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An Assessment of the Shrimp Stock off West Greenland

by

C. Hvingel

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

Abstract

Assessment of the West Greenland Stock of *Pandalus borealis* was performed using the new assessment framework adopted by STACFIS and Scientific Council in 2002. The stock biomass has increased since the early-1990s and reached its highest level recorded in 2004. Biomass is 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, available equally to the fishery and cod (*MSY*) was 128 000 tons.

Projections showed that catches of 130 000 tons/yr is not likely to drive the stock below B_{MSY} in the short to medium term (<5 years). However, this level of exploitation is not likely to be sustainable in the longer term.

Introduction

The shrimp (*Pandalus borealis*) stock off West Greenland is distributed in Div. 0A and Subarea 1 east of 60°W. Shrimp within this area is assessed as a single population. The Greenland 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 east of 60°W since 1981.

Until 2002 management advice for this stock was basically formulated by qualitative assessment of trends in various indices of stock condition in response to 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 consented 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 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 are made for five levels of annual catch: 110, 120, 130, 140 and 150 thousand tons under the assumption that the cod stock remain at its current low level. The associated risk of transgressing the reference parameters maximum sustainable yield level of biomass (B_{MSY}) and mortality (Z_{MSY}) are estimated. Likely consequences of cod resurgence is discussed.

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).

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 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); a 29-year series of combined CPUE indices (Hvingel, 2004); 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); 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) (see Table 1 and Fig. 1). The data link functions of the biomass indices were:

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

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 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 fishery data until October (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:

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

Results, Model Performance

The addition of an extra year of data did not change the model diagnostics and derived conclusions about model performance reported in Hvingel (2003). The model was able to produce a reasonable simulation of the observed data (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 except for the 2003 survey biomass index value the observations did not lie in the tails of their posterior distributions. The survey series was generally less well estimated; the 1991, 2003 and 2004 values had the largest residuals and smallest CPOs (Conditional Predctive Ordinate).

Some of the parameters showed high linear correlations (Table 3). The catchabilities of the CPUE series, q_c and of the survey series, q_s, were negatively correlated with the parameter for carrying capacity, K, and Maximum Sustainable Yield, MSY. These correlations meant that a large number of iterations were needed to secure a complete representation of the posterior distributions of the parameters.

For the parameters P_1 (Biomass ratio of year 1), τ (CV of consumption by cod) and O_{max} (maximum predation rate) the posterior distributions tended to approximate the input priors (Fig. 3). The distribution of the carrying capacity, K, showed a mode around 1 000 Mtons (Fig. 3) but had a long tail towards higher values. The catchabilities, q_s and q_c, showed peaks at 0.41 and 0.0012, respectively, but had relatively wide posterior distributions. However, the posterior for MSY was determined with a distinct mode at 119000 and a smooth distribution skewed to the right (Fig. 3).

The estimated CV of the observed CPUE series, ω, had a median of about 8.0% and for the survey series, κ, of 16.8%. The process error, ν, had a median of 11.6% (Table 4). The parameter set to be the main determinant of cod predation rate, $P_{50\%}$ (biomass ratio at which the predator is 50% saturated), was markedly updated with a posterior showing a mode at 2.91 (Fig. 3).

Assessment Results

The model estimated the median annual consumption by cod 1956-2004 in the range of 200 tons to about 122 000 tons (Fig. 4), which is in the same order of magnitude as the catches taken by the fishery. The estimated consumption declined since 1960 as a result of a decline in cod abundance at West Greenland. A short-lived resurgence of the cod stock in the late-1980s caused consumption to increase dramatically. The cod disappeared in the beginning of the 1990s and estimates of consumption went to zero (Fig. 4). In the most recent years slight increases in cod abundance have been noted in routine surveys. However, whether this is a beginning of a major return of cod to this ecosystem is still unclear. Cod was estimated to consume about 8 000 tons shrimp in 2004.

