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A Provisional Assessment of the Shrimp Stock off West Greenland in 2015

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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 now averaged compared with the most recent 20 years. Offshore, the fishable biomass has increased by nearly 120% over 2014, but is still below the median of the most recent 20 years; areas north of the northern margin of Store Hellefiskebanke have three-quarters of the offshore biomass. The fishable biomass inshore, in Disko Bay and Vaigat, although 19% lower than in 2014, is now at its mean when compared with its history. As a result of this contrast, the proportions of biomass in the offshore area and inshore are 72% and 28% respectively, a bit lower but close to their 20-year mean in both regions.

Both inshore and offshore the number of age-2 shrimps, about 130% higher than in 2014, and above their 20-year upper 20-year quantile both in numbers and in relation to survey biomass. This is also true for proportion of large pre-recruits of 14.5–16 mm carapace length and indicating possible good prospects for short-term recruitment to the fishable stock. Overall, in 2015 the proportion fishable of the survey biomass is low and close to the minimum for the last 20 years, caused by a drop in the proportion of females - however still at a 20-mean value and increasing proportion of small fishable males. Fishing on the stock in its present state will to some extend hit the spawning stock of females and considering lower proportions of females, 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 2015 numbers of age 2-shrimps increased significantly offshore in numbers, twice the numbers of inshore; but there are 1.3 as many age-2 shrimps a survey ton inshore as offshore, but large pre-recruits are for the first time in 10 years slightly less than offshorer.

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 45 000 tons or 65 000 tons. The median estimate for 2015 was 55 900 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 2015). The assessment also refers to indices that summarize survey information on the distribution of the stock and its structure (Kingsley 2008b; Burmeister et al. 2015).

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 1997–2015. 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. 2015). 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 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, especially in the southern part of the West Greenland (south of

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

64°N), while abundance of cod remain comparable with 2014. The increase in cod biomass is due to increase growth in the population.

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). In 2015 survey biomass overall increased by 60% over 2014, but is still 18% less than the temporary maximum of 2010. In 2015, the number and biomass of females are both 16% higher than in 2014, and are near to their 20-year median, whereas male biomass and fishable biomass both are almost double over 2014 and is little above their 20-year medians (Burmeister et al. 2015).

Survey Measures of Stock Size

	Biomass (Kt)					Number (bn)		
	Survey							
	Disko B. & Vaigat	Offshore	Total	Fishable	Female	Male	Female	Age 2
2015 value[1]	78.2	214.0	292.2	255.5	101.8	52.9	10.9	11.2
20-year[2] upper quartile	93.0	291.7	372.5	344.4	127.1	66.4	15.2	7.6
20-year median	80.2	220.4	280.3	258.8	104.4	42.5	11.9	5.1
20-year lower quartile	52.4	166.8	247.2	227.7	92.4	38.0	9.9	3.6
2015 rank	9.9	10.2	11.3	10.1	9.4	12.0	7.9	16.7
2014 value	93.5	89.4	182.9	170.0	87.6	23.2	9.4	4.88[3]

[1] survey estimates of stock size for 2011, 2012, 2014 and 2015 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. 1995–2014.

[3] value recalculated in 2014

In the inshore area comprising Disko Bay and Vaigat the estimated survey biomass decreased by 16% from 2014 to a 2015 value close to its 20-year median. The offshore biomass collectively, in 2014 close to its lowest for 20 years, increased by 170% in 2015, although close to its 20-year median but higher than its 20-year lower quartile. Relative to stock size, previous years' values indicated no sign of an incoming recruitment pulse, but offshore male fishable biomass is three times higher than in 2014. Also, absolute number at age 2 is 130% higher in 2015 than in 2014, and is above its 20-year upper quartile (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
2015 value	38.2	35.0	87.5	52.6	34.9	39.9
Upper quartile[1]	25.3	26.2	93.4	57.8	38.0	41.3
Median[1]	17.7	24.8	92.1	56.6	35.6	38.5
Lower quartile[1]	10.7	22.3	90.3	53.9	34.8	37.4
2015 rank[1]	16.7/20	9.3/10	1.8/20	4.9/20	5.6/20	14.0/20
2014 value	26.7[3]	20.3	93.0	45.1	47.9	51.5

[1] quartiles and 2015 rank generally referred to 20 preceding years 1995–2014;
[2] quartiles and 2015 rank referred to 9 preceding years 2005–2013 (for which data is available);
[3] value recalculated in 2014

The overall stock composition in 2015 is marked, by a high proportion of males, both in the survey and in the fishable biomass, however still in its lower 20-year quantile; females compose a considerable lower proportion of the fishable biomass in 2015 than in the previous years. Relative to stock size the number of age-2 shrimps is well above its 20-yr upper quartile. The relative number of large pre-recruits is close to its ten-year maximum, so prospects for short-term recruitment are good; this is true both in Disko and offshore as well.

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
2015 value	46.3	33.7	88.6	49.0	39.5	44.6
Upper quartile[1]	36.9	33.7	90.8	56.2	40.4	45.2
Median[1]	28.7	31.2	89.5	51.5	34.3	39.4
Lower quartile[1]	21.0	21.0	86.1	48.7	32.9	37.8
2015 rank[1]	17.0/20	7.8/10	8.4/20	4.1/10	7.5/10	7.6/10
2014 value	35.3	25.2	91.5	46.4	45.0	49.2

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
2015 value	35.2	35.4	87.1	53.9	33.1	38.1
Upper quartile[1]	20.0	24.2	94.6	57.0	44.1	47.9
Median[1]	14.1	20.4	93.7	54.2	39.8	42.4
Lower quartile[1]	8.1	17.9	92.0	49.0	36.7	39.0
2015 rank[1]	17.9/20	11/10	1.7/20	5.4/10	0.2/10	1.8/10
2014 value	17.7	15.2	94.5	43.7	50.8	53.8

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 for both regions 2015 value are at or above the upper 20-year quantile. In contrast to previous years, offshore regions have higher number of pre-recruits, and where fishable-male proportions of the survey biomass are averaged larger offshore, the female proportion of the survey biomass as well as fishable biomass are much lower offshore and at is lower quartile. 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 2013 some of these differences were less evident than in 2012 or in the past averages, and the inshore stock had in some ways converged on the offshore structure: its values were more like the offshore values than like its own past. This has not been maintained, and in both 2014 and 2015 there are again marked differences in composition between the stock in Disko Bay and that offshore.

