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A Provisional Assessment of the Shrimp Stock off West Greenland, Updated 2005

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 frameworks incorporates a Pella-Tomlinson 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 fitting process.

Results from the modeling were that the stock biomass has increased since the early 1990s and reached its highest level recorded in 2005, 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 150 000 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 drive the stock lower.

Projections showed that catches of 140 000 tons/yr are not likely to drive the stock below B_{MSY} in the short term, but that this level of exploitation is not likely to be sustainable in the longer 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 three levels of annual catch: 125, 140 and 155 thousand 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 annualized 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. 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 17-year series of a survey biomass indices of shrimp ≥17 mm CL (Wieland *et al*., 2004; Wieland and Bergström 2005); a 29-year series of combined CPUE indices (Kingsley and Hvingel, 2005); a 50 year series of catches by the fishery (Hvingel, 2004; Hvingel and Kingsley, 2002); a 50-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. The error terms, ω and κ, are normally, independently and identically distributed with mean 0 and variance σ_ω^2 and σ_κ^2 . The std. error for the final year, N, 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.

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 run for 750 000 iterations, of which every 100th was retained giving 7 500 available samples. Of these, the first 1 500, corresponding to 150 000 iterations, were discarded as 'burn-in' and of the remainder, every 3rd retained for analyses.

It will in this document be appropriate to make comparison with the results obtained in the previous year, as the assessment model is attempting to use the fishery data to draw quantitative conclusions as to the biological parameters underlying the dynamics of the stock and its response to fishing and other predation, and it is to be expected, or at least hoped, that the addition of data at the margin should not make a lot of difference. We note that a complete new file on Canadian catch and effort was received, which made some difference to the standardized 0A CPUE series; however, the Canadian fishery accounts for so small a proportion of the catch, and effort, that changes to the combined standardized CPUE series were mostly small. An exception occurred in 2003, the last year of the 0A series in the 2004 assessment. The 0A CPUE for 2003 was estimated at 2.46 in 2004, and at 1.68 in 2005, and this reduced the combined standardized index for that year from 1.11 to 1.05.

The series of biomass estimates from the annual West Greenland bottom-trawl survey was revised as a consequence of switching from the *Skjervøy 3000* trawl with bobbin ground gear to a Cosmos 2000 with rockhopper ground gear (Wieland 2005), and the revised sequence was used in the updated assessment. The cod biomass series used was also revised to include future values equal to the present estimate (Storr-Paulsen and Wieland 2005).

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

Results, Model Performance

Owing to lack of time in 2005, little investigation of model diagnostics and model performance were carried out, and reference is made to Hvingel (2003). The model produced a reasonable simulation of the observed data series. The probabilities of getting a more extreme observation than the realized 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; the 1991, 1997 and 2003 values had relatively large residuals 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). Notably, 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, of course, very high positive correlation, as they are both fitting the modeled biomass series to observed index series, and they were, equally obviously, 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 150 Kt, higher than 128 estimated in 2004; carrying capacity, which was poorly estimated, had a median estimate of 2 500 Kt, nearly double the estimate made in 2004. Survey catchability was estimated at only 0.28, much lower than in 2004. Compared with the results from 2004, the stock is, and has been, larger, but has lower inherent productivity.

The estimated CV of the observed CPUE series, ω, had a median of about 8.0% and for the survey series, κ, of about 16.0%—both similar to 2004. The process error, ν, had a median of 10% (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 2.9, not very different from 2004.

Assessment Results

Estimates of the parameters governing the modelled predation by cod on the shrimp stock changed very little between the 2004 assessment and the 2005 update. 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. 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 102 000 t in 1987 and 86 000 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 4 00 tons of shrimp in 2004, but the median estimate of predation increased to about 32 000 tons in 2005 owing to the 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. 3) was stable in a region of biomass 1–1.2 times B_{MSY} and mortality near 0.6 times Z_{MSY}. A brief return of high cod stocks in the late 1980s caused a short episode of mortality ratios rising to 1.2–1.4, 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 the biomass consequently increased after the late 90s. 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. 3).