The trajectory of the median estimate of 'biomass-ratio' (B_t/B_{MSY}) plotted against 'mortality-ratio' (Z_t/Z_{MSY}) (Fig. 5) starts in 1956 at about half the optimum biomass ratio and at a mortality-ratio well above 1. The stock stayed in this region during the years when cod were abundant. When the cod stock declined in the late-1960s and predation pressure was lifted (Fig. 4), shrimp stock biomass increased and eventually began cycling in the left upper corner of the graph (Fig. 5) during the current regime of low cod abundance.

Since the early-1970s when the offshore fishery was developed, the estimated median biomass-ratio ranged from about 1 to 1.81 (Fig. 5) and the probability that it had been below the optimum level was small for most years (Fig. 6), i.e. it seemed likely that the stock had been at or above its MSY level throughout the modern fishery. A steep decline in CPUE was noted in the late-1980s and early-1990s following a short-lived resurgence of the cod stock and the median estimate of biomass-ratio went below the optimum (Fig. 5). Since the late-1990s the stock has increased and reached its highest level ever in 2004 with a median estimate of biomass-ratio of 1.81, corresponding to about 78% of estimated median carrying capacity. The estimated risk of stock biomass being below B_{MSY} was 0.04 (Fig. 6).

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 effected by high cod predation in the late-1980s to early-1990s (Fig. 5). Since 1997, annual median Z-ratio has been stable at approximately 0.7, i.e. well below the value that maximizes yield. The median of estimate for 2004 is 0.7 with a risk of 0.09 of being above 1 (Fig. 6).

The median estimate of the maximum annual production surplus, available equally to the fishery the cod (*MSY*) was estimated to 128 000 tons (Table 3). The posterior showed a mode at 119000 tons and upper and lower quartiles at 150 000 and 116 000 tons (Fig. 7). The risk function relating the probability of exceeding *MSY* to the combined removal by fishery and cod predation is given as the integral of this distribution (Fig. 7 right panel).

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 associated with five optional catch levels for 2005 are as follows:

Catch option ('000 tons)	110	120	130	140	150
Risk of falling below B_{MSY}	4%	5%	5%	6%	6%
Risk of exceeding Z_{MSY}	5%	9%	17%	27%	37%

Predation by cod can be significant (Fig. 4) and have a major impact on shrimp stock size. Currently the cod stock at West Greenland is at a very low level. 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 slight 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 is needed to scale these findings. Although there are indications of an increasing cod stock absolute estimates are still way below those in the late-1980s and certainly in the 1950s and 1960s (Fig.1; Storr-Paulsen and Wieland, 2004; Wieland and Storr-Paulsen, 2004)

Ten-year projections of stock development were therefore made under the assumption that the cod stock will remain at its current low abundance. Five levels of annual catch: 110 000, 120 000, 130 000, 140 000 and 150 000 tons were investigated (Fig. 8).

The investigated catch options of 110 000 ton/yr have a small risk of being above *MSY* (Fig. 7) and the stock is therefore likely to remain above B_{MSY} (Fig. 8) during the ten years of projection. The combined relative fishing and cod predation mortality, Z_t/Z_{MSY}, has a high probability of being below 1 within this period (Fig. 9).

A catch option of 120 000 tons/yr is not likely to drive the stock below B_{MSY} in the short to medium term (Fig. 8), i.e. the risk is less than 10% within the first three years and less than 25% after 10 years (Fig. 9). However, this level of exploitation might not be sustainable in the longer term (>10 years), as risk of exceeding B_{MSY} continues to increase through time.

A catch option of 130 000 tons/yr will just about meet the estimated median *MSY* and is not likely to drive the stock below B_{MSY} in the shorter term (Fig. 8), i.e. the risk is less than 10% within the first three years (Fig. 9). However, this level of exploitation is not likely to be sustainable in the medium to longer term. After 10 years the risk of the stock dropping below optimum size is 32%.

Fishing 140 000 or 150 000 tons/yr bears a 69% and 78% risk respectively of being above *MSY* (Fig. 7), thus these catch levels are not likely to be sustainable in the medium to long term. Owing to the current high stock level the risk of exceeding B_{MSY} is no more than 16% after three years at 150 000 tons/yr, although after 10 years it is more than 50% (Fig. 9).

