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A Provisional Assessment of the Shrimp Stock off West Greenland in 2022

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.

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 were CPUE increased and preliminary data for both fleet components indicating a comparable level in 2022.

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.

The 2022 survey was conducted with the new Greenlandic research ship r/v Tarajoq. The survey index of total biomass remained fairly stable from 1988 to 1997. It then increased until 2003. Subsequent values were consecutively lower, with the second lowest level in the last 21 years occurring in 2014. Over the past 5 years biomass has increased, dropped little in 2022, but remained comparable to the most recent years. In 2022 overall survey as well as fishable biomass is well below their 20-year median.

In offshore regions, fishable biomass is above the 20-year median, while inshore 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 fishable biomass in the offshore area and inshore are 83% and 17% respectively.

Proportion fishable of the survey biomass were in 2022 a little below the median for the last 20 years, owing to relatively large proportions of age-2 shrimps and pre-recruits in the stock, mainly in offshore regions. Both the proportion of females and males of fishable biomass are close to their 20-year median.

Overall, the number of age 2 shrimps, remained unchanged in 2022, 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. In 2020, inshore numbers of age 2 shrimps remained at a low level but is in 2022 increased to a value above the 20-year upper quartile. However, the number of age-2 shrimp declined in offshore regions and is in numbers and in relation to survey biomass well above the 20-year upper quartile.

The stock is in 2022 composed, despite a decline, by a relative high number of large pre-recruits 14.5–16 mm carapace length, almost only in offshore regions, where the numbers are above the 20-year median. Inshore, large pre-recruits were both in numbers and by survey biomass, at a record low value, below or close to their lower quartile respectively.

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 generating 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 shrimp 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. 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 Greenland survey act as tuning fleet in the SAM assessment. The survey has a coverage from NAFO Div. 1A in the north to Div. 1F in the south and covers the period from 1992 until today.

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.

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```
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
```

In 2022 the survey was conducted with the new research ship r/v Tarajoq, and the survey was performed as in all previous years. A more detailed description of the survey and results are found in (Burmeister et al 2022). Consequently, the standard model was used for 2022 assessment.

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 19 Kt tons. The median estimate for 2022 was 19 200 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; Burmeister at al. 2022).

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. From 2015 temperature have continuously declined to low at 2.1°C in 2018 but has since slightly raise each year to 3° in 2022. 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; Burmeister et al., 2022)). This move into shallower water looks like a continuing trend since the early 2000s.

Since 2019 the cod stock estimation was done by a state-space model (SAM) (Rigét & Burmeister,2020; Nielsen &Berg, 2014). The SAM model includes catch-at-age date from the commercial fishery and the Greenlandic survey catch-at-age data as the tuning fleet (Burmeister & Rigét, 2021). Catches from the commercial fishery were low and mainly restricted to NAFO Div. 1F. No biological samples have been taken in 2021 and 2022 (Retzel, 2022) therefore input to SAM where set to missing. No survey was performed in 2021 and the survey data from 2022 were used for input data for both 2021 and 2022. The cod stock biomass has been increasing since 2017 and was estimated to 67 000 t in 2022 and composed of many year-classes. This estimate is considered uncertain because of the lack of input data for both the commercial fishery (2021 and 2022) and the survey data (2021). The cod biomass is mainly distributed in southern regions of West Greenland where there is a lower density of shrimps, and the 'effective' cod stock appeared to be low.

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 0.417. 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). Despite the increased cod biomass in 2022, the overlap between cod and shrimp changes only little to 0.301, and 2022 'effective' cod is estimated to 19.2 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

The survey index of total biomass remained fairly stable from 1988 to 1997. It then increased until 2003. Subsequent values were consecutively lower, with the second lowest level in the last 21 years occurring in 2014 (Figure 6). Over the past 5 years biomass has increased, dropped little in 2022, but remained comparable to the most recent years. In 2022 overall survey as well as fishable biomass is well below their 20-year upper quartile. The number and biomass of males and females are little lower than 2020 values. 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
2022 value[1]	55.5	291.0	346.5	315.0	134.2	57.4	14.9	10.2
20-year[2] upper quartile	93.2	329.0	406.0	355.2	141.3	73.0	16.0	6.6
20-year median	83.8	239.5	319.9	284.6	122.4	52.9	13.5	5.1
20-year lower quartile	71.1	191.7	273.1	250.4	102.9	39.5	11.9	4.1
2022 rank	2.3	16.6	12.1	11.5	13.2	13.2	12.9	16.4
2020 value	67.3	324.5	391.8	340.9	145.9	67.7	15.9	10.1

[1] survey estimates of stock size for 2011, 2012, 2014, 2018, 2019, 2020 and 2022 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 decreased by 18% from 2020 to a 2022, and remain 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, increases until 2020 to value above its 20-year upper quartile, dropped in 2022 but still at a value above its past 20-year median. 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 in 2022, were considerably lower than the past two years and at their 20-year median, absolute number at age 2, remained stable in absolute numbers but increases in numbers of survey tons 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
2022 value	29.5	26.5	90.9	52.2	38.7	42.6
20-year[1] upper quartile	22.4	37.6	92.9	56.6	41.2	45.1
20-year median [1]	17.4	26.4	91.7	52.9	37.7	41.7
20-year lower quartile[1]	10.7	23.2	90.0	49.3	35.6	39.1
2022 rank[1]	17.5	11.1	6.7	8.6	11.0	10.8
2020 value	25.8	42.8	87.0	49.8	37.2	42.8

[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 2022 is marked, by a high proportion of males in the survey and in the fishable biomass and is at its 20-year median; females has composed a lower proportion of the fishable biomass in the most recent years but is still above its 20-year median. Relative to stock size the number of age-2 shrimps is above its 20-year upper quartile, and the relative number of large pre-recruits are, despite a decline in 2022 at the 20-year 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
2022 value	73.3	31.6	86.7	42.4	44.3	51.0
Upper quartile[1]	32.3	39.7	91.4	52.6	45.9	49.4
Median[1]	24.9	31.8	89.9	48.9	40.4	45.4
Lower quartile[1]	13.8	27.7	88.1	46.2	34.0	38.9
2022 rank[1]	20.0	9.9	21.0	1.8/16	10.6/16	14.1/16
2020 value	12.8	9.5	96.5	49.3	47.3	49.0

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 averaged 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 have over the past years been considerably higher in offshore regions compared to Disko Bay & Vaigat. However, in 2022 numbers of both age-2 shrimp, pre-recruits and females relative to biomass are considerable higher in Disko Bay & Vaigat compared to offshore regions. 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. While as this pattern contradicts size distribution from 2018 to 2020, it was true for 2022. Offshore stock still seems to be biased toward smaller shrimps (age-2, pre-recruits and fishable males).

