Northwest Atlantic Fisheries Organization

Serial No. N6870 **NAFO SCR Doc. 18/056**

NAFO/ICES *PANDALUS* ASSESSMENT GROUP—October 2018

A Provisional Assessment of the Shrimp Stock off West Greenland in 2018

by

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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 2018, survey total biomass is almost at its median compared with the most recent 20 years. In total, fishable biomass remained comparable to the 2017 value, offshore; the fishable biomass was 4% less, and 11% less inshore. In both regions, fishable biomass is a little lower than the median of the most recent 20 years. Areas north of the northern margin of Store Hellefiskebanke have more than three-quarters of the offshore biomass. As a result of this, the proportions of biomass in the offshore area and inshore are 75% and 25% respectively, almost at their 20-year mean in both regions.

Proportion fishable of the survey biomass in 2018 is above the median for the last 20 years, owing to low proportion of pre-recruits in the stock. Where proportion of females of survey biomass are close to a record 20-year value, fishable males are a little below the 20-year median.

The stock composition inshore has historically been characterized by a higher proportion of young shrimps than that offshore. For the age-2 and pre-recruit index, relative to survey biomass, the inshore quartile points have higher values than those of the offshore. Overall the number of age 2 shrimps, increased in 2018 and is at the 20-year median. Inshore, numbers of age 2 shrimps remained unchanged from 2017, below the 20-year lower quartile, but increased offshore both in numbers and in relation to survey biomass and is above the 20-year median. However, the proportion of large pre-recruits 14.5–16 mm carapace length decreased in both regions, little inshore but were bisected at offshore regions.

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 76°00'N (Div's 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 a 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 30 000 tons. The median estimate for 2018 was 33 900 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 (Burmeister and Rigèt 2018). 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; Burmeister and Rigét 2018).

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 to 2.1°C in 2018. 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 400 m, with a significant amount between 200 to 300 m (Burmeister and Rigét 2018). 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

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

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 was in 2015 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 again in 2017, but was still considerably lower than compared to values from 2012 – 2015. The 2017 increase was not maintained in 2018, were cod biomass were 35% less. The decrease were most noticeably south of 66°N in NAFO Div. 1C and 1E. Owing to this, and the fact that more shrimp biomass were situated in NAFO 1D, the overlap between the cod and the shrimp stock increased and was in 2018 record high (0.9) resulting the 'effective' cod stock close to the 'true' cod biomass. A further decline in the cod biomass at West Greenland is expected in 2019, while predicted value of the cod biomass, based on the Greenlandic survey, is estimated to 13.8 KT.

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, remained almost stable in 2018 and is just below its 20-year median and 87% of the temporary maximum of 2010. In 2018, the number and biomass of females are both respectively 12% and 8% lower than in 2017 values and both female biomass and numbers is above it 20-year median. Whereas male survey biomass remained comparable to 2017, the part of male fishable biomass increased by 8%. Both are at their 20-year median.

Survey Measures of Stock Size

	Biomass (Kt)					Number (bn)		
	Survey							
	Disko B. & Vaigat	Offshore	Total	Fishable	Female	Male	Female	Age 2
2018 value[1]	72.2	229.0	301.2	279.0	119.7	45.7	13.0	5.5
20-year[2] upper quartile	93.0	291.7	372.5	344.4	130.7	66.4	15.2	7.7
20-year median	81.1	235.2	304.5	271.5	106.6	50.5	12.0	5.1
20-year lower quartile	71.6	199.9	261.1	242.6	100.0	40.2	10.9	4.1
2018 rank	6.1	9.9	10.3	10.9	12.6	9.6	11.7	11.7
2017 value	80.9	239.1	319.9	284.6	136.7	48.2	14.2	3.1

[1] survey estimates of stock size for 2011, 2012, 2014, 2018 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. 1998–2017.

[3] value recalculated in 2014.

In the inshore area, comprising Disko Bay and Vaigat, the estimated survey biomass decreased by 11% from 2017 to a 2018 value below its 20-year median. The offshore biomass collectively, in 2014 close to its lowest for 20 years, followed by ups and downs from 2015 to 2017, remained almost stable in 2018 to value close to its 20-year median. Relative to stock size, last year' values indicated some sign of an incoming recruitment pulse, which could explain the increase of the fishable male biomass over 2017. Whereas pre-recruits, both in numbers and of total surveyed tons, dropped significantly by more than 40% in 2018, still close to their 13-year median, absolute number at age 2, almost double over 2018 and is also close to its 20-year median (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
2018 value	18.3	24.0	92.6	52.9	39.7	42.9
Upper quartile[1]	25.3	31.7	93.0	56.9	40.2	44.2
Median[1]	17.8	25.2	91.7	54.1	36.1	39.8
Lower quartile[1]	10.8	22.3	89.4	51.0	34.9	38.2
2018 rank[1]	11.1/20	5.8/13	13.4/20	8.2/20	15.1/20	14.8/20
2017 value	9.6	41.1	89.0	46.3	42.7	48.0

[1] quartiles and 2018 rank generally referred to 20 preceding years 1998–2017;
[2] quartiles and 2018 rank referred to 12 preceding years 2005–2017 (for which data is available);
[3] value recalculated in 2014

The overall stock composition in 2018 is marked, by a high proportion of males in the survey and in the fishable biomass, however a little lower than its 20-year median; females compose a considerable lower proportion of the fishable biomass in 2018 than in the previous years, but is still above its 20-year median. Relative to stock size the number of age-2 shrimps is almost at its 20-year median, and so is the relative number of large pre-recruits, so prospects for short-term recruitment are assumed fair.

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
2018 value	16.3	27.3	91.9	45.1	46.8	51.0
Upper quartile[1]	42.8	33.7	90.4	55.9	42.9	46.9
Median[1]	29.2	30.7	89.5	49.0	38.1	42.5
Lower quartile[1]	21.0	28.2	86.1	48.3	33.4	38.0
2018 rank[1]	4.8/20	3.2/12	20/20	1.8/13	13.1/13	12.5/13
2017 value	14.6	29.1	91.3	45.6	45.6	50.0

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
2018 value	18.9	22.9	92.8	55.4	37.5	40.4
Upper quartile[1]	20.0	30.4	94.2	55.7	44.2	48.0
Median[1]	12.6	21.4	93.1	53.1	40.5	42.4
Lower quartile[1]	7.6	19.7	91.2	47.3	36.6	38.7
2018 rank[1]	14.7/20	7.6 /13	9.7/20	9.4/13	5.2/13	5.2/13
2017 value	7.9	45.9	88.2	46.5	41.7	47.3

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 and pre-recruit index, relative to survey biomass, the inshore quartile points have higher values than those of the offshore. Consistently with previous years, except for 2015 and 2017, offshore regions have lower relative number of pre-recruits. 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.

