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A Provisional Assessment of the Shrimp Stock off West Greenland in 2021

by

AnnDorte Burmeister

and

Frank F. Rigét

Pinngortitaleriffik, Greenland Institute of Natural Resources
Box 570, DK-3900 Nuuk, Greenland

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.

CPUEs were standardized by linearized multiplicative models including terms for vessel, month, gear type, year, and statistical area. In the recent three years the CPUE of the coastal fleet were slightly decreased while the CPUE of the offshore fleet increased from 2016 to 2017 and dropped little from 2018 to 2020. This trend was stopped in 2021 and preliminary data for both fleet components indicating increasing CPUE.

Standardized CPUE for the Canadian fleet fishing in Div. 0A has not been updated since 2011 because it is not possible to receive new logbook information from Canada.

No new survey data is available for assessment in 2021, because of no available research ship. However, in 2020 overall, the stock biomass, distribution and composition were 'safe' in several respects. In its history survey biomass have been fluctuated with ups and downs, and in some year, biomass increased by more than 45% (1998, 2003 and 2015). In 2020, both total survey and fishable biomass increased little and are above or close to their upper quartiles compared with the most recent 20 years. Offshore, the fishable biomass remained almost unchanged from 2019 but rise 37% inshore compared to 2019. In offshore regions, fishable biomass is close to the upper quartile of the most recent 20 years, while inshore close to its lower quartile. Areas north of 66°N have almost three-quarters of the offshore biomass. As a result of this, the proportions of fishable biomass in the offshore area and inshore are 81% and 19% respectively, where proportion in inshore is at a record low level.

Proportion fishable of the survey biomass were in 2020 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.

Overall, the number of age 2 shrimps, remained unchanged in 2020, still well above the 20-year upper quartile. The stock composition inshore has historically been characterized by a higher proportion of young shrimps than that offshore. But in 2020, inshore numbers of age 2 shrimps remained at a low level, below the 20-year lower quartile, so small shrimp are "all offshore", and are in those regions both in numbers and in relation to survey biomass and is way above the 20-year upper quartile.

The stock is in 2020 composed, by a relative high number of large pre-recruits 14.5–16 mm carapace length, almost only in offshore regions, where the numbers are well above the upper quartile for the past 20-year. Inshore, large pre-recruits were both in numbers and by survey biomass, at a record low value, far below their lower quartile.

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. 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 CPUE (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).

Two research survey (Greenland and German) act as tuning fleets in the SAM assessment. The German survey covers the period from 1982 to 2015 and the coverage has been restricted to NAFO Div. 1D, 1E and 1F in several years during the last ca. 20 years. The Greenland survey has a coverage from NAFO Div. 1A in the north to Div. 1F in the south but only covers the period from 1992 until today. Because of the differences in both time and area coverages of the two surveys, the cod biomass estimation was uncertain and systematically lead to overestimation (Rigét and Burmeister 2020d). Therefore, in 2020 estimation of cod biomass in SAM only include the Greenland research survey as tuning fleet in the SAM assessment.

Due to the lack of survey in 2021, no new data covering fishable shrimp biomass, cod biomass and overlap factor were available as input index to the assessment model. As a consequence of the models need to have input data for cod biomass as well as overlap factor, different scenarios based on average cod biomass and overlap factor for the past two, three, four, five and ten years was applied (all results are not shown in the paper). Further, larger uncertainty was added to the estimation of estimated overlap and effective cod biomass in 2021.

```
for (i in Present.Year:Present.Year)
{    Past.cod[i] <- True.cod[i] * Est.Overlap.2021 #Past.cod is 'effective cod' to enter #predation function New coding 2021 due to lack of survey info

Est.Overlap.2021 ~ dnorm (0.26,4.21) #New coding 2021 due to lack of survey info
```

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 95 000 to 130 000 tons under assumptions that the cod stock, allowance made for its overlap with shrimp distribution, might be at 6 000 tons. The median estimate for 2021 was 6 000 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 2021). 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; Burmeister and Rigét 2020).

Environment

The mean survey 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 2.6° in 2019 and 2020. 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-1990s, 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 2020). 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, 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 be 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. However, the cod biomass declined in 2020 to a value comparable with most recent values and the three years average used for 2021 assessment was only little lower.

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 2021 the estimated overlap, based on the average of the most three resent years was 0.284 resulting an estimated 'effective' cod stock at 6 Kt (Table 2 and Fig. 6).

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. Since 2017 biomass have slightly been increasing and is in 2020, above its 20-year upper quartile and little higher than the temporary maximum of 2010 and fishable biomass remained above its 20-year median. The number and biomass of females are both comparable to 2019 values. Both female and male biomass is above their 20-year upper quartile. 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
2020 value[1]	67.3	324.5	391.8	340.9	145.9	67.7	15.9	10.1
20-year[2] upper quartile	93.0	308.0	372.5	344.4	134.2	66.4	15.2	7.7
20-year median	81.1	241.5	318.4	280.5	117.5	52.9	13.2	5.1
20-year lower quartile	72.2	200.0	275.8	252.7	101.7	40.4	11.6	4.1
2020 rank	3.5	15.7	15.5	15.1	16.2	15.3	15.9	15.9
2019 value	44.9	299.1	344.0	311.1	133.4	54.9	14.7	10.9

[1] survey estimates of stock size for 2011, 2012, 2014, 2018, 2019 and 2020 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 2020 rank, are referred to the 20 preceding years, i.e. 2000–2019.

This table has not been updated in 2021 due to the lack of survey data.

In the inshore area, comprising Disko Bay and Vaigat, the estimated survey biomass increased by 50% from 2019 to a 2020, but still below its 20-year lower quartile. The offshore biomass in 2014 was close to its lowest for 20 years, followed by ups and downs from 2015 to 2017, remained almost stable in 2018 but increased in both 2019 and 2020, to value above its 20-year upper quartile. Relative to stock size, 2017-2019 values indicated some sign of an incoming recruitment pulse, which could explain the increase of the fishable male biomass in the most recent three years. Whereas pre-recruits, both in numbers and of total surveyed tons, were considerably higher than in 2019 and above their 20-year upper quartile, absolute number at age 2, remained stable 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	Fishable, of survey	Fishable males, of survey	Females, of survey	Females, of fishable
2020 value	25.8	42.8	87.0	49.8	37.2	42.8
20-year[1] upper quartile	25.3	36.3	92.9	56.8	40.5	44.2
20-year median [1]	17.8	26.4	91.7	53.4	37.5	40.5
20-year lower quartile[1]	10.8	23.6	89.4	51.0	35.2	38.4
2020 rank[1]	15.5/20	18.0/20	1.7/20	5.3/20	9.9/20	12.9/20
2019 value	31.7	28.2	90.4	51.7	38.8	42.9

[1] quartiles and 2020 rank generally referred to 20 preceding years 2000–2019.
This table has not been updated in 2021 due to the lack of survey data.