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
2022 value	21.1	25.6	91.7	54.1	37.7	41.1
Upper quartile[1]	18.5	33.5	94.0	55.5	44.0	47.5
Median[1]	11.9	24.1	92.8	53.3	38.3	41.8
Lower quartile[1]	7.4	20.4	90.9	48.5	36.5	39.6
2022 rank[1]	16.2	11.4	6.3	10.1/16	8.1/16	7.5/16
2020 value	28.1	49.8	85.0	49.4	35.2	41.3

[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 below the 20-year lower quartile, but offshore well above the 20-year median and mean. While both fishable-male and fishable-female proportions of the survey biomass are close to the 20-year median offshore, inshore, fishable shrimps is a little below the 20-year lower quartile, with an increasing proportion of shrimps below the fishable size (17 mm CL) in 2022.

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 2005–2022 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/W10	Distribution Index	Disko B. and Vaigat
2022 value	37.3	36.2	16.6	9.9	0.1	19.9	16.6
20-year[1] upper quartile	34.9	35.8	22.4	22.5	1.7	42.5	29.8
20-year[1] median	30.1	33.1	18.9	13.2	0.4	34.3	25.6
20-year[1] lower quartile	22.9	30.8	16.6	8.4	0.1	24.9	19.9
2022 rank	15.3	14.6	5.5	7.0	6.4	2.6	2.6
2020 value	28.6	28.2	18.1	25.0	0.1	21.3	17.8

[1] percentiles and 2022 rank are referred to the 20 preceding years, i.e. 2000–2022.
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 in total more than the half of the total biomass. Even biomass since 2020 have been increasing in W4 (Holsteinsborg Dyb) the proportion of biomass in W3-W4 was below its 20-year lower quartile. In the central regions (W5-W6) a larger proportion of biomass have been observed over the past three years but declined in 2022 and is well below the 20-year median (Burmeister and Rigét, 2020a, Burmeister et al., 2022). 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 both 2020 and 2022.

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 increase again in 2021 and remain almost stable in 2022 (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, Burmeister 2022).

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 125.4 Kt with quartiles at 103.9 and 149.7 Kt; an estimated mode is at 120 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 2022 is estimated to be a bit higher but close to the 2021 value and 25,4% above B_{msy}. With a low effective cod biomass at 19 Kt and catches projected at 120 000 t, total mortality in 2022 is estimated to be below the MSY level and the mortality risk at 35% exceeds a management threshold of 43.2%.

Table: *P. borealis* in West Greenland: model estimates of stock status at end of, or during, 2022.

Biomass ratio *B/Bmsy* (median estimate, %)	125.4
Prob. *B<Bmsy* (%)	21.8
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	92.4
Prob. *Z>Zmsy* (%)	43.2
Prob. *B<Bmsy80%* (%)	6.3

Risks associated with eight possible catch levels for 2022, with an 'effective' cod stock at 18 000 t, 19 000 t and 20 000 t, are estimated to be:

18 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2023 (%)	23.3	24.1	24.2	24.8	25.0	25.6	25.9	25.9
falling below Blim end 2023 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2023 (%)	21.6	24.9	28.6	31.9	35.6	39.2	42.3	45.2
exceeding Zmsy in 2024 (%)	21.9	25.7	29.3	33.6	36.9	40.6	43.6	47.0
falling below Bmsy 80% end 2023 (%)	7.5	8.3	8.2	8.4	9.0	9.1	8.9	9.3

19 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2023 (%)	23.6	23.5	23.4	24.9	25.3	25.3	26.2	25.6
falling below Blim end 2023 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2023 (%)	21.9	25.4	28.9	32.3	36.0	39.4	42.5	45.5
exceeding Zmsy in 2024 (%)	22.5	26.2	29.8	33.5	37.6	40.5	43.6	47.0
falling below Bmsy 80% end 2023 (%)	7.6	7.7	7.9	8.3	9.0	8.6	9.3	8.8

20 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2023 (%)	23.5	23.8	24.0	24.5	25.3	25.5	26.2	26.4
falling below Blim end 2023 (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
exceeding Zmsy in 2023 (%)	22.3	25.8	29.4	32.8	36.3	39.6	42.9	45.8
exceeding Zmsy in 2024 (%)	22.3	27.0	30.2	34.0	37.1	41.1	44.2	46.8
falling below Bmsy 80% end 2023 (%)	7.8	7.7	8.0	8.6	9.2	8.7	9.3	9.7

With a mortality risk (i.e. that estimated 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 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. 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 2022. 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.

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Table 1. *Pandalus borealis* in West Greenland: input data series 1976–2022 for stock-dynamic assessment model.