Compared with values for the previous 20 years, inshore fishable biomass is above their 20-year upper quartile, but offshore close to the 20-year median. Where fishable-male and female proportions of the survey biomass are averaged a bit larger offshore than inshore, the average of female proportion of fishable biomass is identical in both regions.

As a total stock, males compose a high proportion of the biomass, both survey and fishable. Offshore in 2018, males constitute a high proportion of the surveyed biomass with a value at its 20-year upper quartile and males of fishable biomass is above its 20-year median. The opposite is true in Disko Bay & Vaigat, where the proportion of males both of surveyed biomass as well as of fishable biomass since 2016 have been below the 20-year lower quartile. Female proportions of fishable biomass in Disko Bay is above the 20-year upper quartile and close to a record value, but in offshore regions below the 20-year median. Like in most recent years, the stock in 2018, seems to be 'all females" inshore and "males" in offshore regions.

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 2005–18—a period characterized by a decline in the stock. There are average numbers of pre-recruits offshore which are assumed to enter the fishery within the next two year; high number of fishable males to recruit to the spawning stock; and, concomitantly, lower proportions of spawning females in the fishable biomass, so the stock is assumed to be in a "save condition. The perception of the stock inshore is somewhat reverse. Inshore is having low numbers of pre-recruits, low number of fishable males to recruit to the spawning stock; exceptionally high proportions of females in the fishable biomass and the fishable stock is a high proportion of the total, so if the fishable stock gets fished, there won't be much left. However, overall the stock is assumed to be in a fair condition.

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
2018 value	29.9	30.8	19.1	20.2	0.0	3.8	24.7
20-year[1] upper quartile	34.6	35.2	24.9	23.4	7.6	3.9	29.4
20-year median	27.5	32.3	19.1	16.7	1.0	3.3	25.4
20-year lower quartile	15.9	29.4	16.7	8.7	0.4	3.2	21.0
2018 rank	11.0/20	8/20	10.3/20	11/20	3.0/20	14.3/20	9.7/20
2017 value	30.1	31.3	25.9	12.7	0.0	3.7	25.8

[1] percentiles and 2018 rank are referred to the 20 preceding years, i.e. 1998–2017.

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 2018, 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 decline over 2017 but is at the 20-year median. The proportion of biomass in W5-W7 increased over the past two years, and is now above the median. Shrimp is almost absent in regions W8-W9.

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 CPUE relative biomass series based on re-coded shrimp model (Rigèt et al 2018) with time variant catchability and with the years 2003 to 2006 removed, in general, follow the survey estimate of fishable biomass. From the beginning of 1990s both indices increased until 2002. From 2007 the indices decreased to 2013-2014 followed by an increased until 2017. In 2018, both indices slightly decreased (CPUE for 2018 is only preliminary half year data). During the last 20 years the survey biomass index has fluctuated more than observed in the CPUE index.

The distribution of the fishery, like that of the survey biomass, has varied over time (Fig. 5). In the 1990s over half the catches were taken south of Holsteinsborg Dyb, 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 (Burmeister and Rigét 2018).

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 and in 2017, 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 126.1 Kt with quartiles at 110 and 148 Kt; an estimated mode is at 111 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 2018 is estimated to be close to the 2017 value and 14% above B_{msy}. With a moderate effective cod biomass, even with catches projected at 101

250 t, total mortality in 2018 is estimated to be below the MSY level and the mortality risk at 36% exceeds a management threshold of 35%.

Table: *P. borealis* in West Greenland: model estimates of stock status at end of, or during, 2018.

Biomass ratio *B/Bmsy* (median estimate, %)	114.2
Prob. *B<Bmsy* (%)	30.4
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	88.4
Prob. *Z>Zmsy* (%)	36.2

Risks associated with eight possible catch levels for 2019, with an 'effective' cod stock at 25 000 t, 30 000 t and 35 000 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 2019 (%)	32.2	32.3	33.1	32.9	33.9	35.1	34.7	36.4
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2019 (%)	26.4	30.6	35.1	40.0	44.7	49.3	53.1	56.8
exceeding Zmsy in 2020 (%)	26.8	31.9	36.4	41.1	46.3	50.4	55.0	58.6

30 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2019 (%)	31.6	32.1	33.1	33.7	34.4	35.5	35.3	36.8
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2019 (%)	28.4	33.1	37.6	42.5	47.2	51.4	55.0	58.7
exceeding Zmsy in 2020 (%)	29.2	34.4	38.5	44.0	48.8	53.0	56.9	60.6

35 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2019 (%)	31.5	33.3	34.5	33.8	34.3	35.7	34.7	36.1
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2019 (%)	30.8	35.5	40.4	44.9	49.5	53.2	56.9	60.5
exceeding Zmsy in 2020 (%)	31.6	36.7	42.2	46.4	50.3	54.7	58.0	62.0

If a mortality risk (i.e. that estimable mortality will exceed Z_{msy}) criterion of 35% is observed, catches of 100–105 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 mid 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 43-year data series. Eight levels of annual catch were investigated from 100 000 to 135 000 tons (Figs 10–11), (Table 4 and Table 5).

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 Table 5) and are low.

Conclusions

The stock is predicted to remain above its *MSY* level at end 2018. 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 100 - 105 Kt would keep the risk of exceeding Z_{msy} below 35%, assuming certain limits on the evolution of the biomass of Atlantic cod.

Acknowledgements

Thanks are due to Anja Retzel for updating the information on the behaviour of the cod stock in southern West Greenland, and Dr Carsten Hvingel developed the improvements of the initial version of the surplus-production model and wrote the WinBUGS coding for it.

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Table 1. *Pandalus borealis* in West Greenland: input data series 1976–2018 for stock-dynamic assessment model.