The overall stock composition in 2020 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 lower proportion of the fishable biomass in 2019 and 2020 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 at its 20-year upper quartile, and the relative number of large pre-recruits are way above the 20-year upper quartile, 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
2020 value	12.8	9.5	96.5	49.3	47.3	49.0
Upper quartile[1]	39.5	46.1	90.8	53.7	45.3	49.6
Median[1]	26.0	31.8	89.6	48.7	39.5	44.6
Lower quartile[1]	15.9	28.8	87.4	46.0	33.8	38.6
2020 rank[1]	3.8	0.0	21.0	9.1/15	14.1/15	10.9/15
2019 value	7.8	31.8	91.8	39.8	51.9	56.6

This table has not been updated in 2021 due to the lack of survey data.

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. Nevertheless, numbers of both age-2 shrimps and pre-recruits are in 2020 considerably higher in offshore regions compared to Disko Bay & Vaigat. 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 contradicts size distribution in 2020, while offshore stock seems to be biased toward smaller shrimps (age-2, pre-recruits and fishable males), whereas in Disko Bay & Vaigat shrimps below the fishable size seems had been at low in most recent years.

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
2020 value	28.5	49.8	85.0	49.9	35.2	41.3
Upper quartile[1]	19.0	33.3	93.8	55.5	44.1	47.7
Median[1]	12.6	24.2	92.7	53.4	39.8	42.3
Lower quartile[1]	7.6	20.7	90.3	48.1	36.7	39.3
2020 rank[1]	16.6	19.2	0.9	0.3/15	4.6/15	7.4/15
2019 value	35.3	27.7	90.2	53.4	36.8	40.8

[1] percentiles and 2020 rank are referred to the 20 preceding years, i.e. 2000–2019.
This table has not been updated in 2021 due to the lack of survey data.

Compared with values for the previous 20 years, inshore fishable biomass is close to the 20-year lower quartile, but offshore close to the 20-year upper quartile. While both fishable-male and fishable-female proportions of the survey biomass are below averaged offshore, inshore, most shrimps are fishable shrimps, with only a small proportion of shrimps below the fishable size (17 mm CL).

As a total stock, males compose a high proportion of the biomass, both survey and fishable. Offshore in 2020, males of fishable biomass are above its 15-year upper quartile. 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 15-year median. Female proportion of fishable biomass in Disko Bay is almost at the 15-year upper quartile, but in offshore regions below the 15-year median. Unlike the most recent years, the stock in 2020, seems to be a mix of both males and females inshore as well as 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 2005–2020 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 "safe condition". The perception of the stock inshore is somewhat reverse. Inshore is having low numbers of age-2 shrimps and pre-recruits to recruit to the spawning stock in the future; relatively high proportions of females in the fishable biomass and in 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
2020 value	28.6	28.2	18.1	25.0	0.1	3.9	17.8
20-year[1] upper quartile	34.6	35.2	23.6	23.4	3.4	3.8	29.4
20-year[1] median	30.0	32.8	19.0	16.7	0.5	3.4	25.4
20-year[1] lower quartile	22.4	30.8	17.0	8.7	0.1	3.2	21.9
2020 rank	9.7	2.8	6.7	16.3	5.5	16.0	2.9
2019 value	22.5	33.9	15.8	27.8	0.0	3.7	13.4

[1] percentiles and 2020 rank are referred to the 20 preceding years, i.e. 2000–2019.
This table has not been updated in 2021 due to the lack of survey data.

Within the offshore area, 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 only little biomass is available in that region. The proportion of the biomass in most northern regions and areas West of Disko Bay & Vaigat (W1-W2), comprise each a little more than a quarter of the total biomass, even the proportion of the biomass in 2020 have been declining in (W1-W2). Even biomass in 2020 have been increasing in W4 (Holsteinsborg Dyb) the proportion of biomass in W3-W4 remained a little below its 20-year median. In the central regions (W5-W7) a larger proportion of biomass have been observed over the past three years, and is now above the upper quartile, but the increase in biomass in that region is based on few hauls with larges catches in W6 (Burmeister and Rigét, 2020a). Few years ago, Disko Bay & Vaigat constitute about 25% of the total biomass, but the proportion drop to a low value in 2019 and remain below the 20-year lower quartile in 2020.

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. From 2018 to 2020, CPUE indices continued a slightly decrease, but preliminary 2021 data indicating an increase (CPUE for 2021 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 2021).

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 123.2 Kt with quartiles at 102.1 and 154.6 Kt; an estimated mode is at 95.6 Kt.
The model estimates show 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 2021 is estimated to be a bit higher but close to the 2020 value and 23,2% above B_{msy}. With a low effective cod biomass at 6 Kt and catches projected at 108 000 t, total mortality in 2021 is estimated to be below the MSY level and the mortality risk at 35% exceeds a management threshold of 40.4%.

Table: *P. borealis* in West Greenland: model estimates of stock status at end of, or during, 2021.

Biomass ratio *B /Bmsy* (median estimate, %)	123.2
Prob. *B<Bmsy* (%)	24.4
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	81.8
Prob. *Z>Zmsy* (%)	32.9
Prob. *B<Bmsy80%* (%)	8.1

Risks associated with eight possible catch levels for 2021, with an 'effective' cod stock at 5 000 t, 6 000 t and 7 000 t, are estimated to be:

5 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2021 (%)	24.1	24.8	25.3	25.9	25.5	26.3	27.3	27.7
falling below Blim end 2021 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2021 (%)	17.7	21.5	25.4	28.7	32.4	35.8	39.4	42.6
exceeding Zmsy in 2022 (%)	19.0	21.8	25.6	29.3	33.6	37.3	40.9	44.1
falling below Bmsy 80% end 2021 (%)	7.6	7.9	8.2	8.7	9.0	9.5	10.0	9.5

6 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2022 (%)	25.6	26.1	26.3	26.4	27.5	26.9	27.4	27.4
falling below Blim end 2022 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2022 (%)	19.7	23.3	26.4	29.7	33.4	36.6	39.8	43.4
exceeding Zmsy in 2023 (%)	20.7	24.1	27.2	30.7	34.9	38.0	41.1	43.9
falling below Bmsy 80% end 2022 (%)	9.3	9.7	10.1	10.1	10.1	10.6	10.4	10.9

7 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2022 (%)	25.0	25.7	26.8	27.2	26.6	26.9	27.6	27.9
falling below Blim end 2022 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2022 (%)	20.1	23.5	26.7	30.1	33.7	37.0	40.3	43.8
exceeding Zmsy in 2023 (%)	20.4	23.9	28.2	31.2	34.5	37.4	41.9	45.1
falling below Bmsy 80% end 2022 (%)	9.3	9.6	9.8	10.2	10.6	10.3	11.0	10.7

With a mortality risk (i.e. that estimated mortality will exceed Z_{msy}) criterion of 35% is observed, catches of 115 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 compared to the period before the collapse in the beginning of 1990s, but has since 2010 shown a slow, but progressive, increases and remained almost stable since 2015. 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 46-year data series. Eight levels of annual catch were investigated from 95 000 to 130 000 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.