In contrasts to previous years, both regions males compose higher proportion close to their 10-year median of the biomass, both survey and fishable, but females a record low proportion offshore well below the lower quartile. Where the stock in 2014 both offshore and inshore were 'all females', it tend to be more 'all small males' (17 – 23 mm CL), especially offshore. In the most recent two years, it has been commented that fishing on the stock in its then condition of comprising a high proportion of females would impact the spawning stock; and now the proportion of females is at historically low level. The length classes of large pre-recruits have been scarce both inshore and offshore in 2013 and again in 2014, are in 2015, relative to stock size, near well above their median inshore and above its upper quartile offshore.

We don't know 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 2005–12—a period characterized by a 75% decline in the offshore stock while the inshore has fluctuated. The stock seemed for the past years 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 2014 high proportion of the total, so if the fishable stock gets fished, it was assumed that there wouldn't be much left.

2014 survey data indicate that the relative number of large pre-recruits were at its ten-year minimum, and it was assumed that prospects for short-term recruitment were poor in both regions. However, male biomass, mainly offshore, increased considerable over 2014, and we can't explain the huge increase in number of age-2 and pre-recruits shrimps and the increase in the male biomass.

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
2015 value	42.5	25.6	28.9	0.0	0.0	3.0	27.9
20-year[1] upper quartile	33.3	35.2	23.6	28.2	9.0	3.9	25.6
20-year median	22.4	31.4	18.9	21.5	1.7	3.3	23.1
20-year lower quartile	5.3	27.1	14.6	11.5	0.4	3.2	20.7
2015 rank	19.0/20	2.3/20	17.6/20	0.0/20	1.0/20	1.4/20	15.6/20
2014 value	34.0	39.9	14.0	12.1	0.0	3.2	52.0

[1] percentiles and 2015 rank are referred to the 20 preceding years, i.e. 1995–2014.

Compared with values for the previous 20 years, the offshore biomass is close to its average and the inshore biomass relatively high, and in contrast to near previous years, proportions is now 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 continue to hold high proportion of the offshore biomass, well above the upper quartile, proportion in W1-W2, of the mouth of Disko Bay decline to a value below the quantile. In the results from the 2015 survey, W3-W4 around Store Hellefiske banke double over 2014 and regained its former position, while W5-W9 has now only a small proportion of the biomass.

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, 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

In every respect, the results of the quantitative assessment reflected the remarkable change in stock biomass estimated by the trawl survey. The median estimate of the *MSY* was 141Kt—i.e. 10 Kt more than the estimate made in 2014—with quartiles at 106 and 187 Kt; an estimated mode is at 109 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 2015 is projected above the 2014 value and 23% above B_{msy}. The low catches projected for 2015 are expected to hold total mortality below 60% of Z_{msy}

Risks[2] associated with eight possible catch levels for 2016, with an 'effective' cod stock at 45 000 t[3], are estimated to be:

45 000 t cod	Catch option ('000 tons)							
Risk of:	60	70	75	80	85	90	95	100
falling below Bmsy end 2016 (%)	23.5	24.6	25.0	25.5	25.9	26.2	27.0	26.7
falling below Blim end 2016 (%)	0.9	1.0	1.0	1.1	0.9	1.1	0.8	1.1
exceeding Zmsy in 2016 (%)	19.1	22.5	24.2	25.8	28.3	30.1	32.3	34.5
exceeding Zmsy in 2017 (%)	20.2	23.5	25.5	27.7	29.4	31.4	34.1	36.8

and with an 'effective' cod stock at 55 000 t:

55 000 t cod	Catch option ('000 tons)							
Risk of:	60	70	75	80	85	90	95	100
falling below Bmsy end 2016 (%)	25.0	25.0	25.4	26.2	26.6	26.6	27.0	27.2
falling below Blim end 2016 (%)	1.2	1.3	1.1	1.3	1.4	1.1	1.2	1.2
exceeding Zmsy in 2016 (%)	21.7	24.5	26.6	28.2	30.7	32.3	34.7	36.9
exceeding Zmsy in 2017 (%)	23.0	26.3	27.6	29.4	31.9	33.4	36.8	38.8

and with an 'effective' cod stock at 65 000 t:

65 000 t cod	Catch option ('000 tons)							
Risk of:	60	70	75	80	85	90	95	100
falling below Bmsy end 2016 (%)	25.0	25.9	26.3	26.8	26.9	27.4	27.9	28.3
falling below Blim end 2016 (%)	1.4	1.4	1.3	1.4	1.4	1.4	1.4	1.5
exceeding Zmsy in 2016 (%)	23.6	26.6	28.3	30.5	32.0	34.1	36.4	39.3
exceeding Zmsy in 2017 (%)	25.3	28.0	30.0	32.3	34.5	36.7	38.7	40.9

If a mortality risk (i.e. of exceeding Z_{msy}) criterion of 35% is observed, catches of 90–95 Kt might be sustainable, provided that the effective cod biomass does not make further 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.

Three- and five-year projections of stock development were made under the assumption that the 'effective' cod stock will remain at levels consistent with recent estimates, and under assumptions that constants governing the predation mechanism will retain the values estimated from the 30-year data series of the interaction between the two species. Seven levels of annual catch were investigated from 50 000 to 90 000 tons (Figs 10–12, Table 4; Appendix).

P. borealis in West Greenland spread more widely after 1990, the fishery extended into more southerly areas, and the annual trawl survey was extended to southern West Greenland. However, since the late 1990s both the survey biomass and the fishery have contracted towards the north (Figs 3–5). In the 2015 survey, the proportion of survey biomass north of 69°30'N was over 40% and near its highest-ever value.

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[2] 'risk' in this document includes all three of uncertainty of knowledge, uncertainty of prediction, and uncertainty of outcome.

[3] the median estimate for 2014 is 44 300 tons.