Year	VPA.obs[]	ICES.obs[]	Grld.Skj.obs[]	Grld.Cos.obs[]	Overlap[]	Past.Catch[]	Prov.Catch[]	ln.CPUE[]	surv[]	Grunwald[]	Grunwald.cod[]
1976	228.8	NA	NA	NA	0.579	51.6	NA	0.3776	NA	NA	NA
1977	251.7	NA	NA	NA	0.574	42.3	NA	0.3127	NA	NA	NA
1978	253.5	NA	NA	NA	0.672	42.8	NA	0.07889	NA	NA	NA
1979	217.3	NA	NA	NA	0.67	55.9	NA	-0.01998	NA	NA	NA
1980	240.4	NA	NA	NA	0.68	53.8	NA	0.1673	NA	NA	NA
1981	178.3	NA	NA	NA	0.619	54.3	NA	0.1098	NA	NA	NA
1982	190.9	72.7	NA	NA	0.518	56.2	NA	0.3394	NA	NA	NA
1983	134	46.6	NA	NA	0.461	52.8	NA	0.2304	NA	NA	NA
1984	79	14.2	NA	NA	0.479	52.8057	NA	0.17	NA	NA	NA
1985	51.7	19	NA	NA	0.482	66.2079	NA	0.2367	NA	NA	NA
1986	38.4	38.9	NA	NA	0.51	76.9	NA	0.2729	NA	NA	NA
1987	466.7	316.5	NA	NA	0.604	77.391	NA	0.402	NA	NA	NA
1988	481.2	323.4	NA	NA	0.618	73.616	NA	0.1372	223	NA	NA
1989	403.2	202.3	NA	NA	0.37	80.671	NA	0.03041	209	213.7	470.919
1990	NA	21.1	NA	NA	0.289	83.97	NA	0	207	27.8	184.1405
1991	NA	3.4	NA	NA	0.313	91.489	NA	0.02306	146	2.7	19.7905
1992	NA	0.363	0.251	NA	0.523	105.487	NA	0.09891	194	0.8	2.8785
1993	NA	0.212	0.2	NA	0.6455	91.013	NA	0.08629	216	NA	NA
1994	NA	0.07	0.051	NA	0.599	92.805	NA	0.08523	223	NA	NA
1995	NA	0.03	0.155	NA	0.483	87.388	NA	0.1801	183	NA	NA
1996	NA	0.2	0.113	NA	0.28	84.095	NA	0.2254	192	NA	NA
1997	NA	0.138	0.055	NA	0.49	78.128	NA	0.1977	167	NA	NA
1998	NA	0.07	0.101	NA	0.39	80.495	NA	0.345	244	NA	NA
1999	NA	0.143	0.053	NA	0.496	92.198	NA	0.4559	237	NA	NA
2000	NA	0.319	0.357	NA	0.643	97.968	NA	0.5554	280	NA	NA
2001	NA	1.302	0.603	NA	0.462	102.926	NA	0.5101	280	NA	NA
2002	NA	1.224	1.863	NA	0.278	135.172	NA	0.6923	369	NA	NA
2003	NA	1.288	1.332	NA	0.398	130.173	NA	0.7616	548	NA	NA
2004	NA	3.429	2.394	NA	0.257	149.332	141	0.8644	528	NA	NA
2005	NA	13.596	NA	63.952	0.074	156.899	140.5	0.9041	494	NA	NA
2006	NA	81.063	NA	24.514	0.22	157.315	140.2	0.8866	451	NA	NA
2007	NA	86.59	NA	28.488	0.139	144.19	135.2	0.94	336	NA	NA
2008	NA	31.812	NA	28.481	0.156	153.889	131.6	0.973	263	NA	NA
2009	NA	2.006	NA	3.604	0.602	135.458	108.8	0.8626	255	NA	NA
2010	NA	10.302	NA	8.133	0.315	133.99	138.5	0.8349	319	NA	NA
2011	NA	14.3334	NA	18.73	0.888	123.985	126	0.8723	246	NA	NA
2012	NA	100.802	NA	37.098	0.305	115.975	110	0.7879	176	NA	NA
2013	NA	114.345	NA	85.812	0.206	95.381	100	0.6554	218	NA	NA
2014	NA	186.006	NA	112.174	0.211	88.765	90	0.7124	170	NA	NA
2015	NA	146.447	NA	148.606	0.2046	72.256	65	0.7536	256	NA	NA
2016	NA	26.216	NA	17.872	0.079	85.527	82	0.794	201	NA	NA
2017	NA	NA	NA	29.48	0.373	90	90	0.9687	285	NA	NA
2018	NA	NA	NA	19.228	0.8908	NA	101.25	0.9119	279	NA	NA

[1] ‘effective cod biomass’ was not an input data series in 2018; 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 2014–18 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, 2018.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2017)
Max.sustainable yield	134.2	46.3	109.6	126.1	147.3	109.9	124.5
B/Bmsy, end current year (proj.)(%)	117.5	30.5	95.7	114.2	136.0	107.6	113.7
Biomass risk, end current year(%)	30.4	46.0	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	67.4	88.4	111.7	–	82.4
Carrying capacity	2734	1630	1607	2237	3311	1243	2186
Max. sustainable yield ratio (%)	12.2	5.4	8.1	11.7	15.8	10.9	11.7
Survey catchability (%)	23.9	13.0	13.8	21.7	32.0	17.3	22.3
CPUE(1) catchability	1.4	0.7	0.8	1.2	1.8	1.0	1.3
CPUE(2) catchability	2.2	1.2	1.3	2.0	2.9	1.6	2.1
Effective cod biomass 2018 (Kt)	41.6	43.7	24.5	33.9	47.2	18.5	21.6
$P_{50\%}$	4.4	6.3	0.4	1.9	5.7	-2.9	1.8
V_{max}	2.3	2.4	0.5	1.3	3.3	-0.7	1.2
CV of process (%)	13.4	3.0	11.3	13.2	15.2	12.7	13.3
CV of survey fit (%)	16.3	3.1	14.1	15.9	18.0	15.1	16.5
CV of CPUE (1) fit (%)	6.8	1.4	5.7	6.5	7.5	5.9	6.6
CV of CPUE (2) fit (%)	0.1	0.0	0.1	0.1	0.1	0.1	0.1

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2018.

	Start biom. ratio	*CV cpu*	*CV s*	*CV proc*	*Vmax*	*P50%*	*Qc1*	*Qc2*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield	14			12			-28	-29	-29	12	38
Carrying capacity	11		-6	12	-11		-74	-74	-74	-72	
Max. sustainable yield ratio (%)	-9		5	-6	13		80	80	80		
Survey catchability (%)	-43		6	-16	16		100	99			
CPUE catchability q1	-44		5	-14	16		100				
CPUE catchability q2											
P50%	15				76						
Vmax	-13			-12							
CV of process (%)	14		-32								
CV of survey fit (%)											
CV of CPUE 1 fit (%)											
CV of CPUE 2 fit (%)											

[1] those over 5%

Table 4. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2019 assuming effective cod biomass 25 Kt - 35 Kt.

