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A Provisional Assessment of the Shrimp Stock off West Greenland in 2006

by

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Abstract

Assessment of the West Greenland Stock of *Pandalus borealis* was performed using an assessment framework adopted by STACFIS and Scientific Council in 2002. The assessment framework incorporates a logistic stock-recruitment model, indices of biomass from trawl survey and from commercial-fishery CPUE, catch data from records, and a model of cod predation including available series of cod biomass. The model parameters are fitted by a Bayesian process.

Results from the modelling were that the stock biomass has increased since the early 1990s and reached its highest level recorded in 2004, reflecting the course of CPUE and survey analyses. Biomass appears to be well above its maximum sustainable yield level (B_{MSY}) and mortality by fishery and cod predation is well below the value that maximizes yield (Z_{MSY}).

The median estimate of the maximum annual production surplus (*MSY*), available equally to the fishery and cod was estimated by this model at about 160 000 tons. However, as the stock is estimated by the model to be well above its MSY level and therefore less than maximally productive, even catches less than this are predicted to be associated with decreasing stock biomass.

Projections showed that catches of 140 000 tons/yr are not likely to drive the stock below B_{MSY} in the short term.

Introduction

The stock of northern shrimp (*Pandalus borealis*) off West Greenland is distributed in NAFO Div. 0A and a part of the eastern limit of NAFO Subarea 1. The shrimp stock within this area is assessed as a unit. A Greenlandic fishery exploits the stock in Subarea 1 (Div. 1A to 1F) in offshore and inshore areas (primarily Disko Bay). The Canadian fishery has been restricted to Div. 0A since 1981.

Until 2002 management advice for this stock was basically formulated by qualitative assessment of trends in various indices of stock condition and an equally qualitative assessment of the influence of the parameters of the catch history (Anon., 2001). Management advice was given as an annual Total Allowable Catch (TAC) and a statement about the sustainability of the applied fishing practice as agreed to by the assessment board.

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. This paper presents the results of applying this model to the updated available data series of shrimp catches and shrimp and cod biomass, to evaluate management options for the West Greenland shrimp stock.

Short-term (1-year) and medium-term (ten-year) projections of stock development were made for five levels of annual catch at 10 000-t intervals from 110 000 to 150 000 tons under the assumption that the cod stock remains at its current level, and 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.

Speculation is rife on the possible return of significant cod stocks to West Greenland, since recent increases in apparent biomass, while small in absolute terms, have been large in relative terms. The possible effects of a cod resurgence on the future trajectory of the shrimp stock are therefore of interest, but have not been investigated in detail in this assessment.

Estimation of Parameters

Parameters relevant for the assessment and management of the stock were estimated, based on a stochastic version of a surplus-production model that included an explicit term for predation by cod (*Gadus morhua*). The model was formulated in a state-space framework, and Bayesian methods were used to construct posterior likelihood distributions of the parameters. Model background, formulation, checking, validation and further details are given in Hvingel and Kingsley (2002). In the context of the present assessment, the model behaviour was not checked in great detail.

Absolute biomass estimates had relatively high variances. For management purposes therefore it is desirable to work with biomass on a relative scale in order to cancel out the uncertainty of the "catchability" parameters (the parameters that scale absolute stock size). Biomass, B, is thus measured relative to the biomass that yields Maximum Sustainable Yield, B_{MSY}. The state equation describing the transition of shrimp biomass from one state, t, to the next, t+1 was:

$$P_{t+1} = \left(P_t - \left(\frac{C_t + O_t}{B_{MSY}} \right) + \frac{mMSYP_t}{B_{MSY}(m-1)} \left(1 - \frac{P_t^{m-1}}{m} \right) \right) \cdot \exp(\nu)$$

where MSY is the annualised value of the instantaneous maximum sustainable yield rate. P_t is the stock biomass relative to biomass at MSY (P_t=B_t/B_{MSY}) in year t. C_t is the catch taken by the fishery and O_t is the consumption by cod, in year t. m is a shape parameter for the Pella-Tomlinson (1969) stock–recruitment curve: a value of 2 gives the standard logistic, or Schaefer (1954), trajectory[1]. The 'process errors', ν are normally, independently and identically distributed with mean 0 and variance σ_ν^2.

