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A Provisional Assessment of the Shrimp Stock off West Greenland in 2020

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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 year, biomass increased by more than 45% (1998, 2003 and 2015). In 2020, both total survey and fishable 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 in 2020 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.

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, were 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 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).

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.

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 7 000 tons. The median estimate for 2020 was 7 000 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 2020). 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 survey mean bottom temperature—weighted by area, not by shrimp stock density—increased quite abruptly from a mean of 1.83°C in 1990–96 to 3.5°C in 1997–2014. Since 2015 temperature have continuously declined to 2.1°C in 2018, 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[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 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.

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 2020 the estimated overlap was 0.199 resulting an estimated 'effective' cod stock at 7 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.

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.

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

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.

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 proportions 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 "save 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 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.

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 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 2018. In 2020, CPUE indices continued a slightly decrease (CPUE for 2020 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 2020).

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 Kt with quartiles at 103.1 and 153.3 Kt; an estimated mode is at 98.4 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 2020 is estimated to be a bit higher but close to the 2019 value and 23% above B_{msy}. With a low effective cod biomass at 7 Kt, even with catches projected at 117 000 t, total mortality in 2020 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, 2020.

Biomass ratio *B/Bmsy* (median estimate, %)	122.5
Prob. *B<Bmsy* (%)	23.6
Prob. *B<Blim* (%)	0.0
Mortality ratio *Z/Zmsy* (median estimate, %)	89.3
Prob. *Z>Zmsy* (%)	40.4
Prob. *B<Bmsy80%* (%)	6.6

Risks associated with eight possible catch levels for 2021, with an 'effective' cod stock at 5 000 t, 7 000 t and 9 000 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

7 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2021 (%)	23.9	24.2	25.2	27.2	26.1	27.0	26.9	28.0
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 (%)	18.6	22.3	26.2	29.6	33.2	36.8	40.3	43.5
exceeding Zmsy in 2022 (%)	18.8	22.4	26.7	30.8	33.8	38.7	41.8	45.1
falling below Bmsy 80% end 2021 (%)	8.1	8.2	8.9	8.8	9.0	9.4	9.8	9.5

9 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2021 (%)	24.8	24.7	25.7	26.2	26.3	26.4	27.6	27.4
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 (%)	19.4	23.4	27.0	30.3	34.0	37.7	41.1	44.5
exceeding Zmsy in 2022 (%)	20.2	23.7	27.4	32.5	35.4	38.7	43.1	45.9
falling below Bmsy 80% end 2021 (%)	8.3	8.4	8.2	8.4	9.3	9.1	9.9	10.2

With a mortality risk (i.e. that estimable 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 45-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.

Conclusions

The stock is predicted to remain above its *MSY* level at end 2020. 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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References

BURMEISTER, AD. and F.F RIGET. 2020b. The Fishery for Northern Shrimp (*Pandalus borealis*) off West Greenland, 1970–2020. *NAFO SCR Doc.* 20/054, Ser. No. 7128. 44 pp.

BURMEISTER, AD. 2020. Catch table update for the West Greenland shrimp fishery. *NAFO SCR Doc*. 20/055 Ser. No. N7129.5 pp.

BURMEISTER, AD. and F.F RIGET. 2020a. The West Greenland trawl survey for *Pandalus borealis*, 2020, with reference to earlier results. *NAFO SCR Doc*. 020/053, Ser. No. N7127.39 pp.

BURMEISTER, AD. and F.F RIGET. 2019. The Fishery for Northern Shrimp (*Pandalus borealis*) off West Greenland, 1970–2019. *NAFO SCR Doc.* 19/044, Ser. No. 7008. 44 pp.

BURMEISTER, AD. 2019. Catch table update for the West Greenland shrimp fishery. *NAFO SCR Doc*. 19/045Ser. No. N7009.5 pp.

BURMEISTER, AD. and F.F RIGET. 2019. The West Greenland trawl survey for *Pandalus borealis*, 2019, with reference to earlier results. *NAFO SCR Doc*. 019/043, Ser. No. N7007.39 pp.

BURMEISTER, AD. and F.F RIGET. 2018. The Fishery for Northern Shrimp (*Pandalus borealis*) off West Greenland, 1970–2018. *NAFO SCR Doc.* 18/057, Ser. No. 6871. 44 pp.

BURMEISTER, AD. and F.F RIGET. 2018. Catch table update for the West Greenland shrimp fishery. *NAFO SCR Doc*. 18/072 Ser. No. N6872.5 pp.

BURMEISTER, AD. and F.F RIGET. 2018. The West Greenland trawl survey for *Pandalus borealis*, 2018, with reference to earlier results. *NAFO SCR Doc*. 018/055, Ser. No. N6869. 39 pp.

BURMEISTER, AD. and F.F RIGET. 2017. The West Greenland trawl survey for *Pandalus borealis*, 2017, with reference to earlier results. *NAFO SCR Doc*. 017/051, Ser. No. N6720. 39 pp.

BURMEISTER, AD. and M.C.S. KINGSLEY. 2016. The West Greenland trawl survey for *Pandalus borealis*, 2016, with reference to earlier results. *NAFO SCR Doc*. 016/041, Ser. No. N6590. 39 pp.

BURMEISTER, AD. and M.C.S. KINGSLEY. 2015. The West Greenland trawl survey for *Pandalus borealis*, 2015, with reference to earlier results. *NAFO SCR Doc*. 015/043, Ser. No. N6478. 39 pp.

GRUNWALD, E. 1998. Nahrungsökologishe Untersuchungen an Fischbeständen im Seegebiet vor Westgrönland. Ph.D. Dissertation, Christian-Albrechts-Universität, Kiel, Germany. 208 pp.

HOLLING, C.S. 1959. Some characteristics of simple types of predation and parasitism. *Can. Entomol.* **91**: 385–398.

HVINGEL, C. 2004. The fishery for northern shrimp (*Pandalus borealis*) off West Greenland, 1970–2004. *NAFO SCR Doc.* 04/75, Ser. No. N5045.

HVINGEL, C. and M.C.S. KINGSLEY. 2002. A framework for the development of management advice on a shrimp stock using a Bayesian approach. *NAFO SCR Doc.* 02/158, Ser. No. N4787.