Model performance

The process error of model fit for the model is shown in Fig 12.d. There is a tendency of the process error increasing in the period from 2006 to 2009, followed by a decline. This could be explained by input index of CPUE, from where CPUE data has been removed from the model.

The model was able to produce a reasonable simulation of the observed data (Fig. 12a, 12.b, 12.c). The probability of getting more extreme observation than the realized ones given in the data series on stock size were inside the 90% confidence limit (Table 6). The CPUE series was generally better estimated than the survey series. However, the model did not capture the survey peak around 2004. Otherwise, no major problems in Capturing the variability of the data were detected.

Conclusions

The stock is predicted to remain above its *MSY* level at end 2021. 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 115 Kt would keep the risk of exceeding Z_{msy} below 35%, assuming certain limits on the evolution of the biomass of Atlantic cod.

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Table 1. *Pandalus borealis* in West Greenland: input data series 1976–2021 for stock-dynamic assessment model.

Year	Sam.obs[]	Overlap[]	Past.Catch[]	Prov.Catch[]	In.CPUE[	surv[]	Grunwald[]	Grunwalc
1976	119.677	0.579	51.6	NA	0.389	NA	NA	NA
1977	133.432	0.574	42.3	NA	0.3281	NA	NA	NA
1978	93.6	0.672	42.8	NA	0.09047	NA	NA	NA
1979	92.364	0.67	55.9	NA	-0.00498	NA	NA	NA
1980	61.22	0.68	53.8	NA	0.1802	NA	NA	NA
1981	68.474	0.619	54.3	NA	0.1181	NA	NA	NA
1982	95.094	0.518	56.2	NA	0.3597	NA	NA	NA
1983	56.737	0.461	52.8	NA	0.2426	NA	NA	NA
1984	20.261	0.479	52.8057	NA	0.1761	NA	NA	NA
1985	29.579	0.482	66.2079	NA	0.2455	NA	NA	NA
1986	41.625	0.51	76.9	NA	0.2823	NA	NA	NA
1987	91.942	0.604	77.391	NA	0.4151	NA	NA	NA
1988	134.72	0.618	73.616	NA	0.146	223.1907	NA	NA
1989	103.888	0.37	80.671	NA	0.05078	208.9535	213.7	470.919
1990	43.602	0.289	83.97	NA	0	207.0053	27.8	184.1405
1991	2.093	0.313	91.489	NA	0.04419	146.0081	2.7	19.7905
1992	0.361	0.523	105.487	NA	0.1125	194.1563	0.8	2.8785
1993	0.157	0.6455	91.013	NA	0.1093	216.4703	NA	NA
1994	0.073	0.599	92.805	NA	0.1131	223.1433	NA	NA
1995	0.063	0.483	87.388	NA	0.2071	183.2427	NA	NA
1996	0.039	0.28	84.095	NA	0.2505	192.0819	NA	NA
1997	0.052	0.49	78.128	NA	0.2248	167.0946	NA	NA
1998	0.061	0.39	80.495	NA	0.367	244.2933	NA	NA
1999	0.095	0.496	92.198	NA	0.4843	237.2942	NA	NA
2000	0.233	0.643	97.968	NA	0.5773	280.336	NA	NA
2001	0.299	0.462	102.926	NA	0.5384	280.4643	NA	NA
2002	0.729	0.278	135.172	NA	0.7143	369.4608	NA	NA
2003	1.219	0.398	130.173	NA	0.7976	548.2839	NA	NA
2004	3.918	0.257	149.332	141	0.8882	528.3298	NA	NA
2005	4.868	0.074	156.899	140.5	0.9218	494.2	NA	NA
2006	7.116	0.22	157.315	140.2	0.9242	451	NA	NA
2007	11.981	0.139	144.19	135.2	0.9548	336.1	NA	NA
2008	11.716	0.156	153.889	131.6	1.003	262.6	NA	NA
2009	7.233	0.602	135.458	108.8	0.9037	255.1	NA	NA
2010	5.209	0.315	133.99	138.5	0.8638	318.7	NA	NA
2011	10.829	0.888	123.985	126	0.9121	245.69	NA	NA
2012	17.666	0.305	115.975	110	0.8345	176.44	NA	NA
2013	19.883	0.206	95.381	100	0.7056	218.1	NA	NA
2014	27.494	0.211	88.765	90	0.7791	170.01	NA	NA
2015	32.975	0.2046	72.256	65	0.822	255.54	NA	NA
2016	31.294	0.079	85.527	82	0.8838	201.3461	NA	NA
2017	26.444	0.373	92.37	90	1.005	284.6407	NA	NA
2018	27.335	0.3841	94.878	101.25	0.9318	279.02	NA	NA
2019	28.256	0.2696	104.314	100	0.8814	311.12	NA	NA
2020	35.567	0.1994	113.868	117	0.7784	340.900959	NA	NA
2021	30.386	0.284367	NA	108	0.94	NA	NA	NA

[1] 'effective cod biomass' was not an input data series in 2021; 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 2014–2020 were adjusted for incomplete coverage of offshore strata.
[4] estimates of cod biomass and overlap factor are based on average of the most 3 recent years.