Catch (Kt/yr)	Prob. biomass < B_{MSY} (%)		Prob. biomass<B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	35 Kt	25 Kt	35 Kt	25 Kt	35 Kt	25 Kt
100	31.5	32.2	0.0	0.0	30.8	26.4
105	33.3	32.3	0.0	0.0	35.5	30.6
110	34.5	33.1	0.0	0.0	40.4	35.1
115	33.8	32.9	0.0	0.0	44.9	40.0
120	34.3	33.9	0.0	0.0	49.5	44.7
125	35.7	35.1	0.0	0.0	53.2	49.3
130	34.7	34.7	0.0	0.0	56.9	53.1
135	36.1	36.4	0.0	0.0	60.5	56.8

Table 5. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2019 – 2021 and of falling below B_{msy} or limit* biomass at the end of 2019 – 2021 assuming effective cod biomass 25 Kt - 35 Kt.

25 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2019 (%)	32.2	32.3	33.1	32.9	33.9	35.1	34.7	36.4
falling below Bmsy end 2020 (%)	32.7	34.3	35.2	35.4	37.3	38.1	39.4	41.3
falling below Bmsy end 2021 (%)	33.6	34.5	36.5	37.3	39.2	41.0	42.4	45.0
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
falling below Blim end 2020 (%)	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1
falling below Blim end 2021 (%)	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.6
exceeding Zmsy in 2019 (%)	26.4	30.6	35.1	40.0	44.7	49.3	53.1	56.8
exceeding Zmsy in 2020 (%)	26.8	31.9	36.4	41.1	46.3	50.4	55.0	58.6
exceeding Zmsy in 2021 (%)	28.2	32.9	38.0	42.0	47.3	51.5	56.4	60.5

* limit biomass is 30% of B_{msy}

30 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2019 (%)	31.6	32.1	33.1	33.7	34.4	35.5	35.3	36.8
falling below Bmsy end 2020 (%)	33.1	34.1	35.8	37.3	37.5	38.9	40.5	42.6
falling below Bmsy end 2021 (%)	34.3	35.7	36.9	39.3	40.4	42.2	44.6	46.1
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
falling below Blim end 2020 (%)	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
falling below Blim end 2021 (%)	0.1	0.1	0.0	0.1	0.2	0.3	0.2	0.4
exceeding Zmsy in 2019 (%)	28.4	33.1	37.6	42.5	47.2	51.4	55.0	58.7
exceeding Zmsy in 2020 (%)	29.2	34.4	38.5	44.0	48.8	53.0	56.9	60.6
exceeding Zmsy in 2021 (%)	30.1	35.0	40.1	45.4	49.8	54.4	58.3	62.4

* limit biomass is 30% of B_{msy}

35 000 t cod	Catch option ('000 tons)							
Risk of:	100	105	110	115	120	125	130	135
falling below Bmsy end 2019 (%)	31.5	33.3	34.5	33.8	34.3	35.7	34.7	36.1
falling below Bmsy end 2020 (%)	33.4	35.4	36.5	37.1	37.6	39.6	39.3	41.4
falling below Bmsy end 2021 (%)	34.0	36.2	38.2	39.6	41.0	42.7	43.6	45.3
falling below Blim end 2019 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
falling below Blim end 2020 (%)	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1
falling below Blim end 2021 (%)	0.0	0.1	0.2	0.2	0.2	0.4	0.3	0.5
exceeding Zmsy in 2019 (%)	30.8	35.5	40.4	44.9	49.5	53.2	56.9	60.5
exceeding Zmsy in 2020 (%)	31.6	36.7	42.2	46.4	50.3	54.7	58.0	62.0
exceeding Zmsy in 2021 (%)	32.8	37.5	43.1	47.2	51.1	55.9	59.0	63.1

* limit biomass is 30% of B_{msy}

Figures

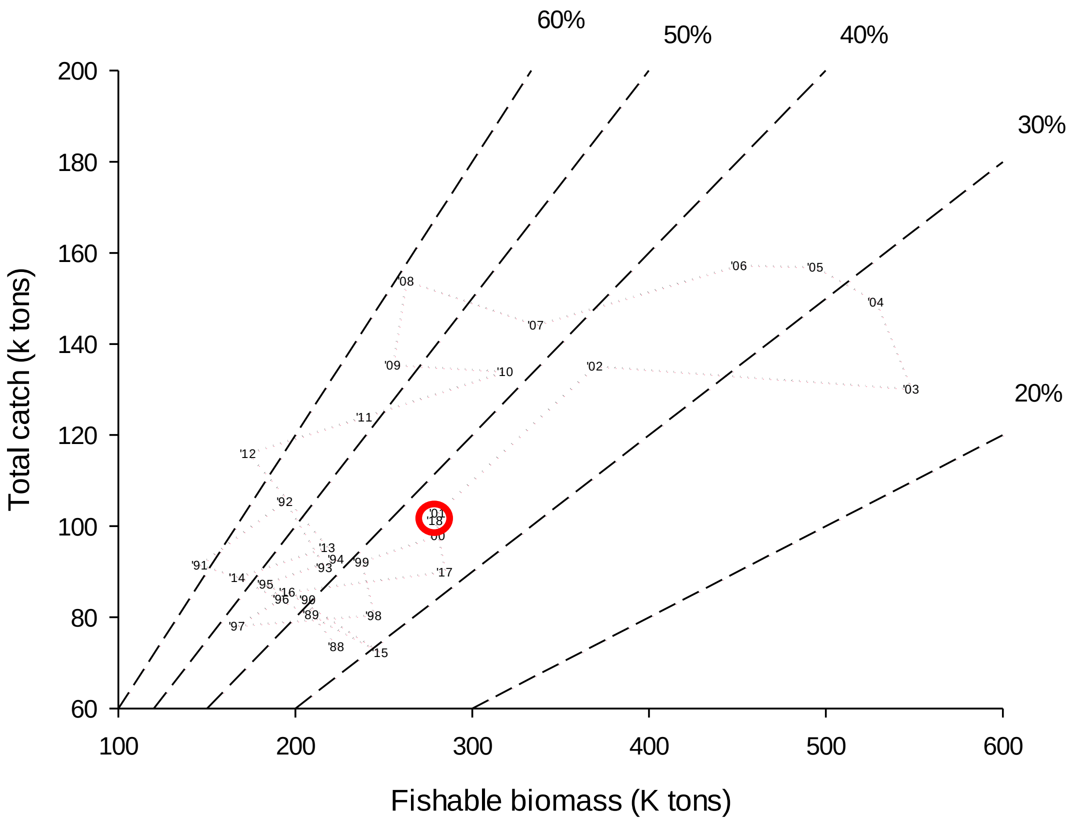

Fig. 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1976–2018 (2018 catch is provisional).