KINGSLEY, M.C.S. 2008a. CPU Series for the West Greenland Shrimp Fishery. *NAFO SCR Doc*. 08/62 Ser. No. N5591. 6 pp.

KINGSLEY, M.C.S. 2008b. Indices of distribution and location of shrimp biomass for the West Greenland research trawl survey. *NAFO SCR Doc*. 08/78 Ser. No. N5610. 4 pp.

KINGSLEY, M.C.S. 2011. A provisional assessment of the shrimp stock off West Greenland in 2011. *NAFO SCR Doc*. 11/058, Ser. No. N5983. 23 pp.

KINGSLEY, M.C.S. 2012. A provisional assessment of the shrimp stock off West Greenland in 2012. *NAFO SCR Doc*. 12/046, Ser. No. N6107. 23 pp.

KINGSLEY, M.C.S. 2013. A Naive Simulator for a Harvest Control Rule for the West Greenland Fishery for P. borealis. *NAFO SCR Doc*. 13/055, Ser. No. N6215. 7 pp.

KINGSLEY, M.C.S. 2015. A Stock-Dynamic Model of the West Greenland Stock of Northern Shrimp. *NAFO SCR Doc*. 15/050, Ser. No. N6485. 17 pp.

KINGSLEY, M.C.S. 2016. A Stock-Dynamic Model of the West Greenland Stock of Northern Shrimp. *NAFO SCR Doc*. 16/047, Ser. No. N6596. 16 pp.

PELLA, J.S. and P.K. TOMLINSON. 1969. A generalised stock-production model. *Bull. Inter-Am. Trop. Tuna Comm.* 13: 421–496.

RIGET, F.F., BURMEISTER, AD., Hvingel, C. 2018. Improvement of the Greenland shrimp model. *NAFO SCR Doc*. 18/060 Ser. No. N6874. 16 pp.

SCHAEFER, M.B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bull. Inter-Am. Trop. Tuna Comm.*, **1**: 27–56.

SIEGSTAD, H. and M.C.S. KINGSLEY 2014. A preliminary estimate of Atlantic cod (*Gadus morhua*) biomass in West Greenland offshore waters (NAFO Subarea 1) for 2014 and recent changes in the spatial overlap with Northern Shrimp (*Pandalus borealis*). *NAFO SCR Doc*. 14/xxx, Ser. No. Nxxxx. xx pp.

STORR-PAULSEN, M., J. CARL and K. WIELAND. 2006. The importance of Atlantic Cod (*Gadus morhua*) predation on Northern Shrimp (*Pandalus borealis*) in Greenland waters 2005. *NAFO SCR Doc*. 06/68*.* Ser. No. N5318. 16 pp.

WIELAND, K. 2005. Conversion of northern shrimp (*Pandalus borealis*) biomass, recruitment and mean size from previous years (1988–2004) to the new standard trawl used in the Greenland bottom trawl survey at West Greenland in 2005. *NAFO SCR Doc.* 05/75, Ser. No. N5180. 6pp.

WIELAND, K and M. STORR-PAULSEN. 2004. A comparison of different time series of Atlantic cod (*Gadus morhua*) biomass at West Greenland and their potential use for the assessment of Northern shrimp (*Pandalus borealis*) in NAFO Subareas 0+1. *NAFO SCR Doc.* 04/71*,* Ser. No. N5041.

Table 1. *Pandalus borealis* in West Greenland: input data series 1976–2020 for stock-dynamic assessment model.

Year	Sam.obs[]	Overlap[]	Past.Catch[]	Prov.Catch[]	ln.CPUE[	surv[]	Grunwald[]	Grunwalc
1976	119.677	0.579	51.6	NA	0.3919	NA	NA	NA
1977	133.432	0.574	42.3	NA	0.3267	NA	NA	NA
1978	93.6	0.672	42.8	NA	0.0916	NA	NA	NA
1979	92.364	0.67	55.9	NA	-0.00988	NA	NA	NA
1980	61.22	0.68	53.8	NA	0.1776	NA	NA	NA
1981	68.474	0.619	54.3	NA	0.12	NA	NA	NA
1982	95.094	0.518	56.2	NA	0.3598	NA	NA	NA
1983	56.737	0.461	52.8	NA	0.2361	NA	NA	NA
1984	20.261	0.479	52.8057	NA	0.1749	NA	NA	NA
1985	29.579	0.482	66.2079	NA	0.2458	NA	NA	NA
1986	41.625	0.51	76.9	NA	0.2845	NA	NA	NA
1987	91.942	0.604	77.391	NA	0.4179	NA	NA	NA
1988	134.72	0.618	73.616	NA	0.1459	223.1907	NA	NA
1989	103.888	0.37	80.671	NA	0.04966	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	0.04447	146.0081	2.7	19.7905
1992	0.361	0.523	105.487	NA	0.1134	194.1563	0.8	2.8785
1993	0.157	0.6455	91.013	NA	0.1084	216.4703	NA	NA
1994	0.073	0.599	92.805	NA	0.1138	223.1433	NA	NA
1995	0.063	0.483	87.388	NA	0.2065	183.2427	NA	NA
1996	0.039	0.28	84.095	NA	0.2493	192.0819	NA	NA
1997	0.052	0.49	78.128	NA	0.2256	167.0946	NA	NA
1998	0.061	0.39	80.495	NA	0.3657	244.2933	NA	NA
1999	0.095	0.496	92.198	NA	0.4839	237.2942	NA	NA
2000	0.233	0.643	97.968	NA	0.5775	280.336	NA	NA
2001	0.299	0.462	102.926	NA	0.5382	280.4643	NA	NA
2002	0.729	0.278	135.172	NA	0.7146	369.4608	NA	NA
2003	1.219	0.398	130.173	NA	0.7967	548.2839	NA	NA
2004	3.918	0.257	149.332	141	0.8875	528.3298	NA	NA
2005	4.868	0.074	156.899	140.5	0.9182	494.2	NA	NA
2006	7.116	0.22	157.315	140.2	0.9232	451	NA	NA
2007	11.981	0.139	144.19	135.2	0.9538	336.1	NA	NA
2008	11.716	0.156	153.889	131.6	1.002	262.6	NA	NA
2009	7.233	0.602	135.458	108.8	0.9039	255.1	NA	NA
2010	5.209	0.315	133.99	138.5	0.8644	318.7	NA	NA
2011	10.829	0.888	123.985	126	0.9136	245.69	NA	NA
2012	17.666	0.305	115.975	110	0.8352	176.44	NA	NA
2013	19.883	0.206	95.381	100	0.7052	218.1	NA	NA
2014	27.494	0.211	88.765	90	0.7794	170.01	NA	NA
2015	32.975	0.2046	72.256	65	0.8221	255.54	NA	NA
2016	31.294	0.079	85.527	82	0.8841	201.3461	NA	NA
2017	26.444	0.373	92.37	90	1.009	284.6407	NA	NA
2018	27.335	0.3841	94.878	101.25	0.9354	279.02	NA	NA
2019	28.256	0.2696	104.44	100	0.8953	311.12	NA	NA
2020	35.567	0.199	NA	117	0.8031	340.900959	NA	NA

