Northwest Atlantic Fisheries Organization

Serial No. N7010 **NAFO SCR Doc. 19/046**

NAFO/ICES *PANDALUS* ASSESSMENT GROUP—November 2019

A Provisional Assessment of the Shrimp Stock off West Greenland in 2019

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 2019, both total survey and fishable biomass increased and are above their medians compared with the most recent 20 years. Offshore; the fishable biomass was 28% higher, and 38% less inshore compared to 2018. In offshore regions, fishable biomass is close to the upper quartile of the most recent 20 years, while inshore is way below its lower quartile. Areas north of 66°N have almost three-quarters of the offshore biomass. As a result of this, the proportions of biomass in the offshore area and inshore are 87% and 13% respectively, where proportion inshore is at a record low level.

Proportion fishable of the survey biomass in 2019 is little below the median for the last 20 years, owing to relatively proportions of age-2 shrimps and pre-recruits in the stock, mainly in offshore regions. Where proportion of females of fishable biomass are above 20-year median, 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, but in 2019 inshore has far lower quartile point than those offshore. Overall the number of age 2 shrimps, increased in 2019 and is well above the 20-year upper quartile. Inshore, numbers of age 2 shrimps declined to a record low level, below the 20-year lower quartile, but doubled offshore both in numbers and in relation to survey biomass and is way above the 20-year upper quartile. Proportion of large pre-recruits 14.5–16 mm carapace length increased in offshore regions, and remained at a comparable 2018 level 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 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 and until 2018 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.

Model estimation of 'True cod' biomass, based on the four cod biomass indices, were found to be overestimated and resulted in an unrealistic removal of shrimp biomass caused by overestimated predation by cod. Therefore, the four cod biomass indices were replaced by an absolute cod biomass index, modelled in a state-space stock assessment model SAM. More detailed information can be found in Rigét and Burmeister 2019 (d).

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 85 000 to 120 000 tons under assumptions that the cod stock, allowance made for its overlap with shrimp distribution, might be at 21 000 tons. The median estimate for 2019 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 (Burmeister and Rigèt 2019). 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, Burmeister and Rigét 2019).

Environment

The survey mean bottom temperature—weighted by area—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, but slightly raise to 2.5° in 2019. 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 2019). 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 2005. It increased continuously from 2006–2016 to about 74 Kt[1], distributed mainly in southern West Greenland, before a minor decline again in 2017. Since 2018 there was a smaller increase, and the cod is still distributed in the more southern regions, where there is a lower density of shrimps, and the 'effective' cod stock appeared to low. In 2012–2014 the survey 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 2019 a significant increase of the survey biomass of cod were observed at two stations (one station in NAFO 1 D and one station in NAFO 1E), in the southern part of the West Greenland (south of 64°N), and those two stations accounted for 90% of the total cod survey biomass.

The estimated overlap between the cod and the shrimp stock varied over time, peaked at a high value (0.888) in 2011, dropped significantly in 2012, and have since averaged at 0.254. In 2019 the estimated overlap was 0.2696 resulting an estimated 'effective' cod stock at 20.9 Kt (Table 2 and Fig. 6).

Stocks of Atlantic cod in West Greenland estimated from the research survey 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

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

in 2018. Increased by 14% in 2019, to a value above its 20-year upper quartile and equals the temporary maximum of 2010 and fishable biomass remained above its 20-year median. The number and biomass of females are both comparable to 2018 values. Where female biomass now is above its 20-year upper quartile, male survey biomass remained above its 20-year median. In numbers of survey both males and females are above 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
2019 value[1]	44.9	299.1	344.0	311.1	133.4	54.9	14.7	10.9
20-year[2] upper quartile	93.0	291.7	339.7	344.4	130.7	66.4	15.2	7.7
20-year median	81.1	235.2	309.1	279.7	111.8	50.5	12.5	5.1
20-year lower quartile	72.2	199.7	266.0	243.6	101.0	40.4	11.1	4.1
2019 rank	0.0	15.4	14.0	13.8	15.6	12.9	14.5	16.7
2018 value	72.2	229.0	301.2	279.0	133.4	54.9	13.0	5.5

[1] survey estimates of stock size for 2011, 2012, 2014, 2018, 2019 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 2019 rank, are referred to the 20 preceding years, i.e. 1998–2018.
[3] value recalculated in 2014.

In the inshore area, comprising Disko Bay and Vaigat, the estimated survey biomass decreased by 44% from 2017 to a 2019 value way below its 20-year lower quartile, in fact to a record low value over its past 20 years. 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 but increased in 2019, to value above its 20-year upper quartile. Relative to stock size, 2017 values indicated some sign of an incoming recruitment pulse, which could explain the increase of the fishable male biomass in the most recent two years. Whereas pre-recruits, both in numbers and of total surveyed tons, were little higher than in 2018 and close to their 20-year median, absolute number at age 2, almost double over 2018 and is above its 20-year upper 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
2019 value	31.7	28.2	90.4	51.7	38.8	42.9
20-year[1] upper quartile	25.3	40.4	92.9	56.8	40.5	44.2
20-year median [1]	17.8	26.4	91.7	53.9	36.7	39.8
20-year lower quartile[1]	10.8	23.6	89.4	51.0	35.2	38.4
2019 rank[1]	16.4/20	11.3/20	6.6/20	6.0/20	13.1/20	14.0/20
2018 value	18.3	24.0	92.6	52.9	39.7	42.9

[1] quartiles and 2019 rank generally referred to 20 preceding years 1999–2018;
[2] quartiles and 2019 rank referred to 20 preceding years 1999–2018 (in 2019 values is recalculated from 1999 to 2004);
[3] value recalculated in 2014