Fig. 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1996–2018.

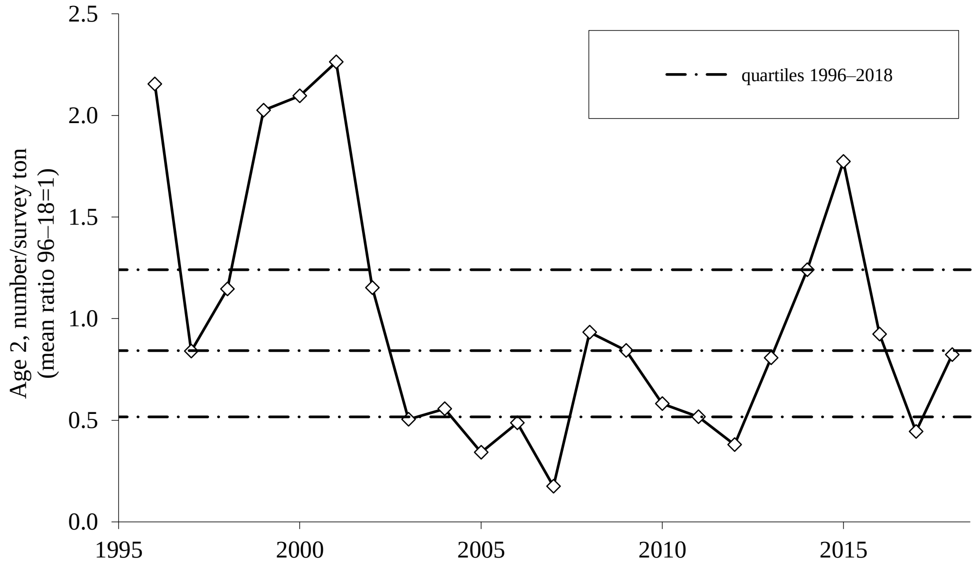

Fig. 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1996–2018.

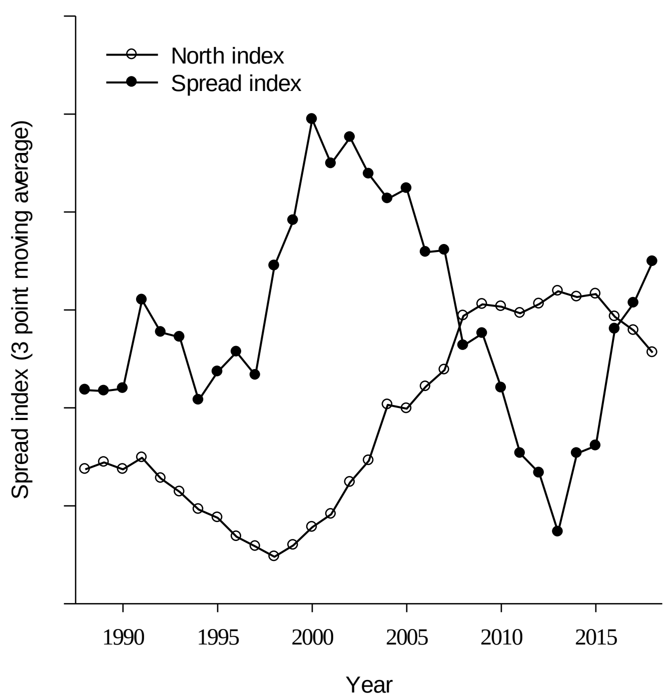

Fig. 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2018 (3-point moving means.)

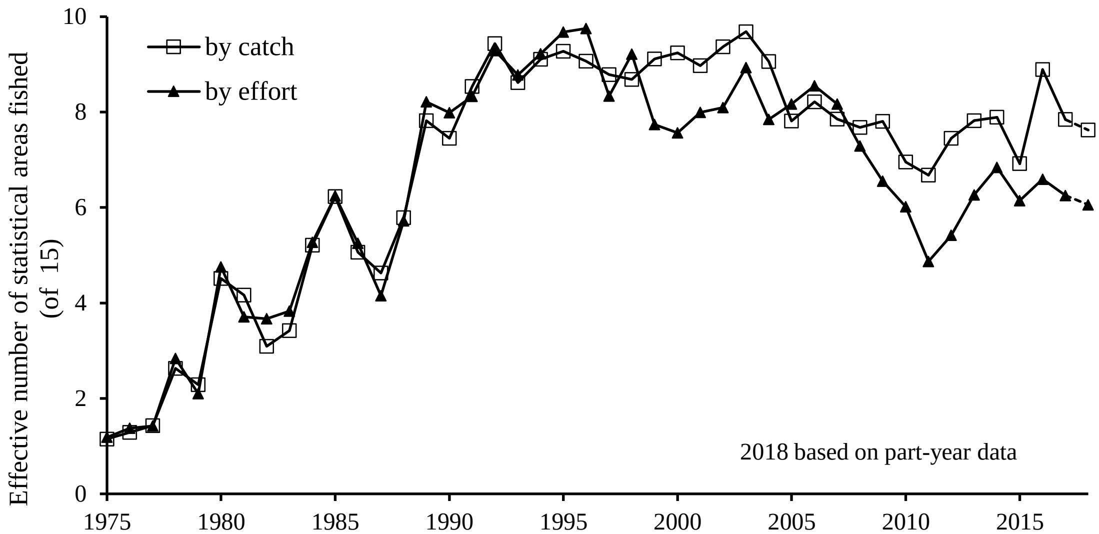

Fig. 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2018.

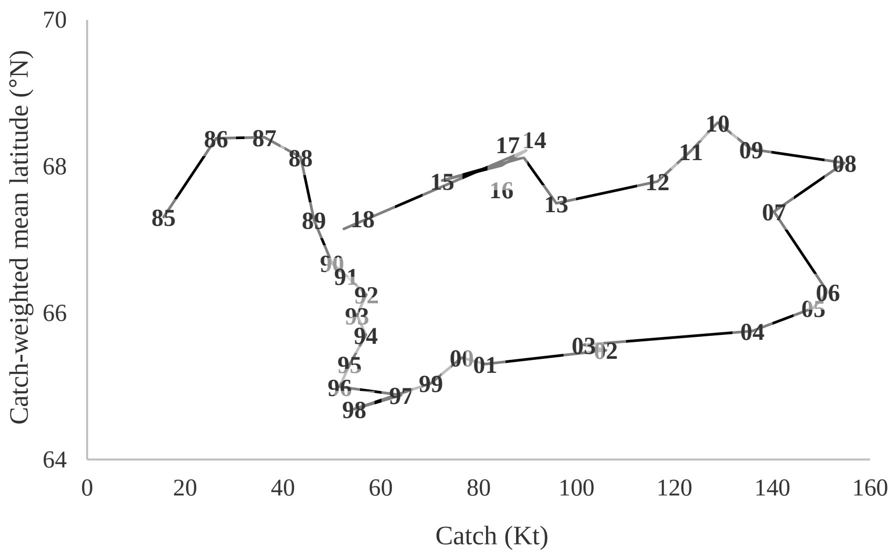

Fig. 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1984–2018 (2018 is only preliminary catch).