The present assessment based on the existing modelling approach estimates a stock that has been decreasing, but appears to have paused, and is above B_{msy}. The fishery is now more concentrated than in 1992–2003 (Fig. 4), so CPUEs that indicate high densities in the fished areas do not necessarily translate to an equally high biomass. The contraction of the biomass distribution, and the fishery, is continuing. The assessment model does not take the distribution of the fishery into account, but considers CPUE in fished areas to be a linear index of stock biomass. It might therefore under present conditions be overly sanguine in its evaluation of stock status.

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 still moderately low, although higher than we have seen in past assessments.

Conclusions

Projections for stock status at the end of 2015 look brighter than they have for some time. The estimate of *MSY* has increased, the fishable biomass estimated by the survey has increased by a surprising amount, and there are good prospects for recruitment to the fishable biomass indicated by numbers of both 'age 2' shrimps and large pre-recruits at 14–16.5 mm. The quantitative model indicates a stock well above its *MSY* level and currently exploited at well below Z_{msy}.

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Table 1. *Pandalus borealis* in West Greenland: input data series 1986–2015 for stock-dynamic assessment model.

	Effective cod biomass[1] (Kt)	Catch (Kt)	Provisional catch (Kt)	Survey index of fishable biomass (Kt)	Predation estimate2 (Kt)	Cod-stock estimate2 (Kt)	ln CPUE (1990=0)
1986	25.9	76.9					0.289
1987	329.9	73.6					0.432
1988	313.5	77.9		223.2			0.144
1989	146.5	80.7		209			0.048
1990	10.1	84.0		207	213.7	470.9	0.000
1991	1.8	91.5		146	27.8	184.1	0.042
1992	0.3	105.5		194.2	2.7	19.8	0.115
1993	0.2	91.0		216.5	0.8	2.9	0.106
1994	0.1	92.8		223.1			0.108
1995	0.1	87.4		183.2			0.201
1996	0.1	84.1		192.1			0.248
1997	0.1	78.1		167.1			0.218
1998	0.1	80.5		244.3			0.358
1999	0.1	92.2		237.3			0.469
2000	0.4	98.0		280.3			0.572
2001	0.8	102.9		280.5			0.530
2002	0.7	135.2		369.5			0.697
2003	0.9	130.2		548.3			0.758
2004	1.4	149.3		528.3			0.859
2005	2.7	156.9	141.0	494.2			0.902
2006	21.8	157.3	140.5	451			0.880
2007	15.0	144.2	140.2	336.1			0.948
2008	8.4	153.9	135.2	262.6			0.978
2009	2.5	135.5	131.6	255.1			0.860
2010	5.4	134.0	108.8	318.7			0.833
2011	24.2	124.0	138.5	245.7			0.863
2012	39.7	116.0	126.0	176.4			0.784
2013	37.7	95.4	110.0	218.1			0.655
2014	58.3	88.8	100.0	170			0.749
2015	55.9	—	90.0	255.5			0.758

[1] 'effective cod biomass' was not an input data series in 2014; 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 a series of 'effective cod' estimates; tabulated are the median estimates (see Kingsley 2014; Siegstad and Kingsley 2014, Renzel 2014).

[2] Grunwald (1998).

[3] demographic analyses for 2005–2010 had been re-run in 2011 and resulted in especially large changes in the survey estimates of fishable biomass for 2005 (3.1% increase) and 2006 (3.1% increase);

[4] survey estimates of fishable biomass for 2011, 2012, 2014 and 2015 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.

Table 2. *Pandalus borealis* in West Greenland: summary of estimates of selected parameters from Bayesian fitting of a surplus production model, 2015.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2014)
Max. sustainable yield (Kt)	155.3	94.7	104.7	140.2	186.2	110.0	131.3
B/B_{msy}, end current yr (proj.)	126.9	35.7	102.0	123.0	147.3	115.2	97.3
Biom. risk, end current yr (%)	23.0	42.1	–	–	–	–	–
Z/Z_{msy}, current yr (proj.)	–	–	37.4	58.6	94.1	–	103.1
Carrying capacity	4255	3166	2226	3365	5257	1585	3126
M.S.Y. ratio (%)	10.1	6.6	5.2	9.2	13.8	7.5	9.0
Survey catchability (%)	15.8	12.6	7.3	12.3	20.2	5.1	14.1
CPUE catchability	1.0	0.8	0.5	0.8	1.3	0.3	0.9
Effective cod biomass 2015 (Kt)	75.2	88.4	36.1	55.9	84.5	17.2	44.3
$P_{50\%}$	4.5	10.6	0.2	1.1	4.7	-5.9	7.2
V_{max}	1.5	2.0	0.3	0.6	1.8	-1.2	3.0
CV of process (%)	14.2	3.7	11.5	13.7	16.4	12.7	12.1
CV of survey fit (%)	16.4	1.8	15.2	16.5	17.8	16.6	15.9
CV of CPUE fit (%)	19.3	2.7	17.5	19.0	20.6	18.3	19.0
CV of predation fit (%)	139.9	90.5	66.1	124.7	198.2	94.3	115.4

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2015.

	Start biom. ratio	*CV pred*	*CV cpu*	*CV surv*	*CV proc*	*V_{max}*	*P50%*	*Qc*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield		15						-17	-17	32	25
Carrying capacity	17	20						-61	-61	-57	
Max. sustainable yield ratio (%)	-28	-12						77	77		
Survey catchability (%)	-39	-21					-8	100			
CPUE catchability	-40	-21					-8				
P50%	11					68					
Vmax	-7	-5									
CV of process (%)	13		18	-12							
CV of survey fit (%)			15								
CV of CPUE fit (%)											
CV of predation fit (%)	7										

[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 55 or 65 Kt.