If on the other hand an abrupt increase in cod biomass resulting from immigration from other areas changes of shrimp stock condition may be much more rapid. Preliminary investigations of the event of an immigration of two large year-classes of cod were made by simulating a repetition of the short-lived resurgence of the cod stock seen in the late-1980s. The simulation showed that predation could within a 3-4 year period go from negligible to between 88 000 and 163 000 tons (upper and lower quartiles) (Fig.10).

Precautionary Approach

The Precautionary Approach Framework developed by Scientific Council defines limit reference points as follows:
Blim = A biomass level, below which stock productivity is likely to be seriously impaired, that should have a very low probability of being violated.
Flim = A fishing mortality rate that should only have a low probability of being exceeded. Flim cannot be greater than Fmsy. If Fmsy cannot be estimated, then an appropriate surrogate may be used instead.

The limit reference point for mortality in the current assessment framework is ZMSY, i.e. Z-ratio=1 and the risk of exceeding this point is given in this assessment. Blim could not be defined. For one thing stock-recruitment figures were only available for relative high stock sizes and extrapolation to define an area of "low recruitment" was not readily justified.

TAC allocation

TAC may be allocated to the Greenland and Canadian zones in Subarea 1 and Div. 0A, east of 60°W according to the distribution of stock biomass. Surveys conducted by Greenland covered the distribution of the stock (Wieland et al 2004). The surveys carried out between 1994-2004 (with the exception of 2003) have consistent coverage, allowing estimations and comparisons of biomass distribution in the two areas (Table 5). Annual estimates of biomass have inherent uncertainties and high variance. To minimize effects of these uncertainties the average and range for this period are calculated and used in the analysis. The average percentage of the biomass in Div. 0A was 1.6%, ranging from 0.1% to 4.1%. If TAC for shrimp in Subarea 1 and Div. 0A is split according to the average biomass distribution, the split would be 98.4% in Subarea 1 and 1.6% in Div. 0A. There is no information on the abundance of shrimp in Div. 0A outside of the survey area.

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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 (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004); a series of shrimp consumption by cod (Grünwald, 1998).

Year	Catch ('000 t)	CPUE (index)	Survey (index)	Cod ('000 t)	Consump. (´000 t)
1955	5.0			1729.3	
1956	5.0			1662.5	
1957	5.0			1286.1	
1958	5.0			1333.1	
1959	5.1			1294.3	
1960	5.1			1589.2	
1961	5.0			1591.9	
1962	5.1			1459.7	
1963	5.3			1448.6	
1964	5.5			1457.0	
1965	5.7			1348.4	
1966	5.9			1386.9	
1967	5.9			1241.8	
1968	6.1			877.5	
1969	7.5			535.9	
1970	10.5			392.7	
1971	11.6			334.9	
1972	11.9			227.5	
1973	15.5			136.8	
1974	27.0			85.8	
1975	46.5			62.9	
1976	61.4	1.00		133.0	
1977	51.6	0.90		122.4	
1978	42.3	0.70		120.3	
1979	42.8	0.64		135.3	
1980	55.9	0.77		106.9	
1981	53.8	0.74		103.6	
1982	54.3	0.94		135.1	
1983	56.2	0.81		87.5	
1984	52.8	0.76		52.7	
1985	66.2	0.81		30.6	
1986	76.9	0.81		41.4	
1987	77.9	1.04		231.0	
1988	73.6	0.69	216.8	307.0	
1989	80.7	0.61	199.6	191.6	84.8
1990	84.0	0.57	213.9	57.5	8.5
1991	91.5	0.58	146.3	7.4	1.0
1992	105.5	0.63	202.0	8.4	2.3
1993	91.0	0.62	232.7	0.8	
1994	92.8	0.61	249.5	0.3	
1995	87.4	0.65	201.1	0.1	
1996	84.1	0.66	211.9	0.8	
1997	78.1	0.64	185.3	0.6	
1998	80.5	0.72	263.1	0.3	
1999	92.2	0.80	251.5	0.5	
2000	97.2	0.88	301.0	1.3	
2001	102.8	0.85	304.3	5.8	
2002	132.2	1.03	393.3	4.6	
2003	126.5	1.11	582.0	5.0	
2004	141.0	1.31	581.3	15.9	