The overall stock composition in 2019 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 both 2018 and 2019 compared to the most previous years, but is still above its 20-year median. Relative to stock size the number of age-2 shrimps is way above its 20-year upper quartile, and the relative number of large pre-recruits above the 20-median, so prospects for short-term recruitment are presumably 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
2019 value	7.8	31.8	91.8	39.8	51.9	56.6
Upper quartile[1]	42.8	50.6	90.4	54.8	44.5	48.6
Median[1]	28.1	32.3	89.5	48.9	38.8	43.6
Lower quartile[1]	16.7	28.8	86.1	46.9	33.6	38.3
2019 rank[1]	0.0/20	10/20	19.5/20	0/14	15/14	15/14
2018 value	16.3	27.3	91.3	45.1	46.8	51.0

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
2019 value	35.3	27.7	90.2	53.4	36.8	40.8
Upper quartile[1]	19.0	35.7	93.9	55.6	44.1	47.9
Median[1]	12.6	24.2	92.9	53.5	39.8	42.4
Lower quartile[1]	7.6	20.7	91.2	47.7	36.7	39.0
2019 rank[1]	18.1/20	11.5 /20	4.4/20	7.4/14	5.2/14	6.2/14
2018 value	18.9	22.9	92.8	55.4	37.5	40.4

Differences between the stock compositions offshore and inshore—in Disko Bay and Vaigat—have tended to be maintained over time. The inshore, has historical averages higher proportions of smaller shrimps. For the age-2 and pre-recruit index, relative to survey biomass, the inshore quartile points used to have higher values than those of the offshore. However, in 2019 the lower quartile points were higher in offshore regions than in Disko Bay & Vaigat. Consistently with previous years, except for 2015 and 2017, offshore regions have lower relative number of pre-recruits, but far higher relative numbers of age-2 shrimps. In most years, 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. This pattern contradict size distribution in 2019, while offshore stock seems to be biased toward smaller shrimps (age-2, pre-recruits and fishable males) but in Disko Bay &Vaigat shrimps below the fishable size seems absent.

Compared with values for the previous 20 years, inshore fishable biomass is below their 20-year lower quartile, but offshore close to the 20-year upper quartile. Where fishable-male proportions of the survey biomass are averaged offshore, females proportion of fishable is at the lower quartile. Inshore, most shrimps are fishable females, with only a small proportions of males in the stock.

As a total stock, males compose a high proportion of the biomass, both survey and fishable. Offshore in 2019, 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 14-year upper quartile and at a record value, but in offshore regions below the 20-year median. Like in most recent years, the stock in 2019, seems to be 'all females" inshore and "males" in offshore regions.

It is uncertain, what the limits are 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 2005–2019 a period, in which some years were characterized by a decline in the stock. There are high numbers of age-2 shrimps and relatively high numbers of pre-recruits offshore, which are assumed to enter the fishery within the next two to four years; 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 age-2 shrimps and 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 constituted 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
2019 value	22.5	33.9	15.8	27.8	0.0	3.7	13.4
20-year[1] upper quartile	34.6	35.2	23.6	23.4	4.7	3.9	29.4
20-year median	30.0	32.3	19.0	16.7	0.5	3.4	25.4
20-year lower quartile	20.8	30.4	16.7	8.7	0.3	3.2	22.0
2019 rank	6.8	13.0	5.4	17.9	4.0	12.5	0.7
2018 value	29.9	30.8	19.1	20.2	0.0	3.8	24.7

[1] percentiles and 2019 rank are referred to the 20 preceding years, i.e. 1999–2018.

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 and areas West of Disko Bay & Vaigat, in 2018 and 2019, continue to hold high proportion of the offshore biomass, well above the 20-year median, but proportions in both W3-W4 has declined since 2017 and is now below the 20-year lower quartile. The proportion of biomass in W5-W7 increased over the past three years, and is now above the upper quartile, but the increase in biomass in those regions is based on few hauls with larges catches (Burmeister and Rigét, 2019a). Shrimp is almost absent in regions W8-W9.

The proportions in W1–2 and Disko Bay &Vaigat had been relatively constant over the preceding 19 years: the inter-quartile ranges were about one quarter of the medians. However, in 2019 the proportion of biomass in Disko Bay & Vaigat is at a record low level.

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 2018. In 2019, CPUE indices slightly decreased (CPUE for 2019 is only preliminary half year data) (Fig. 6). 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 2019).

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 121.6 Kt with quartiles at 98.5 and 153.9 Kt and the estimated mode 98.2 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 the end 2019 is estimated to be a bit higher but close to the 2018 value and 26% above B_{msy}. With a moderate effective cod biomass at 20.9 Kt and catches projected at 100 000 t, the total mortality in 2019 is estimated to be below 80% of Z_{msy}. The level of the mortality risk at 32% do not exceeds a management threshold of 35%.

Table: *P. borealis* in West Greenland: model estimates of stock status at the end of, or during, 2019.

Biomass ratio *B/Bmsy* (median estimate, %)	126.3
Prob. *B<Bmsy* (%)	20.7
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	80.1
Prob. *Z>Zmsy* (%)	31.9

Risks associated with eight possible catch levels for 2020, with an 'effective' cod stock at 15 000 t, 21 000 t and 25 000 t, are estimated to be:

15 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	22.0	22.4	22.7	23.2	23.4	23.8	24.1	25.2
falling below Blim end 2020 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2020 (%)	15.1	18.4	21.6	24.8	28.1	32.0	35.1	37.9
exceeding Zmsy in 2021 (%)	16.0	18.9	22.2	26.0	29.4	32.9	36.7	40.4

21 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	22.7	22.7	22.6	23.6	24.1	24.2	24.1	25.0
falling below Blim end 2020 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2020 (%)	17.3	20.2	23.5	26.9	30.2	34.0	36.9	40.1
exceeding Zmsy in 2021 (%)	17.8	21.2	25.2	27.8	31.9	34.8	37.8	41.3

25 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	22.0	22.7	22.8	23.0	23.3	23.6	24.2	25.7
falling below Blim end 2020 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2020 (%)	18.4	21.6	24.5	28.1	31.8	35.1	38.0	41.1
exceeding Zmsy in 2021 (%)	19.3	22.8	26.2	29.2	32.6	35.9	39.7	42.7

If a mortality risk (i.e. that estimable mortality will exceed Z_{msy}) criterion of 35% is observed, catches of 110 Kt are predicted to be sustainable, provided that the effective cod biomass makes only moderately large gains in the coming year.