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 0.6–0.7, i.e. below the value that maximizes yield. The median estimate for 2005 is 0.74 with a 20% possibility that mortality is higher than it would be if the stock was 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 150 000 tons with upper and lower quartiles at 127 000 and 193 000 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. Risk[1] associated with three optional catch levels for 2006 are as follows:

Catch option ('000 tons)	125	140	155
Risk of falling below B_{MSY}	7.9%	8.6	8.4%
Risk of falling below B_{lim}	<0.1%	<0.1%	<0.1%
Risk of exceeding Z_{MSY}	17.4%	26.6%	36.3%

Predation by cod can be significant (Fig. 2) and have a major impact on shrimp stock size. 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 slowly rebuilding process and/or by immigration of one or two large year-classes from areas around Iceland as seen in the late 1980s.

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. Three levels of annual catch were investigated: 125 000, 140 000 and 155 000 tons (Fig. 5, 6 and 7). When associated with a 40 000-ton biomass of cod, all were associated with risks of transgressing precautionary limits of the biomass or mortality that would be realized at MSY level.

The present assessment based on the existing modeling approach indicates a B_{MSY} less than half of the carrying capacity K, but also is estimating large stocks and large carrying capacity. This is probably because the CPUE has continued to increase, even under the recent high catch regime; the survey results are perhaps downweighted because of their past variability, while CPUE gains weight in the model by fitting the assumed stock-dynamic model. Because the modelled present and 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 low productivity (Fig. 5). The reductions estimated for ten years of catches at 155 Kt entail significant 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.

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

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

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Table 1. Input data series: catch by the fishery; two indices of shrimp stock biomass—a standardized 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)	Predation ('000 t)
1955	6.1			1729.0	
1956	6.1			1663.0	
1957	6.1			1286.0	
1958	6.1			1333.0	
1959	6.1			1294.0	
1960	6.1			1589.0	
1961	6.1			1592.0	
1962	6.1			1460.0	
1963	6.1			1449.0	
1964	6.1			1457.0	
1965	6.1			1348.0	
1966	6.1			1387.0	
1967	6.1			1242.0	
1968	6.1			878.0	
1969	6.1			536.0	
1970	10.5			393.0	
1971	11.6			335.0	
1972	11.9			228.0	
1973	15.5			137.0	
1974	27.0			86.0	
1975	46.5			63.0	
1976	61.4	1.000		133.0	
1977	51.6	0.899		122.0	
1978	42.3	0.700		120.0	
1979	42.8	0.630		135.0	
1980	55.9	0.767		107.0	
1981	53.8	0.729		104.0	
1982	54.3	0.931		135.1	
1983	56.2	0.811		87.5	
1984	52.8	0.767		52.7	
1985	66.2	0.795		30.6	
1986	76.9	0.860		41.4	
1987	77.9	1.017		231.0	
1988	73.6	0.681	256.3	307.0	
1989	80.7	0.588	240.0	191.6	84.8
1990	84.0	0.570	237.7	57.5	8.5
1991	91.5	0.572	167.7	7.4	1.0
1992	105.5	0.626	223.0	8.4	2.3
1993	91.0	0.606	248.6	0.8	
1994	92.8	0.595	256.3	0.3	
1995	87.4	0.632	210.4	0.1	
1996	84.1	0.638	220.6	0.8	
1997	78.1	0.627	191.9	0.6	
1998	80.5	0.708	280.5	0.3	
1999	92.2	0.757	272.5	0.5	
2000	97.0	0.854	321.9	1.3	
2001	102.8	0.830	322.1	5.8	
2002	135.2	0.977	424.3	10.0	
2003	130.1	1.041	629.6	5.0	
2004	141.8	1.255	606.7	5.0	
2005	140.5	1.337	479.5	39.6	