1976	118.991	0.579	51.6	NA	0.391	NA	NA	NA
1977	133.622	0.574	42.3	NA	0.3266	NA	NA	NA
1978	93.469	0.672	42.8	NA	0.09158	NA	NA	NA
1979	92.435	0.67	55.9	NA	-0.00965	NA	NA	NA
1980	60.655	0.68	53.8	NA	0.1752	NA	NA	NA
1981	67.757	0.619	54.3	NA	0.1187	NA	NA	NA
1982	94.373	0.518	56.2	NA	0.3614	NA	NA	NA
1983	56.408	0.461	52.8	NA	0.2355	NA	NA	NA
1984	20.257	0.479	52.8057	NA	0.1752	NA	NA	NA
1985	29.495	0.482	66.2079	NA	0.2418	NA	NA	NA
1986	41.27	0.51	76.9	NA	0.2809	NA	NA	NA
1987	90.575	0.604	77.391	NA	0.4131	NA	NA	NA
1988	132.669	0.618	73.616	NA	0.1451	223.1907	NA	NA
1989	102.355	0.37	80.671	NA	0.04926	208.9535	213.7	470.919
1990	42.221	0.289	83.97	NA	0	207.0053	27.8	184.1405
1991	2.061	0.313	91.489	NA	0.04502	146.0081	2.7	19.7905
1992	0.354	0.523	105.487	NA	0.1124	194.1563	0.8	2.8785
1993	0.154	0.6455	91.013	NA	0.1095	216.4703	NA	NA
1994	0.07	0.599	92.805	NA	0.1138	223.1433	NA	NA
1995	0.06	0.483	87.388	NA	0.2074	183.2427	NA	NA
1996	0.037	0.28	84.095	NA	0.249	192.0819	NA	NA
1997	0.05	0.49	78.128	NA	0.224	167.0946	NA	NA
1998	0.06	0.39	80.495	NA	0.3646	244.2933	NA	NA
1999	0.093	0.496	92.198	NA	0.484	237.2942	NA	NA
2000	0.228	0.643	97.968	NA	0.5779	280.336	NA	NA
2001	0.294	0.462	102.926	NA	0.5387	280.4643	NA	NA
2002	0.717	0.278	135.172	NA	0.7149	369.4608	NA	NA
2003	1.204	0.398	130.173	NA	0.7968	548.2839	NA	NA
2004	3.871	0.257	149.332	141	0.8878	528.3298	NA	NA
2005	4.786	0.074	156.899	140.5	0.9207	494.2	NA	NA
2006	6.99	0.22	157.315	140.2	0.9242	451	NA	NA
2007	11.759	0.139	144.19	135.2	0.9532	336.1	NA	NA
2008	11.539	0.156	153.889	131.6	1.001	262.6	NA	NA
2009	7.256	0.602	135.458	108.8	0.9024	255.1	NA	NA
2010	5.276	0.315	133.99	138.5	0.8628	318.7	NA	NA
2011	10.883	0.888	123.985	126	0.9108	245.69	NA	NA
2012	17.645	0.305	115.975	110	0.8332	176.44	NA	NA
2013	19.952	0.206	95.381	100	0.7034	218.1	NA	NA
2014	27.679	0.211	88.765	90	0.7753	170.01	NA	NA
2015	33.276	0.2046	72.256	65	0.821	255.54	NA	NA
2016	31.799	0.079	85.527	82	0.8808	201.3461	NA	NA
2017	26.948	0.373	92.37	90	0.9979	284.6407	NA	NA
2018	27.635	0.3841	94.878	101.25	0.9269	279.02	NA	NA
2019	27.436	0.2696	104.314	100	0.8644	311.12	NA	NA
2020	32.311	0.1994	113.758	117	0.7617	340.900959	NA	NA
2021	59.24	0.2844	114.569	108	0.8946	NA	NA	NA
2022	65.084	0.3013	NA	120	0.8694	314.999	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, 2022.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2021)
Max.sustainable yield	137.7	60.0	103.9	124.5	155.6	98.1	123.4
B/Bmsy, end current year (proj.)(%)	128.1	34.6	102.7	125.4	149.7	120.0	123.2
Biomass risk, end current year(%)	21.8	41.3	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	64.2	92.4	124.4	–	81.8
Carrying capacity	3601	2030	2064	3047	4592	1939	3048
Max. sustainable yield ratio (%)	9.5	4.9	6.0	8.8	12.4	7.4	8.8
Survey catchability (%)	17.5	11.5	9.1	14.3	23.2	7.8	14.5
CPUE(1) catchability	1.0	0.7	0.5	0.8	1.3	0.5	0.8
CPUE(2) catchability	1.6	1.0	0.8	1.3	2.1	0.7	1.3
Effective cod biomass 2022 (Kt)	25.6	51.9	14.5	19.2	24.7	6.4	6.0
$P_{50\%}$ (prey biomass index with consumption 50% of max.)	4.3	7.4	0.2	1.3	4.9	-4.6	1.3
V_{max} (maximum consumption per cod)	2.0	2.3	0.4	0.9	2.7	-1.2	0.9
CV of process (%)	12.7	2.7	10.8	12.4	14.3	12.0	12.6
CV of survey fit (%)	18.2	3.1	16.1	17.8	20.0	17.1	17.7
CV of CPUE (1) fit (%)	7.0	1.4	5.9	6.7	7.8	6.2	6.7
CV of CPUE (2) fit (%)	7.2	2.1	5.7	6.6	8.1	5.5	6.9

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2022.

	Start biom. ratio	*CV cpu*	*CV s*	*CV proc*	*Vmax*	*P50%*	*Qc1*	*Qc2*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield	27			13			-32	-32	-32	20	37
Carrying capacity	13			8	-13		-74	-74	-74	-69	
Max. sustainable yield ratio (%)		-5			16		75	75	75		
Survey catchability (%)	-43			-14	20	-7	100	100			
CPUE catchability q1	-44			-13	20	-7	100				
CPUE catchability q2											
P50%	15				70						
Vmax	-14			-11							
CV of process (%)	12	-7	-28								
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 2023 assuming effective cod biomass 18 Kt, 19 Kt and 20 Kt.

Catch	18 Kt		19 Kt		20 Kt	
(Kt/yr)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
95	20.5	21.9	21.9	22.5	22.3	22.3
100	23.6	25.7	25.4	26.2	25.8	27.0
105	27.4	29.3	28.9	29.8	29.4	30.2
110	30.8	33.6	32.3	33.5	32.8	34.0
115	34.2	36.9	36.0	37.6	36.3	37.1
120	37.8	40.6	39.4	40.5	39.6	41.1
125	41.3	43.6	42.5	43.6	42.9	44.2
130	44.3	47.0	45.5	47.0	45.8	46.8

Table 5. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2023 – 2025 and of falling below B_{msy} or limit* biomass at the end of 2023 – 2025 assuming effective cod biomass 18 Kt, 19 Kt and 20 Kt.

18 000 t cod	**Catch option ('000 tons)**							
Risk of:	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**
falling below Bmsy end 2023 (%)	23	24	24	25	25	26	26	26
falling below Bmsy end 2024 (%)	24	26	26	27	27	29	29	30
falling below Bmsy end 2025 (%)	26	27	29	29	30	31	32	33
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
falling below Blim end 2025 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2023 (%)	22	25	29	32	36	39	42	45
exceeding Zmsy in 2024 (%)	22	26	29	34	37	41	44	47
exceeding Zmsy in 2025 (%)	22	27	31	34	38	41	45	48
falling below Bmsy 80% end 2023 (%)	8	8	8	8	9	9	9	9
falling below Bmsy 80% end 2024 (%)	9	10	10	10	11	11	12	13
falling below Bmsy 80% end 2025 (%)	10	11	12	13	13	14	15	16

* limit biomass is 30% of B_{msy}

19 000 t cod	**Catch option ('000 tons)**							
Risk of:	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**
falling below Bmsy end 2023 (%)	24	24	23	25	25	25	26	26
falling below Bmsy end 2024 (%)	25	25	26	27	28	29	30	29
falling below Bmsy end 2025 (%)	25	27	27	29	30	32	33	33
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
falling below Blim end 2025 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2023 (%)	22	25	29	32	36	39	43	46
exceeding Zmsy in 2024 (%)	22	26	30	33	38	40	44	47
exceeding Zmsy in 2025 (%)	23	27	30	34	38	42	45	49
falling below Bmsy 80% end 2023 (%)	8	8	8	8	9	9	9	9
falling below Bmsy 80% end 2024 (%)	9	9	10	11	11	11	13	12
falling below Bmsy 80% end 2025 (%)	10	11	12	13	14	13	16	16

20 000 t cod	Catch option ('000 tons)							
Risk of:	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**
falling below Bmsy end 2023 (%)	23	24	24	25	25	25	26	26
falling below Bmsy end 2024 (%)	24	25	26	26	27	29	29	31
falling below Bmsy end 2025 (%)	26	27	28	28	30	31	33	33
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
falling below Blim end 2025 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2023 (%)	22	26	29	33	36	40	43	46
exceeding Zmsy in 2024 (%)	22	27	30	34	37	41	44	47
exceeding Zmsy in 2025 (%)	23	27	31	35	38	42	46	49
falling below Bmsy 80% end 2023 (%)	8	8	8	9	9	9	9	10
falling below Bmsy 80% end 2024 (%)	9	10	10	11	11	12	12	13
falling below Bmsy 80% end 2025 (%)	10	11	11	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).

