.9	34.9
exceeding Zmsy in 2019 (%)	19.0	21.2	23.8	26.8	29.3	31.8	34.5	37.0

If a mortality risk (i.e. that estimable mortality will exceed Z_{msy}) criterion of 35% is observed, catches of 120–130 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 bedeviled 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 100 000 to 120 000 tons (Figs 10–11), 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 2017. 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 at 105 Kt would keep the risk of exceeding Z_{msy} below 21%, assuming certain limits on the evolution of the biomass of Atlantic cod.

According to Kingsley (2013) "There is, however, some emerging evidence that the assessment model and therefore the advice that is produced from its results are both somewhat unstable: favorable stock biomass indicators (i.e. high survey estimates or high CPUE, or both) in a given year tend to produce both a higher modelled estimate of relative stock size and also a higher estimate of MSY, resulting in a high estimate of the catch that will satisfy the mortality-risk criterion. And vice versa when biomass indicators are low. Therefore, a catch-smoothing rule appears to be a necessary component of an HCR that is founded on the present assessment method".

Parameter estimate of MSY was quite different than that estimated in 2016 (Table 2) suggesting some degree of instability of the model. This was further demonstrated by changes in perception of stock trajectory in recent years based on a 5-year retrospective analysis (Figure 12). It was also noted that since 2011, the input data is based on the most recent 30-year period which effectively loses a year of historical data in the current year assessment. This was introduced as a practical computational convenience which has the consequence of eliminating an earlier period in which high cod abundance was realized. The resulting instability should be investigated further.

At the present state the biomass is 39% above its $B_{msy,}$ and in the medium term, model results estimate that catches of up to 105 t/yr would be associated with a stable stock (Figure 10). Medium-term projections were summarized by plotting the risk of exceeding Z_{msy} against the risk of falling below B_{msy} over 5 years (Figure 10). For catches of less than 105 Kt the mortality risk is less than 21% but increasing over the projection period. The relative biomass is relatively insensitive to catch level but changes with time.

The TAC advice for this stock has until recently been set according to an accepted risk level of 35% of exceeding Z_{msy}. However, there is concern that the model in the most recent years does not fully reflect the uncertainty associated with stock status. SC therefore considers that a lower risk tolerance of around 20% is warranted equaling a TAC of approximately 105 000 t in 2018.

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Table 1. *Pandalus borealis* in West Greenland: input data series 1987–2017 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)
1988	314.10	73.616		223.2			0.1484
1989	136.70	80.671		209	213.7	470.9	0.05012
1990	10.06	83.967		207	27.8	184.1	0
1991	1.77	91.487		146	2.7	19.8	0.04061
1992	0.29	105.487		194.2	0.8	2.9	0.1175
1993	0.24	91.013		216.5			0.1045
1994	0.07	92.805		223.1			0.1015
1995	0.05	87.388		183.2			0.1938
1996	0.08	84.095		192.1			0.2405
1997	0.08	78.128		167.1			0.2151
1998	0.06	80.495		244.3			0.3579
1999	0.09	92.198		237.3			0.4692
2000	0.38	97.968		280.3			0.5665
2001	0.80	102.926		280.5			0.5208
2002	0.70	135.172		369.5			0.6977
2003	0.91	130.173		548.3			0.7679
2004	1.36	149.332		528.3			0.8683
2005	2.71	156.899	140.5	494.2			0.9067
2006	21.98	157.315	140.2	451			0.8881
2007	14.95	144.19	135.2	336.1			0.9358
2008	8.31	153.889	131.6	262.6			0.9749
2009	2.52	135.458	108.8	255.1			0.8589
2010	5.40	133.99	138.5	318.7			0.8326
2011	23.75	123.985	126	245.7			0.8691
2012	39.49	115.975	110	176.4			0.7845
2013	37.48	95.381	100	218.1			0.6538
2014	58.60	88.765	90	170			0.7412
2015	52.26	72.256	65	255.5			0.79
2016	3.12	85.527	82	201.3			0.8139
2017	21.4		90	284.6			0.9323