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	-5.7	29	1.0			
1977	-3.7	36	2.1			
1978	3.4	34	3.5			
1979	7.1	23	2.0			
1980	-2.3	40	3.8			
1981	4.0	37	3.5			
1982	-7.0	23	1.2			
1983	-0.5	49	3.9			
1984	2.5	39	4.1			
1985	0.9	47	4.0			
1986	1.7	43	3.6			
1987	-6.3	25	0.9			
1988	2.6	40	4.3	6.3	38	0.77
1989	1.0	46	5.7	-3.3	44	0.89
1990	-1.8	42	5.9	-7.9	33	0.78
1991	-2.0	42	5.3	29.9	8	0.30
1992	-1.3	46	5.4	8.0	33	0.86
1993	1.1	47	5.6	-4.0	40	0.84
1994	2.8	39	5.4	-7.6	35	0.75
1995	-2.2	41	4.9	14.1	22	0.70
1996	-1.3	47	3.1	10.3	29	0.81
1997	0.0	49	5.5	27.6	8	0.33
1998	-0.5	48	4.9	-2.5	45	0.77
1999	0.4	50	4.5	8.2	33	0.70
2000	-2.3	39	3.7	1.0	47	0.68
2001	4.6	31	3.1	4.5	41	0.65
2002	1.9	41	3.4	-8.9	30	0.43
2003	7.2	23	1.2	-31.2	2	0.10
2004	0.1	49	2.5	-20.4	12	0.15
2005	-6.5	27	0.2	1.3	47	0.43

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

	MSY	K	q_s	q_c	B_{MSY}/K	$P_{50\%}$	O_{max}	ω	κ	ν	τ
K	0.65										
q_s	-0.72	-0.79									
q_c	-0.72	-0.80	0.99								
B_{MSY}/K	0.11	0.06	-0.13	-0.14							
$P_{50\%}$	-0.21	-0.40	0.21	0.20	-0.21						
O_{max}	0.04	0.06	-0.03	-0.04	0.02	0.04					
ω	0.01	0.06	-0.03	-0.03	0.01	-0.01	0.00				
κ	-0.03	-0.03	0.00	0.00	0.00	0.03	0.01	-0.03			
ν	-0.31	-0.22	0.30	0.30	-0.15	-0.03	-0.03	0.06	0.08		
τ	-0.10	-0.08	0.13	0.13	-0.01	0.07	0.00	0.02	0.00	0.05	
P_1	0.20	0.20	-0.31	-0.31	0.02	0.15	0.01	0.03	-0.01	-0.10	0.00

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; 140-t. future catches

	Mean	sd	25.00%	Median	75.00%	Median (2004)
MSY	169	63	127	150	193	128
K	2870	1540	1514	2503	4171	1386
q_s	0.31	0.18	0.16	0.28	0.42	0.408
q_c	7.9E-04	4.5E-04	4.1E-04	7.1E-04	1.1E-03	11.6E-04
B_{MSY}/K	0.46	0.07	0.40	0.44	0.50	0.43
$P_{50\%}$	3.01	1.00	2.35	2.88	3.58	2.93
O_{max}	3.00	0.10	2.93	3.00	3.06	3.00
ω	0.083	0.016	0.072	0.081	0.092	0.080
κ	0.16	0.03	0.14	0.16	0.18	0.168
ν	76.06	30.72	54.31	71.29	91.60	0.116
τ	0.30	0.07	0.25	0.29	0.34	0.291
P_1	0.94	0.19	0.80	0.91	1.05	0.878

Table 5. Risk (%) of exceeding limit mortality or falling below *MSY* or limit* biomass after 5 and 10 years of different catch rates, **cod stock assumed stationary at 39.55 Kt.**

	Prob. biomass < B_{MSY}(%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
Catch rate (‘000 t)	5 yr	10 yr	5 yr	10 yr	5 yr	10 yr
125	16.1	29.0	0.15	1.6	29.3	36.9
140	21.3	37.8	0.1	4.1	40.0	47.1
155	25.9	44.3	0.5	11.2	48.6	56.7