The model synthesized information from input priors (Hvingel and Kingsley 2002) (Fig. 3) and the following data: a 19-year series of a survey biomass indices of shrimp ≥17 mm CL (Wieland *et al*., 2004; Wieland and Bergström, 2005); a 31-year series of combined CPUE indices (Kingsley and Hvingel, 2005); a 52-year series of catches by the fishery (Hvingel, 2004; Hvingel and Kingsley, 2002); a 52-year series of a cod biomass estimates (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004, 2005); and a short series (4 years) of estimates of the shrimp biomass consumed by cod (Hvingel and Kingsley, 2002) based on stomach analysis (Grunwald, 1998) (Table 1; Fig. 1). The data link functions of the biomass indices were:

$$CPUE_t = q_c B_{MSY} P_t \exp(\omega) \ \text{, for} \ \ t \in (1,2,,..,..N-1) \text{,} \ \ CPUE_N = q_c B_{MSY} P_N \exp(1.5\omega)$$
$$surv_t = q_s B_{MSY} P_t \exp(\kappa) \ \text{, for} \ \ t \in (2,3,..,..N) \text{,} \ \ surv_1 = q_s B_{MSY} P_1 \exp(1.5\kappa)$$

The catch rate ($CPUE_t$) and survey ($surv_t$) indices were scaled to "true" biomass by the catchability constants, q_c and q_s. Their error terms, ω and κ, are normally, independently and identically distributed with mean 0 and variance σ_ω^2 and σ_κ^2. The standard error for the final year of the CPUE index was assumed to be 1.5 times the error for the rest of the series, as this data point is an interim one based on partial data for the year (the annual assessment takes place in November). Likewise the first year of the survey was assigned a 50% larger error than the rest of the series to allow for a learning process.

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[1] previous years' analyses had estimated a stock-recruitment curve that was very close to logistic (m at 1.62, where the logistic would have 2, and the ratio of B_{msy} to K at 0.46, where the logistic would have 0.5), so the current year's analyses were carried out with m fixed at 2. This greatly speeds up the model-fitting process.

Estimates of annual consumption rate of shrimp by cod were linked to the equations of shrimp stock dynamics through a Holling type III functional response function (Holling, 1959) and a series of cod biomass:

$$O_t = cod_t \frac{V_{\max} P_t^2}{P_t^2 + P_{50\%}^2} \exp(\tau)$$

where O_t is total consumption in year *t*, V_{max} is the maximum consumption of prey per predator (kg·kg^{-1}) reached at large prey biomass, and $P_{50\%}$ is the prey biomass index at which the consumption is half of the maximum. cod_t is biomass of cod in year *t*. The error term, τ , is normally, independently and identically distributed with mean 0 and variance σ_τ^2 .

The mortality caused by cod predation and fishery, *Z*, is scaled to Z_{MSY} (the combined fishing and predation mortality that yields *MSY*) for the same reasons as relative biomass was used instead of absolute. The equations for generating posteriors of the *Z-ratio* were:

$$Zratio_t = \frac{Z_t}{Z_{MSY}} = \frac{-\ln\left(\frac{B_t - (C_t + O_t)}{B_t}\right)}{\frac{MSY}{B_{MSY}}}$$

The model was fitted by Bayesian methods, the integration being carried out by Markov Chain Monte Carlo sampling. The sampling was burnt in for 50 000 iterations and then run for 240 000, every 60th being retained. Of the resulting 40 000 iterations, every 20th was used in the final calculations giving sample sizes of 2000. As repeated runs were made with the same data, differing only in the future catches and predictions, there was opportunity to ensure that estimates of stock-dynamic parameters were stable.

The series of biomass estimates from the annual West Greenland bottom-trawl survey, revised in 2005 as a consequence of switching from the *Skjervøy 3000* trawl with bobbin ground gear to a Cosmos 2000 with rockhopper ground gear (Wieland 2005), was revised again following re-calculation of the track widths of the two trawls. This re-revised sequence was used in the updated assessment (Table 1). The cod biomass series used was also revised to include future values equal to the present estimate (Storr-Paulsen and Wieland, 2005; Wieland pers. comm.).

Otherwise in general differences in data analysis were kept to a minimum: the GLM procedures used to standardise the individual fleet series were changed little, and the Bayesian fitting routine for combining the CPUEs was merely updated with the revisions to the individual series.

Experience has shown that the model is sensitive to the estimates of the historical trajectory of the cod stock—the ability of the shrimp stock to withstand predation from a cod stock that in the 1950s and 60s may have been 1½-2 million tons appears to play a leading role in estimating its productivity. The cod-stock trajectory used in the present assessment is the same as that used previously (Hvingel and Kingsley, 2002; Kingsley and Hvingel, 2005) but using lower values, based on recent ICES surveys, for the most recent years than were used in 2005, and projecting forward with a 22.7-kt biomass.

Results, Model Performance

The model produced a reasonable simulation of the observed data series (Fig. 2). The probabilities of getting a more extreme observation than the realised ones given in the two data series on stock size (Table 2) showed that the observations of CPUE did not lie in the tails of their posterior distributions. The survey series was generally less well estimated and especially the 1991, 1997 and 2003 values had relatively large residuals, relative to the estimated precision of the series, and small CPOs (Conditional Predictive Ordinate), even though the survey series was estimated to have lower precision than the CPUE series (Table 4).

Some of the parameters showed high linear correlations (Table 3). The major parameters of stock size and productivity—*K* and *MSY*—were positively correlated. The catchabilities of the CPUE series, q_c and of the survey series, q_s had high positive correlation, as they are both fitting the modelled biomass series to observed index series, and they were both negatively correlated with both *K* and *MSY*. These correlations meant that a large number of iterations were needed to secure a complete representation of the posterior distributions of the parameters.