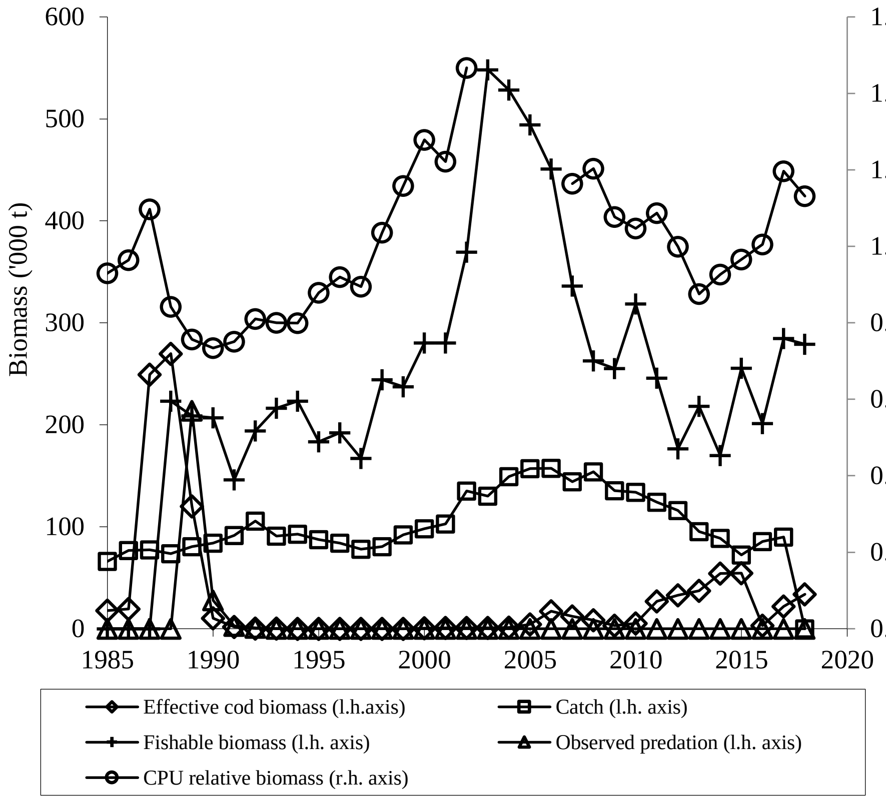

Fig. 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2018 catch is projected; effective cod biomass is synthesised from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

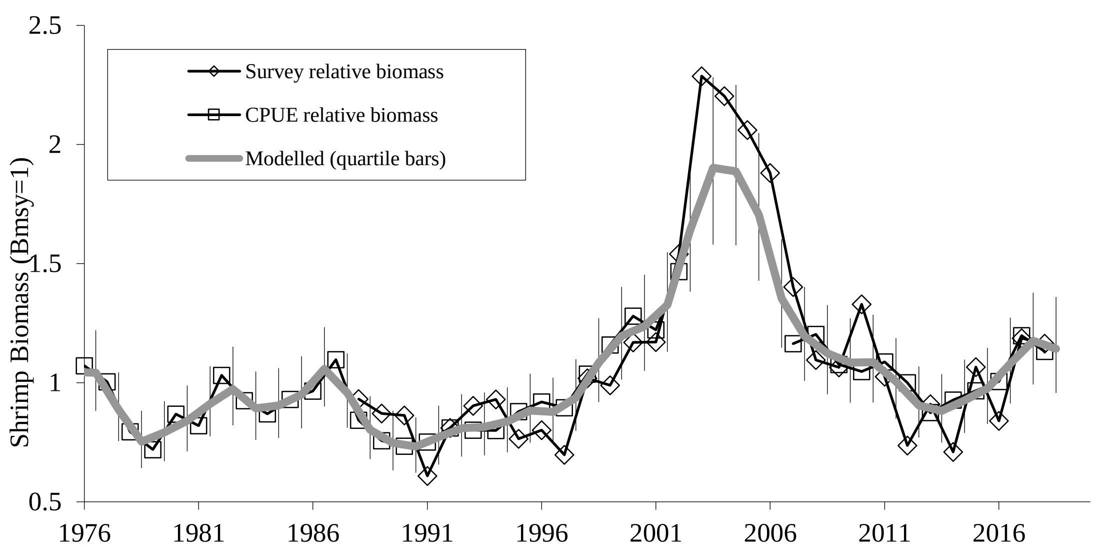

Fig. 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1988–2018.

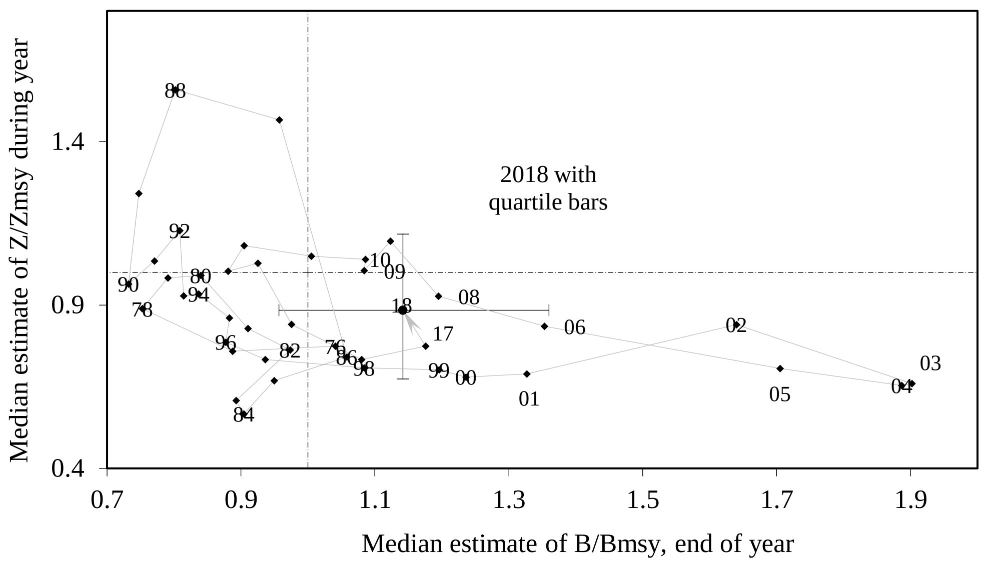

Fig. 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1988–2018.