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

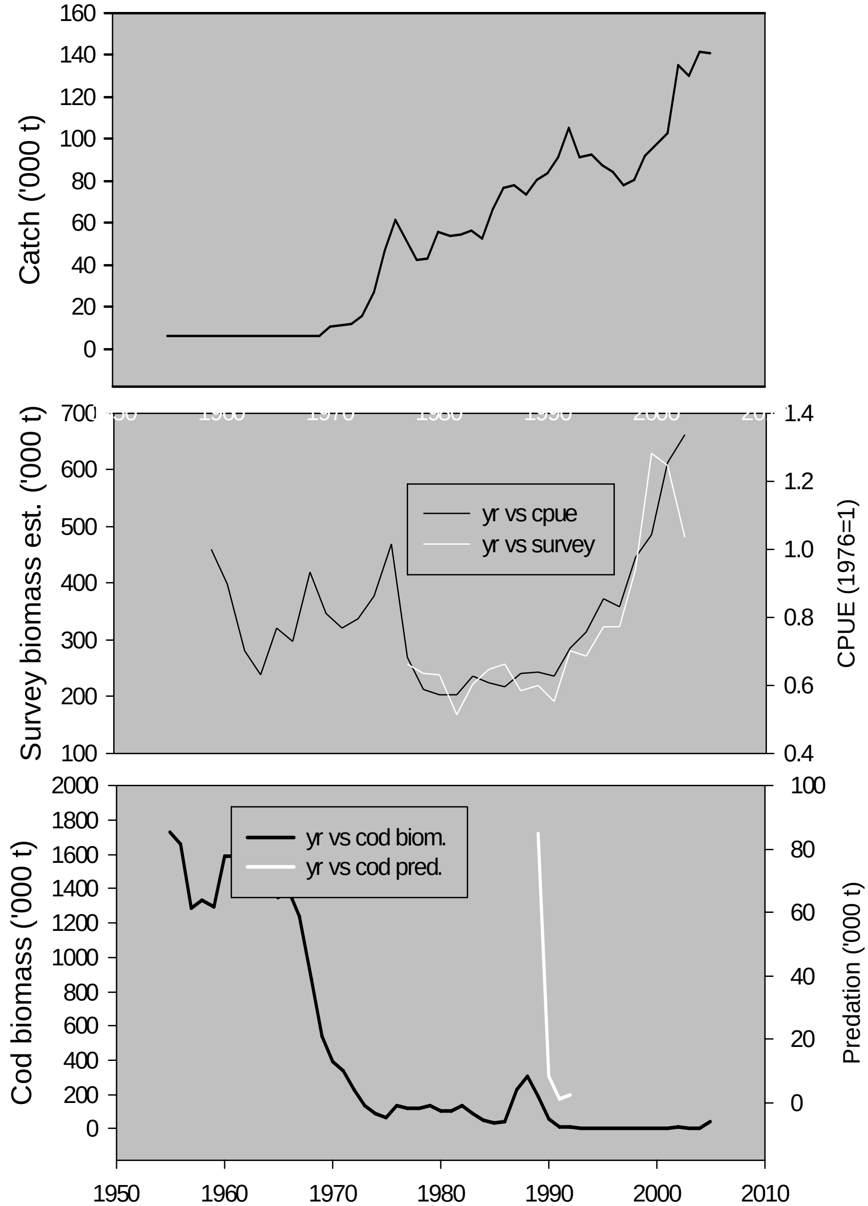

Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model. Upper panel: Shrimp fishable biomass indices (shrimp ≥17 mm CL) based on 1. standardized commercial catch rates (CPUE-index) and 2. research survey data. Middle panel: Catch by the fishery. Lower panel: absolute biomass estimates of cod and a four year series of consumption estimates based on stomach sampling.