The median estimate of the MSY was close to 160 Kt, slightly higher than the 150 estimated in 2004, itself higher than the 2004 value.; carrying capacity, which was poorly estimated, had a median estimate of 2 850 Kt, not very different from the estimate made in 2004. Survey catchability was estimated at 0.23, also not very different from the 2005 estimate of 0.28. Compared with the results from 2004, the stock is, and has been, larger, but has lower inherent productivity, but the results from the present analyses are overall similar to those obtained in 2005.

The estimated CV of the observed CPUE series, ω, had a median of about 8.2% and for the survey series, κ, of abour 15%—both similar to 2005. The process error, ν, had a median of 11.6% (Table 4). The parameter that acts as the main determinant of cod predation rate, $P_{50\%}$ (biomass ratio at which the predator is 50% saturated), was estimated with a median at 2.93.

Assessment Results

Estimates of the parameters governing the modelled predation by cod on the shrimp stock changed little between the 2005 assessment and the 2006 update. The assessment estimates that the stock is still above its MSY level, and also that the MSY is above recent catch levels.

The model estimated the yearly consumption of shrimp by cod to be relatively constant between about 30 and 80 000 tons all the way from 1956 to about 1983 (Fig. 3). The estimated consumption declined after 1960 as a result of a decline in cod abundance at West Greenland, but a short-lived resurgence of the cod stock in the late 1980s caused consumption to increase dramatically—estimated 107 000 t in 1987 and 93 000 t in 1988. The cod disappeared again at the beginning of the 1990s and estimates of consumption went to near zero (Fig. 4). In the most recent years slight increases in cod abundance have been noted in research trawl surveys in West Greenland waters. However, whether this is a beginning of a major return of cod to this ecosystem is still unclear. The present assessment estimates that cod consumed some 5 000 tons of shrimp in 2004, but the median estimate of predation increased to about 23 000 tons in 2005 and 20 000 tons in 2006 owing to the recent increase in the estimated cod biomass.

From the late 1970s to the mid-80s the estimated trajectory of the median estimate of 'biomass-ratio' (B_t/B_{MSY}) plotted against 'mortality-ratio' (Z_t/Z_{MSY}) (Fig. 4) was stable in a region of biomass 0.8-1.2 times B_{MSY} and mortality 0.4-0.8 times Z_{MSY}. A brief return of high cod stocks in the late 1980s caused a short episode of mortality ratios rising to 1.4, with a corresponding decrease in the stock biomass. A steep decline in CPUE was noted at this time. After the cod collapsed again the mortality decreased, and after the late 1990s the biomass consequently increased and is modelled to have reached 1.7 times B_{MSY}. This corresponds to high catch rates and high survey estimates of biomass in the mid-2000s. Associated with a slight increase in the cod stock and high catches in 2005, mortality is modelled to have increased; future high catches accompanied by significant predation are forecast to bring biomass ratio down (Fig. 4).

The mortality ratio (*Z*-ratio, which includes mortality by fishing and predation by cod) has been below 1 for most of the time since 1974, except for the period affected by high cod predation in the late 1980s to early 1990s (Fig. 3) Since 1997, annual median *Z*-ratio has been stable at levels estimated at 0.6-0.8, i.e. below the value that maximises yield. The median estimate for 2006 is 0.72 with a 10% possibility that mortality is higher than it would be if the stock were stationary at the *MSY* level (Fig. 4).

The median estimate of the maximum annual production surplus, available equally to the fishery and to the cod (*MSY*) was estimated at 160 000 tons, not very precisely estimated, with upper and lower quartiles at 130 000 and 200 000 tons (Table 3).

Given the high probabilities of the stock being considerably above B_{MSY}, risk of stock biomass falling below this optimum level within a one-year perspective is low. Risks[2] associated with five possible catch levels for 2007 are as follows:

[2] 'risk' in this document includes all three of uncertainty of knowledge, uncertainty of prediction, and uncertainty of outcome.

Catch option ('000 tons)	110	120	130	140	150
Risk of falling below B_{MSY}	7.8%	7.8%	7.4%	7.8%	9.4%
Risk of falling below B_{lim}	0.1%	0.1%	0.0%	0.1%	0.0%
Risk of exceeding Z_{MSY}	2.9%	5.0%	8.4%	13.5%	21.0%

Predation by cod can be significant (Fig. 2) and have a major impact on shrimp stocks. Currently the cod stock at West Greenland is at a low level, but has recently shown signs of increase. A large cod stock that would significantly increase shrimp mortality could be established in two ways: either by a slow rebuilding process and/or by immigration of one or two large year-classes from areas around Iceland as seen in the late 1980s. However, the question of cod predation is complicated by the question of the extent to which the two species overlap in their distributions. The effect of a cod stock widely distributed over the shrimp-fishing area off West Greenland waters might be reasonably well modelled by the process used here. However, if cod are distributed over only a part of the range of distribution of the shrimp stock so that the opportunities for interaction between the two species are reduced, a different model might be appropriate, and this is to be investigated. For example, instead of being modelled as a predator, the cod stock might be modelled as an excluder, so that the carrying capacity of the West Greenland shrimp-fishing grounds is reduced as cod stocks increase.