[1] 'effective cod biomass' was not an input data series in 2017; 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 2014–17 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, 2017.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2016)
Max.sustainable yield	153.3	90.5	107.5	137.4	180.2	105.6	126.7
B/Bmsy, end current year (proj.)(%)	143.6	40.3	115.0	138.8	166.5	129.2	111.4
Biomass risk, end current year(%)	12.0	32.5	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	39.0	58.3	84.0	–	62.8
Carrying capacity	3878	3248	1920	2969	4721	1151	2818
Max. sustainable yield ratio (%)	11.2	7.1	5.9	10.4	15.4	8.8	9.7
Survey catchability (%)	18.1	15.2	7.8	13.6	23.2	4.4	15.3
CPUE catchability	1.2	1.0	0.5	0.9	1.6	0.3	1.0
Effective cod biomass 2017 (Kt)	26.2	25.5	15.1	21.4	29.6	11.8	3.1
$P_{50\%}$	4.0	7.7	0.2	1.1	4.2	-4.8	1.3
V_{max}	1.5	2.0	0.3	0.6	1.8	-1.2	0.8
CV of process (%)	14.4	3.8	11.7	13.8	16.6	12.6	14.0
CV of survey fit (%)	16.9	1.8	15.8	17.0	18.2	17.2	16.8
CV of CPUE fit (%)	20.1	2.9	18.2	19.6	21.4	18.5	19.7

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2017.

	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								
CV of predation fit (%)										

[1] those over 5%

Table 4. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2018 and of falling below B_{msy} or limit* biomass at the end of 2018 assuming effective cod biomass 25 Kt.

Catch (Kt/yr)	Prob. biomass < B_{msy} (%)	Prob. biomass<B_{lim} (%)	Prob. mort > Z_{msy} (%)
100	13.3	0.0	18.0
105	14.7	0.0	20.5
110	14.6	0.0	22.7
115	15.0	0.0	25.0
120	15.0	0.0	27.6
125	15.4	0.0	30.5
130	16.3	0.0	32.9
135	16.3	0.0	34.9

* limit biomass is 30% of B_{msy}

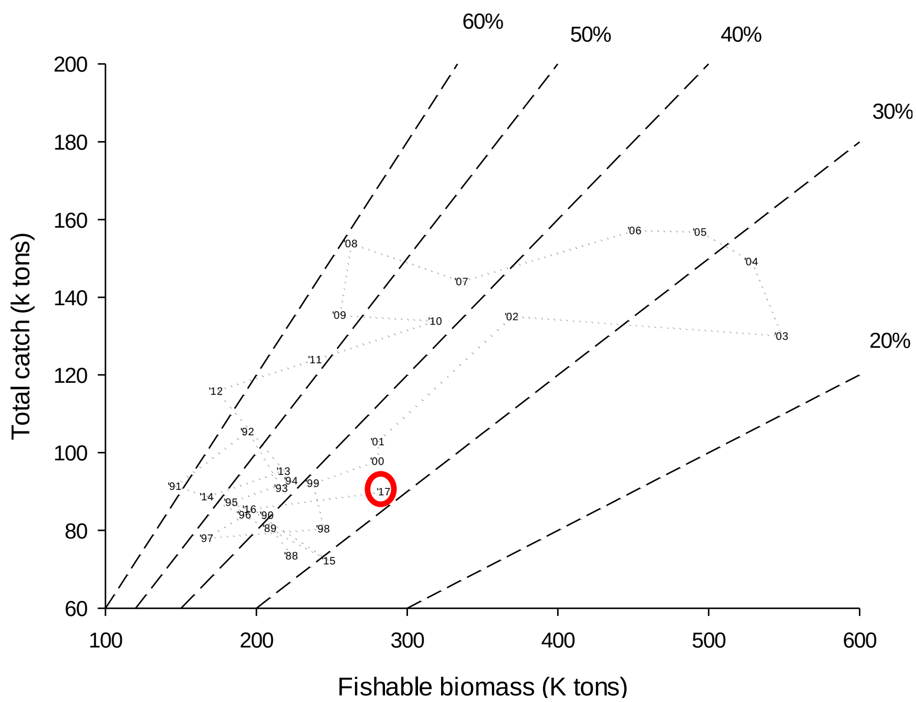

Fig. 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1988–2017 (2017 catch is provisional).

Fig. 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1996–2017.