Catch (Kt/yr)	Prob. biomass < B_{msy} (%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	55 Kt	65 Kt	55 Kt	65 Kt	55 Kt	65 Kt
60	26.4	27.3	3.3	3.9	23.8	25.5
70	27.8	29.4	3.4	3.7	27.3	29.0
75	28.9	30.3	3.5	3.8	28.8	30.9
80	29.7	30.9	3.3	3.6	31.0	32.9
85	30.5	31.8	3.7	4.1	33.2	35.0
90	31.0	32.4	3.3	4.2	35.3	37.5
95	32.1	33.8	3.5	4.0	37.8	40.3
100	33.0	34.2	3.4	4.0	40.0	42.0

* limit biomass is 30% of B_{msy}

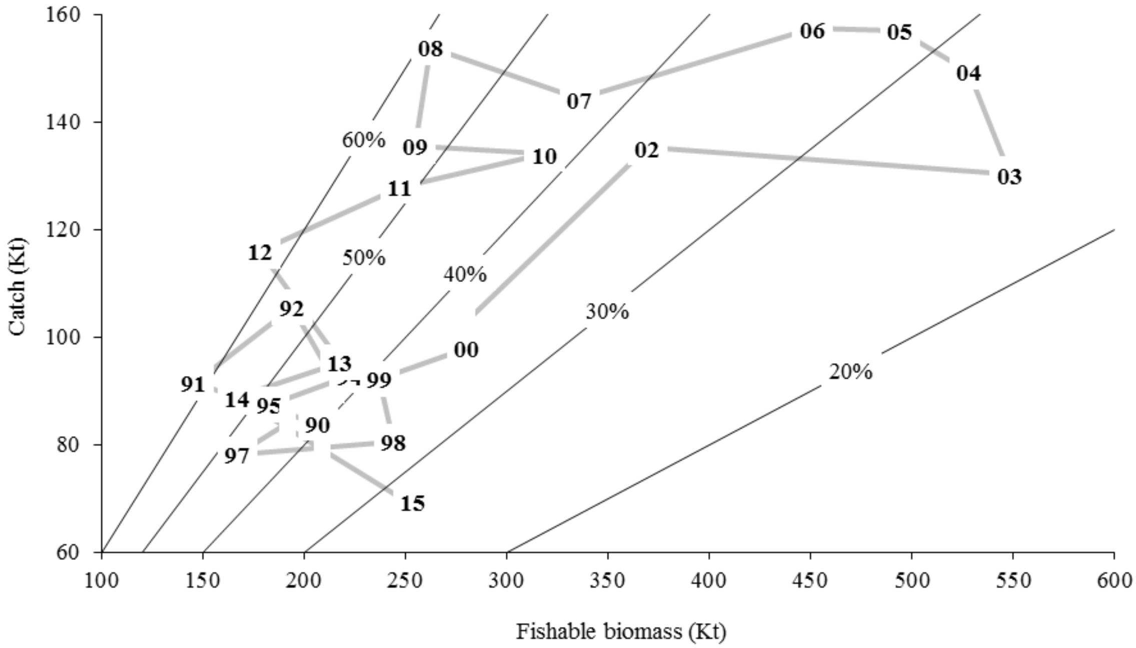

Fig. 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1988–2015 (2015 catch is provisional).

Fig. 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1994–2015.

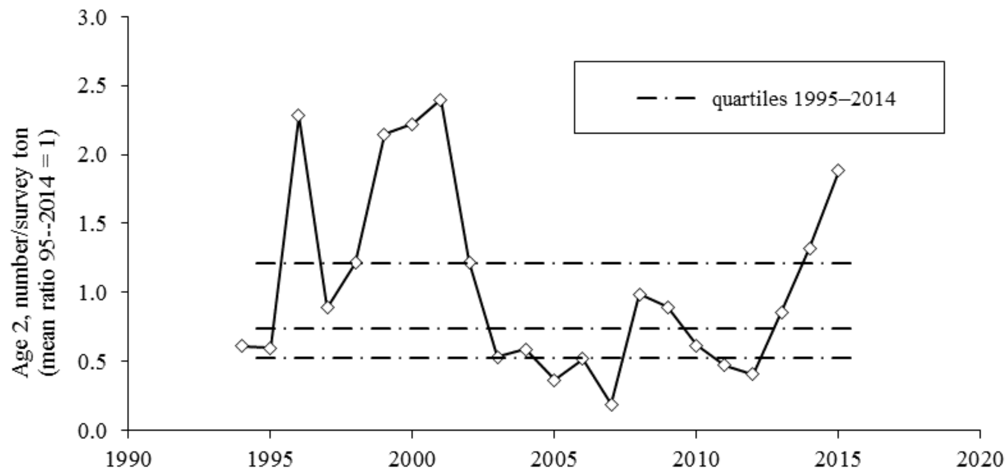

Fig. 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1994–2015.

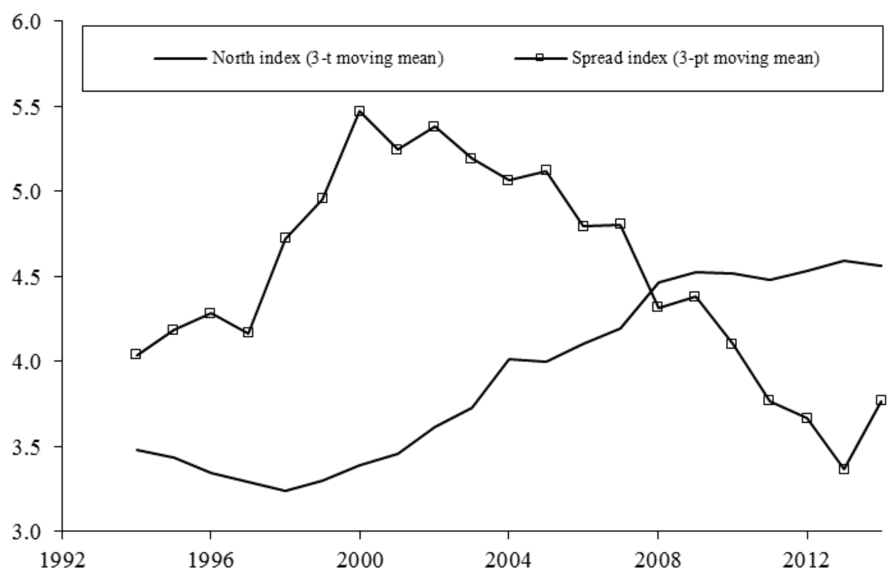

Fig. 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2015 (3-point moving means.)