Model diagnostics							
	x 1000	x 2600	x 800	x 2500	x 800	x 2500	
	Survey		CPUE1		CPUE2		Process er
Year	resid(%)	Pr	resid(%)	Pr	resid(%)	Pr	
1976			2.889	0.6242			-0.01414
1977			4.269	0.6896			-0.1537
1978			-3.483	0.3358			-0.1698
1979			-7.4	0.197			0.01073
1980			5.787	0.7562			0.02754
1981			-7.591	0.1838			0.04472
1982			9.576	0.8678			0.03483
1983			-1.523	0.4328			-0.1175
1984			-3.546	0.3408			-0.03561
1985			-0.09044	0.5108			0.01234
1986			-2.634	0.3678			0.06132
1987			9.846	0.8902			-0.07003
1988	6.005	0.5884	-5.277	0.2568			-0.1453
1989	11.72	0.7252	-2.569	0.362			-0.08633
1990	15.51	0.7982	-2.777	0.3494			-0.04947
1991	-20.78	0.141	0.0856	0.5114			0.03519
1992	2.615	0.563	1.881	0.588			0.0381
1993	10.55	0.717	-1.219	0.455			-0.0073
1994	11.56	0.7452	-2.942	0.3528			0.0123
1995	-12.13	0.2538	2.236	0.6166			0.02648
1996	-10.09	0.2966	3.821	0.6794			-0.02243
1997	-27.26	0.077	-2	0.4016			0.03261
1998	0.2906	0.5168	1.739	0.5862			0.1068
1999	-14.55	0.2116	1.804	0.588			0.08648
2000	-4.742	0.4166	4.445	0.7136			0.03352
2001	-10.22	0.2848	-5.129	0.2696			0.07601
2002	4.102	0.5872	-0.6098	0.4752			0.2073
2003	28.2	0.9188					0.1642
2004	18.55	0.8044					0.05857
2005	16.63	0.7844					-0.02596
2006	21.86	0.8562					-0.1338
2007	7.163	0.6486			-7.735	0.1816	-0.06913
2008	-10.06	0.2996			4.124	0.6964	-0.01775
2009	-8.272	0.327			-1.113	0.4368	-0.02426
2010	16.16	0.8062			-2.737	0.3766	0.0149
2011	-7.059	0.3522			4.524	0.7146	-0.04345
2012	-32.6	0.05			4.264	0.6972	-0.09048
2013	-5.228	0.3972			-2.293	0.3914	-0.03548
2014	-31.98	0.0474			2.9	0.6386	0.03994
2015	2.857	0.5698			1.614	0.5586	0.03162
2016	-28.15	0.0776			0.4853	0.5208	0.06771
2017	0.2809	0.5176			5.943	0.7644	0.0378
2018	-1.44	0.4652			-0.5771	0.4642	-0.03967
2019	14.73	0.7856			-1.454	0.4462	-0.04897
2020	26.54	0.9134			-8.948	0.1422	0.0102
2021	0.2447	0.5066			1.776	0.5842	0.02257
2022	13.59	0.7482			-3.296	0.4046	0.02257

Figures

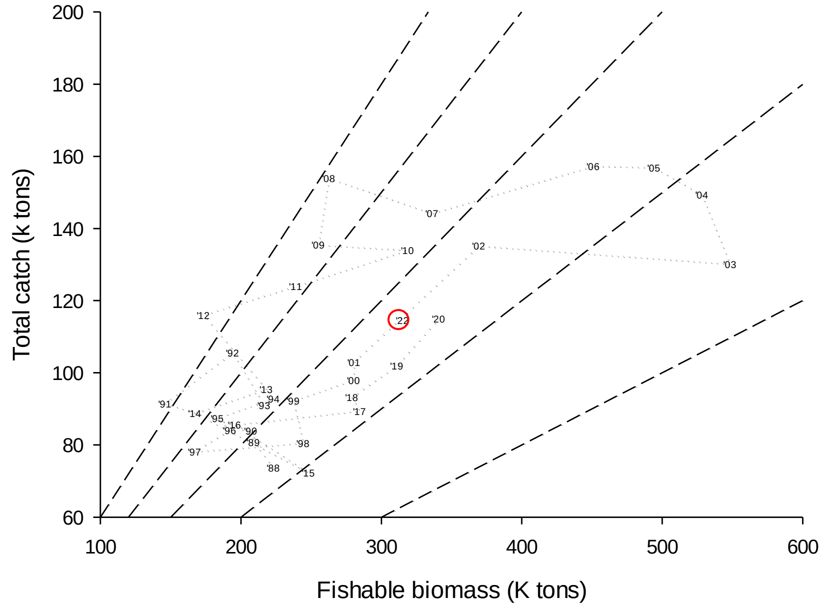

Figure 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1976–2022 (2022 catch is provisional).