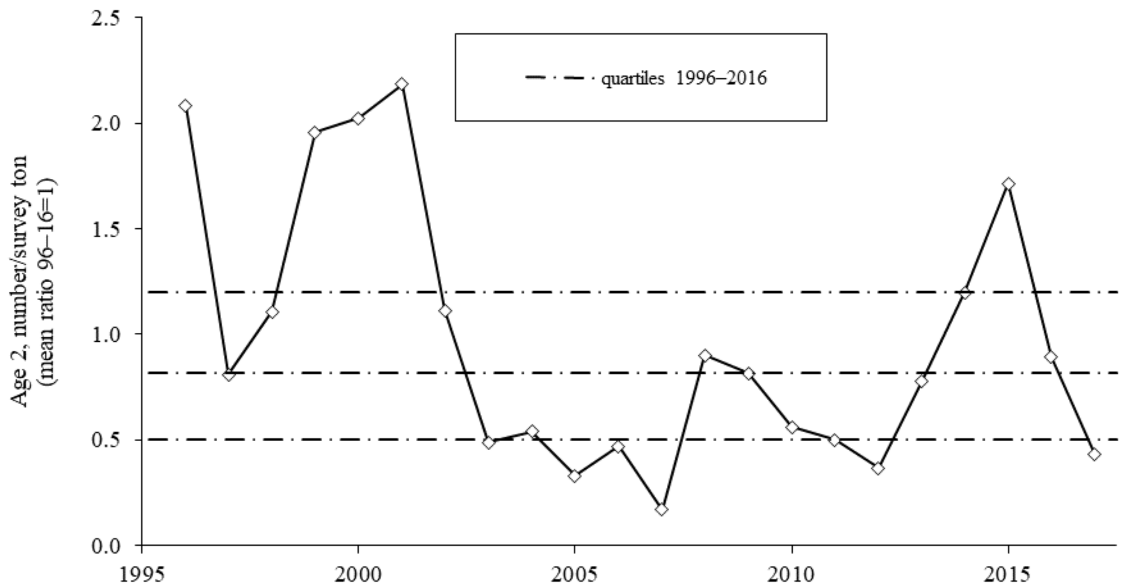

Fig. 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1996–2017.

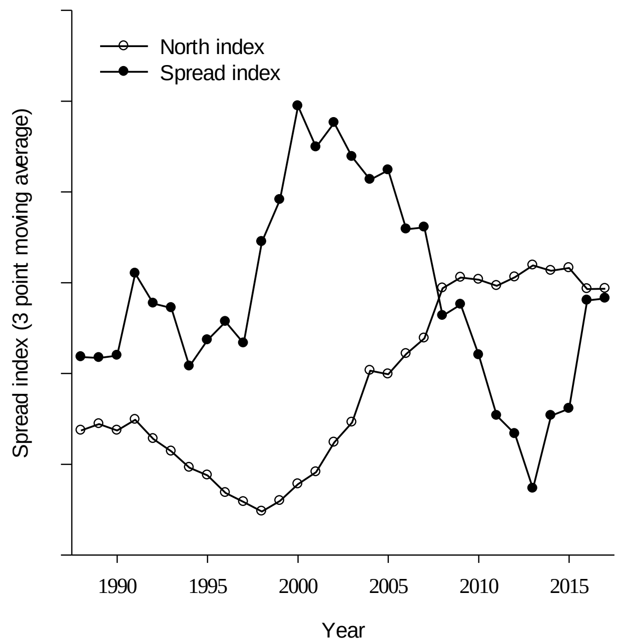

Fig. 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2017 (3-point moving means.)

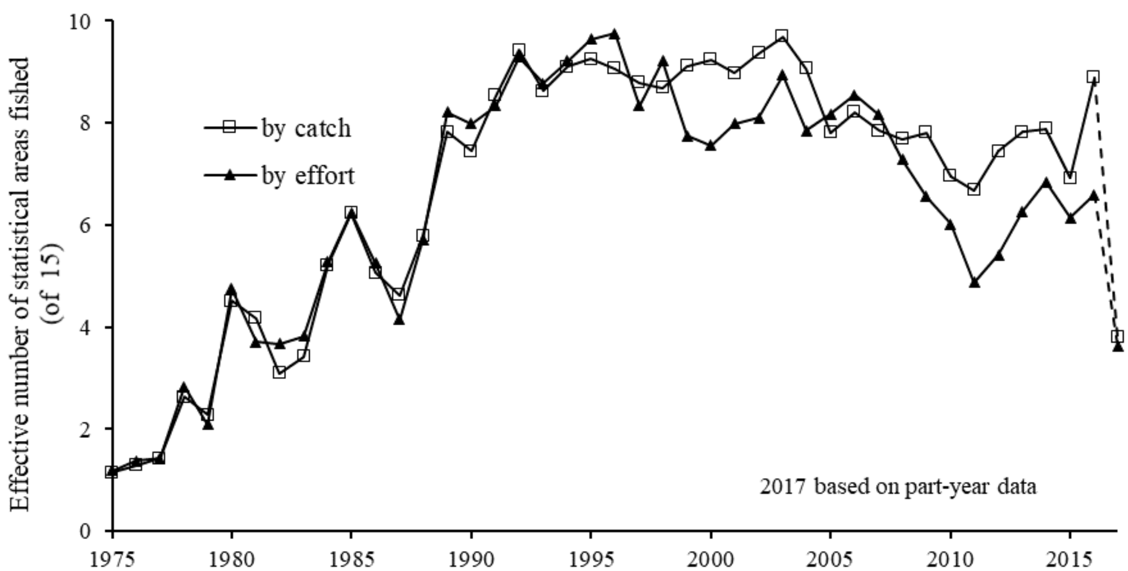

Fig. 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2017.