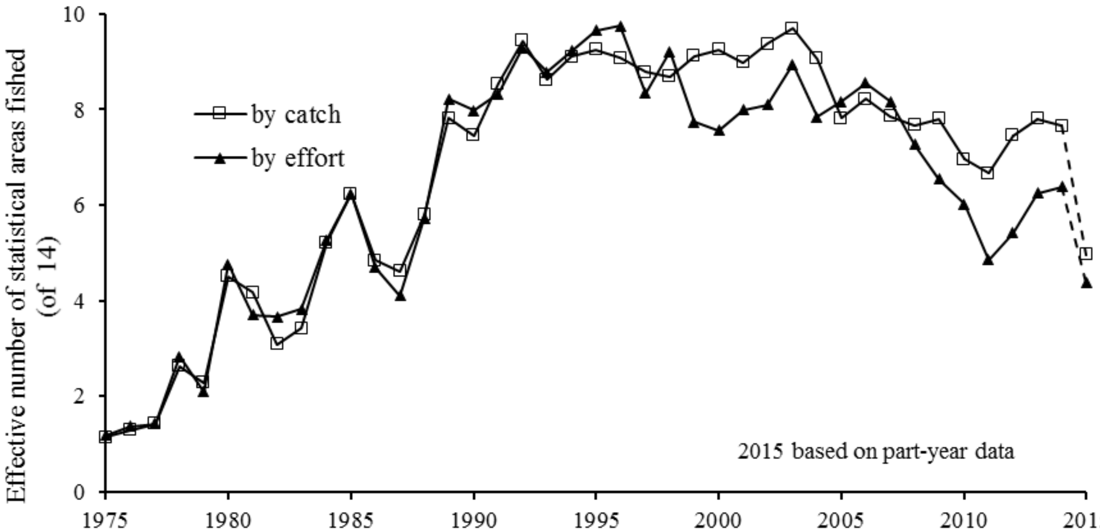

Fig. 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 14 statistical areas, from logbook records, 1975–2015.

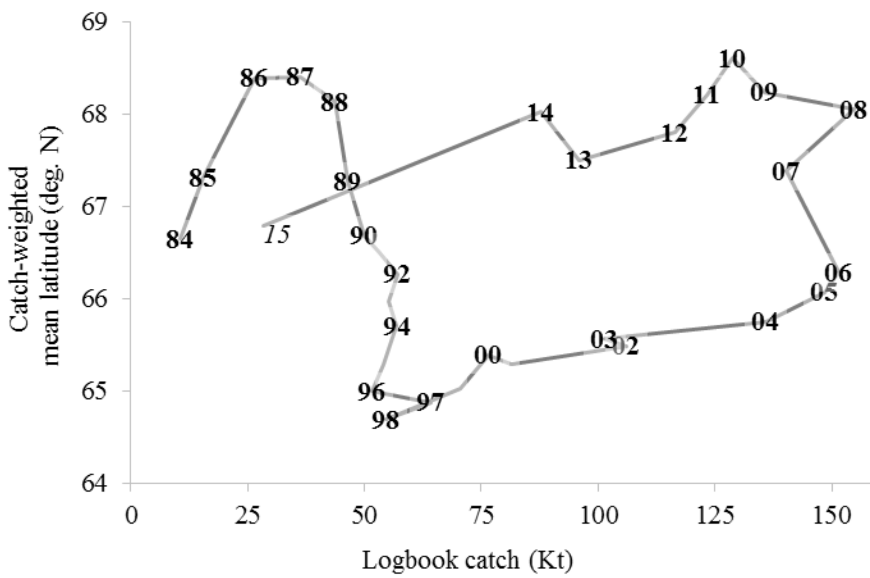

Fig. 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1984–2015.

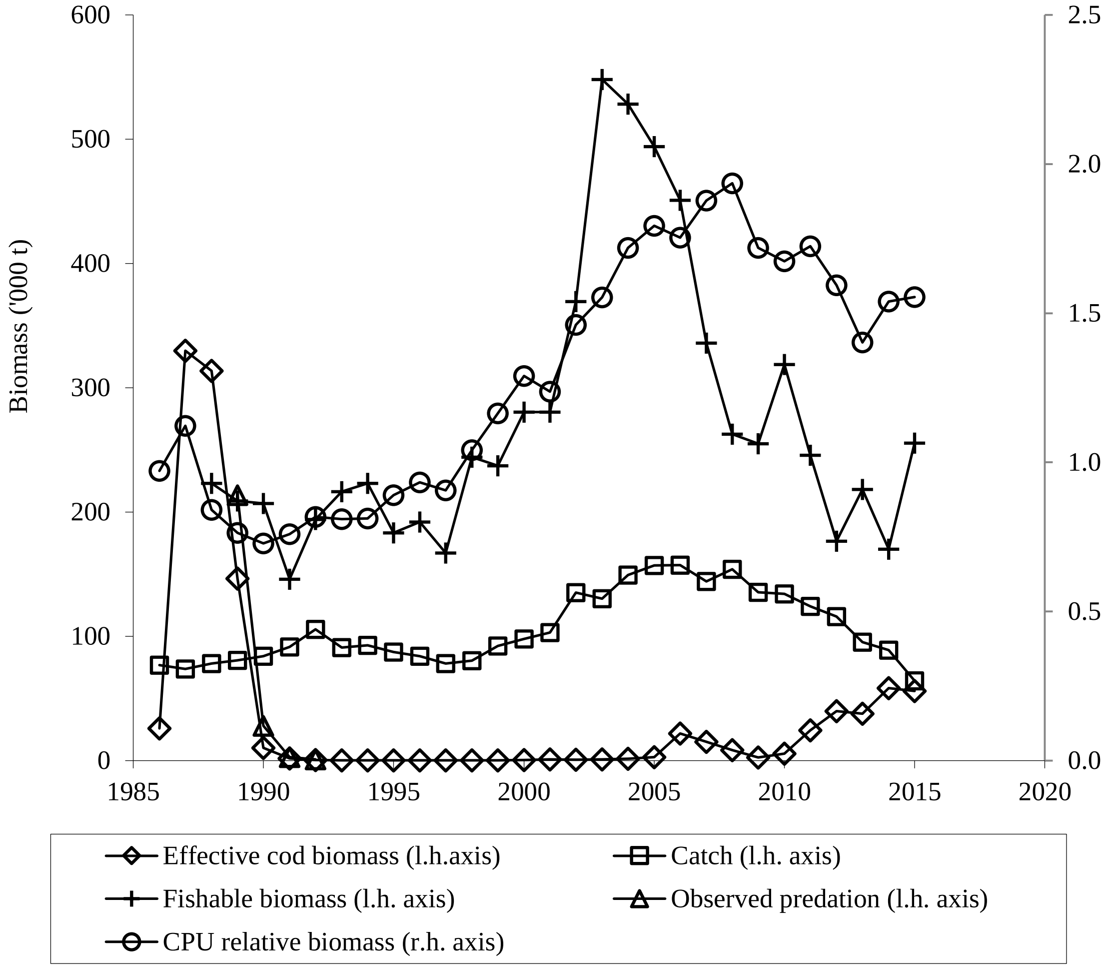

Fig. 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2015 catch is projected; effective cod biomass is synthesised from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