In the most recent years increases in cod abundance have been registered. Also in the 2004 Greenlandic trawl survey, 1-group cod was seen in weighable quantities for the first time (Storr-Paulsen, pers. comm.), but the results of the autumn survey are needed to scale these findings. Although there are indications of an increasing cod stock, absolute estimates are still an order of magnitude lower than those of the late 1980s and certainly in the 1950s and 1960s (Table 1; Storr-Paulsen and Wieland, 2004; Wieland and Storr-Paulsen, 2004). Indications from surveys in 2005 are that marked increases in the cod stock continue, but that the distribution, with respect to depth, temperature, and region, of the cod that have been encountered raises questions as to their aptitude to encounter and prey on shrimp.

Ten-year projections of stock development were made under the assumption that the cod stock will remain at the most recent estimated abundance, and under assumptions that constants governing the predation mechanism will retain the values estimated from the 30-year data series of the interaction between the two species. Five levels of annual catch were investigated: 110 000, 120 000, 130 000, 140 000 and 155 000 tons (Fig. 5, 6 and 7). When associated with a 30 000-ton biomass of cod, all entrained small risks of transgressing precautionary limits of the biomass or mortality that would be realised at MSY level.

The present assessment based on the existing modelling approach indicates a B_{MSY} equal to half of the carrying capacity K, but is also estimating large stocks and large carrying capacity. This is probably because the CPUE has increased, even under the high catch regimes of the past decade, and the most recent survey estimates, although lower than the high values achieved in 2003 and 2004 are nonetheless high when viewed in a historic perspective.

Because the modelled present and recently past stock levels are so high, the estimated cod predation is also high, and predictions may be sensitive to assumptions about the future trajectory of the cod stock.

All the scenarios of future catch that were tested indicated that biomass would decrease: the stock is estimated to be now above its MSY level, on the right-hand limb of the stock-recruitment curve, with somewhat reduced productivity, and cod predation is modelled to a level of close to 20 000 tons (Fig. 5). The reductions estimated for ten years of catches at 150 Kt entail some risk of driving the stock below B_{MSY} and of causing the mortality to exceed Z_{MSY}, but it appears that such catches could be sustained in the short term (Table 5). The risks increase very rapidly with increasing time horizon not only because of the compounding of uncertainties about the parameters of the recruitment process, but also the accumulation of uncertainties about the variability of the process itself.

These predictions have been made assuming that cod stocks stay where they are, and that our confidence in that level remains constant. It would be appropriate to test the effect of a widening uncertainty as to the future trajectory of the cod stock.

Precautionary Approach

The "Precautionary Approach" framework developed by Scientific Council define 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 5) and are low.

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Table 1. Input data series: catch by the fishery; two indices of shrimp stock biomass—a standardised catch-rate index based on fishery data (CPUE) and a research-survey-based index; a series of cod biomass estimates (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004, 2005); a 4-yr series of estimates of shrimp predation by cod (Grünwald, 1998).

	Catch ('000 t)	CPUE (1976=1)	Survey ('000 t)	Cod biomass ('000 t)	Effective cod biom. ('000 t)	Predation ('000 t)
1955	6.1			1729	1818	
1956	6.1			1663	1523	
1957	6.1			1286	1343	
1958	6.1			1333	1223	
1959	6.1			1294	1131	
1960	6.1			1589	1215	
1961	6.1			1592	1195	
1962	6.1			1460	983	
1963	6.1			1449	877	
1964	6.1			1457	872	
1965	6.1			1348	897	
1966	6.1			1387	838	
1967	6.1			1242	769	
1968	6.1			878	577	
1969	6.1			536	396	
1970	10.5			393	254	
1971	11.6			335	225	
1972	11.9			228	186	
1973	15.5			137	115	
1974	27.0			86	84	
1975	46.5			63	69	
1976	61.4	1.000		133	136	
1977	51.6	0.906		122	149	
1978	42.3	0.707		120	166	
1979	42.8	0.638		135	142	
1980	55.9	0.779		107	158	
1981	53.8	0.729		104	112	
1982	54.3	0.938		135	103	
1983	56.2	0.820		88	63	
1984	52.8	0.773		53	39	
1985	66.2	0.809		31	26	
1986	76.9	0.865		41	20	
1987	77.9	1.031		231	288	
1988	73.6	0.705	223	307	301	84.8
1989	80.7	0.579	209	192	139	8.5
1990	84.0	0.589	207	58	8	1
1991	91.5	0.605	146	7	1	2.3
1992	105.5	0.670	194	8	0	