[1] 'effective cod biomass' was not an input data series in 2020; 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.

Table 2. *Pandalus borealis* in West Greenland: summary of estimates of selected parameters from Bayesian fitting of a surplus production model, 2020.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2019)
Max.sustainable yield	135.3	56.6	103.1	123.0	153.3	98.4	121.6
B/Bmsy, end current year (proj.)(%)	126.3	34.2	101.4	122.5	148.2	114.9	126.3
Biomass risk, end current year(%)	23.6	42.5	–	–	–	–	–
Z/Zmsy, current year (proj.)(%)	–	–	61.7	89.3	119.2	–	80.1
Carrying capacity	3444	1981	1931	2896	4522	1800	2999
Max. sustainable yield ratio (%)	10.0	5.4	6.1	9.0	12.9	7.1	8.6
Survey catchability (%)	18.9	13.2	9.5	15.4	24.5	8.2	14.8
CPUE(1) catchability	1.1	0.8	0.6	0.9	1.4	0.5	0.9
CPUE(2) catchability	1.7	1.2	0.9	1.4	2.3	0.7	1.4
Effective cod biomass 2020 (Kt)	9.1	18.1	5.2	7.0	8.9	2.8	20.9
$P_{50\%}$ (prey biomass index with consumption 50% of max.)	4.1	7.2	0.2	1.3	4.6	-4.3	1.2
V_{max} (maximum consumption per cod)	2.0	2.3	0.4	0.9	2.6	-1.1	0.8
CV of process (%)	13.1	2.9	11.2	13.0	14.9	12.7	13.8
CV of survey fit (%)	17.6	3.2	15.3	17.2	19.5	16.6	16.2
CV of CPUE (1) fit (%)	7.0	1.5	5.9	6.7	7.7	6.2	6.7
CV of CPUE (2) fit (%)	7.6	2.4	5.8	7.0	8.6	5.7	6.8

Table 3. *Pandalus borealis* in West Greenland: selected[1] correlations (%) between model parameters, 2020.

	Start biom. ratio	*CV cpu*	*CV s*	*CV proc*	*Vmax*	*P50%*	*Qc1*	*Qc2*	*Qs*	*MSY ratio*	*K*
Max. sustainable yield	23			13			-30	-30	-30	15	39
Carrying capacity	10		-6	10	-16		-72	-72	-72	-68	
Max. sustainable yield ratio (%)	-6		6	-7	22		80	79	79		
Survey catchability (%)	-40		7	-17	24	-8	100	100			
CPUE catchability q1	-41		6	-16	24	-8	100				
CPUE catchability q2											
P50%	16				65						
Vmax	-13			-13							
CV of process (%)	11	-5	-31								
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 2021 assuming effective cod biomass 5 Kt, 7 Kt and 9 Kt.

Catch	5 Kt		7 Kt		9 Kt	
(Kt/yr)	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
95	17.7	19.0	18.6	18.8	19.4	20.2
100	21.5	21.8	22.3	22.4	23.4	23.7
105	25.4	25.6	26.2	26.7	27.0	27.4
110	28.7	29.3	29.6	30.8	30.3	32.5
115	32.4	33.6	33.2	33.8	34.0	35.4
120	35.8	37.3	36.8	38.7	37.7	38.7
125	39.4	40.9	40.3	41.8	41.1	43.1
130	42.6	44.1	43.5	45.1	44.5	45.9

Table 5. *Pandalus borealis* in West Greenland: risks (%) of exceeding limit mortality in 2021 – 2023 and of falling below B_{msy} or limit* biomass at the end of 2021 – 2023 assuming effective cod biomass 5 Kt, 7 Kt and 9 Kt.

5 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2021 (%)	24	25	25	26	26	26	27	28
falling below Bmsy end 2022 (%)	25	26	26	27	28	30	30	31
falling below Bmsy end 2023 (%)	25	27	27	28	30	33	34	33
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
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2021 (%)	18	22	25	29	32	36	39	43
exceeding Zmsy in 2022 (%)	19	22	26	29	34	37	41	44
exceeding Zmsy in 2023 (%)	19	22	26	30	35	39	42	45
falling below Bmsy 80% end 2021 (%)	8	8	8	9	9	10	10	10
falling below Bmsy 80% end 2022 (%)	9	9	9	10	11	12	13	13
falling below Bmsy 80% end 2023 (%)	10	10	11	12	13	15	15	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 2021 (%)	24	24	25	27	26	27	27	28
falling below Bmsy end 2022 (%)	25	25	27	28	29	29	30	31
falling below Bmsy end 2023 (%)	25	26	28	30	31	32	33	33
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
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2021 (%)	19	22	26	30	33	37	40	44
exceeding Zmsy in 2022 (%)	19	22	27	31	34	39	42	45
exceeding Zmsy in 2023 (%)	20	23	28	32	35	39	43	46
falling below Bmsy 80% end 2021 (%)	8	8	9	9	9	9	10	9
falling below Bmsy 80% end 2022 (%)	9	10	11	11	11	12	13	13
falling below Bmsy 80% end 2023 (%)	10	10	12	12	13	14	16	17