Table 2. *Pandalus borealis* in West Greenland: summary of estimates of selected parameters from Bayesian fitting of a surplus production model, 2021.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2020)
Max.sustainable yield	137.3	62.9	102.1	123.4	154.6	95.6	123.0
B/Bmsy, end current year (proj.)(%)	126.2	35.3	100.7	123.2	148.0	117.2	122.5
Biomass risk, end current year(%)	24.4	43.0	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	55.6	81.8	110.6	–	89.3
Carrying capacity	3559	1972	2040	3048	4544	2026	2896
Max. sustainable yield ratio (%)	9.4	4.7	5.9	8.8	12.4	7.5	9.0
Survey catchability (%)	17.3	11.1	9.1	14.5	22.7	8.9	15.4
CPUE(1) catchability	1.0	0.6	0.5	0.8	1.3	0.5	0.9
CPUE(2) catchability	1.6	1.0	0.8	1.3	2.1	0.8	1.4
Effective cod biomass 2021 (Kt)	10.5	49.1	-2.2	6.0	17.7	-3.0	7.0
$P_{50\%}$ (prey biomass index with consumption 50% of max.)	4.5	11.3	0.2	1.3	4.7	-5.2	1.3
V_{max} (maximum consumption per cod)	1.9	2.2	0.4	0.9	2.5	-1.0	0.9
CV of process (%)	12.8	2.8	10.9	12.6	14.6	12.2	13.0
CV of survey fit (%)	18.0	3.2	15.7	17.7	19.8	17.1	17.2
CV of CPUE (1) fit (%)	7.0	1.5	5.9	6.7	7.8	6.1	6.7
CV of CPUE (2) fit (%)	7.6	2.3	5.9	6.9	8.5	5.7	7.0

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2021.

	Start biom. ratio	*CV cpu*	*CV s*	*CV proc*	*Vmax*	*P50%*	*Qc1*	*Qc2*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield	25			12		5	-32	-32	-32	22	42
Carrying capacity	14			8	-12		-74	-74	-74	-66	
Max. sustainable yield ratio (%)					16		72	72	72		
Survey catchability (%)	-45			-14	19	-9	100	100			
CPUE catchability q1	-46			-13	19	-9	100				
CPUE catchability q2											
P50%	14				50						
Vmax	-12			-11							
CV of process (%)	10	-8	-29								
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 2022 assuming effective cod biomass 5 Kt, 6 Kt and 7Kt.

Catch	5 Kt		6 Kt		7 Kt	
(Kt/yr)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
95	19.4	19.6	19.7	20.7	20.1	20.4
100	22.9	23.6	23.3	24.1	23.5	23.9
105	26.1	27.4	26.4	27.2	26.7	28.2
110	29.4	30.4	29.7	30.7	30.1	31.2
115	33.1	34.1	33.4	34.9	33.7	34.5
120	36.2	37.4	36.6	38.0	37.0	37.4
125	39.5	40.9	39.8	41.1	40.3	41.9
130	43.0	43.8	43.4	43.9	43.8	45.1

Table 5. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2022 – 2024 and of falling below B_{msy} or limit* biomass at the end of 2022 – 2024 assuming effective cod biomass 5 Kt, 6 Kt and 7 Kt.

5 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2022 (%)	25	26	26	26	26	27	28	28
falling below Bmsy end 2023 (%)	26	27	27	28	28	29	31	31
falling below Bmsy end 2024 (%)	26	27	29	29	30	31	32	33
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2024 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2022 (%)	19	23	26	29	33	36	39	43
exceeding Zmsy in 2023 (%)	20	24	27	30	34	37	41	44
exceeding Zmsy in 2024 (%)	20	25	28	32	35	38	42	45
falling below Bmsy 80% end 2022 (%)	9	9	10	10	10	10	11	11
falling below Bmsy 80% end 2023 (%)	10	11	11	11	12	12	13	14
falling below Bmsy 80% end 2024 (%)	12	12	12	13	14	14	16	16

* limit biomass is 30% of B_{msy}

6 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2022 (%)	26	26	26	26	28	27	27	27
falling below Bmsy end 2023 (%)	26	27	27	27	29	30	30	30
falling below Bmsy end 2024 (%)	26	28	28	29	30	32	32	34
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2024 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2022 (%)	20	23	26	30	33	37	40	43
exceeding Zmsy in 2023 (%)	21	24	27	31	35	38	41	44
exceeding Zmsy in 2024 (%)	21	25	28	31	35	38	42	45
falling below Bmsy 80% end 2022 (%)	9	10	10	10	10	11	10	11
falling below Bmsy 80% end 2023 (%)	10	11	11	11	13	13	13	14
falling below Bmsy 80% end 2024 (%)	11	12	12	13	14	16	16	16

* limit biomass is 30% of B_{msy}

7 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2022 (%)	25	26	27	27	27	27	28	28
falling below Bmsy end 2023 (%)	26	26	28	29	29	29	30	31
falling below Bmsy end 2024 (%)	26	27	28	29	30	31	33	34
falling below Blim end 2022 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
falling below Blim end 2024 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2022 (%)	20	24	27	30	34	37	40	44
exceeding Zmsy in 2023 (%)	20	24	28	31	35	37	42	45
exceeding Zmsy in 2024 (%)	21	25	28	33	36	39	43	46
falling below Bmsy 80% end 2022 (%)	9	10	10	10	11	10	11	11
falling below Bmsy 80% end 2023 (%)	10	11	11	12	12	12	13	14
falling below Bmsy 80% end 2024 (%)	11	12	13	13	14	15	16	17

* limit biomass is 30% of B_{msy}

Table 6. Model diagnostics: Residuals (% of observed value) and probability of getting a more extreme observation (Pr).

	Survey		CPUE1		CPUE2		Process error
Year	resid(%)	Pr	resid(%)	Pr	resid(%)	Pr	CV%
1976			2.671	0.6218			
1977			4.305	0.6962			
1978			-3.796	0.3396			
1979			-7.368	0.1938			
1980			5.746	0.7576			
1981			-7.741	0.178			
1982			9.206	0.861			
1983			-1.353	0.4348			
1984			-3.805	0.3314			
1985			0.2896	0.5178			
1986			-2.687	0.3748			
1987			9.957	0.8786			
1988	5.948	0.584	-5.417	0.256			
1989	11.43	0.7346	-2.769	0.379			
1990	15.76	0.7964	-2.685	0.3702			
1991	-20.75	0.1314	0.1571	0.5164			
1992	2.768	0.5654	1.914	0.5894			
1993	10.59	0.7132	-1.311	0.4366			
1994	11.59	0.7412	-3.139	0.3496			13.16
1995	-12.2	0.2628	2.208	0.6042			12.59
1996	-10.14	0.2916	3.892	0.6852			11.6
1997	-27.32	0.0756	-1.996	0.3966			11.3
1998	0.413	0.5124	1.979	0.6006			11.2
1999	-14.32	0.2182	1.878	0.586			11.7
2000	-4.497	0.3996	4.27	0.707			11.8
2001	-9.901	0.2988	-4.917	0.2756			11.6
2002	4.199	0.5872	-0.6541	0.478			11.9
2003	27.78	0.9188					13.2
2004	18.31	0.8096					13
2005	16.27	0.7798					12.79
2006	21.72	0.8644					12.54
2007	7.986	0.6482			-8.436	0.1788	14.96
2008	-8.893	0.3254			3.878	0.6726	15.5
2009	-7.149	0.3624			-1.388	0.431	15.47
2010	17.37	0.8196			-3.106	0.3532	14.84
2011	-5.642	0.3736			4.686	0.7102	14.47
2012	-31.1	0.0532			4.539	0.6956	14.86
2013	-3.794	0.4368			-2.171	0.4036	14.4
2014	-30.57	0.0512			3.087	0.6464	14.26
2015	4.23	0.5828			1.521	0.5718	13.71
2016	-26.86	0.0764			0.4026	0.5156	13.54
2017	1.321	0.538			6.261	0.7582	13.68
2018	-0.9099	0.4812			-1.203	0.4358	13.2
2019	14.5	0.7856			-1.502	0.4362	13.8
2020	26.09	0.9074			-9.377	0.1414	13
2021	-5.1E-05	0.489			5.809	0.6844	12.6