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

	CPUE-series			Survey-series		
Year	resid.(%)	p.extr.	CPO	resid.(%)	p.extr.	CPO
1976	-4.9	0.32	1.13			
1977	-4.0	0.36	2.52			
1978	3.9	0.35	3.31			
1979	7.7	0.23	1.49			
1980	-1.9	0.43	3.39			
1981	4.3	0.33	3.00			
1982	-6.7	0.26	1.43			
1983	0.3	0.48	3.72			
1984	2.5	0.40	3.60			
1985	0.8	0.46	3.68			
1986	4.3	0.34	2.77			
1987	-8.8	0.19	0.58			
1988	4.2	0.34	3.20	16.2	0.21	0.58
1989	3.3	0.38	4.67	11.1	0.28	0.83
1990	-1.8	0.42	5.67	-7.5	0.33	0.87
1991	-5.4	0.29	3.40	31.5	0.07	0.31
1992	-2.7	0.39	4.95	6.3	0.37	0.98
1993	0.1	0.49	5.32	-6.4	0.36	0.83
1994	3.2	0.37	4.73	-11.8	0.25	0.6
1995	-2.6	0.39	4.52	10.7	0.28	0.85
1996	-2.3	0.41	4.76	6.8	0.37	0.91
1997	0.5	0.49	5.12	21.9	0.14	0.5
1998	0.4	0.49	4.71	-3.6	0.42	0.78
1999	-1.1	0.45	4.08	10.2	0.29	0.69
2000	-2.0	0.43	3.50	1.0	0.48	0.7
2001	5.0	0.31	2.69	3.4	0.43	0.68
2002	1.6	0.44	3.06	-6.6	0.36	0.49
2003	5.5	0.30	1.33	-29.3	0.03	0.11
2004	-3.0	0.40	0.27	-22.5	0.10	0.14

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

	MSY	K	q_s	q_c	$B_{MSY} \cdot K^{-1}$	$P_{50\%}$	O_{max}	ω	κ	ν	τ
K	0.67										
q_s	-0.58	-0.70									
q_c	-0.59	-0.71	0.99								
$B_{MSY} \cdot K^{-1}$	0.27	0.08	-0.18	-0.18							
$P_{50\%}$	-0.15	-0.47	0.03	0.03	-0.17						
O_{max}	-0.03	-0.01	0.00	0.00	0.00	0.07					
ω	0.09	0.14	-0.13	-0.13	0.02	-0.08	0.00				
κ	-0.07	-0.09	0.07	0.06	0.01	0.07	0.00	-0.04			
ν	0.26	0.17	-0.19	-0.19	0.17	0.03	0.00	0.02	-0.13		
τ	-0.01	-0.01	0.01	0.01	-0.02	-0.01	0.00	-0.04	0.02	-0.06	
P_1	0.17	0.17	-0.34	-0.34	0.03	0.19	-0.01	0.03	-0.02	0.10	-0.01

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).

	Mean	sd	25%	Median	75%
MSY	139	40	116	128	150
K	1830	1209	1013	1386	2137
q_s	0.418	0.164	0.294	0.408	0.532
q_c	0.00119	0.00046	0.00084	0.00116	0.00151
$B_{MSY} \cdot K^{-1}$	0.44	0.06	0.40	0.43	0.48
$P_{50\%}$	2.92	0.82	2.45	2.93	3.41
O_{max}	3.00	0.099	2.93	3.00	3.06
ω	0.082	0.016	0.071	0.080	0.091
κ	0.171	0.029	0.150	0.168	0.188
ν	0.119	0.025	0.101	0.116	0.134
τ	0.301	0.070	0.253	0.291	0.338
P_1	0.897	0.183	0.766	0.878	1.002

Table 5. Absolute and percentage distribution of biomass in the Greenland and Canadian zones – SA 1 and Div. 0A west of 60°W. Biomass are survey estimates (Wieland et al 2004).