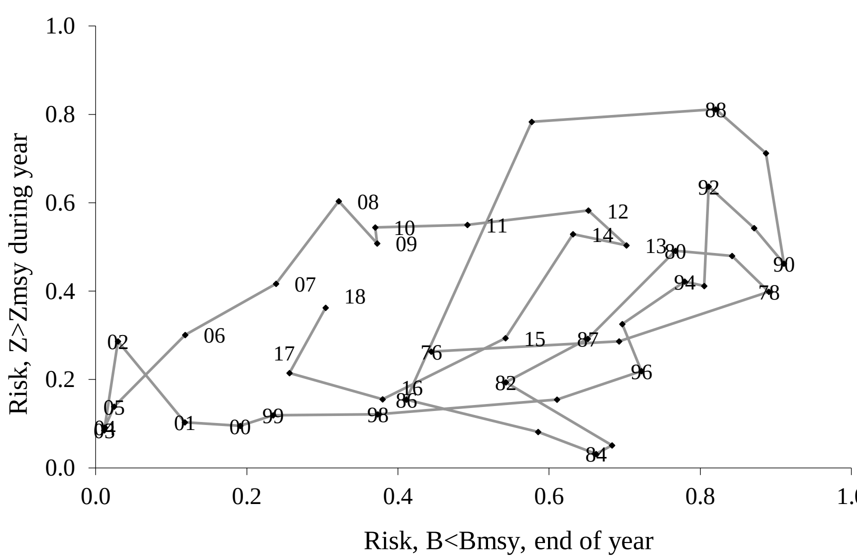

Fig. 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1988–2018.

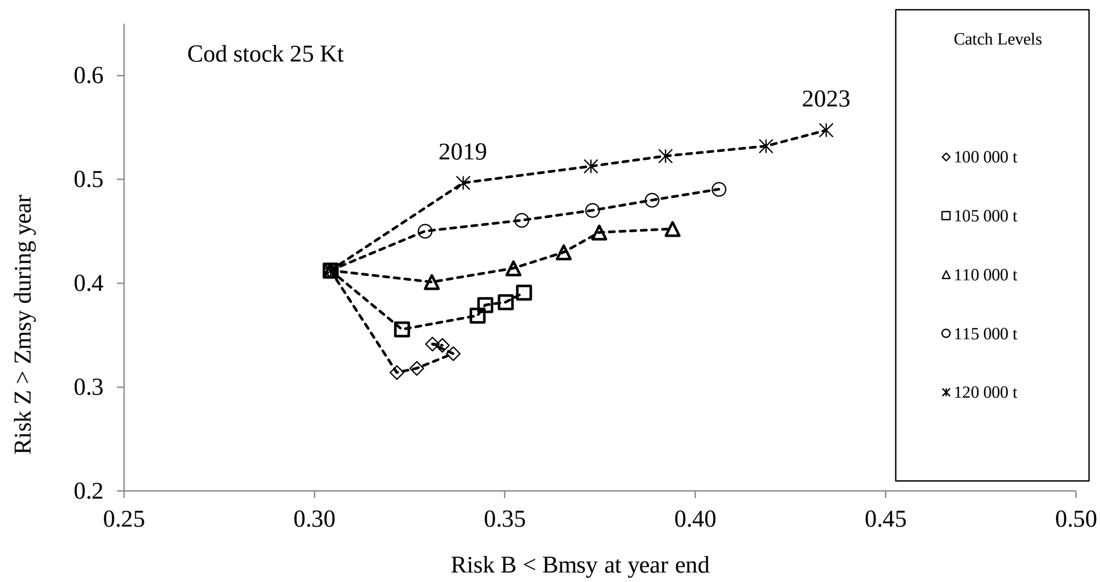

Fig. 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2019–23 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–130 Kt/yr; with effective cod biomass 25 Kt.

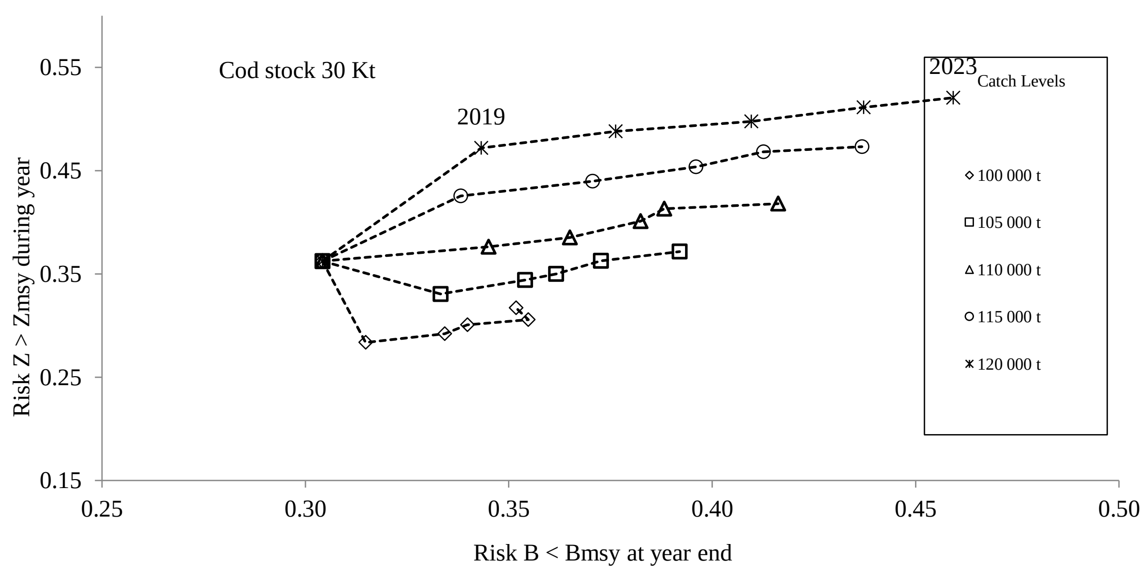

Fig. 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2019–23 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–130 Kt/yr; with effective cod biomass 30 Kt.