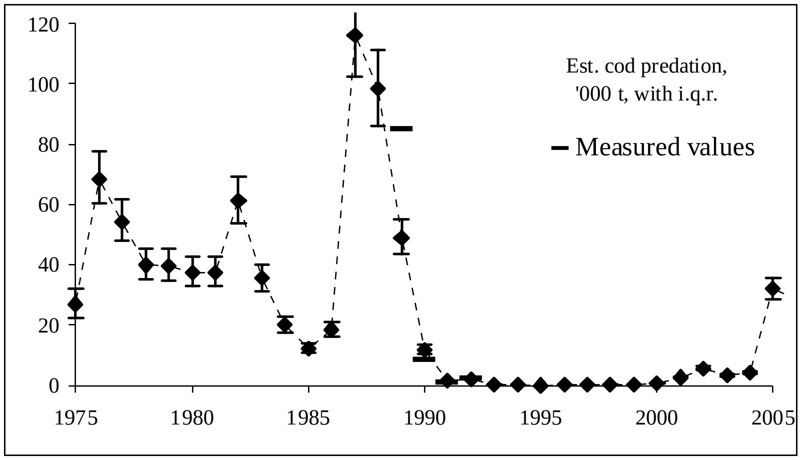

Fig. 2. Shrimp in West Greenland: estimated median consumption of shrimp by cod.

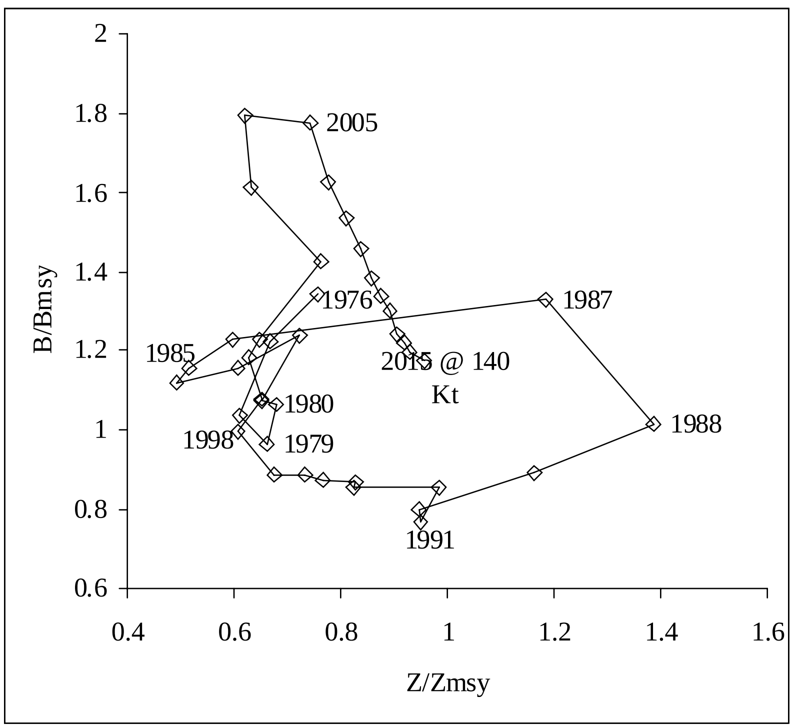

Fig. 3. Shrimp in West Greenland: median estimates of biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1976-2015.