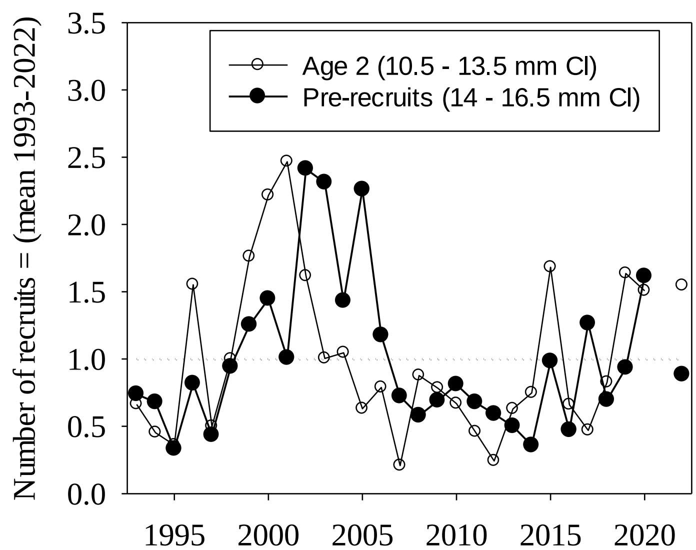

Figure 2. *Pandalus borealis* in West Greenland: number at age 2 and pre-recruits from research trawl survey, 1996–2022.

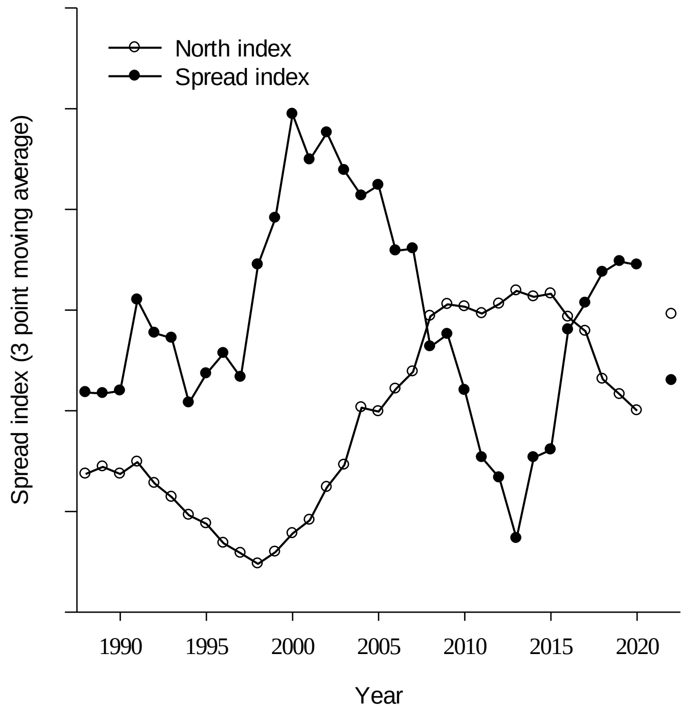

Figure 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2022 (3-point moving means).

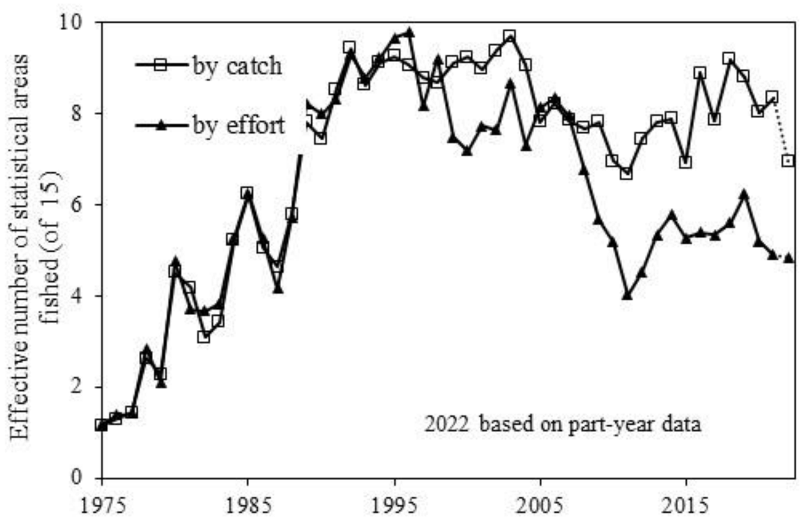

Figure 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2022. (2022 is preliminary data).

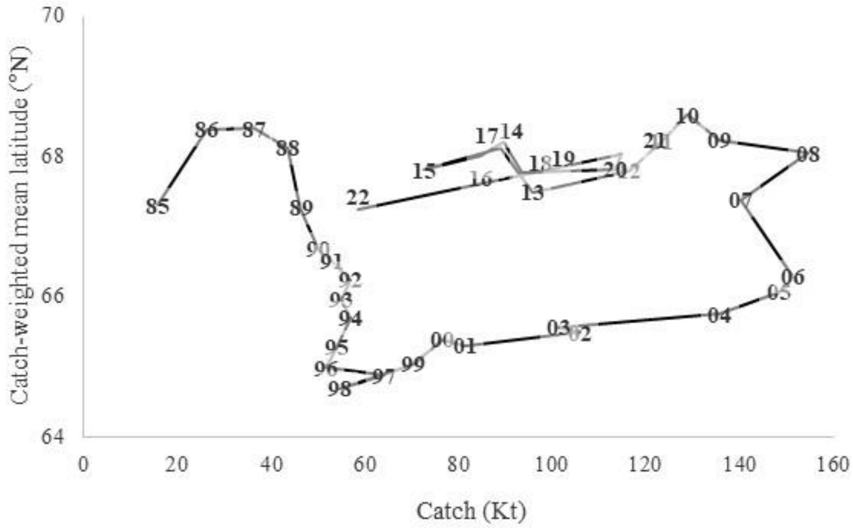

Figure 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1985–2022 (2022 is only preliminary catch).