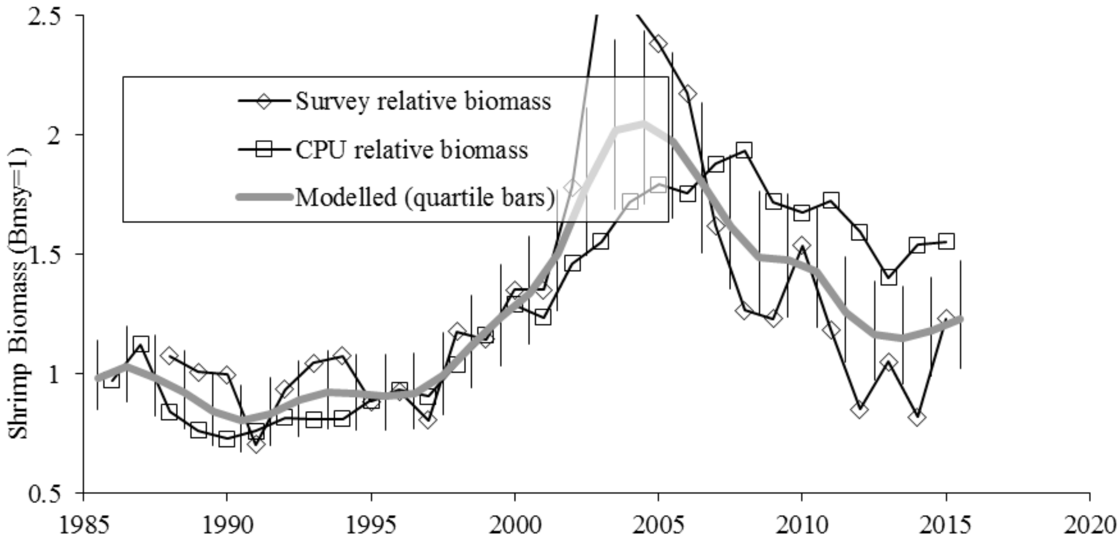

Fig. 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1986–2015.

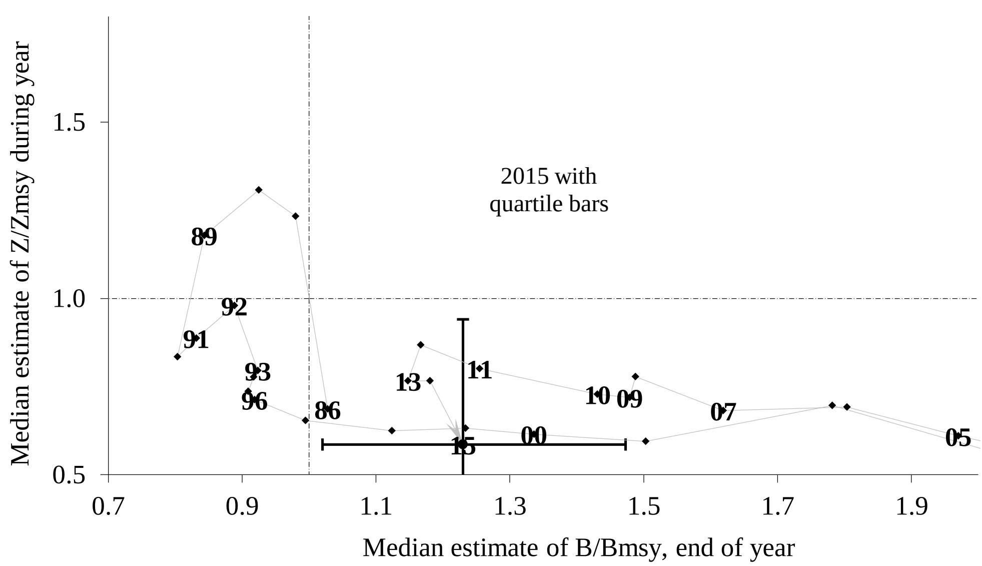

Fig. 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1986–2015.

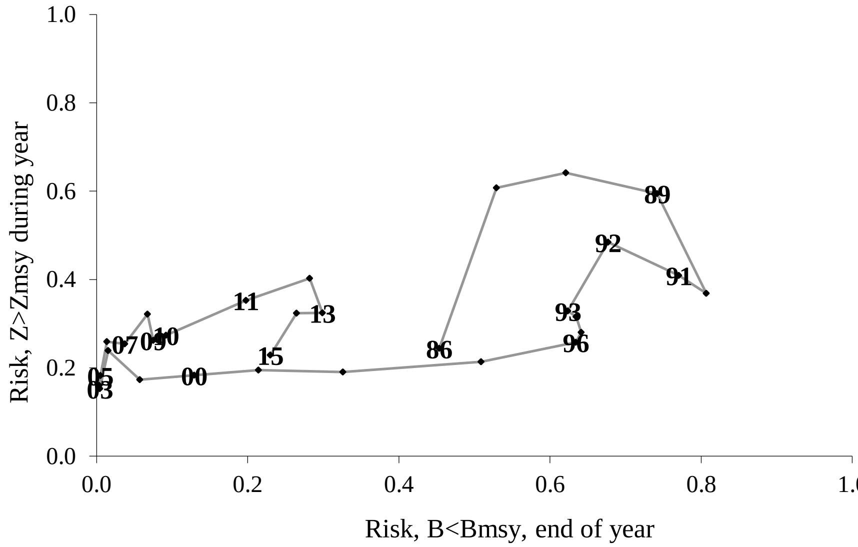

Fig. 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1985–2015.