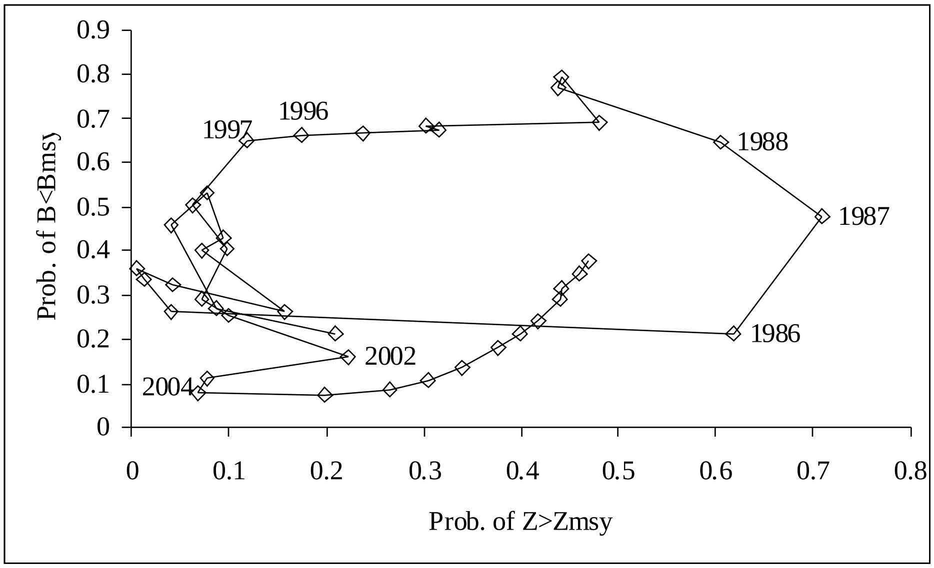

Fig. 4. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{MSY} and that mortality caused by fishing and cod predation has been above Z_{MSY} 1976-2004.

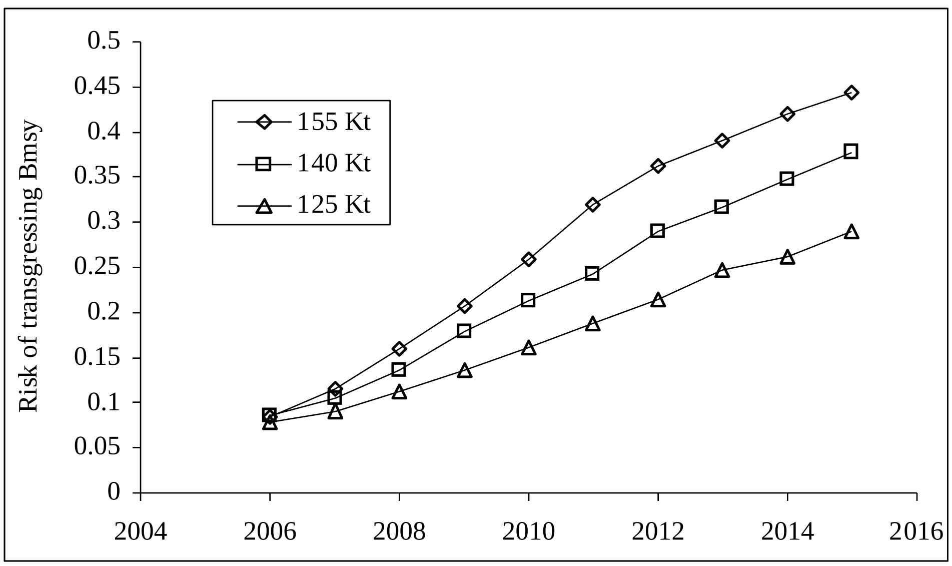

Fig. 5. Increasing risk with time of transgressing B_{msy} at different catch levels