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 cod larvae of one or two large year-classes derived from spawning 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 44-year data series. Eight levels of annual catch were investigated from 85 000 to 120 000 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 2019. 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 110 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 1976–2019 for stock-dynamic assessment model.

Year	Sam.obs[]	Overlap[]	Past.Catch[]	Prov.Catch[]	ln.CPUE[	surv[]	Grunwald[]	Grunwalc
1976	117.227	0.579	51.6	NA	0.3965	NA	NA	NA
1977	133.347	0.574	42.3	NA	0.3251	NA	NA	NA
1978	92.058	0.672	42.8	NA	0.09345	NA	NA	NA
1979	87.881	0.67	55.9	NA	-0.0085	NA	NA	NA
1980	52.761	0.68	53.8	NA	0.1822	NA	NA	NA
1981	55.555	0.619	54.3	NA	0.1184	NA	NA	NA
1982	73.928	0.518	56.2	NA	0.3559	NA	NA	NA
1983	42.23	0.461	52.8	NA	0.2317	NA	NA	NA
1984	16.078	0.479	52.8057	NA	0.1729	NA	NA	NA
1985	15.369	0.482	66.2079	NA	0.2396	NA	NA	NA
1986	17.751	0.51	76.9	NA	0.282	NA	NA	NA
1987	37.031	0.604	77.391	NA	0.4156	NA	NA	NA
1988	61.1	0.618	73.616	NA	0.1446	223.1907	NA	NA
1989	60.769	0.37	80.671	NA	0.04702	208.9535	213.7	470.919
1990	40.269	0.289	83.97	NA	0	207.0053	27.8	184.1405
1991	8.307	0.313	91.489	NA	0.04366	146.0081	2.7	19.7905
1992	3.788	0.523	105.487	NA	0.1139	194.1563	0.8	2.8785
1993	0.918	0.6455	91.013	NA	0.1093	216.4703	NA	NA
1994	0.469	0.599	92.805	NA	0.1145	223.1433	NA	NA
1995	0.487	0.483	87.388	NA	0.2079	183.2427	NA	NA
1996	0.38	0.28	84.095	NA	0.2516	192.0819	NA	NA
1997	0.465	0.49	78.128	NA	0.2264	167.0946	NA	NA
1998	0.372	0.39	80.495	NA	0.3707	244.2933	NA	NA
1999	0.442	0.496	92.198	NA	0.4821	237.2942	NA	NA
2000	0.796	0.643	97.968	NA	0.5814	280.336	NA	NA
2001	0.92	0.462	102.926	NA	0.5399	280.4643	NA	NA
2002	1.876	0.278	135.172	NA	0.7225	369.4608	NA	NA
2003	2.352	0.398	130.173	NA	0.7975	548.2839	NA	NA
2004	5.652	0.257	149.332	141	0.8928	528.3298	NA	NA
2005	6.861	0.074	156.899	140.5	0.9239	494.2	NA	NA
2006	10.009	0.22	157.315	140.2	0.9145	451	NA	NA
2007	16.153	0.139	144.19	135.2	0.9505	336.1	NA	NA
2008	15.724	0.156	153.889	131.6	0.9979	262.6	NA	NA
2009	14.832	0.602	135.458	108.8	0.8731	255.1	NA	NA
2010	11.702	0.315	133.99	138.5	0.8457	318.7	NA	NA
2011	19.437	0.888	123.985	126	0.8974	245.69	NA	NA
2012	27.251	0.305	115.975	110	0.8141	176.44	NA	NA
2013	32.546	0.206	95.381	100	0.6925	218.1	NA	NA
2014	47.295	0.211	88.765	90	0.7672	170.01	NA	NA
2015	61.53	0.2046	72.256	65	0.815	255.54	NA	NA
2016	71.797	0.079	85.527	82	0.8728	201.3461	NA	NA
2017	65.17	0.373	92.37	90	0.9888	284.6407	NA	NA
2018	73.618	0.3841	94.878	101.25	0.9174	279.02	NA	NA
2019	78.967	0.2696	NA	100	0.8928	311.12	NA	NA

[1] 'effective cod biomass' was not an input data series in 2019; instead, a SAM cod biomass input series 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 2014–19 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, 2019.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2018)
Max.sustainable yield	133.3	58.7	98.5	121.6	153.9	98.2	123.1
B/Bmsy, end current year (proj.)(%)	129.5	34.3	104.2	126.3	151.6	119.9	123.6
Biomass risk, end current year(%)	20.7	40.5	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	55.2	80.1	109.6	–	80.4
Carrying capacity	3561	1953	2094	2999	4558	1875	3108
Max. sustainable yield ratio (%)	9.1	4.7	5.8	8.6	11.8	7.4	8.5
Survey catchability (%)	17.1	10.4	9.3	14.8	22.3	10.2	14.3
CPUE(1) catchability	1.0	0.6	0.5	0.9	1.3	0.6	0.8
CPUE(2) catchability	1.6	1.0	0.9	1.4	2.1	0.9	1.3
Effective cod biomass 2019 (Kt)	26.1	30.0	16.4	20.9	26.4	10.6	28.0
$P_{50\%}$ *(prey biomass index with consumption 50% of max.)*	4.2	7.6	0.2	1.2	4.6	-4.9	1.2
V_{max} *(maximum consumption per cod)*	1.8	2.2	0.3	0.8	2.3	-1.3	0.8
CV of process (%)	14.0	2.9	12.0	13.8	15.8	13.3	14.2
CV of survey fit (%)	16.6	3.0	14.4	16.2	18.3	15.3	15.5
CV of CPUE (1) fit (%)	7.1	1.5	5.9	6.7	7.9	6.1	6.6
CV of CPUE (2) fit (%)	7.5	2.3	5.8	6.8	8.4	5.6	7.0

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2019.