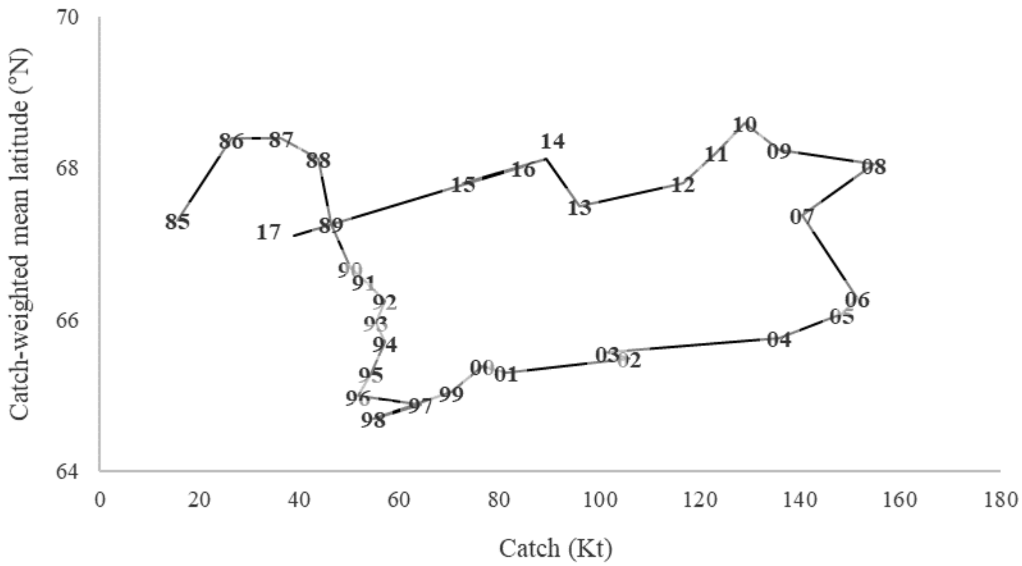

Fig. 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1984–2017.