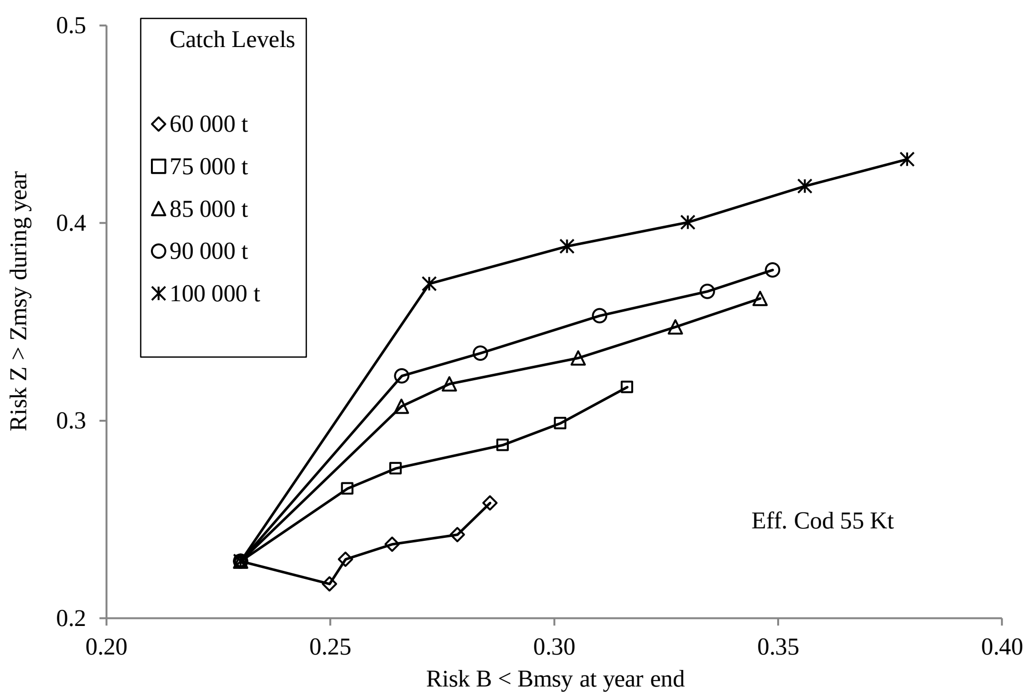

Fig. 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2016–20 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 60–100 Kt/yr; with effective cod biomass 55 Kt.

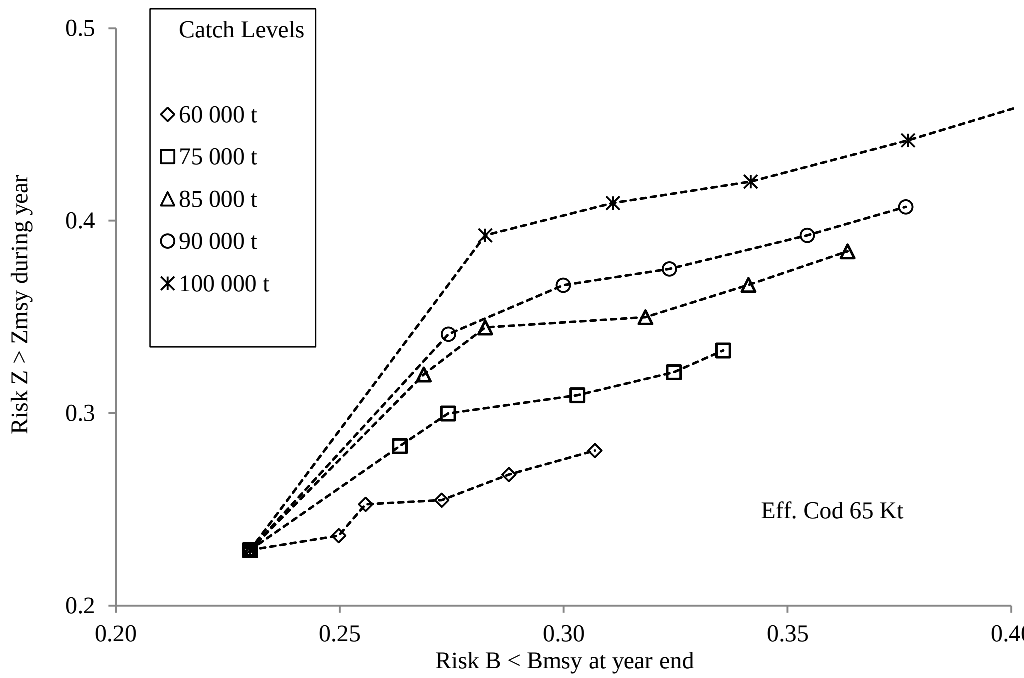

Fig. 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2016–20 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 60–100 Kt/yr; with effective cod biomass 65 Kt.