	Start biom. ratio	*CV cpu*	*CV s*	*CV proc*	*Vmax*	*P50%*	*Qc1*	*Qc2*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield	21			11		5	-32	-32	-32	25	39
Carrying capacity	7				-8		-73	-73	-73	-65	
Max. sustainable yield ratio (%)				10	13		71	70	71		
Survey catchability (%)	-38				17	-6	100	100			
CPUE catchability q1	-39				17	-6	100				
CPUE catchability q2											
P50%	16				73						
Vmax	-10			-5							
CV of process (%)	6	-7	-27								
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 2020 assuming effective cod biomass 15 Kt - 25 Kt.

Catch	15 Kt		21 Kt		25 Kt	
(Kt/yr)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
85	15.1	16.0	17.3	17.8	18.4	19.3
90	18.4	18.9	20.2	21.2	21.6	22.8
95	21.6	22.2	23.5	25.2	24.5	26.2
100	24.8	26.0	26.9	27.8	28.1	29.2
105	28.1	29.4	30.2	31.9	31.8	32.6
110	32.0	32.9	34.0	34.8	35.1	35.9
115	35.1	36.7	36.9	37.8	38.0	39.7
120	37.9	40.4	40.1	41.3	41.1	42.7

Table 5. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2020 – 2022 and of falling below B_{msy} or limit* biomass at the end of 2020 – 2022 assuming effective cod biomass 15 Kt - 25 Kt.

15 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	22	22	23	23	23	24	24	25
falling below Bmsy end 2021 (%)	23	23	24	25	25	27	27	29
falling below Bmsy end 2022 (%)	24	25	25	27	27	28	29	32
falling below Blim end 2020 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2021 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2020 (%)	15	18	22	25	28	32	35	38
exceeding Zmsy in 2021 (%)	16	19	22	26	29	33	37	40
exceeding Zmsy in 2022 (%)	17	20	24	27	30	33	38	41

* limit biomass is 30% of B_{msy}

21 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	23	23	23	24	24	24	24	25
falling below Bmsy end 2021 (%)	24	24	25	25	26	27	27	27
falling below Bmsy end 2022 (%)	24	25	26	27	29	29	30	31
falling below Blim end 2020 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2021 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2020 (%)	17	20	24	27	30	34	37	40
exceeding Zmsy in 2021 (%)	18	21	25	28	32	35	38	41
exceeding Zmsy in 2022 (%)	19	22	26	29	33	36	39	43

* limit biomass is 30% of B_{msy}

25 000 t cod	Catch option ('000 tons)							
Risk of:	85	90	95	100	105	110	115	120
falling below Bmsy end 2020 (%)	22	23	23	23	23	24	24	26
falling below Bmsy end 2021 (%)	24	25	25	25	26	26	27	29
falling below Bmsy end 2022 (%)	24	26	27	27	27	29	31	32
falling below Blim end 2020 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2021 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2020 (%)	18	22	25	28	32	35	38	41
exceeding Zmsy in 2021 (%)	19	23	26	29	33	36	40	43
exceeding Zmsy in 2022 (%)	20	23	27	30	33	37	40	44

* limit biomass is 30% of B_{msy}

Figures

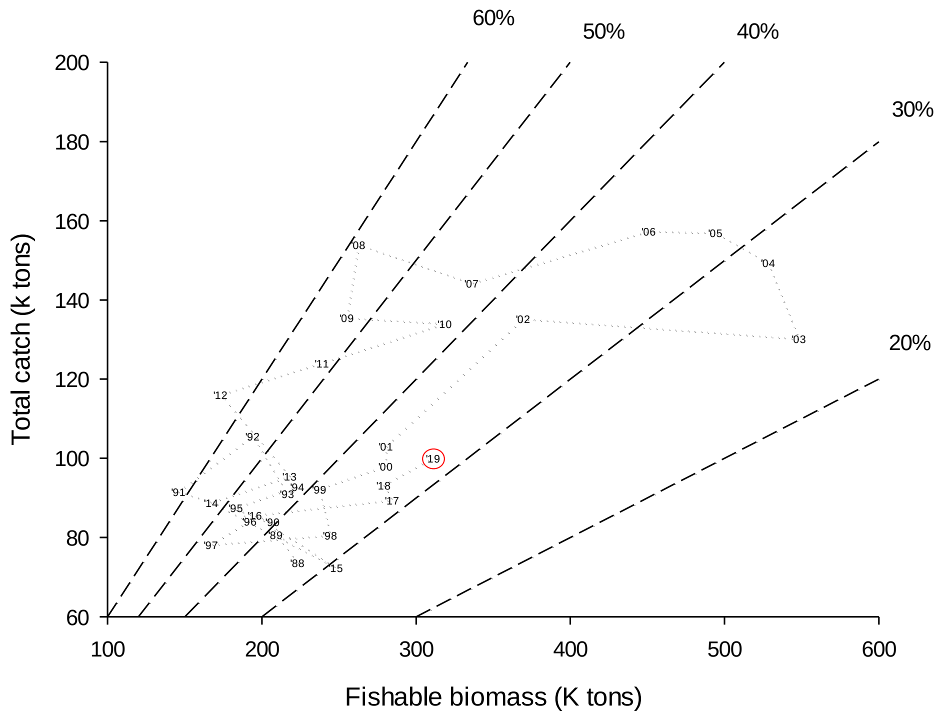

Figure 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1976–2019 (2019 catch is provisional).