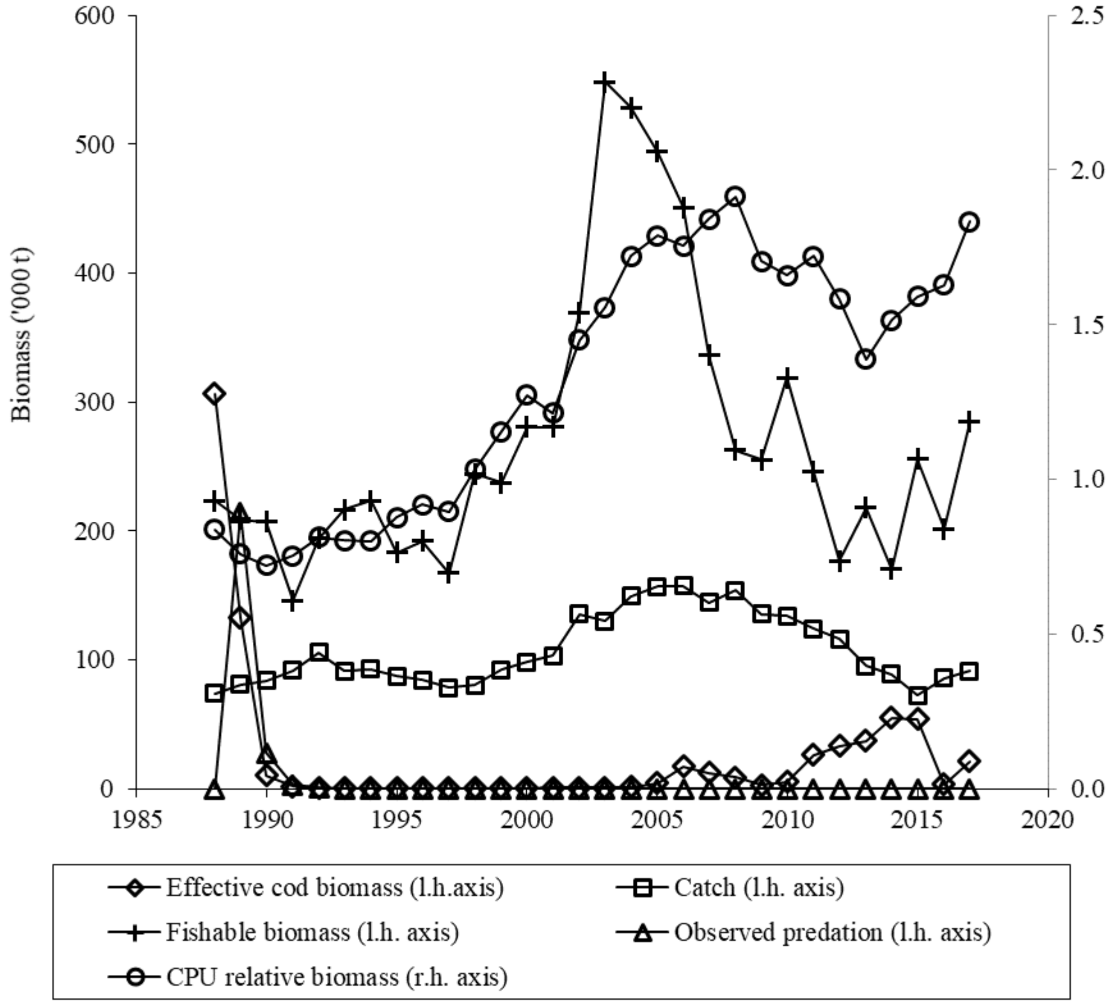

Fig. 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2017 catch is projected; effective cod biomass is synthesised from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

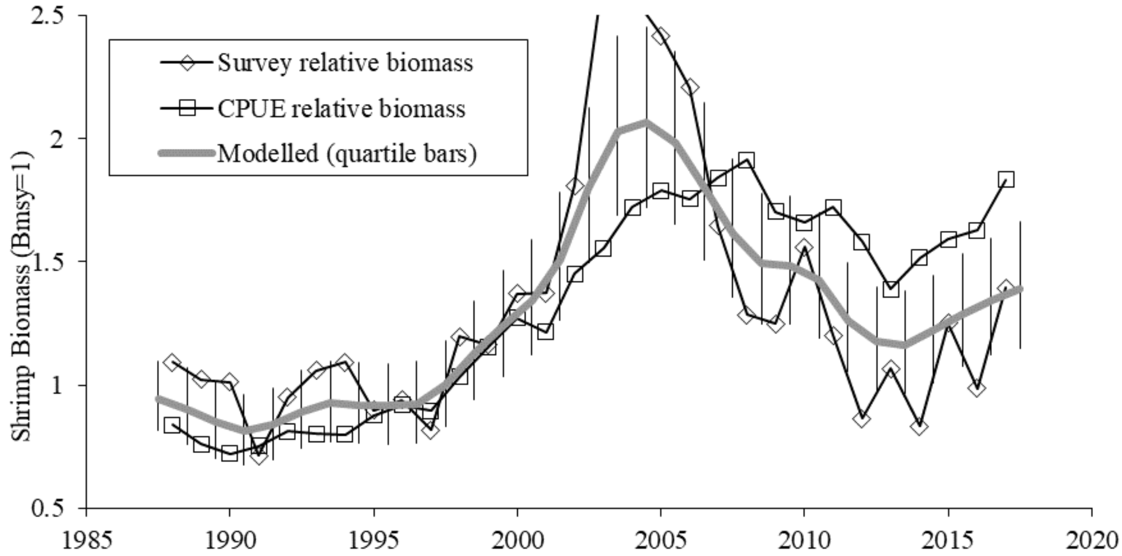

Fig. 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1988–2017.