Table 1. (continued)

	Catch ('000 t)	CPUE (1976=1)	Survey ('000 t)	Cod biomass ('000 t)	Effective cod biom. ('000 t)	Predation ('000 t)
1993	91.0	0.652	216	1	0	
1994	92.8	0.638	223	0	0	
1995	87.4	0.688	183	0	0	
1996	84.1	0.706	192	1	0	
1997	78.1	0.727	167	1	0	
1998	80.5	0.808	244	0	0	
1999	92.2	0.901	237	1	0	
2000	98.0	1.044	280	1	0	
2001	102.9	1.027	280	6	1	
2002	136.3	1.214	369	5	1	
2003	120.3	1.278	548	5	1	
2004	128.5	1.488	528	5	2	
2005	138.6	1.441	480	25	2	
2006	140.2	1.423	437	23	5	

Table 2. Model diagnostics: residuals (% of observed value), probability of getting a more extreme observation (p.extr.), conditional predictive ordinate (CPO; unscaled).

	CPU			Survey		
	residual (%)	p extr. (%)	CPO (unscaled)	residual (%)	p extr. (%)	CPO (unscaled)
1976	-6.86	25.4	0.84			
1977	-4.33	32.6	2.05			
1978	4.68	33.7	3.18			
1979	8.51	22.4	1.89			
1980	-2.11	41.2	3.23			
1981	5.23	31.5	2.82			
1982	-6.76	24.3	1.34			
1983	0.28	50.1	3.65			
1984	2.97	41.5	3.67			
1985	1.77	45.1	3.61			
1986	1.70	45.6	3.29			
1987	-9.24	17.4	0.65			
1988	5.14	31.0	3.10	0.82	49.4	1.02
1989	12.11	13.1	1.19	-5.66	34.9	1.00
1990	1.11	46.5	5.89	-12.83	20.5	0.67
1991	-4.06	33.3	4.61	20.43	13.7	0.66
1992	-2.85	38.8	4.85	1.63	48.0	1.20
1993	1.35	46.0	5.17	-7.50	33.2	0.91
1994	4.00	35.3	4.31	-9.92	26.1	0.77
1995	-2.25	38.8	4.26	11.11	26.5	0.95
1996	-2.58	38.9	4.31	8.63	32.4	1.02
1997	-2.66	39.4	3.91	28.41	6.4	0.30
1998	-0.70	46.9	4.24	-0.54	48.4	0.95
1999	-2.02	42.2	3.59	12.97	24.2	0.67
2000	-4.36	32.8	2.37	7.54	34.0	0.72
2001	1.50	44.1	3.24	12.90	25.0	0.57
2002	0.03	49.7	2.83	-0.56	48.3	0.63
2003	6.56	26.6	1.00	-24.59	4.1	0.12
2004	0.46	47.4	0.88	-14.26	18.1	0.23
2005	2.06	42.2	2.17	-7.36	32.3	0.41
2006	0.00	49.7	2.05	-2.10	43.0	0.51

Table 3. Correlations between selected model parameters (for explanation of symbols, see text).

	P_1	τ	v	κ	ω	O_{max}	$P_{50\%}$	qc	qs	K
MSY	0.113	-0.005	-0.168	-0.022	0.037	-0.001	-0.013	-0.538	-0.536	0.663
K	0.184	-0.010	-0.105	-0.042	0.089	0.004	-0.036	-0.794	-0.793	
qs	-0.264	0.008	0.157	0.037	-0.083	-0.004	-0.346	0.996		
qc	-0.265	0.008	0.159	0.036	-0.081	-0.004	-0.349			
$P_{50\%}$	0.078	0.003	-0.118	0.015	-0.012	0.065				
O_{max}	0.002	-0.010	0.006	0.003	0.011					
ω	0.023	-0.087	0.038	-0.092						
κ	-0.011	0.036	0.062							
v	-0.052	0.028								
τ	-0.008									

Table 4. Summary of parameter estimates: Mean, standard deviation (sd) and 25, 50, and 75 percentiles of the posterior distribution of selected parameters (for explanation of symbols, see text). Based on all information; 130-t. future catches

	Mean	S.D.	25%	Median	75%	Median (2005)
MSY	170	49	133	159	199	150
K	3133	1506	1804	2854	4437	2503
q_s	0.228	0.122	0.128	0.208	0.302	0.28
q_c	7.46E-04	3.96E-04	4.19E-04	6.82E-04	9.86E-04	7.1E-04
B_{MSY}/K	0.5	0	0	0.5	0	0.44
$P_{50\%}$	2.58	0.76	2.07	2.52	3.02	2.88
O_{max}	3.00	0.10	2.93	3.00	3.07	3.00
ω	8.35E-02	1.62E-02	7.17E-02	8.21E-02	9.28E-02	0.081
κ	0.153	0.024	0.136	0.150	0.167	0.16
$1/v^2$	77.0	29.8	57.1	71.5	92.8	71.29
τ	0.308	0.070	0.261	0.298	0.346	0.29
P_1	0.933	0.190	0.794	0.912	1.054	0.91