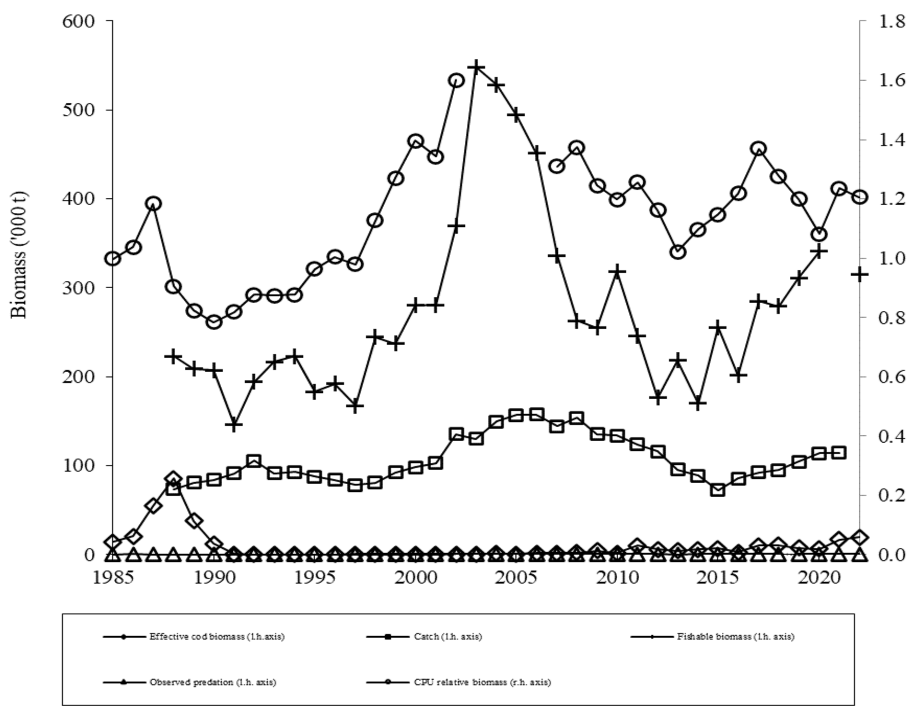

Figure 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2022 catch is projected; effective cod biomass is synthesized from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

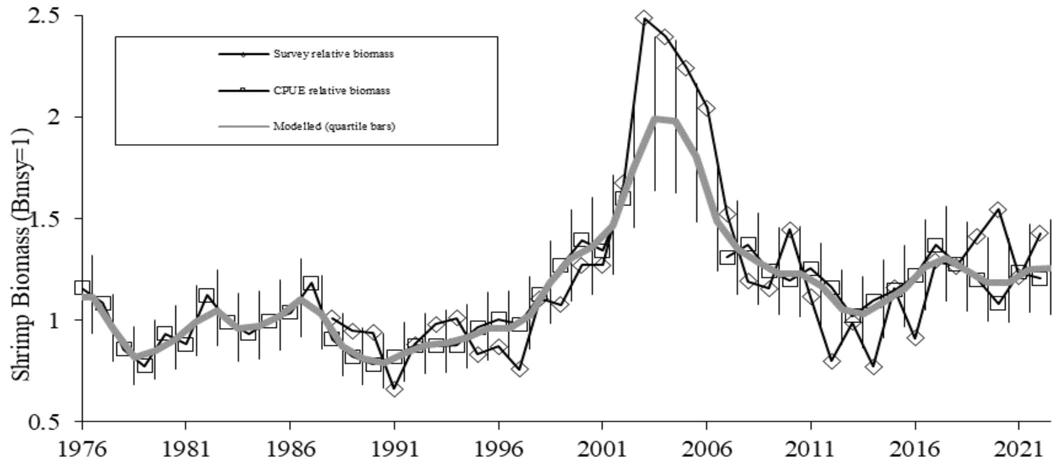

Figure 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2022.

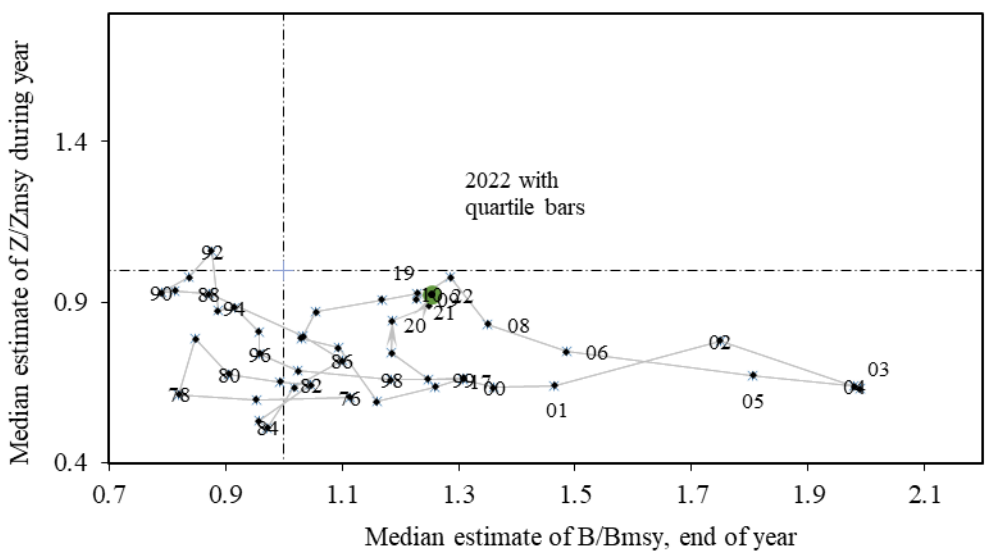

Figure 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1976–2022.

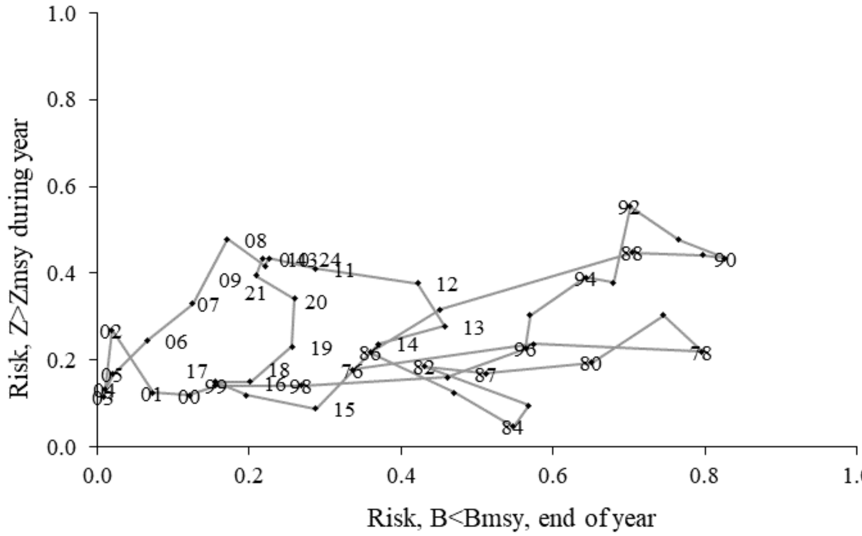

Figure 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1976–2022.