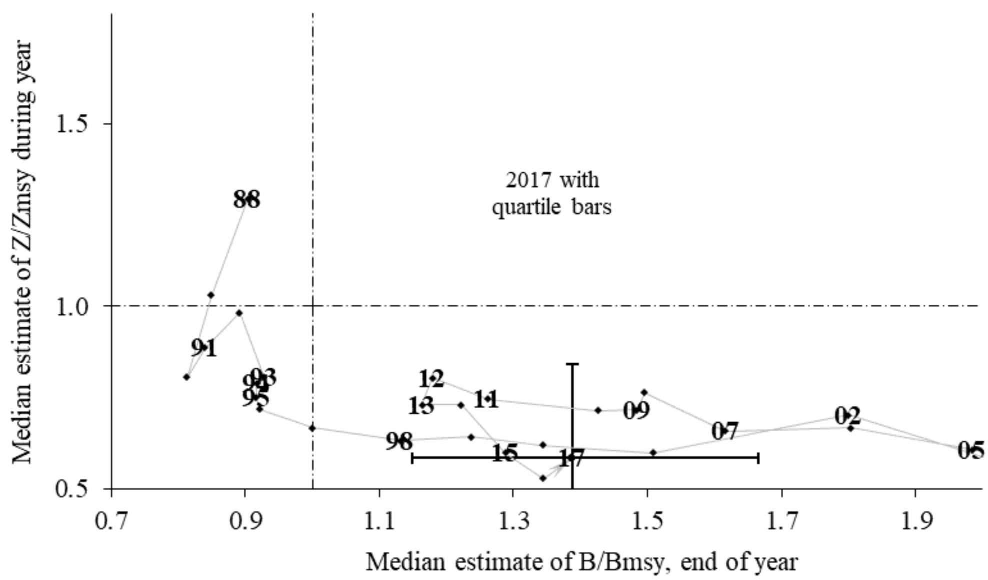

Fig. 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1988–2017.

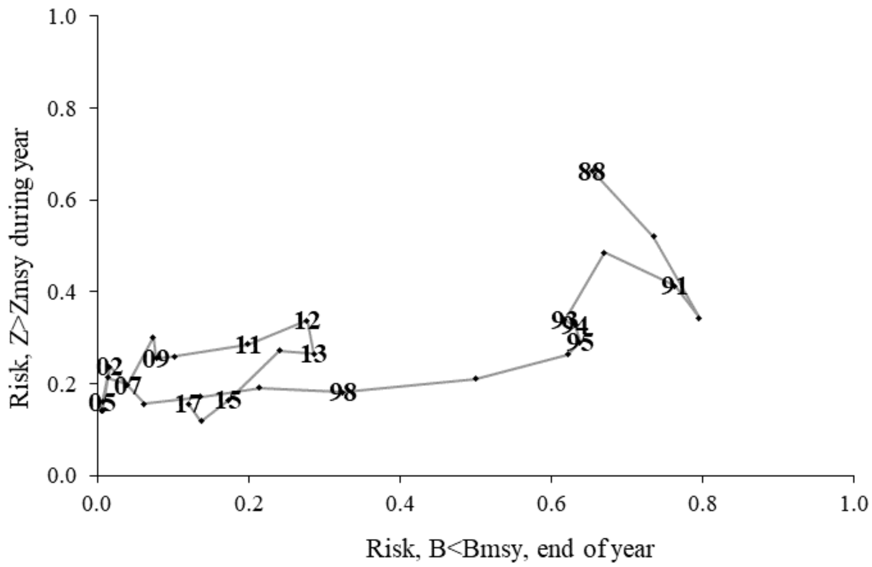

Fig. 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1988–2017.