Table 5. Risk (%) of exceeding limit mortality or falling below *MSY* or limit* biomass after 5 and 10 years of different catch rates, **'effective' cod stock assumed stationary at 22.7 Kt.**

Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	5 yr	10 yr	5 yr	10 yr	5 yr	10 yr
110	10.9	13.9	0.0	0.1	6.5	10.4
120	11.4	17.0	0.0	0.2	11.5	17.2
130	13.2	21.6	0.0	0.6	18.3	24.4
140	18.2	27.5	0.0	1.4	26.0	33.4
150	18.6	31.0	0.1	2.7	33.4	39.8

* limit biomass is taken to be 30% of B_{msy}

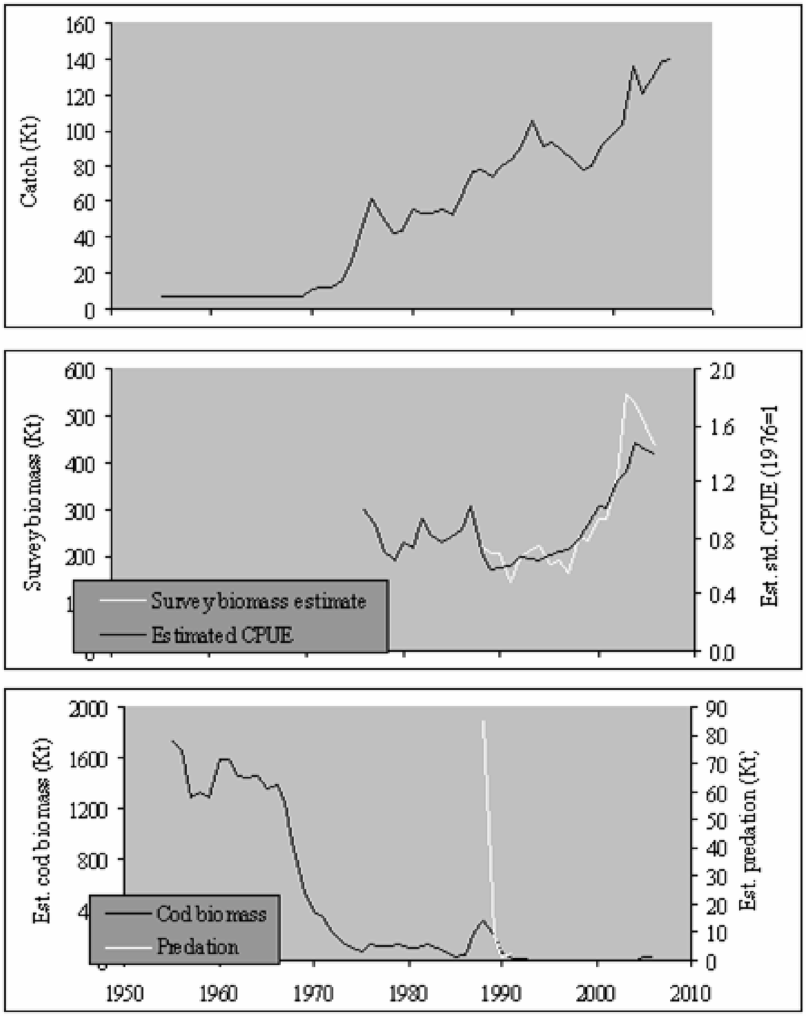

Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model. Catch by the fishery; shrimp fishable biomass indices (shrimp≥17 mm CL) based on standardised commercial catch rates (CPUE-index) and research surveys; biomass estimates of cod and a four-year series of predation estimates based on stomach sampling.

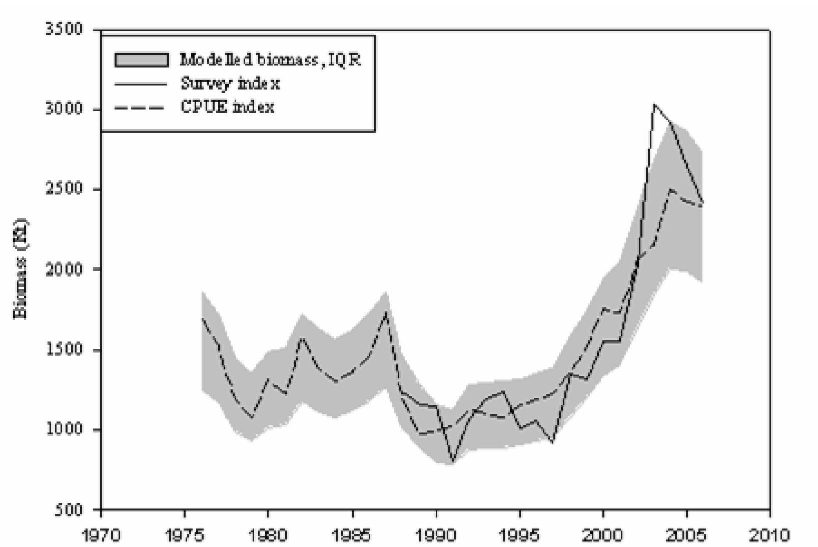

Fig. 2. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices.