Figures

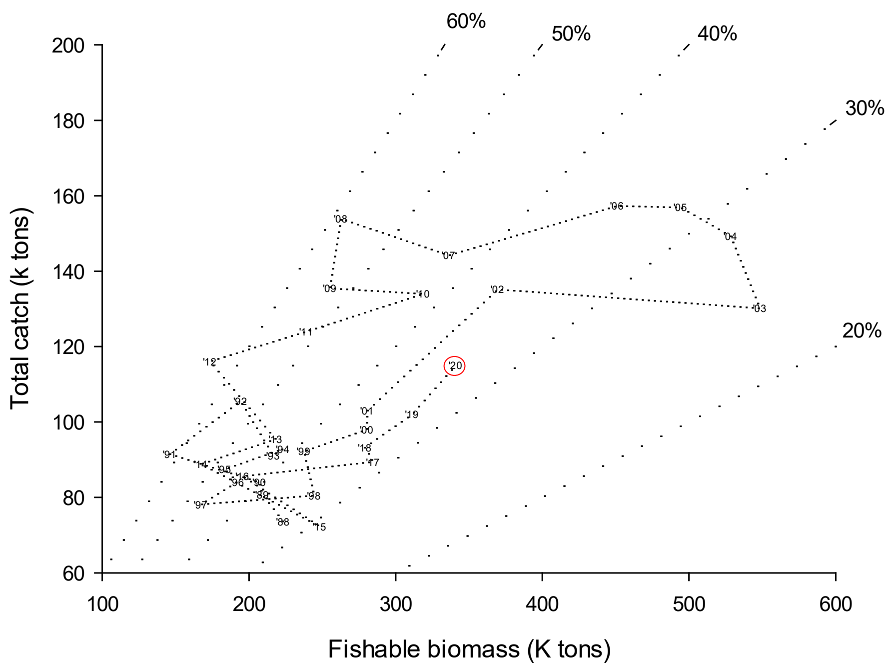

Figure 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1976–2020 (2020 catch is provisional). *This figure is not updated in 2021 due to the lack of new survey data.*

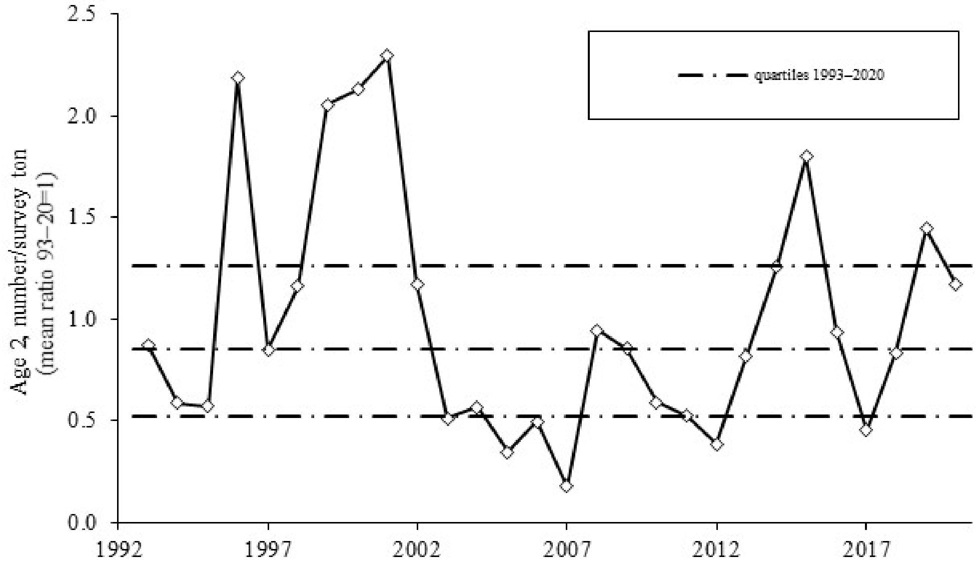

Figure 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1996–2020. *This figure is not updated in 2021 due to the lack of new survey data*

Figure 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1996–2020. *This figure is not updated in 2021 due to the lack of new survey data*

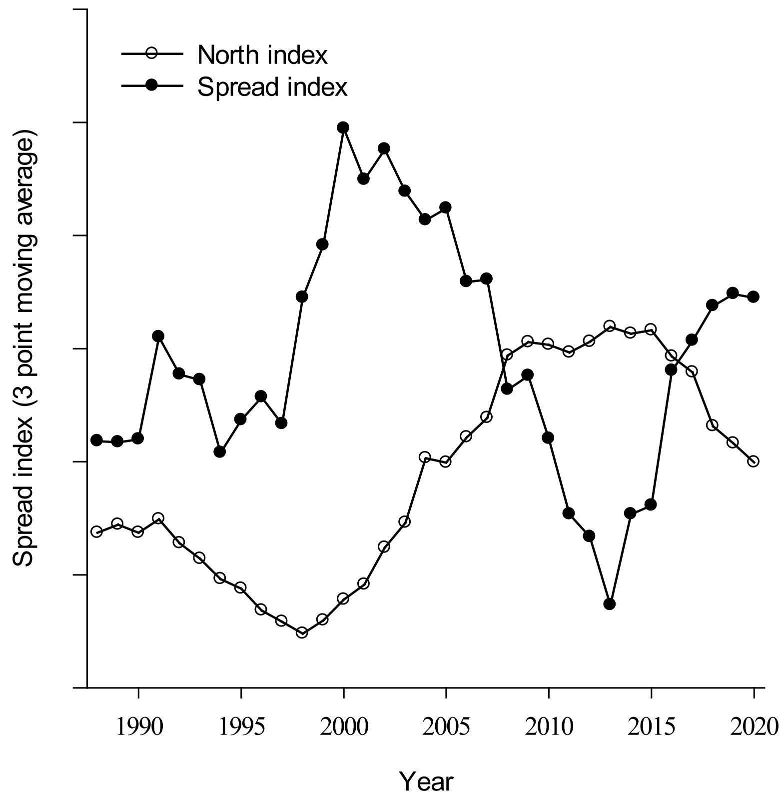

Figure 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2020 (3-point moving means). *This figure is not updated in 2021 due to the lack of new survey data*