Figure 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1996–2019.

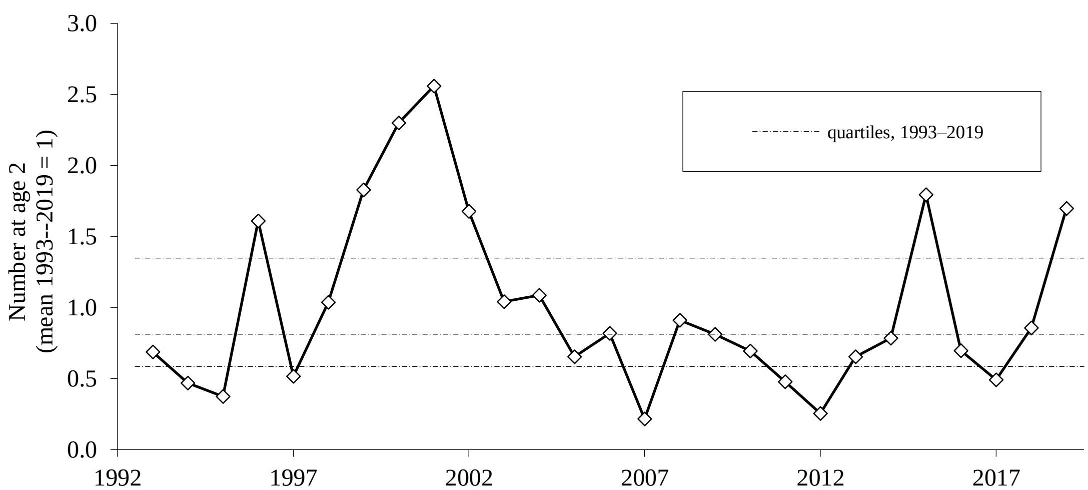

Figure 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1996–2018.

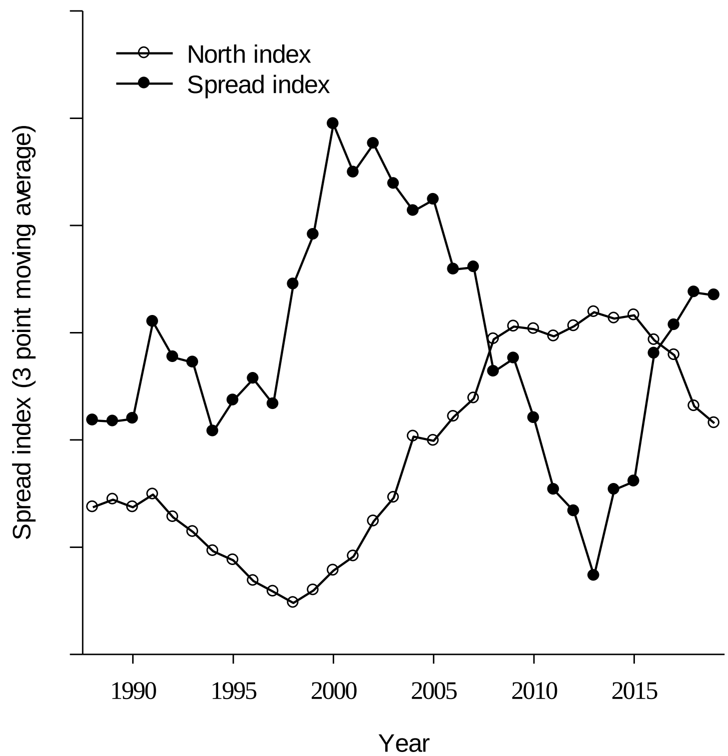

Figure 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2019 (3-point moving means.)

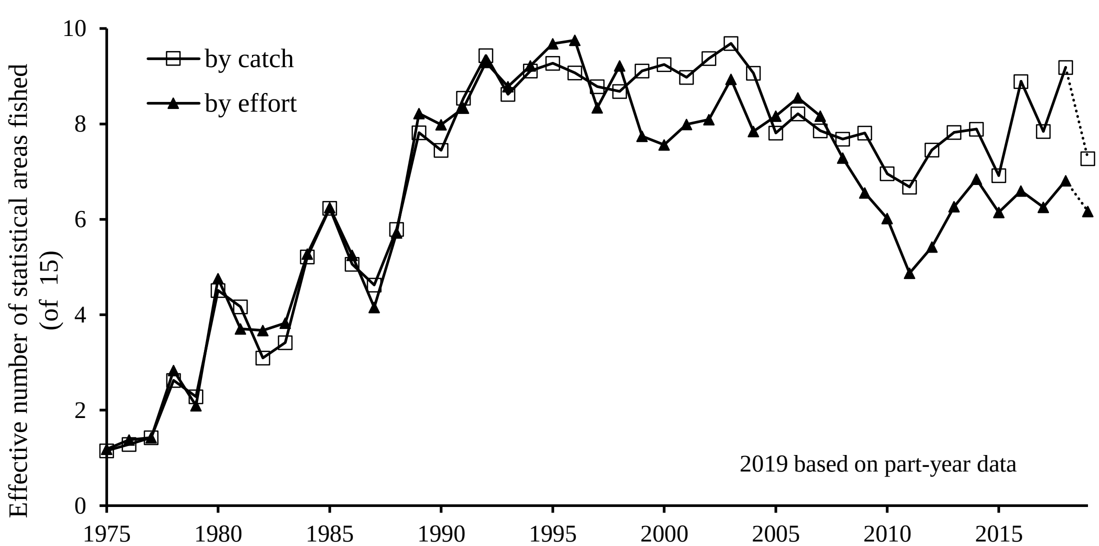

Figure 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2019. (2019 is preliminary data).