	Biomass ('000 tons)												
	Year												Average
Zone	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**1994-2004***
Greenland	253.409	263.8032	212.656	247.215	205.973	292.859	275.501	337.859	344.968	486.66	646.963	651.011	331.850
Canada	3.381	6.799	4.419	1.690	0.245	0.443	11.901	11.660	4.190	5.995	6.296	3.750	5.109
Total	256.790	270.602	217.076	248.904	206.218	293.302	287.402	349.520	349.158	492.655	653.258	654.761	336.960
% in Canadian zone	1.3%	2.5%	2.0%	0.7%	0.1%	0.2%	4.1%	3.3%	1.2%	1.2%	1.0%	0.6%	1.6%

*2003 not included because of incomplete coverage due to ice conditions

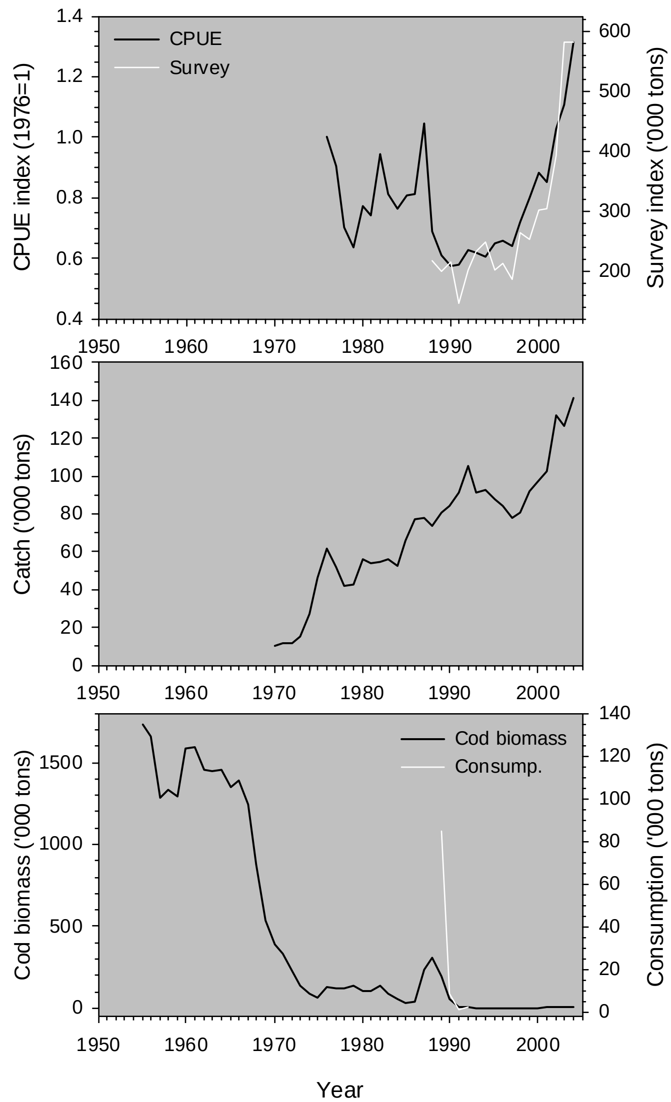

Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model. Upper panel: Shrimp fishable biomass indices (shrimp≥17 mm CL) based on 1. standardised commercial catch rates (CPUE-index) and 2. research survey data. Middle panel: Catch by the fishery. Lower panel: absolute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