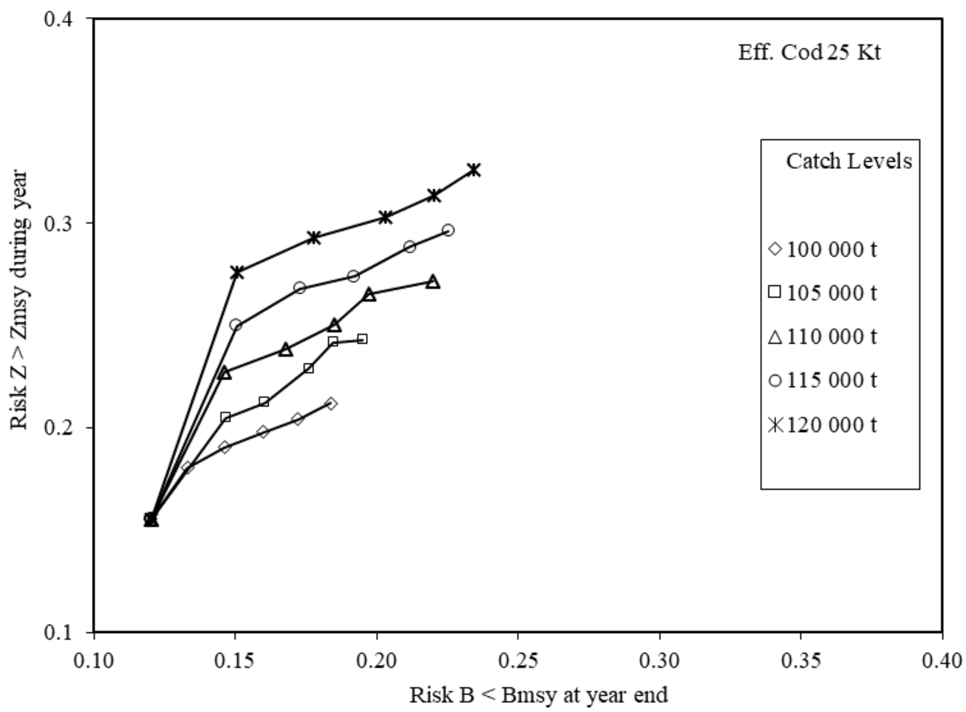

Fig. 10. *Pandalus borealis* in West Greenland: joint 5-year plot 2018–22 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–120 Kt/yr; with effective cod biomass 25 Kt.

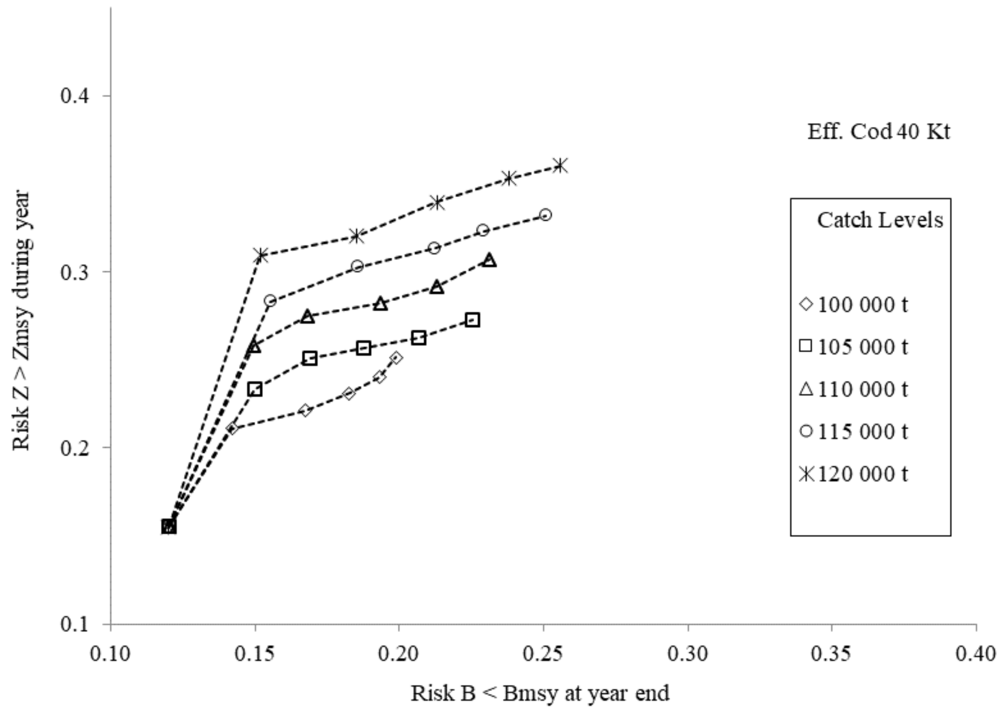

Fig. 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2018–22 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–120 Kt/yr; with effective cod biomass 40 Kt.