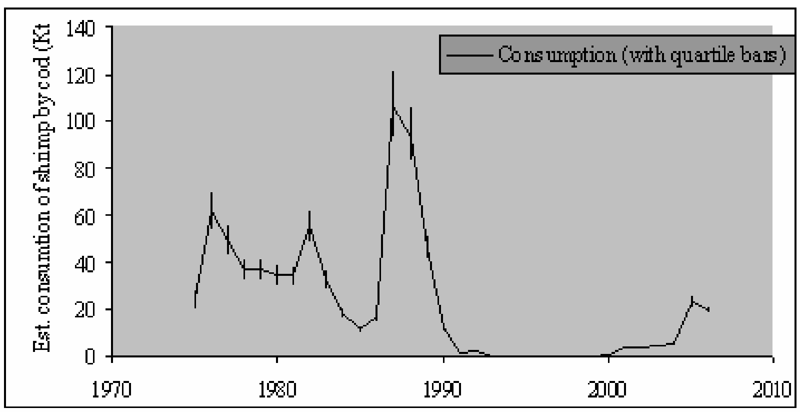

Fig. 3. Shrimp in West Greenland: estimated median consumption of shrimp by cod.

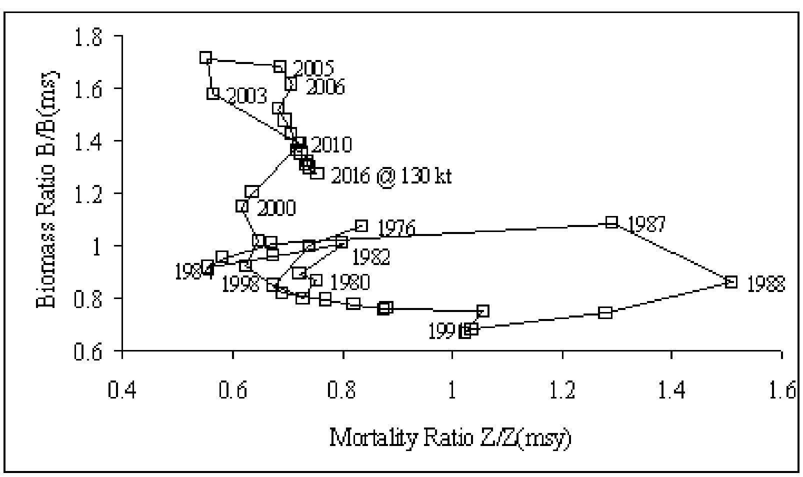

Fig. 4. Shrimp in West Greenland: median estimates of biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1976–2015.

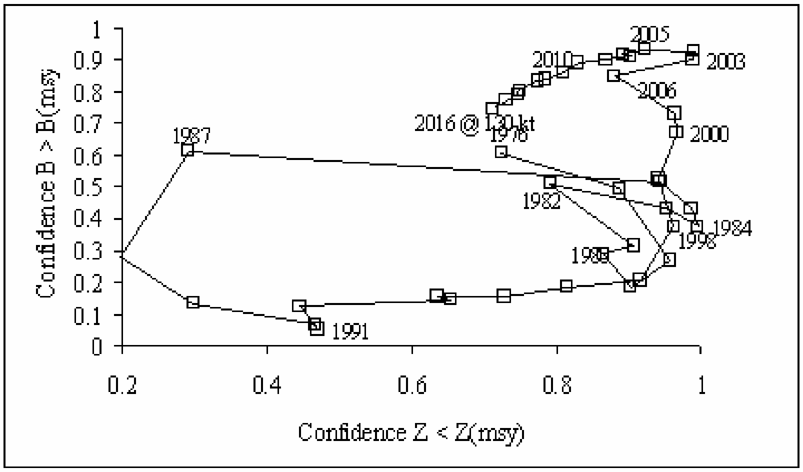

Fig. 5. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{MSY} and that mortality caused by fishing and cod predation has been above Z_{MSY} 1976–2004.