* limit biomass is 30% of B_{msy}

9 000 t cod	Catch option ('000 tons)							
Risk of:	95	100	105	110	115	120	125	130
falling below Bmsy end 2021 (%)	25	25	26	26	26	26	28	27
falling below Bmsy end 2022 (%)	26	26	28	29	29	29	31	32
falling below Bmsy end 2023 (%)	27	26	29	31	31	32	33	34
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
falling below Blim end 2023 (%)	0	0	0	0	0	0	0	0
exceeding Zmsy in 2021 (%)	19	23	27	30	34	38	41	44
exceeding Zmsy in 2022 (%)	20	24	27	33	35	39	43	46
exceeding Zmsy in 2023 (%)	21	24	29	34	37	40	44	47
falling below Bmsy 80% end 2021 (%)	8	8	8	8	9	9	10	10
falling below Bmsy 80% end 2022 (%)	9	10	10	11	12	12	12	14
falling below Bmsy 80% end 2023 (%)	11	10	11	13	14	15	15	17

* limit biomass is 30% of B_{msy}

Figures

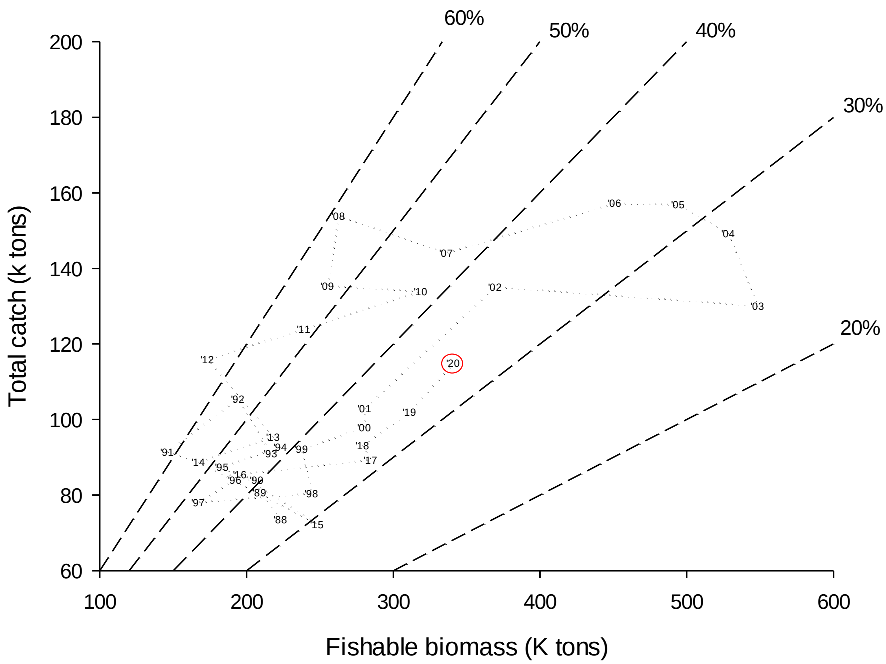

Figure 1. *Pandalus borealis* in West Greenland: catch, fishable biomass and exploitation index, 1976–2020 (2020 catch is provisional).

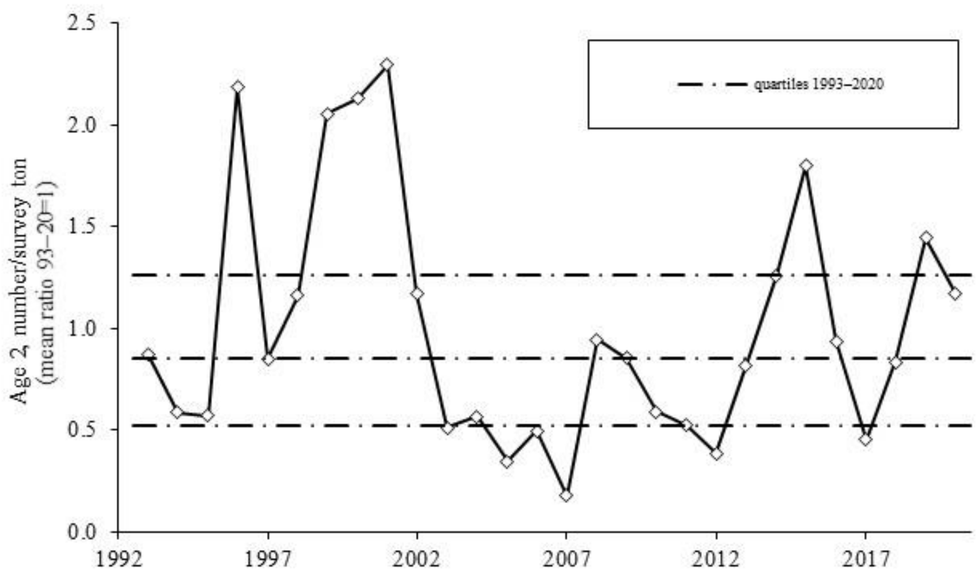

Figure 2a. *Pandalus borealis* in West Greenland: number at age 2 from research trawl survey, 1996–2020.