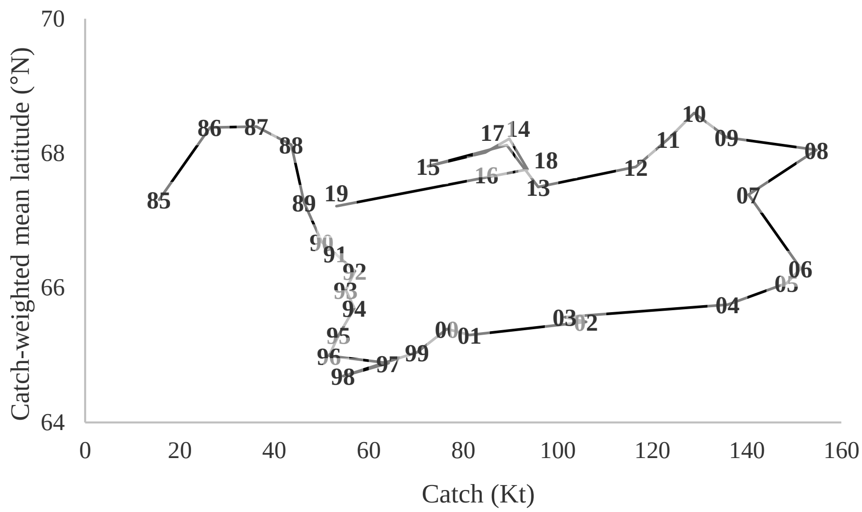

Figure 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1985–2019 (2019 is only preliminary catch).

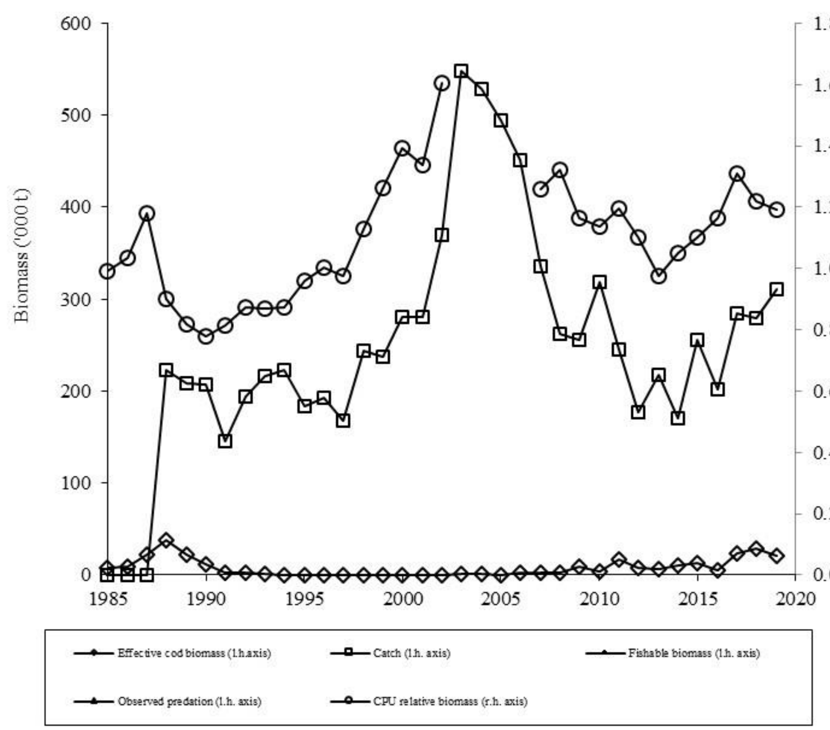

Figure 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2019 catch is projected; effective cod biomass is synthesized from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

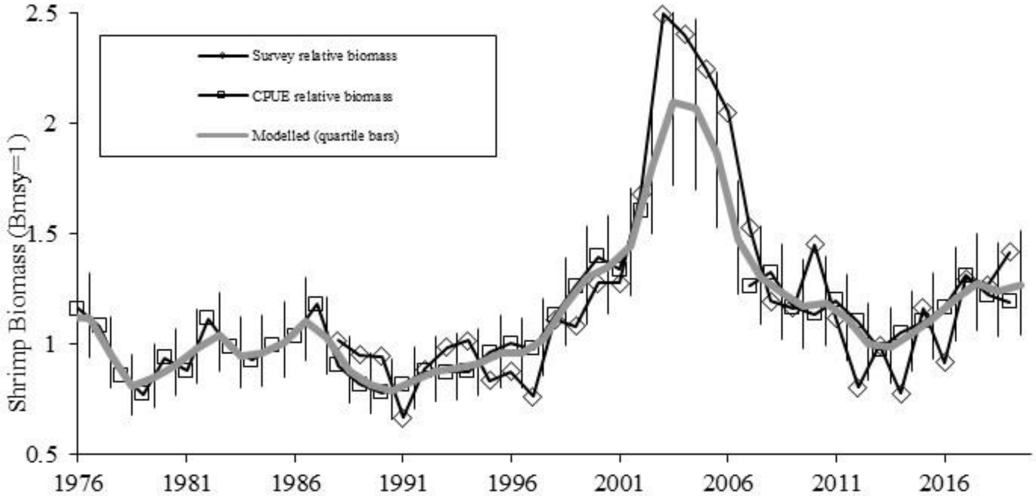

Figure 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2019.