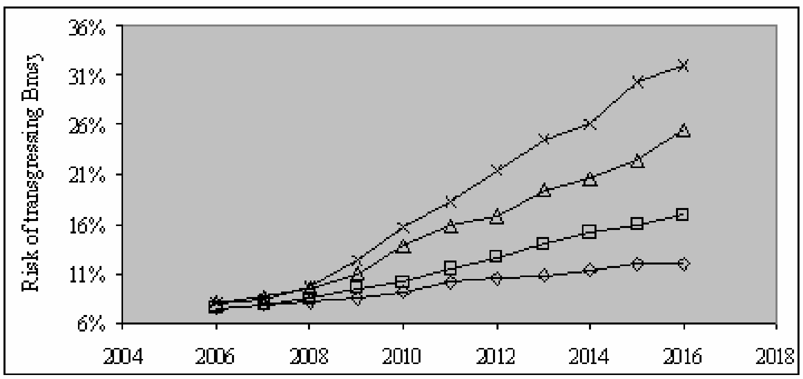

Fig. 6. Increasing risk with time of transgressing B_{msy} at catch levels 110–150 Kt/yr

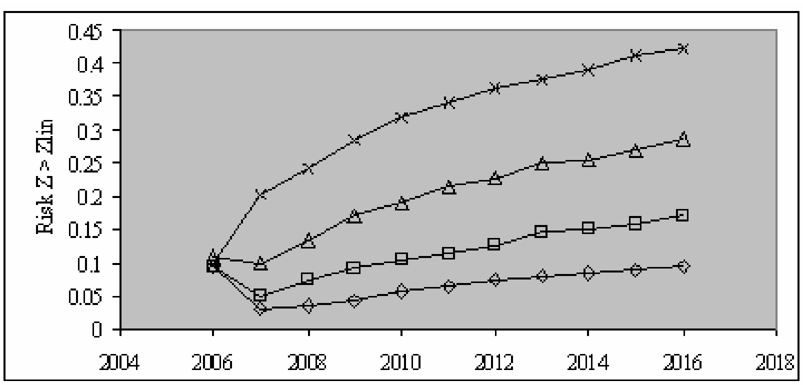

Fig. 7. Increasing risk with time of transgressing Z_{msy} at future catch levels 110–150 Kt/yr.

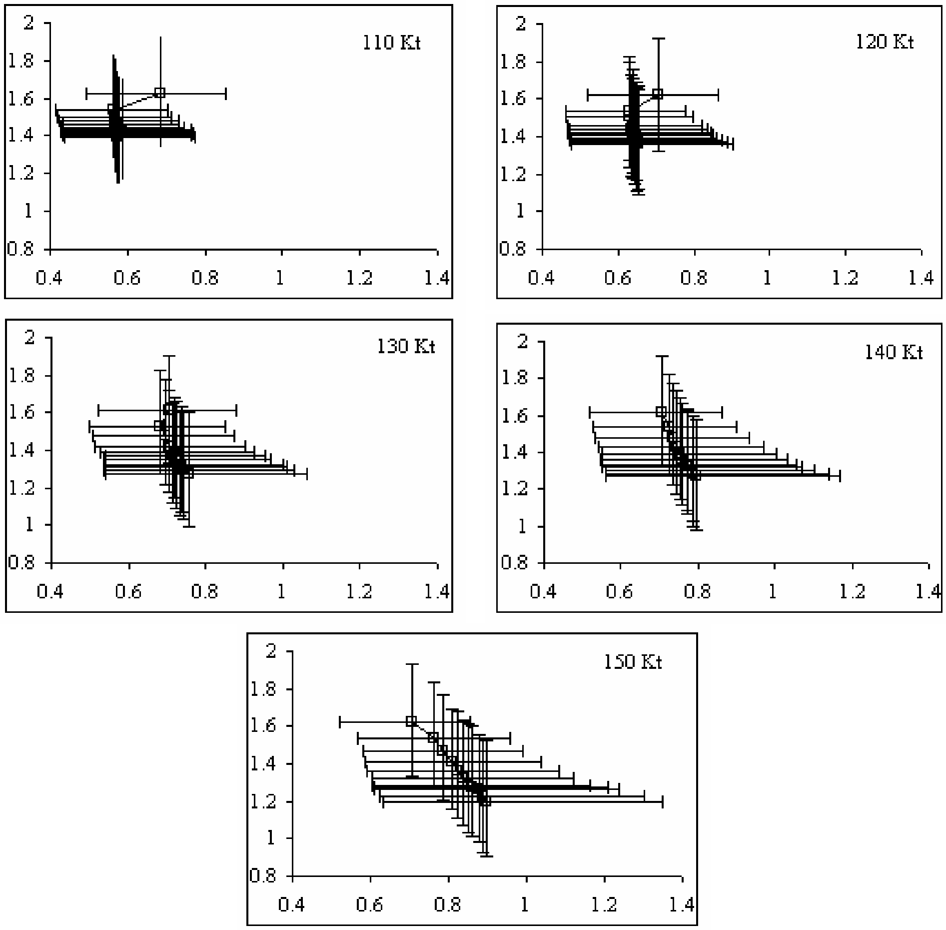

Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2006–2015 plotted as biomass ratio(B/B_{MSY}) *vs* mortality ratio (Z/Z_{MSY}). Estimated stock trajectories at 110–150 thousand tons fixed annual catch levels are shown as medians with quartile error bars.