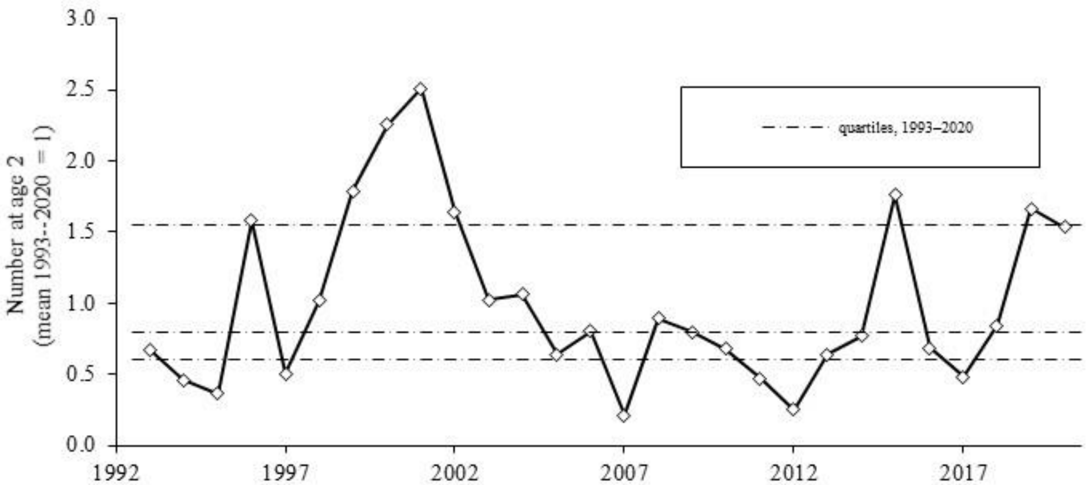

Figure 2b. *Pandalus borealis* in West Greenland: number at age 2 relative to survey biomass, from research trawl survey 1996–2020.

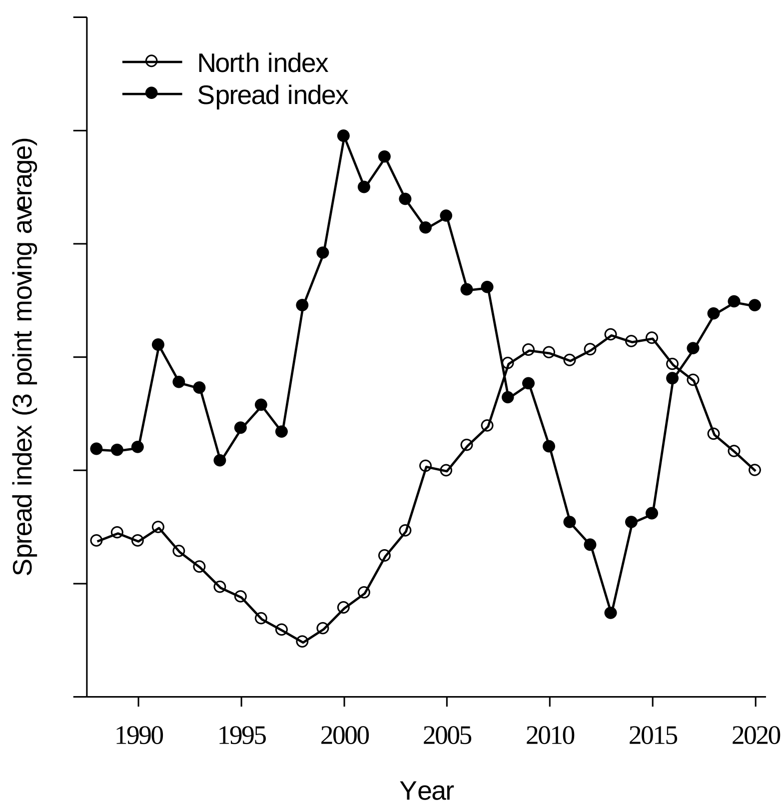

Figure 3. *Pandalus borealis* in West Greenland: indices of distribution of the survey biomass, 1994–2020 (3-point moving means.)

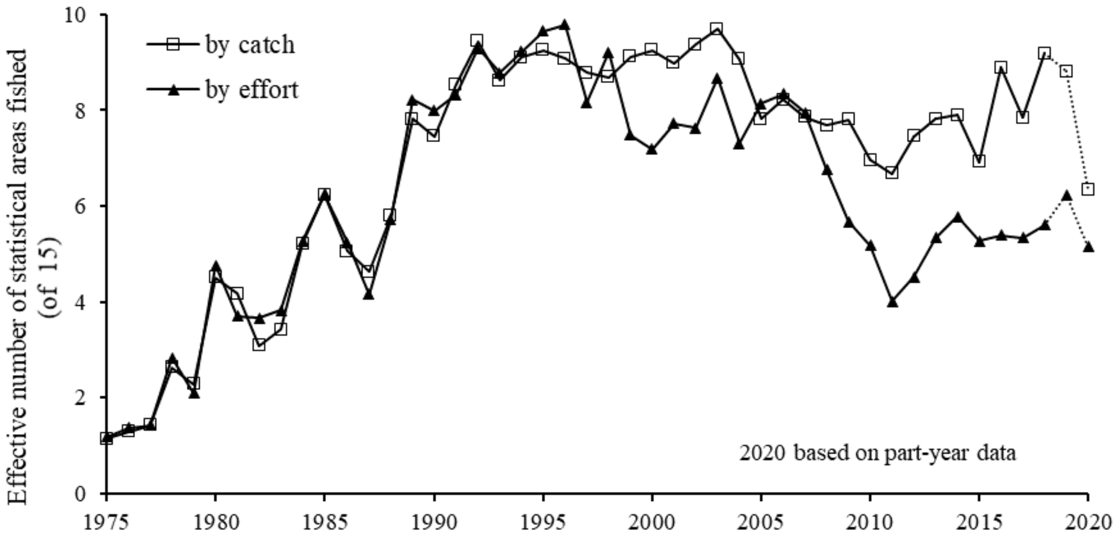

Figure 4. *Pandalus borealis* in West Greenland: indices of the breadth of distribution of the Greenlandic fishery among 15 statistical areas, from logbook records, 1975–2020. (2020 is preliminary data).