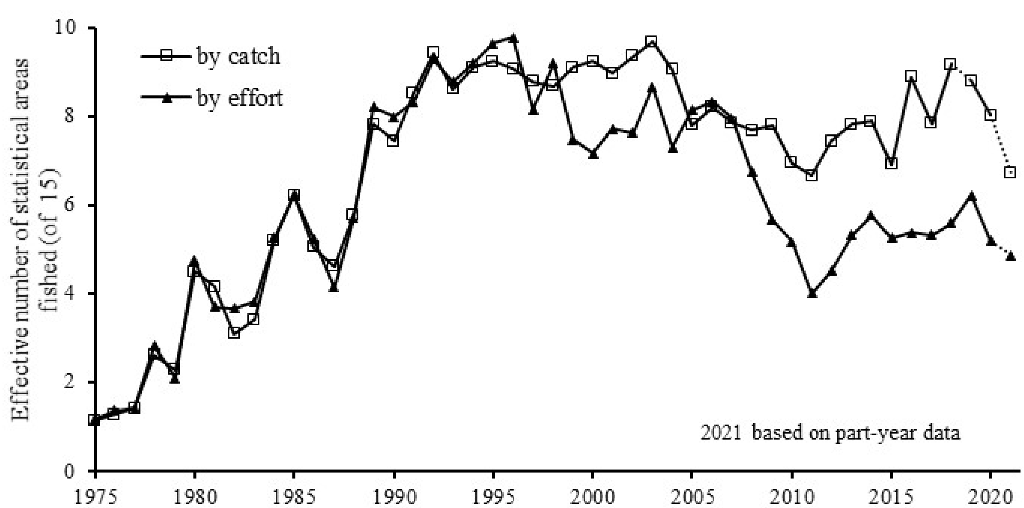

Figure 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2021. (2021 is preliminary data).

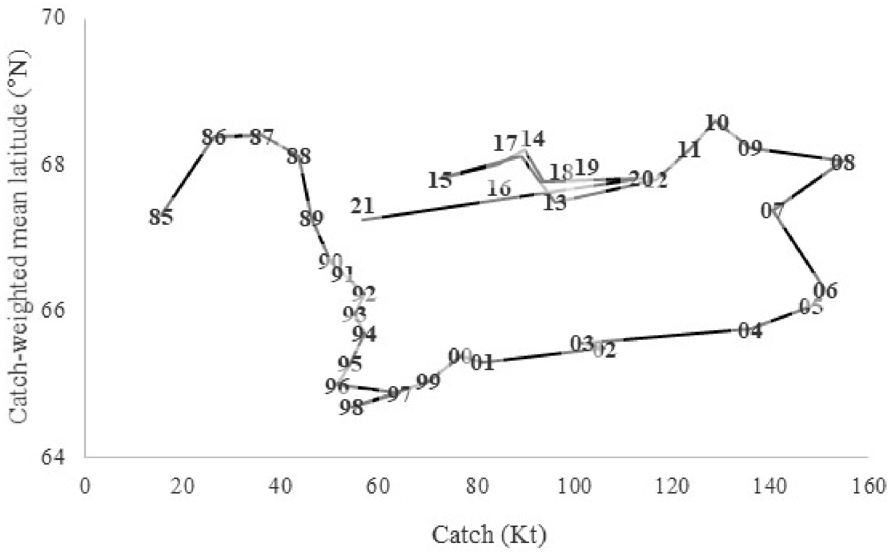

Figure 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1985–2021 (2021 is only preliminary catch).

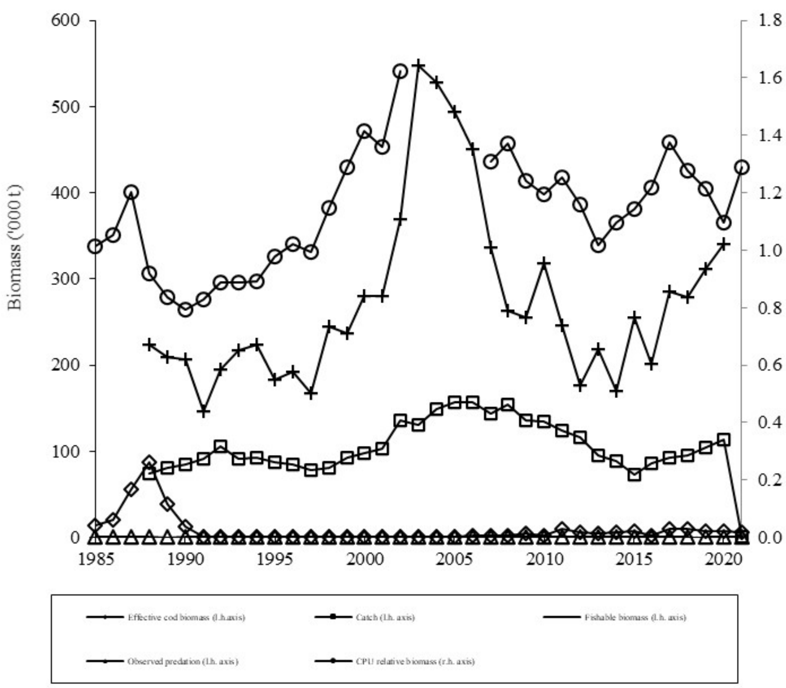

Figure 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2021 catch is projected; effective cod biomass is synthesized from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