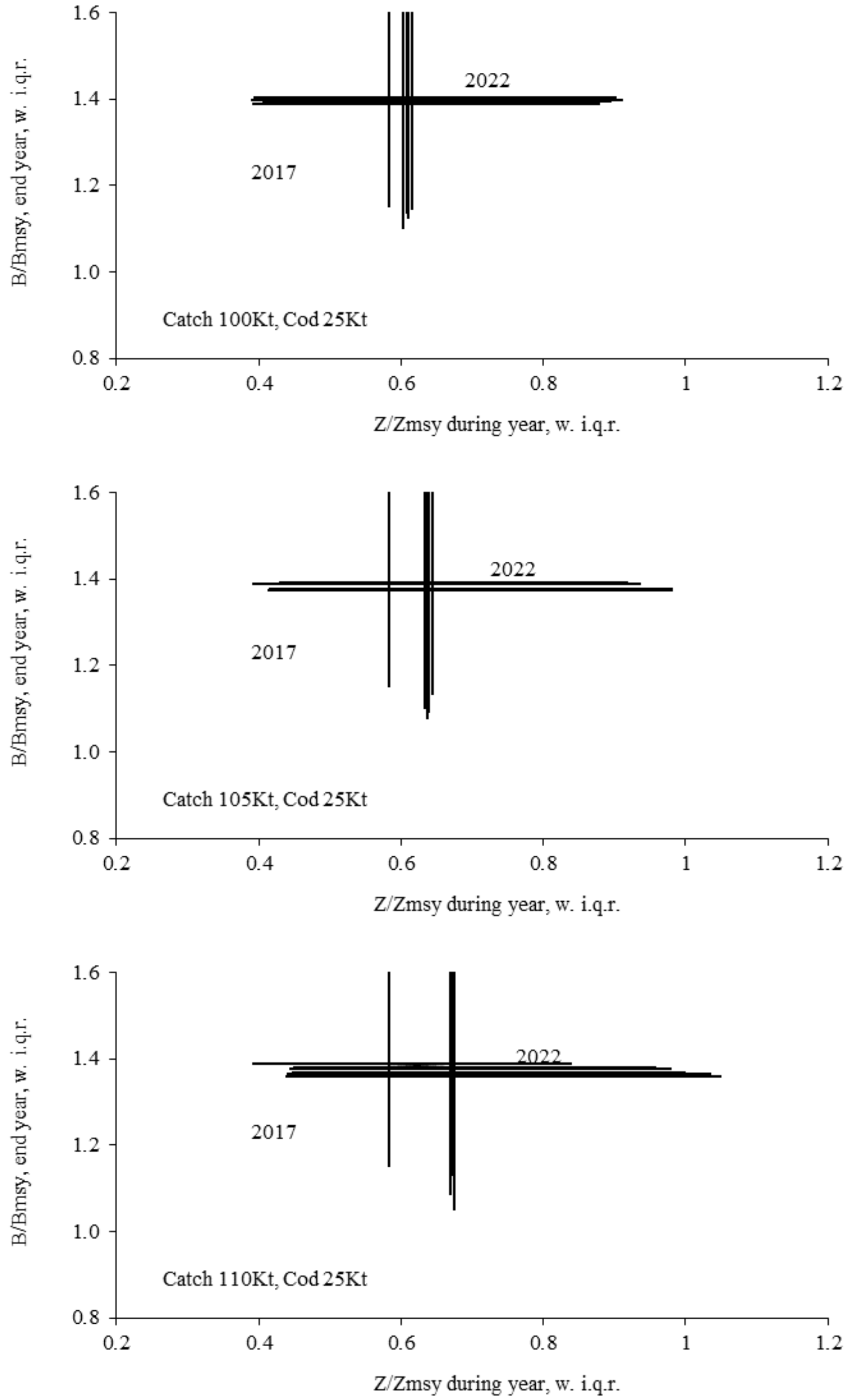

Fig. 11. *Pandalus borealis* in West Greenland: projections of stock development for 2018–2022 with effective cod biomass assumed at 25 000 t: median estimates with quartile error bars.

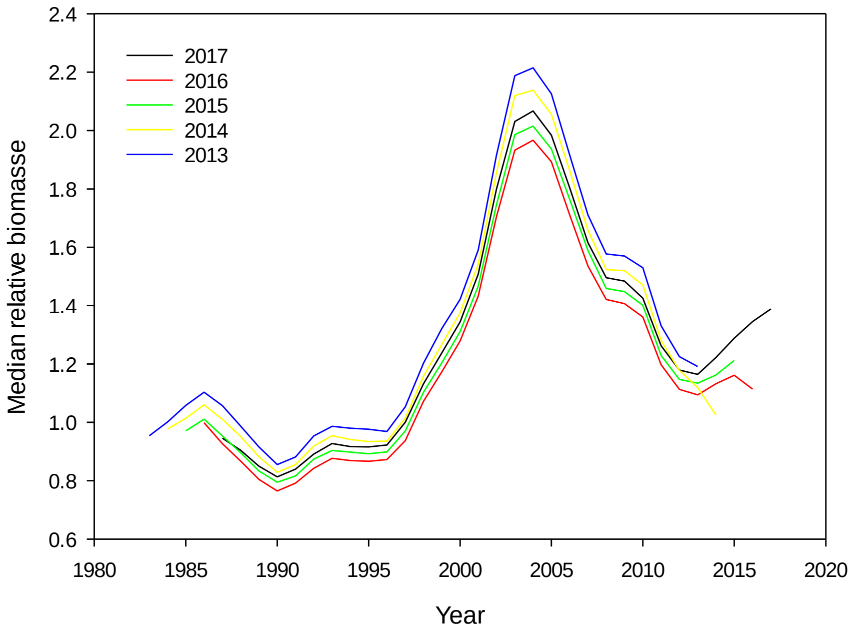

Fig. 12. Retrospective plots of the relative biomass B/B_{msy} 2013 to 2017.