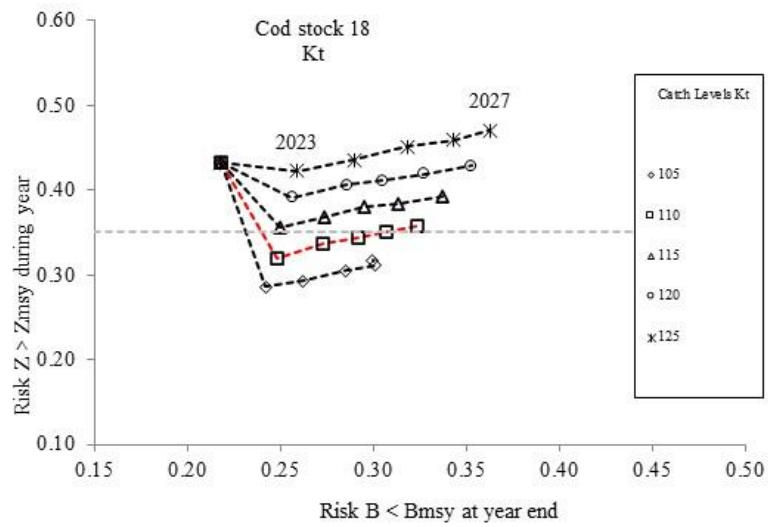

Figure 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2023–27 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–130 Kt/yr; with effective cod biomass 18 Kt.

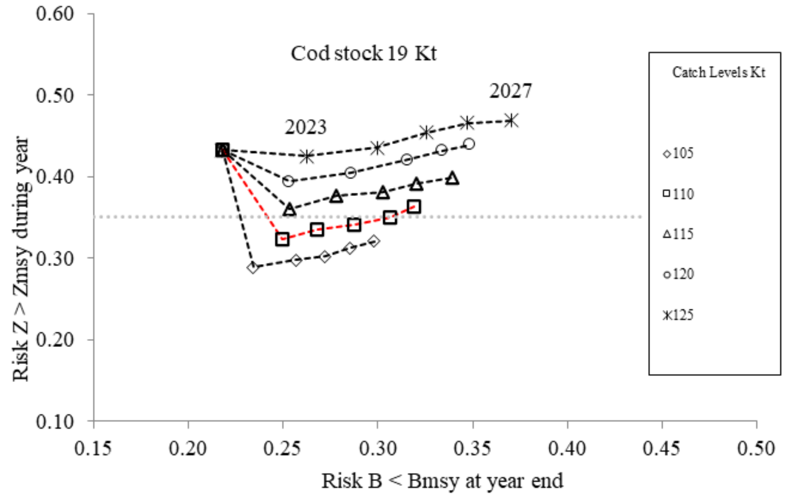

Figure 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2022–27 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–130 Kt/yr; with effective cod biomass 19 Kt.

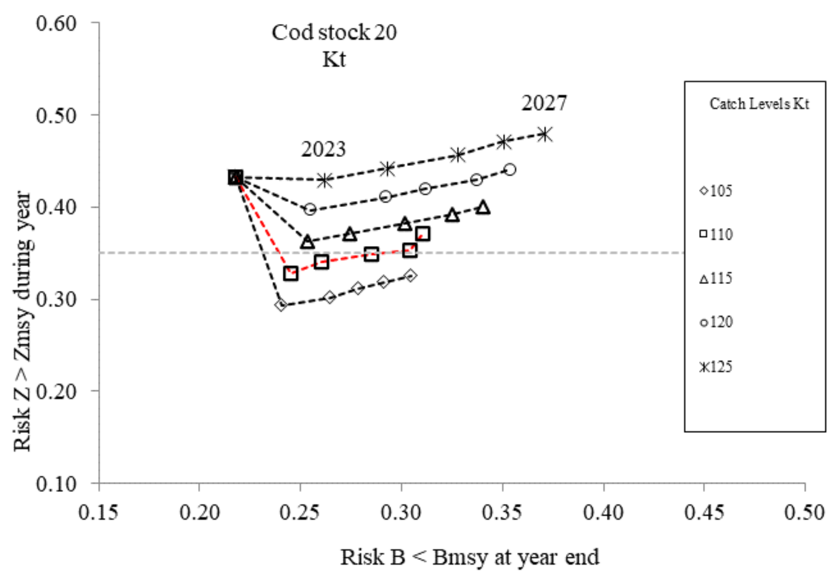

Figure 10c. *Pandalus borealis* in West Greenland: joint 5-year plot 2022–27 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–130 Kt/yr; with effective cod biomass 20 Kt.

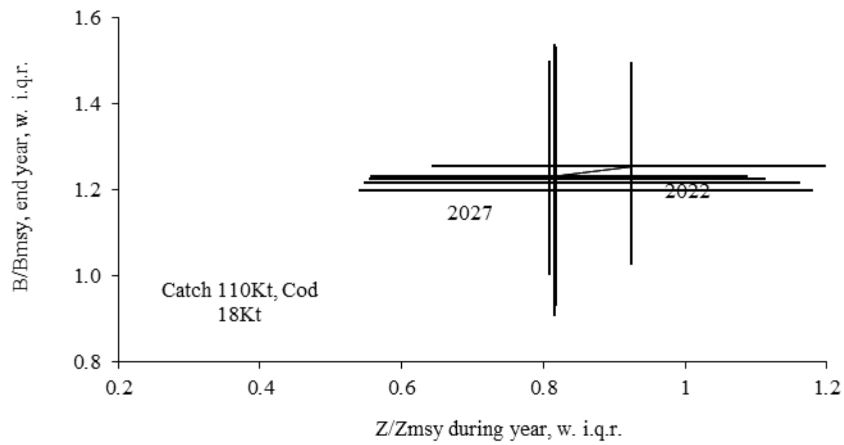

Figure 11a. *Pandalus borealis* in West Greenland: projections of stock development for 2023–2027 with effective cod biomass assumed at 18 Kt.

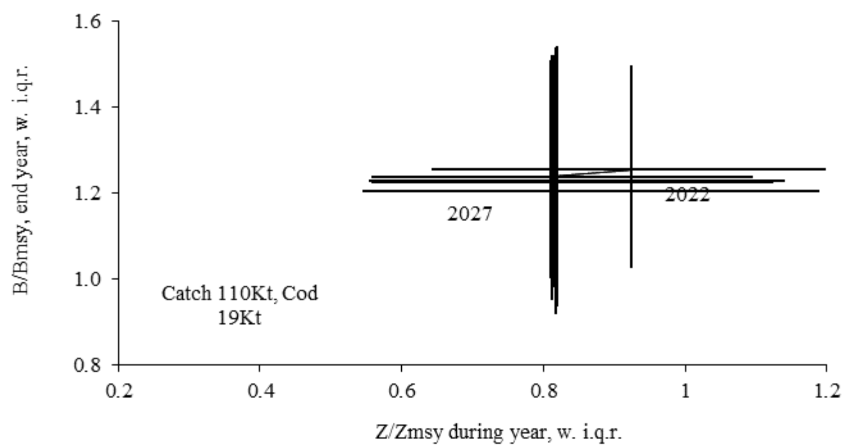

Figure 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2023–2027 with effective cod biomass assumed at 19 000 t: median estimates with quartile error bars.