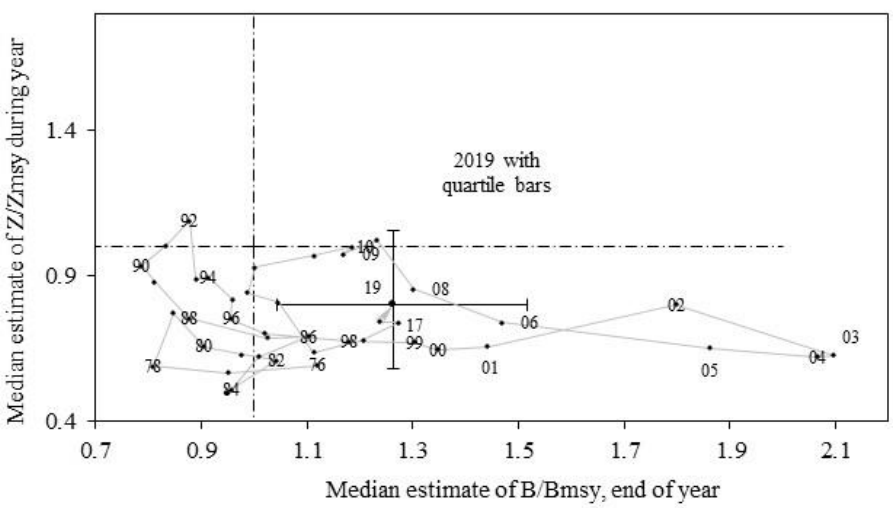

Figure 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1976–2019.

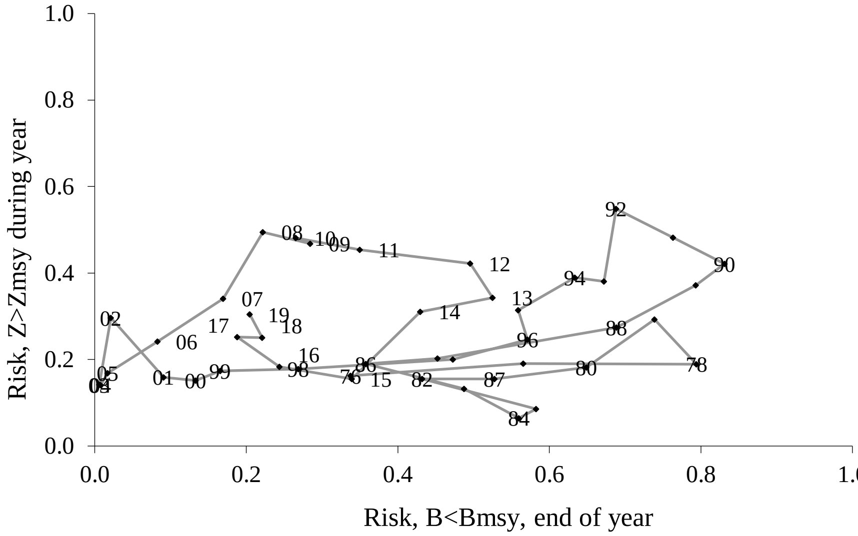

Figure 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1976–2019.

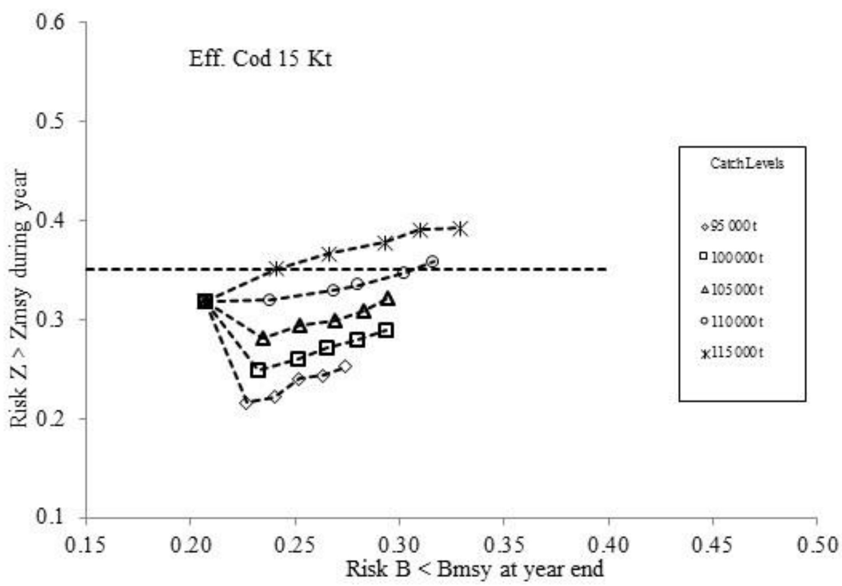

Figure 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2020–24 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 95–1115 Kt/yr; with effective cod biomass 15 Kt.

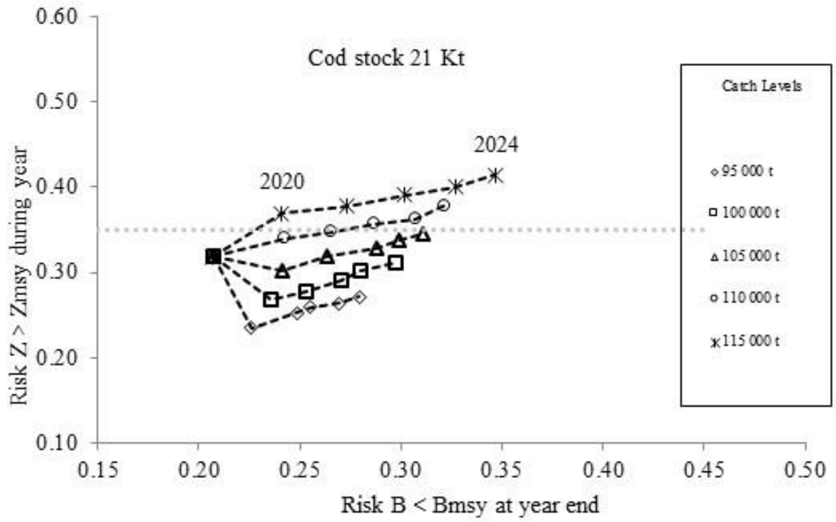

Figure 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2020–24 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 95–115 Kt/yr; with effective cod biomass 21 Kt.