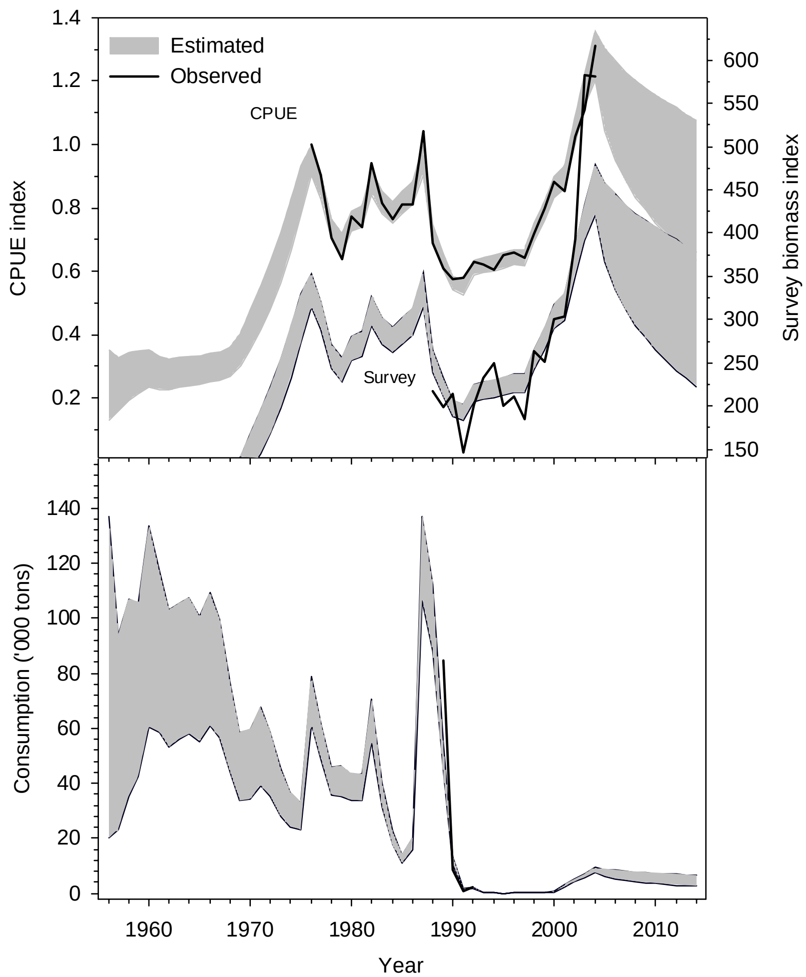

Fig. 2. Comparison of observed and model estimated values: observed values of CPUE and survey fishable biomass indices and of shrimp consumption by cod and corresponding estimates by the model (inter-quartile range of the posteriors) assuming annual catches at 130 M tons and cod biomass at the 2004 level. Upper panel: estimates of relative stock development in the future and historic to the data series are shown in the scale of the CPUE indices only for improved graphical presentation