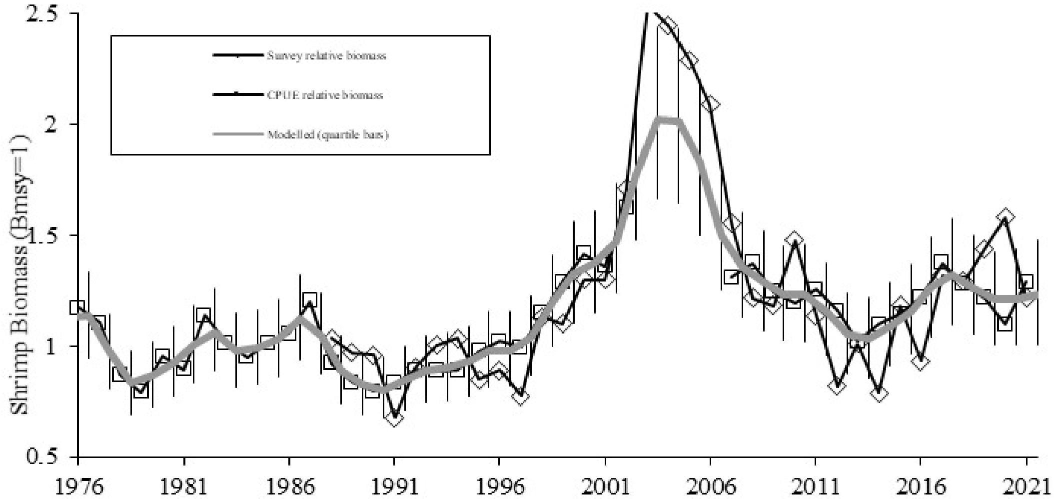

Figure 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2021.

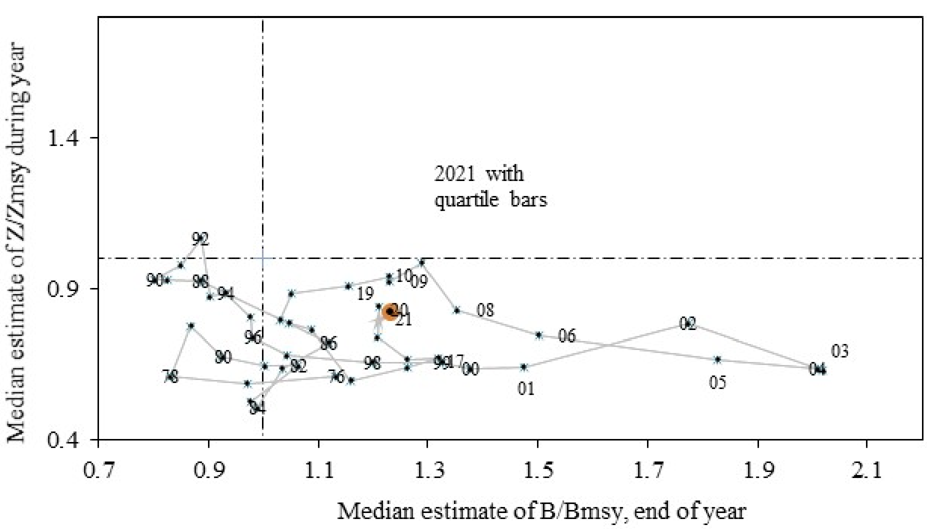

Figure 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1976–2021.

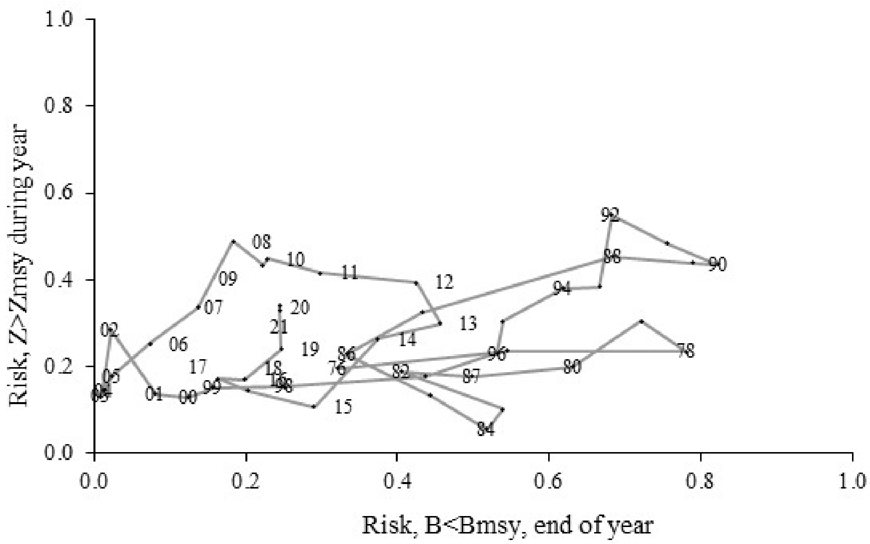

Figure 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1976–2021.

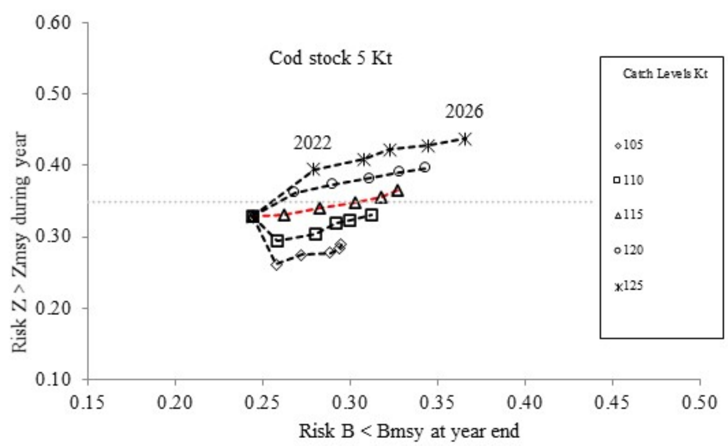

Figure 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2022–26 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 5 Kt.

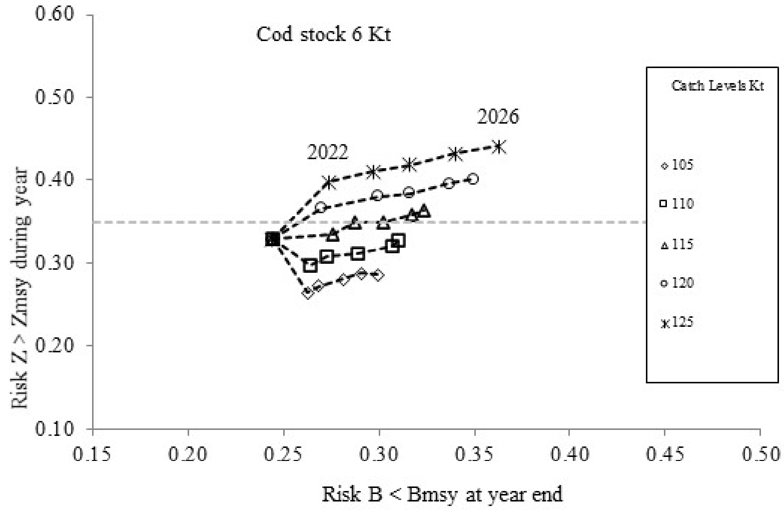

Figure 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2022–26 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 6 Kt.