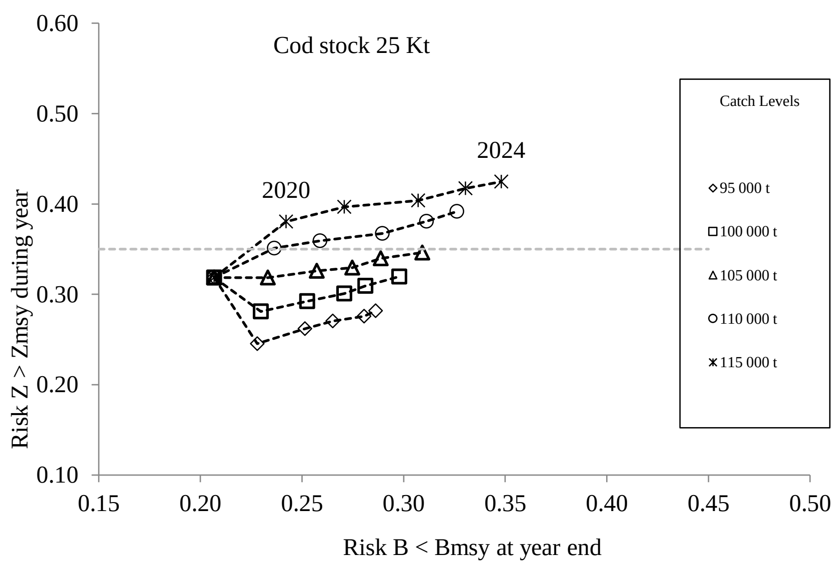

Figure 10c. *Pandalus borealis* in West Greenland: joint 5-year plot 2020–24 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 95–115 Kt/yr; with effective cod biomass 25 Kt.

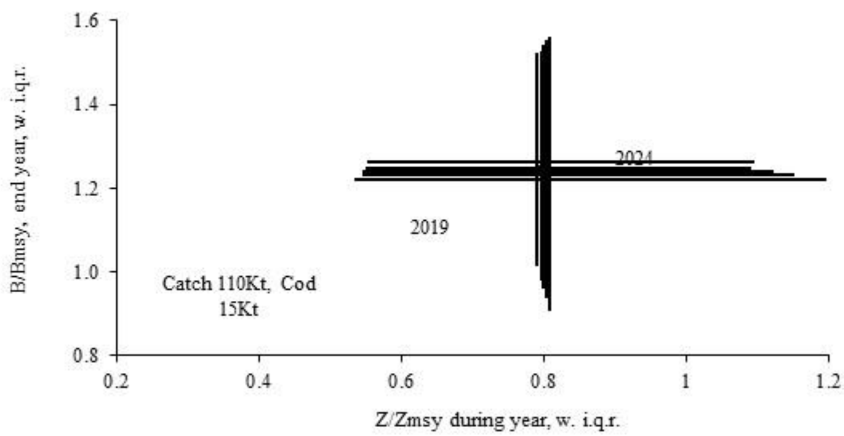

Figure 11a. *Pandalus borealis* in West Greenland: projections of stock development for 2020–2024 with effective cod biomass assumed at 15 000 t: median estimates with quartile error bars.

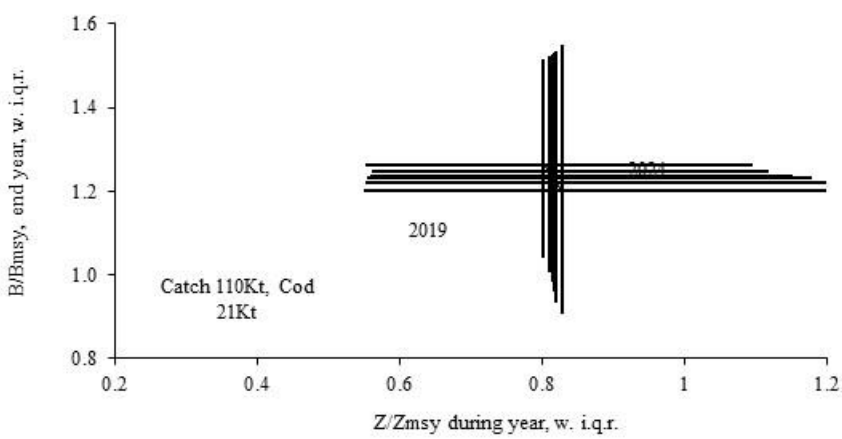

Figure 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2020–2024 with effective cod biomass assumed at 21 000 t: median estimates with quartile error bars.

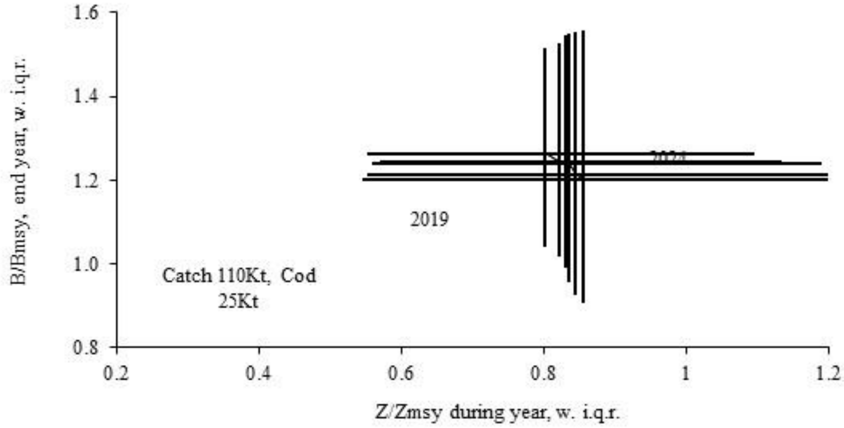

Figure 11c. *Pandalus borealis* in West Greenland: projections of stock development for 2020–2024 with effective cod biomass assumed at 25 000 t: median estimates with quartile error bars.