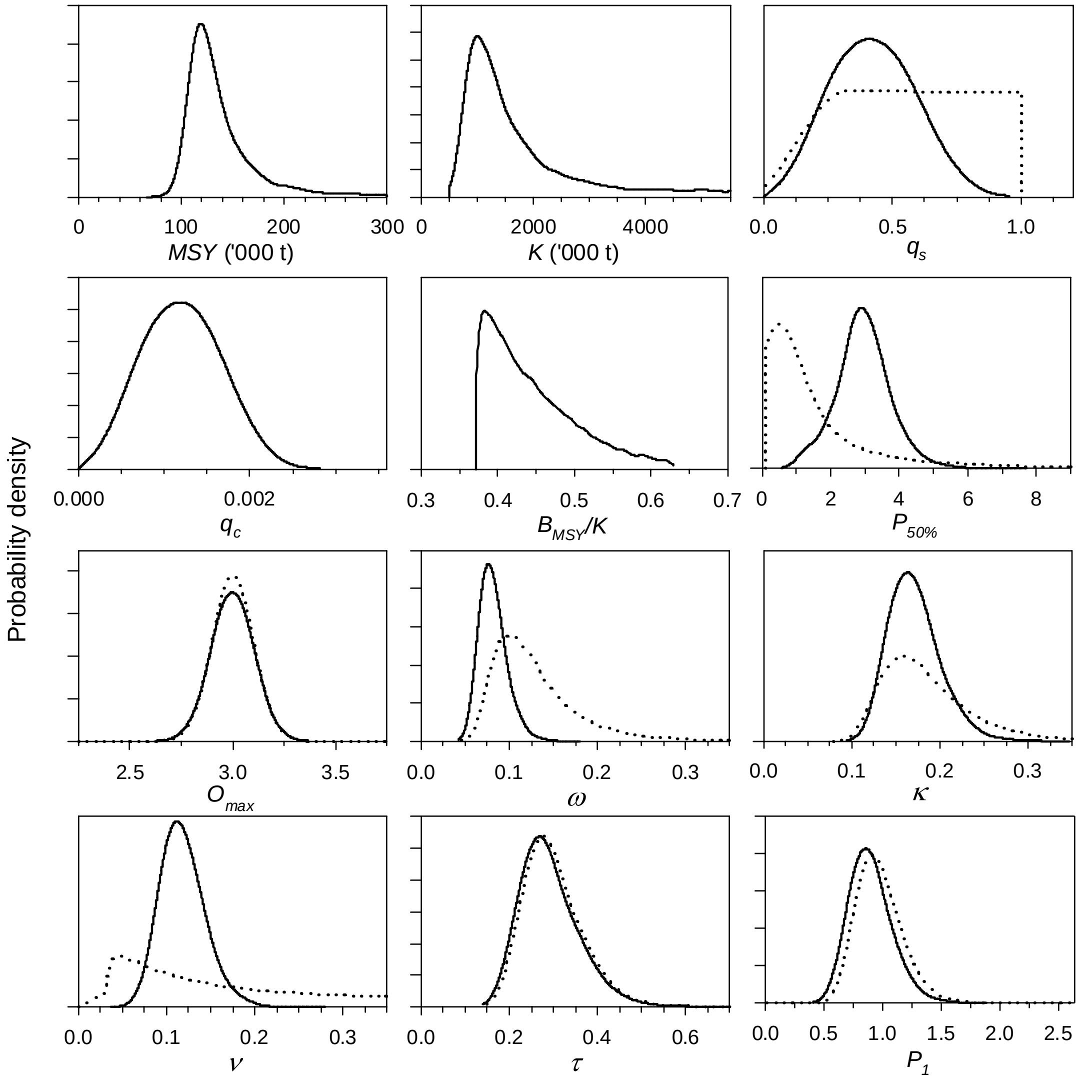

Fig. 3. Probability density distributions of model parameters: estimated: posterior (solid line) and prior (broken line) distributions (only informative priors are shown).

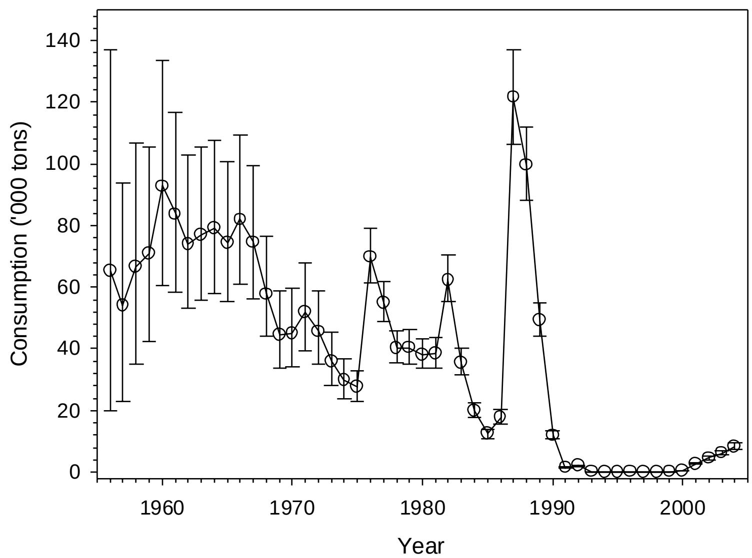

Fig. 4. Shrimp in Subareas 0 and 1: estimated median consumption of shrimp by cod. Error bars indicate upper and lower quartiles.