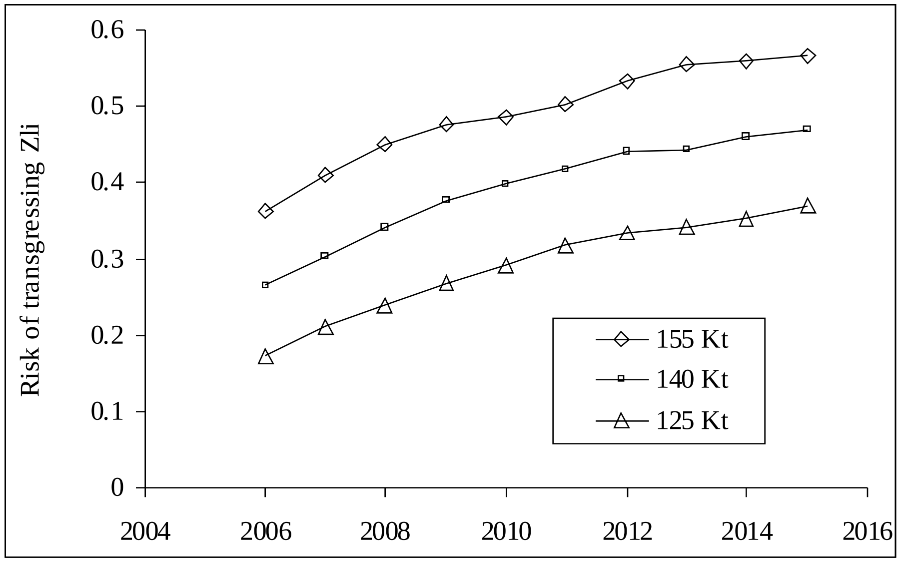

Fig. 6. Increasing risk with time of transgressing Z_{msy} at different catch levels.

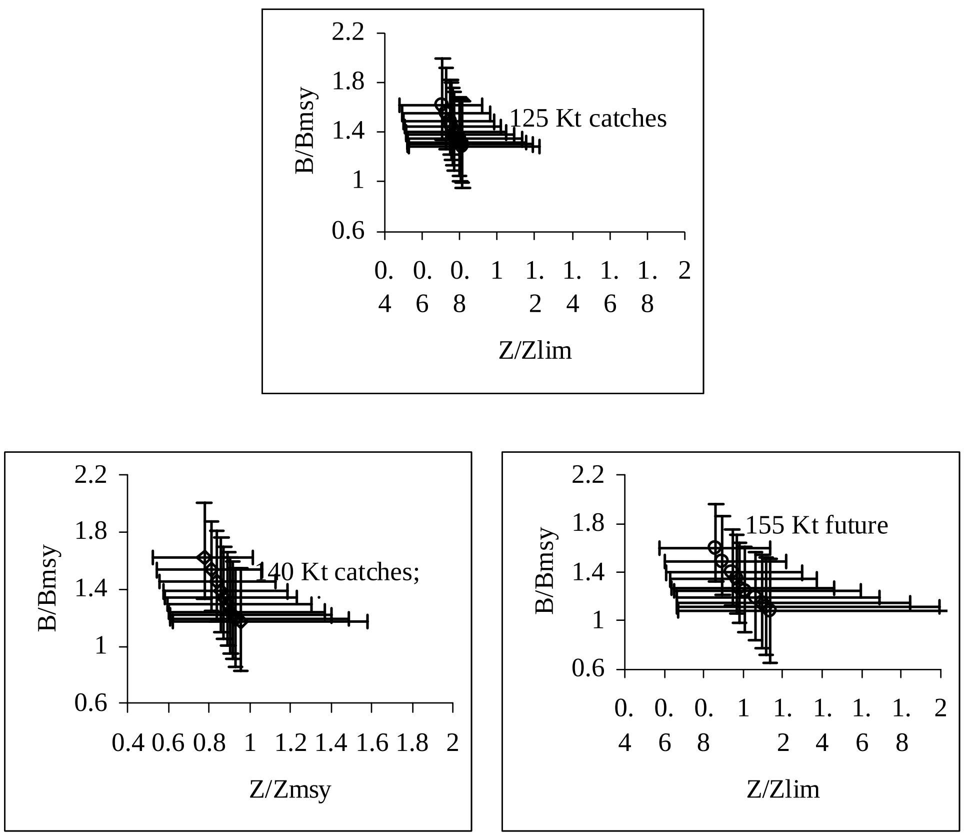

Fig. 7. Shrimp in Subareas 0 and 1: projections of stock development for the period 2006-2015 quantified in a biomass (B/B_{MSY})-mortality (Z/Z_{MSY}) continuum. Dynamics at 125, 140 and 155 thousand tons of fixed annual catch levels are shown as medians with error-bars at the 25th and 75th percentiles.