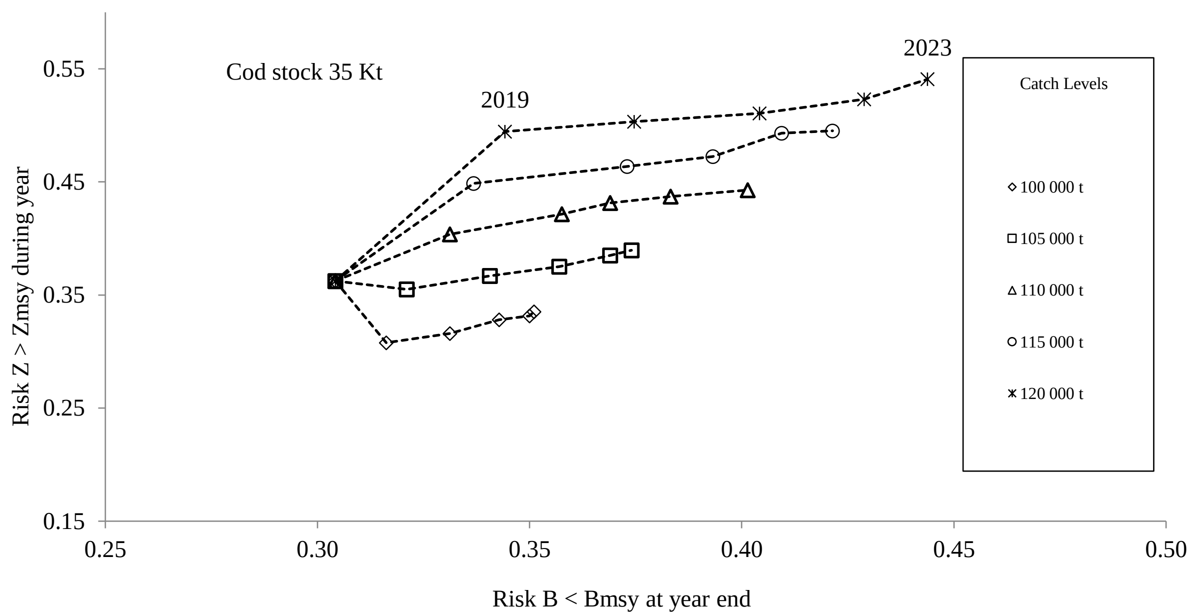

Fig. 10c. *Pandalus borealis* in West Greenland: joint 5-year plot 2019–23 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–130 Kt/yr; with effective cod biomass 35 Kt.

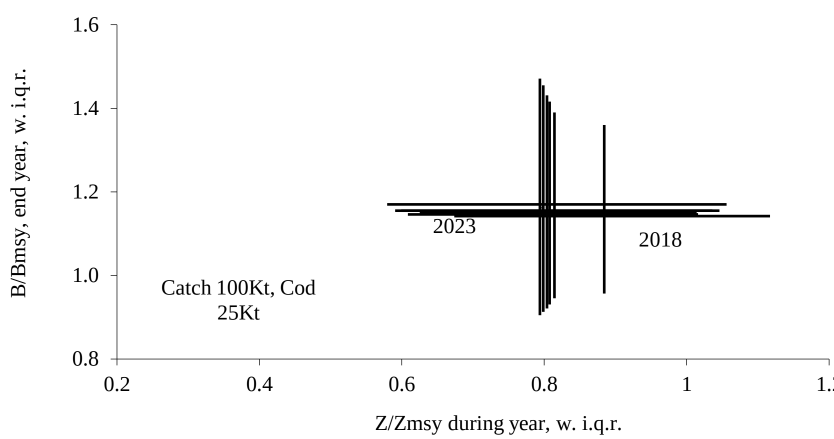

Fig. 11a. *Pandalus borealis* in West Greenland: projections of stock development for 2018–2023 with effective cod biomass assumed at 25 000 t: median estimates with quartile error bars.

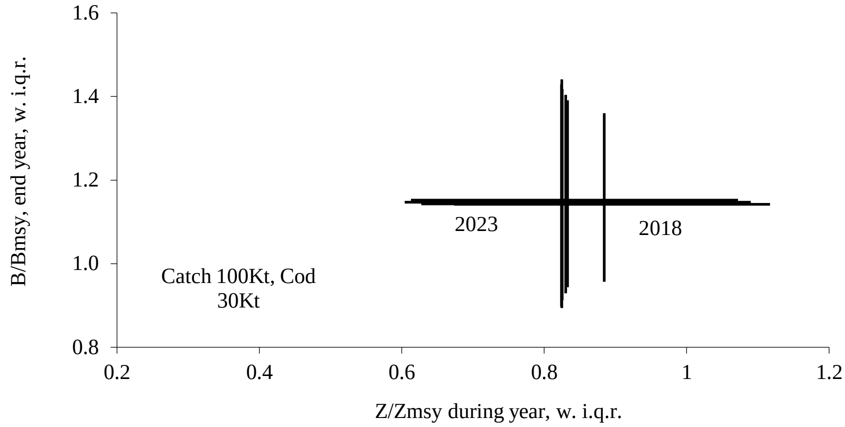

Fig. 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2018–2023 with effective cod biomass assumed at 30 000 t: median estimates with quartile error bars.

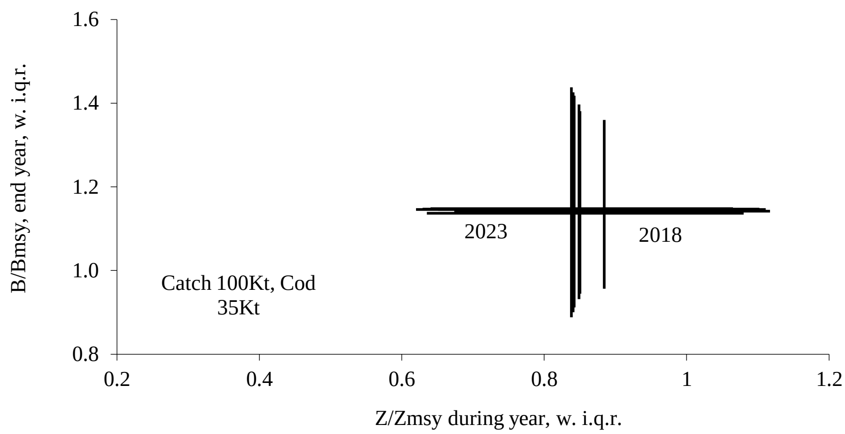

Fig. 11c. *Pandalus borealis* in West Greenland: projections of stock development for 2018–2023 with effective cod biomass assumed at 35 000 t: median estimates with quartile error bars.