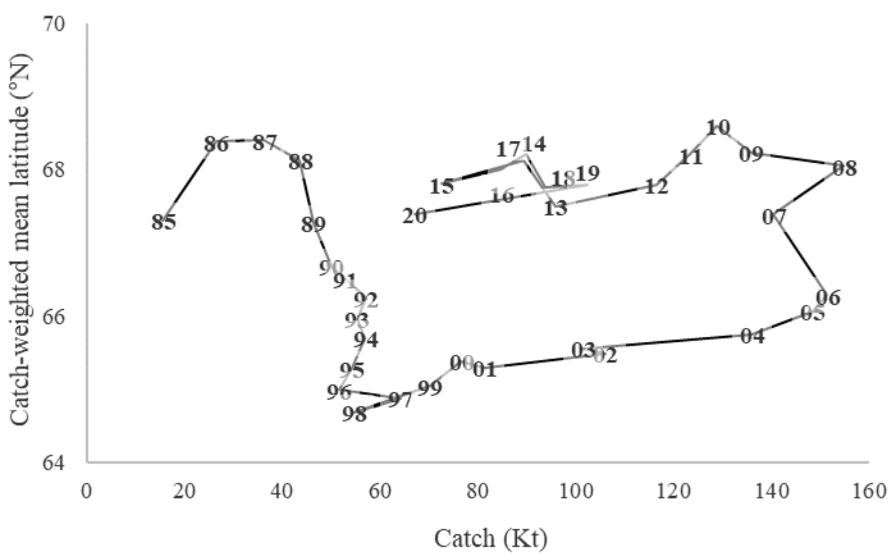

Figure 5. *Pandalus borealis* in West Greenland: mean latitude by weight vs. total weight, for logbook-recorded catch in the Greenland fishery, 1985–2020 (2020 is only preliminary catch).

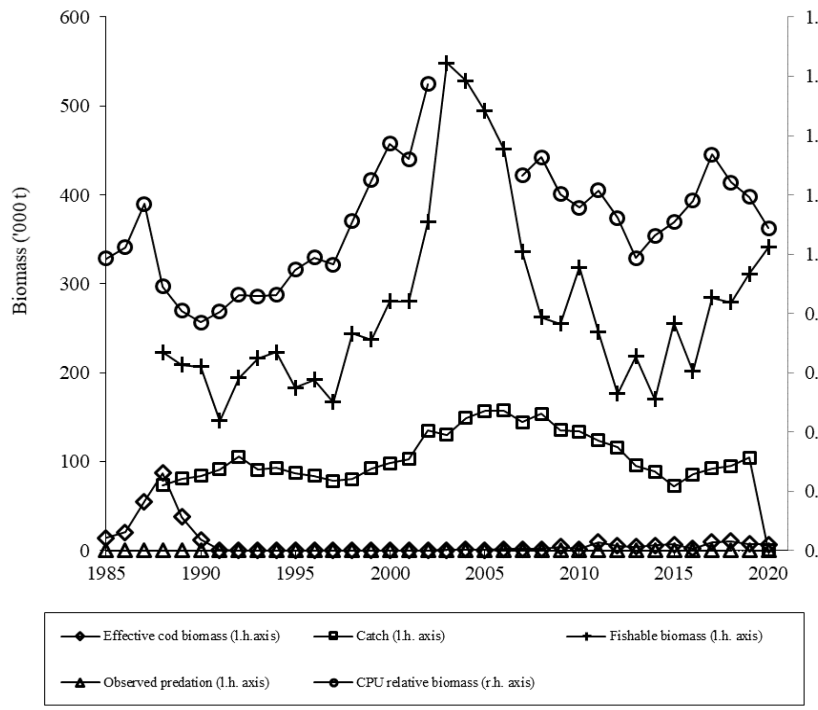

Figure 6. *Pandalus borealis* in West Greenland: thirty-year data series providing information for the assessment model. (2020 catch is projected; effective cod biomass is synthesized from four biomass index series and a series of overlap indices between distributions of cod and shrimps.)

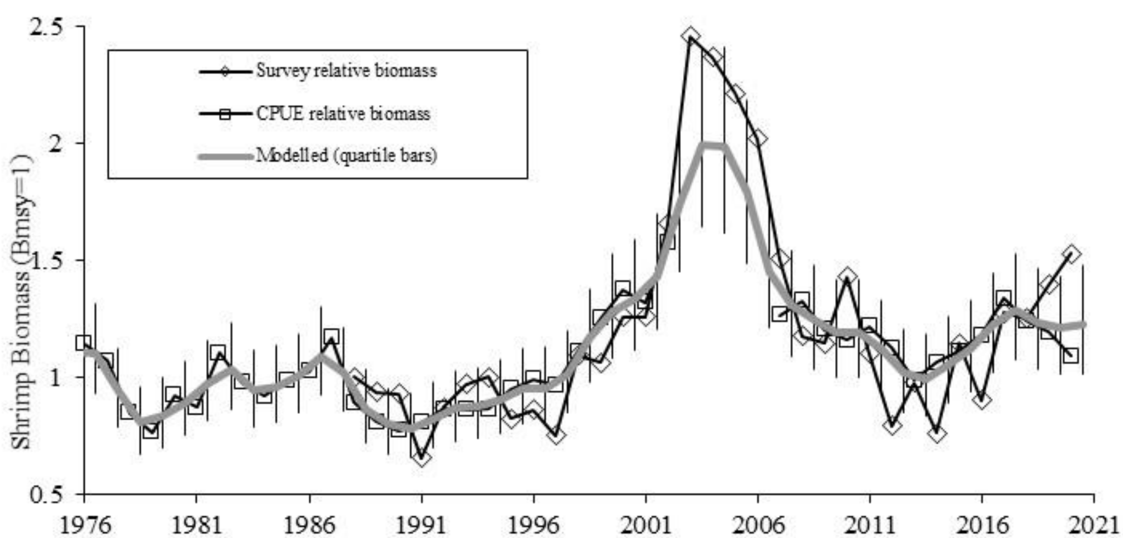

Figure 7. *Pandalus borealis* in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2020.