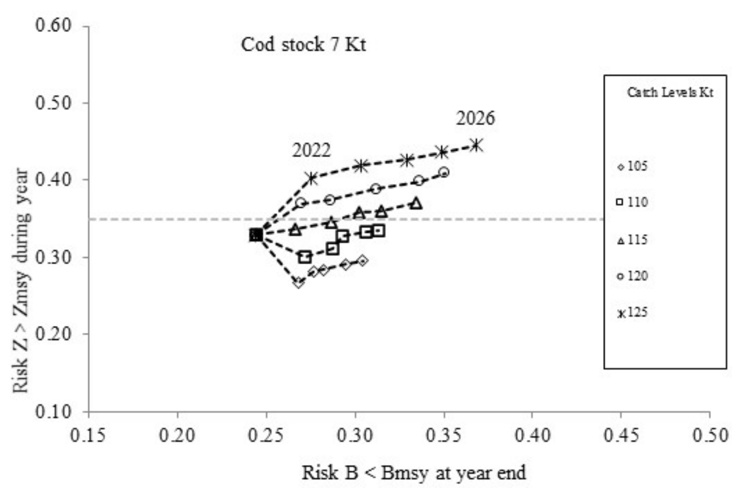

Figure 10c. *Pandalus borealis* in West Greenland: joint 5-year plot 2022–26 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 7 Kt.

Figure 11a. *Pandalus borealis* in West Greenland: projections of stock development for 2022–2026 with effective cod biomass assumed at 5 000 t: median estimates with quartile error bars.

Figure 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2022–2026 with effective cod biomass assumed at 6 000 t: median estimates with quartile error bars.

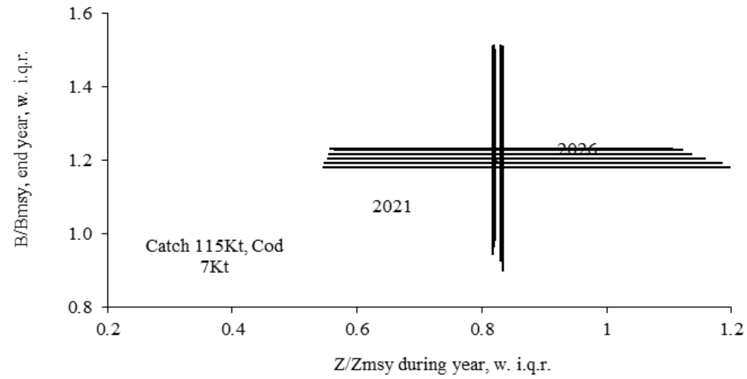

Figure 11c. *Pandalus borealis* in West Greenland: projections of stock development for 2022–2026 with effective cod biomass assumed at 7 000 t: median estimates with quartile error bars.

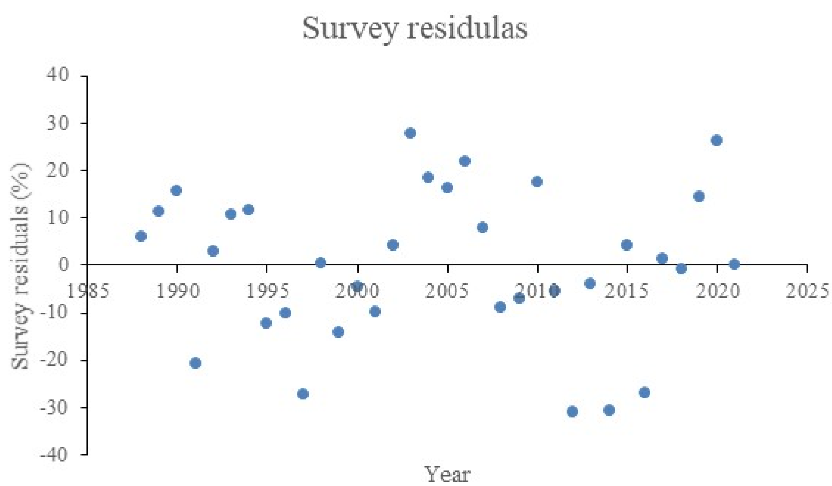

Figure 12a. Model diagnostics: Residuals of survey biomass (% of observed value) 1988 – 2021.

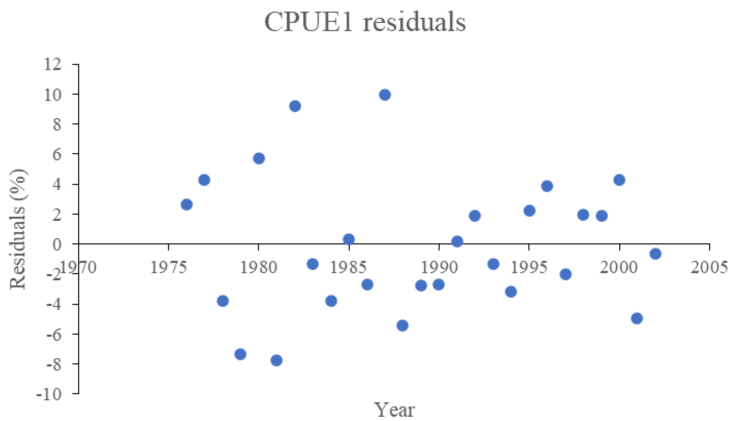

Figure 12b. Model diagnostics: Residuals of CPUE1 (% of observed value) 1976 – 2002.

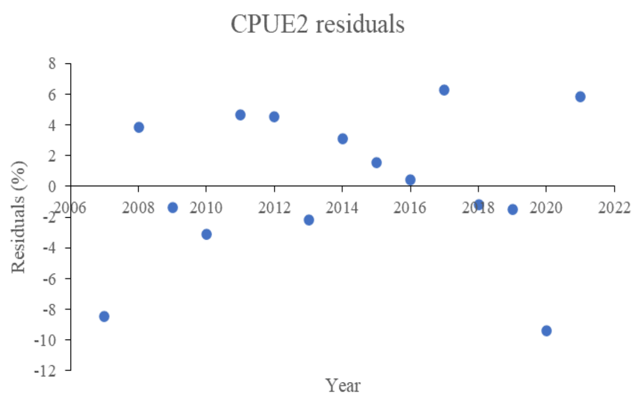

Figure 12c. Model diagnostics: Residuals of CPUE2 (% of observed value) 2007 – 2021.

Figure 12d. Model diagnostics: Process error of fit (CV of process (%) 1994 – 2021.