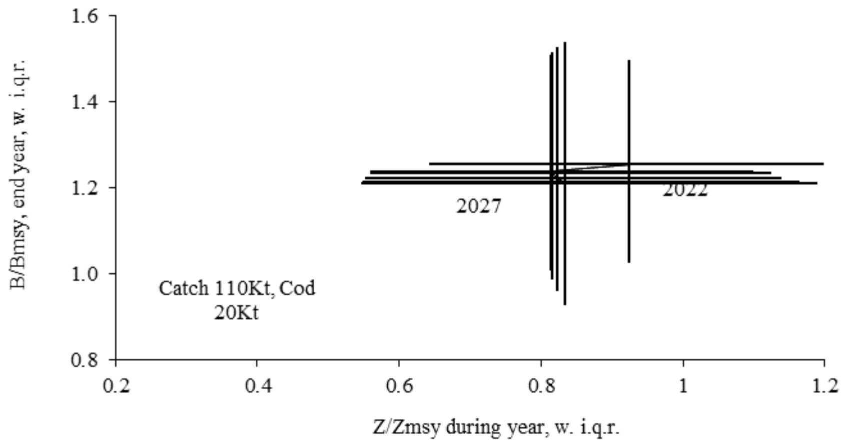

Figure 11c. *Pandalus borealis* in West Greenland: projections of stock development for 2023–2027 with effective cod biomass assumed at 20 000 t: median estimates with quartile error bars.

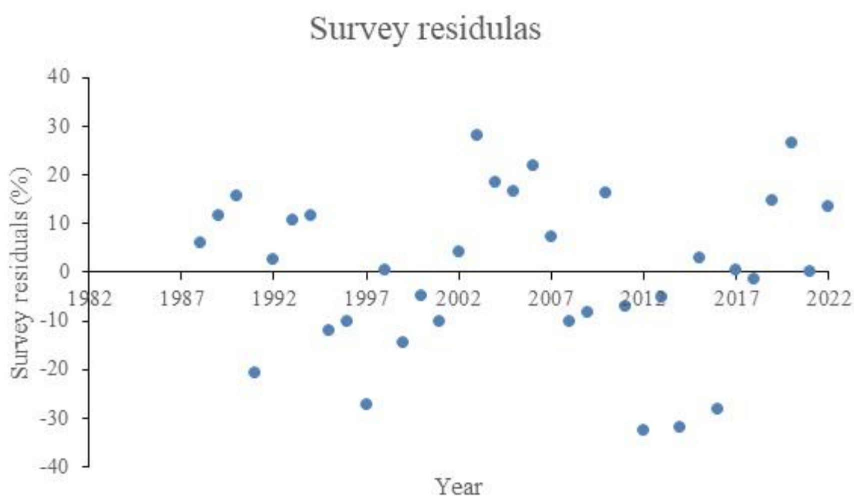

Figure 12a. Model diagnostics: Residuals of survey biomass (% of observed value) 1988 – 2022.

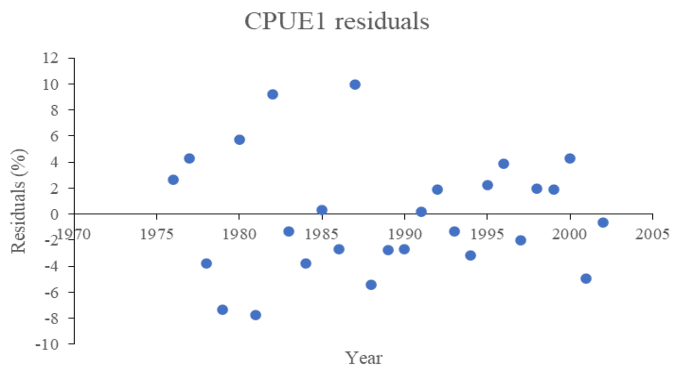

Figure 12b. Model diagnostics: Residuals of CPUE1 (% of observed value) 1976 – 2002.

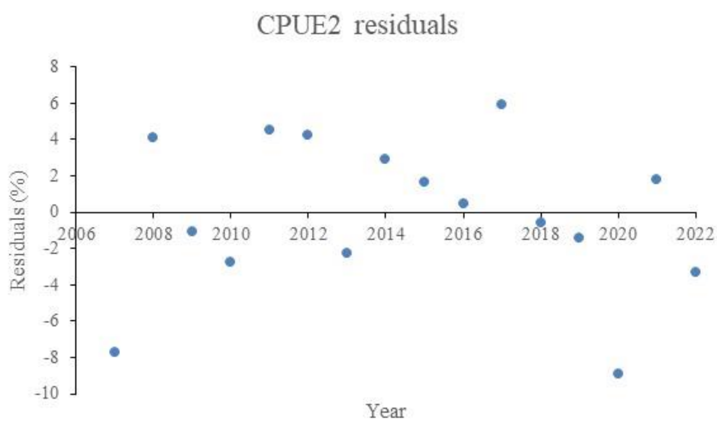

Figure 12c. Model diagnostics: Residuals of CPUE2 (% of observed value) 2007 – 2022.

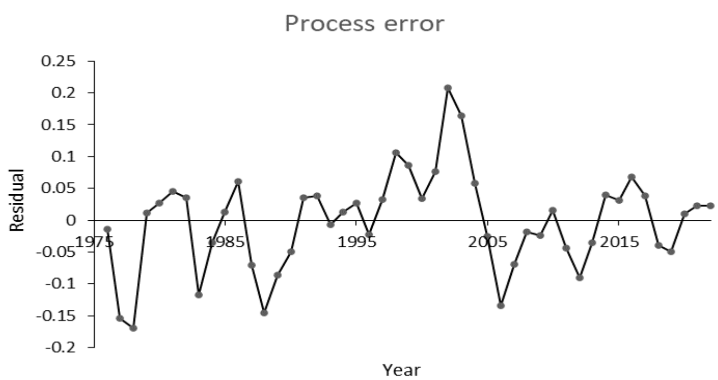

Figure 12d. Model diagnostics: Process error of fit (CV of process (%) 1994 – 2022.