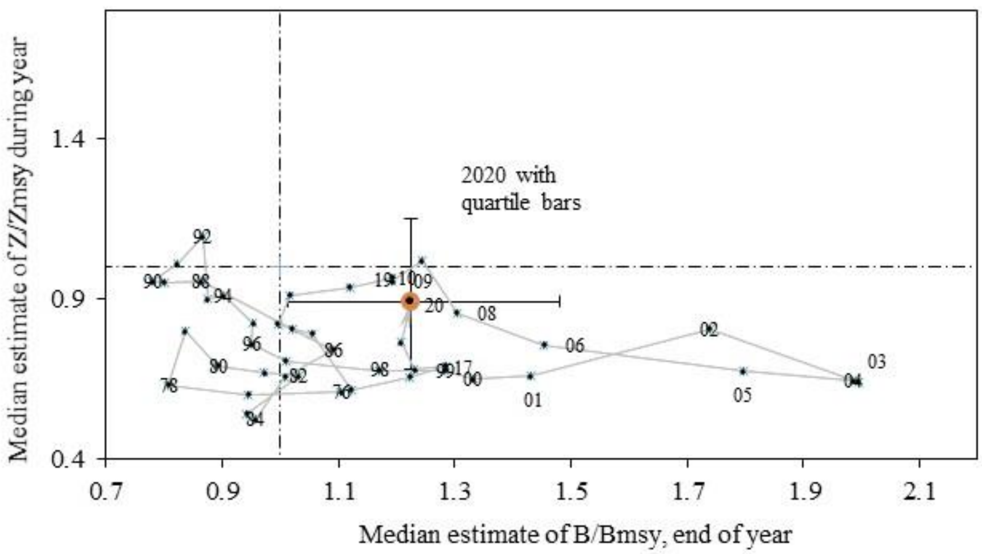

Figure 8. *Pandalus borealis* in West Greenland: median estimates of biomass ratio (B/B_{msy}) and mortality ratio (Z/Z_{msy}) 1976–2020.

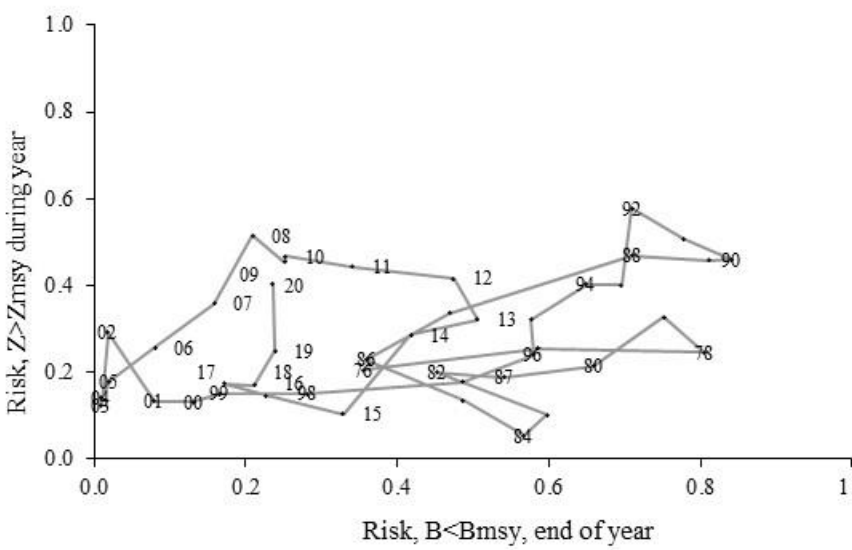

Figure 9. *Pandalus borealis* in West Greenland: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1976–2020.

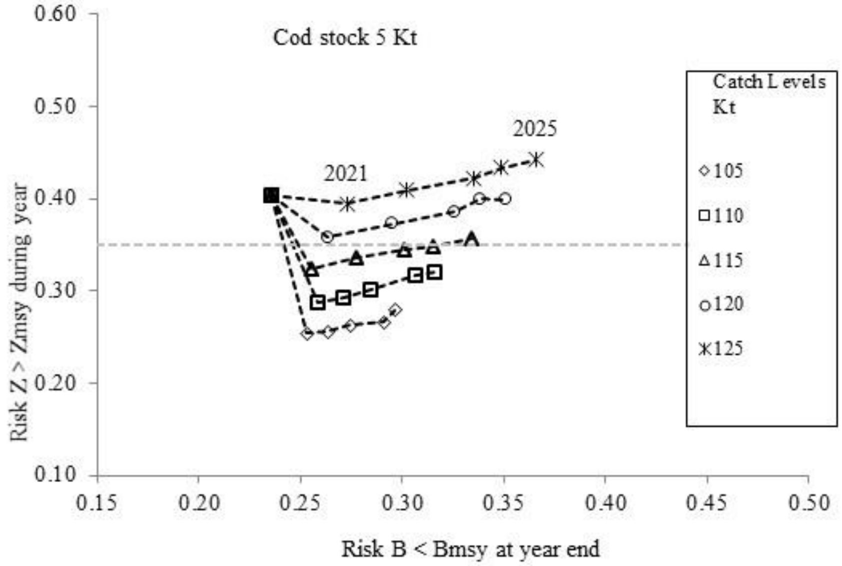

Figure 10a. *Pandalus borealis* in West Greenland: joint 5-year plot 2021–25 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 5 Kt.

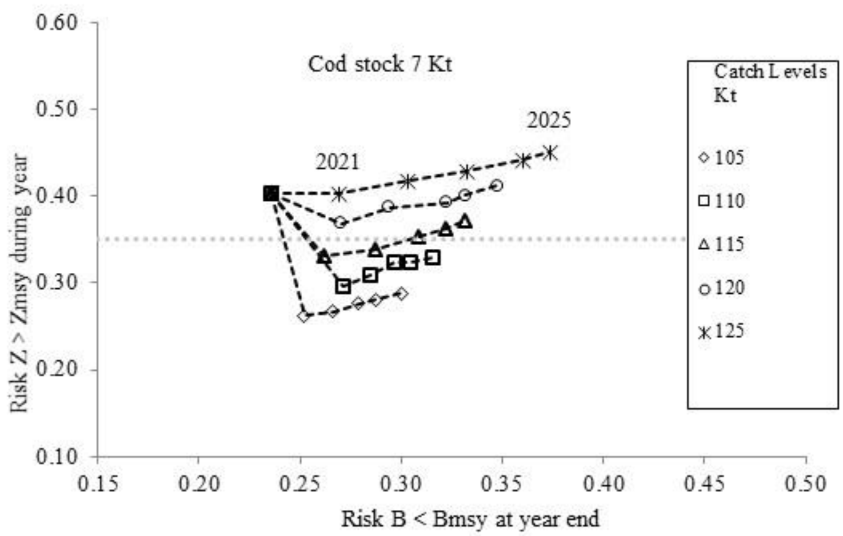

Figure 10b. *Pandalus borealis* in West Greenland: joint 5-year plot 2021–25 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 7 Kt.