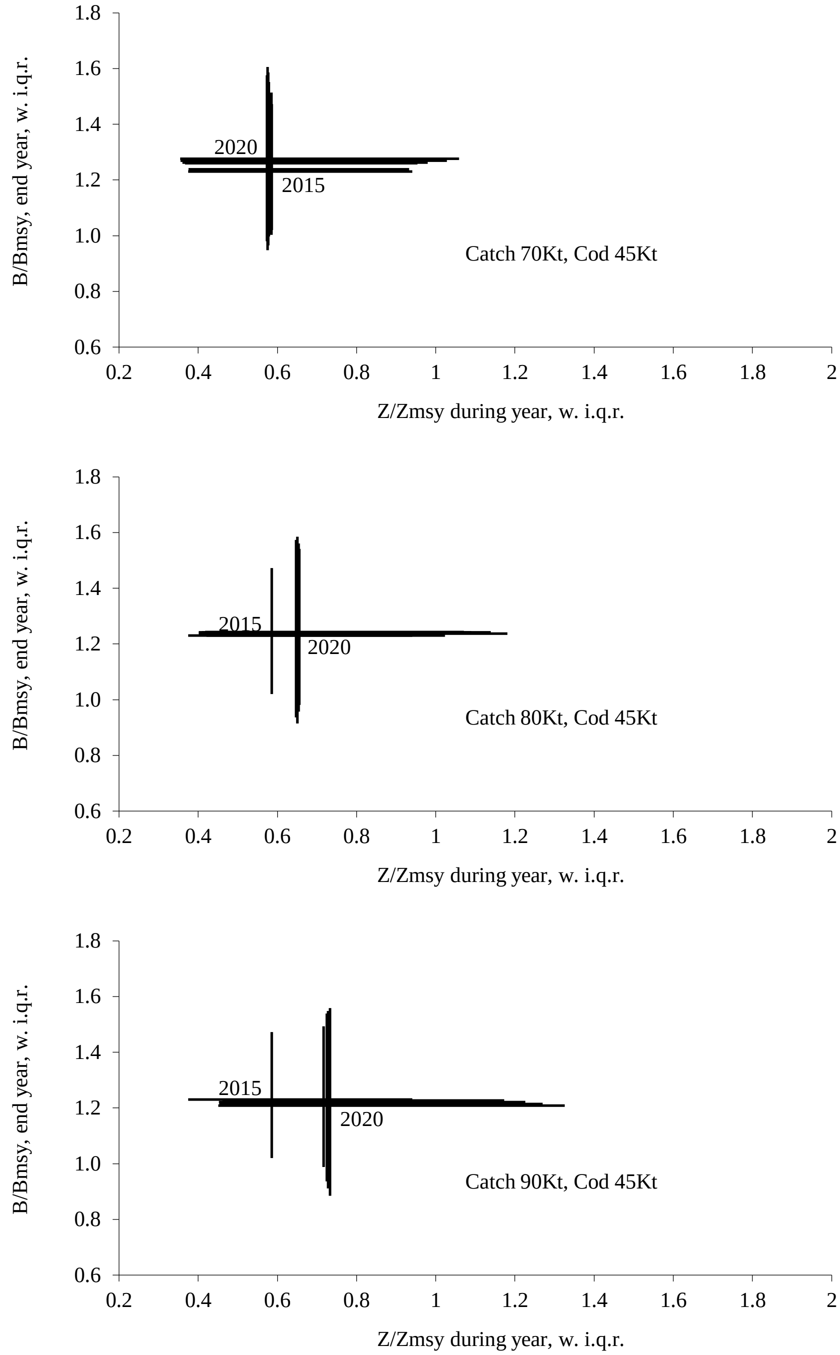

Fig. 11a. *Pandalus borealis* in West Greenland: projections of stock development for 2016–2020 with effective cod biomass assumed at 45 000 t: median estimates with quartile error bars.

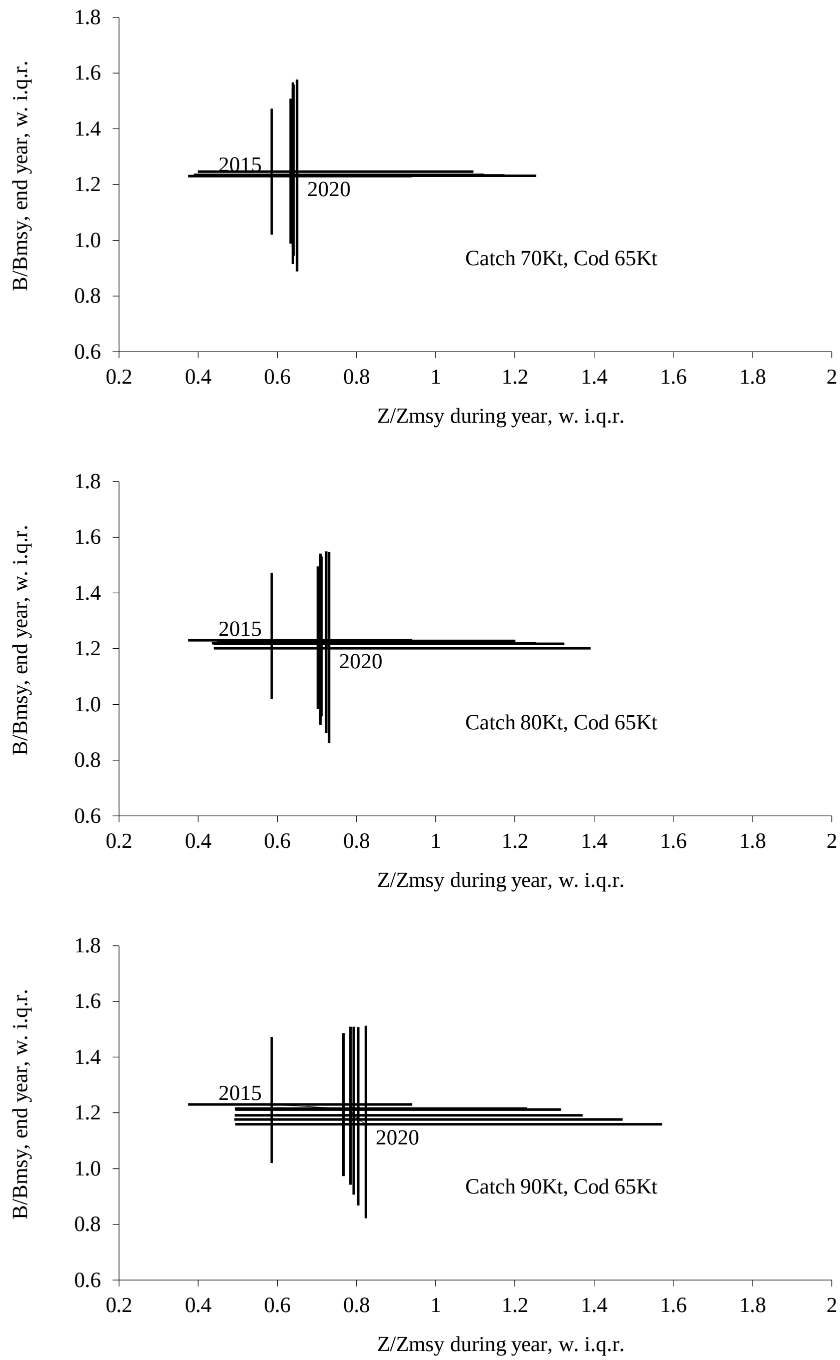

Fig. 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2016–2020 with effective cod biomass assumed at 50 000 t: median estimates with quartile error bars.