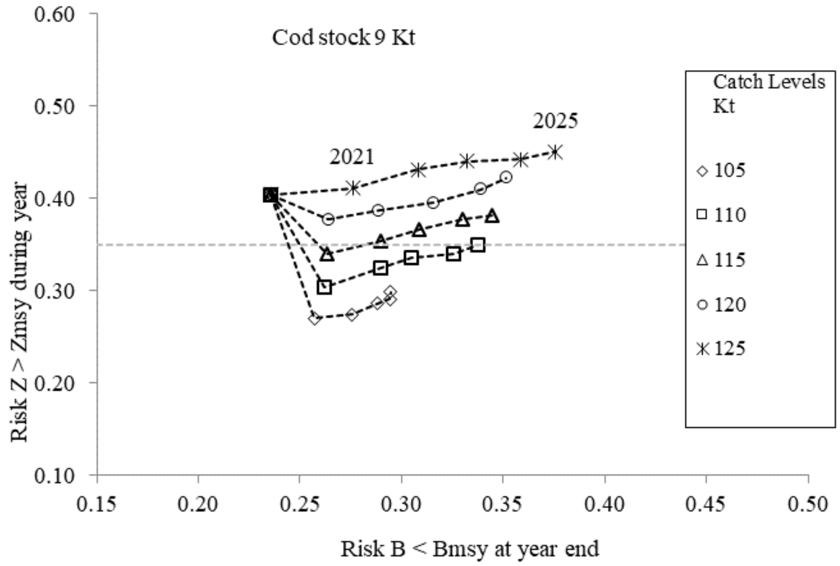

Figure 10c. *Pandalus borealis* in West Greenland: joint 5-year plot 2021–25 of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–125 Kt/yr; with effective cod biomass 9 Kt.

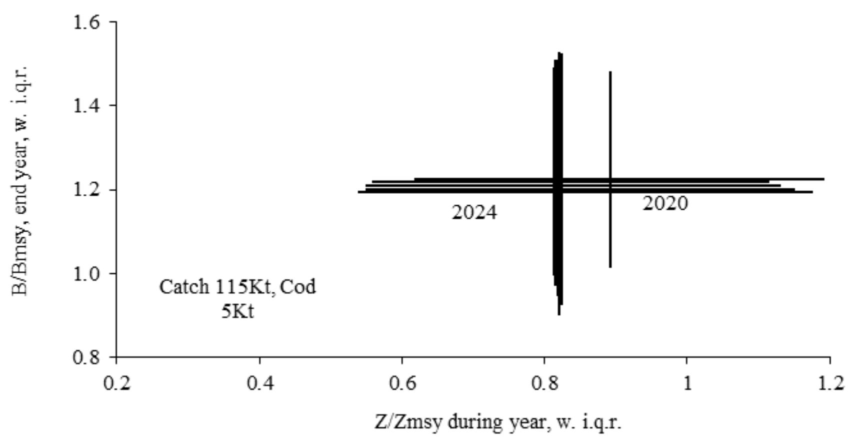

Figure11a. *Pandalus borealis* in West Greenland: projections of stock development for 2021–2025 with effective cod biomass assumed at 5 000 t: median estimates with quartile error bars.

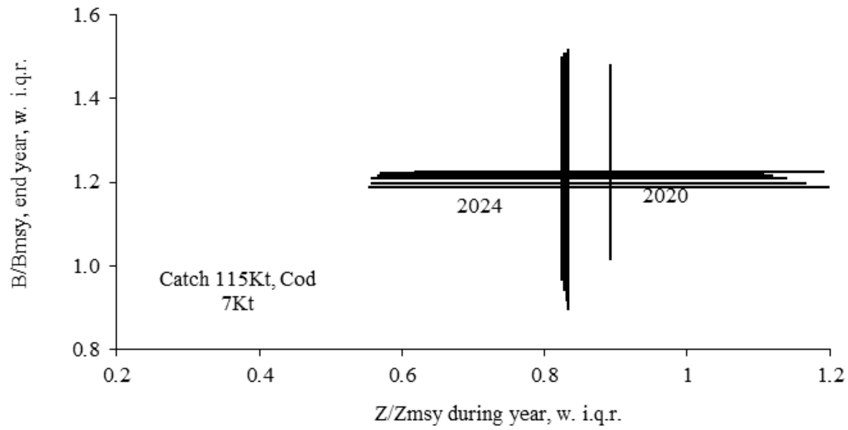

Figure 11b. *Pandalus borealis* in West Greenland: projections of stock development for 2021–2025 with effective cod biomass assumed at 7 000 t: median estimates with quartile error bars.

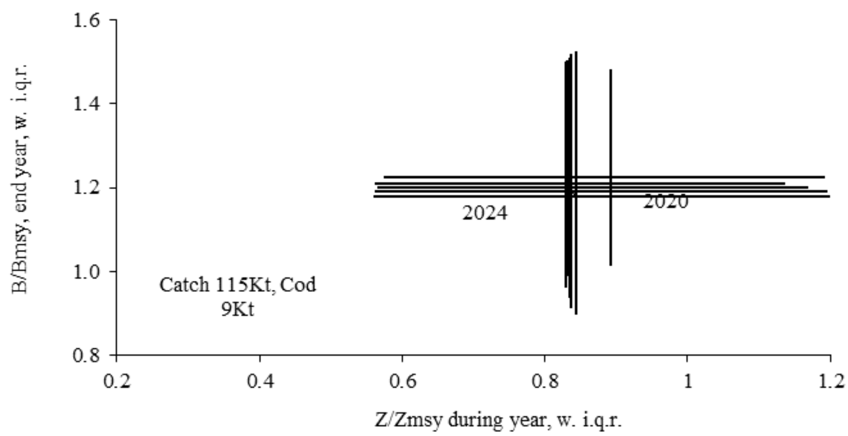

Figure 11c. *Pandalus borealis* in West Greenland: projections of stock development for 2021–2025 with effective cod biomass assumed at 9 000 t: median estimates with quartile error bars.