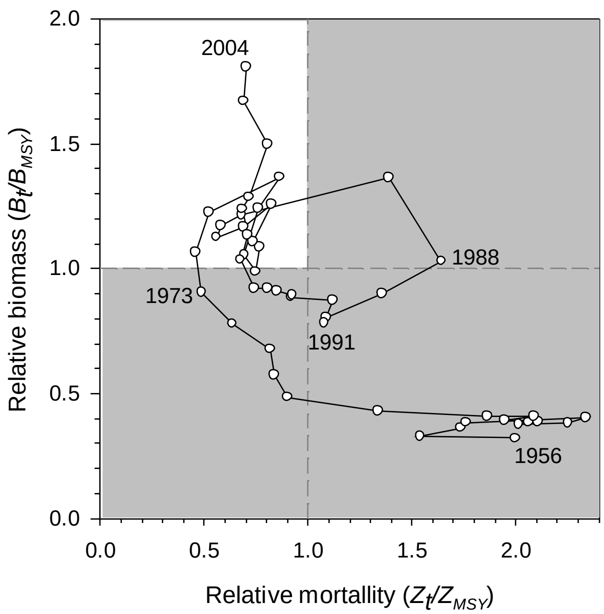

Fig. 5. Shrimp in Subareas 0 and 1: estimated annual median biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1956-2004.

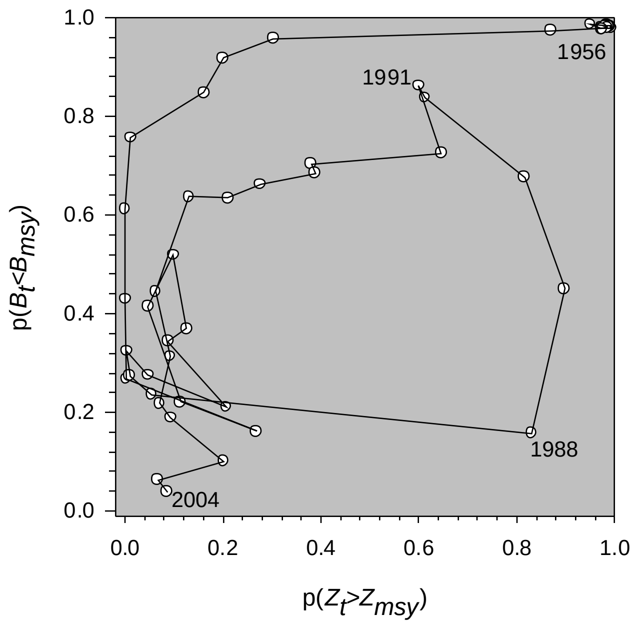

Fig. 6. Shrimp in Subareas 0 and 1: risk of annual biomass being below B_{MSY} and of mortality caused by fishing and cod predation being above Z_{MSY} 1956-2004

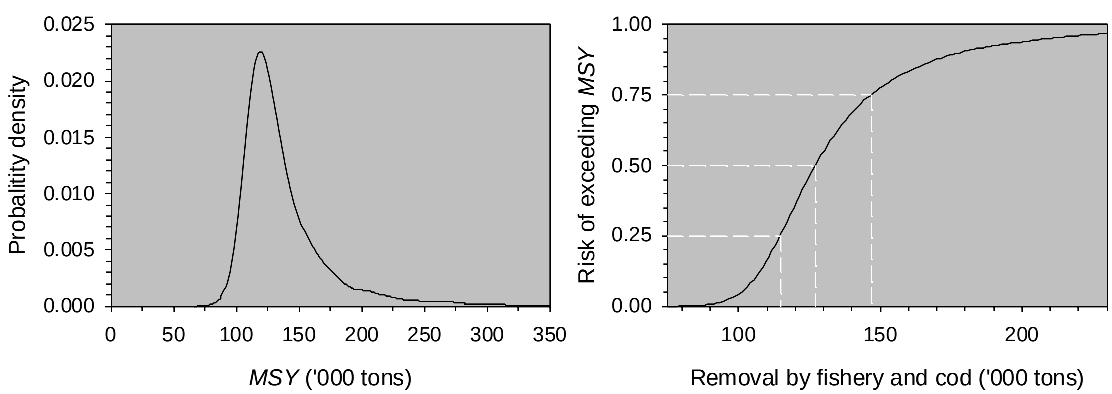

Fig. 7. Shrimp in Subareas 0 and 1: Posterior probability distribution of the maximum annual production surplus (*MSY*), available equally to the fishery the cod (left panel) and the cumulative probability of exceeding *MSY* (right panel).

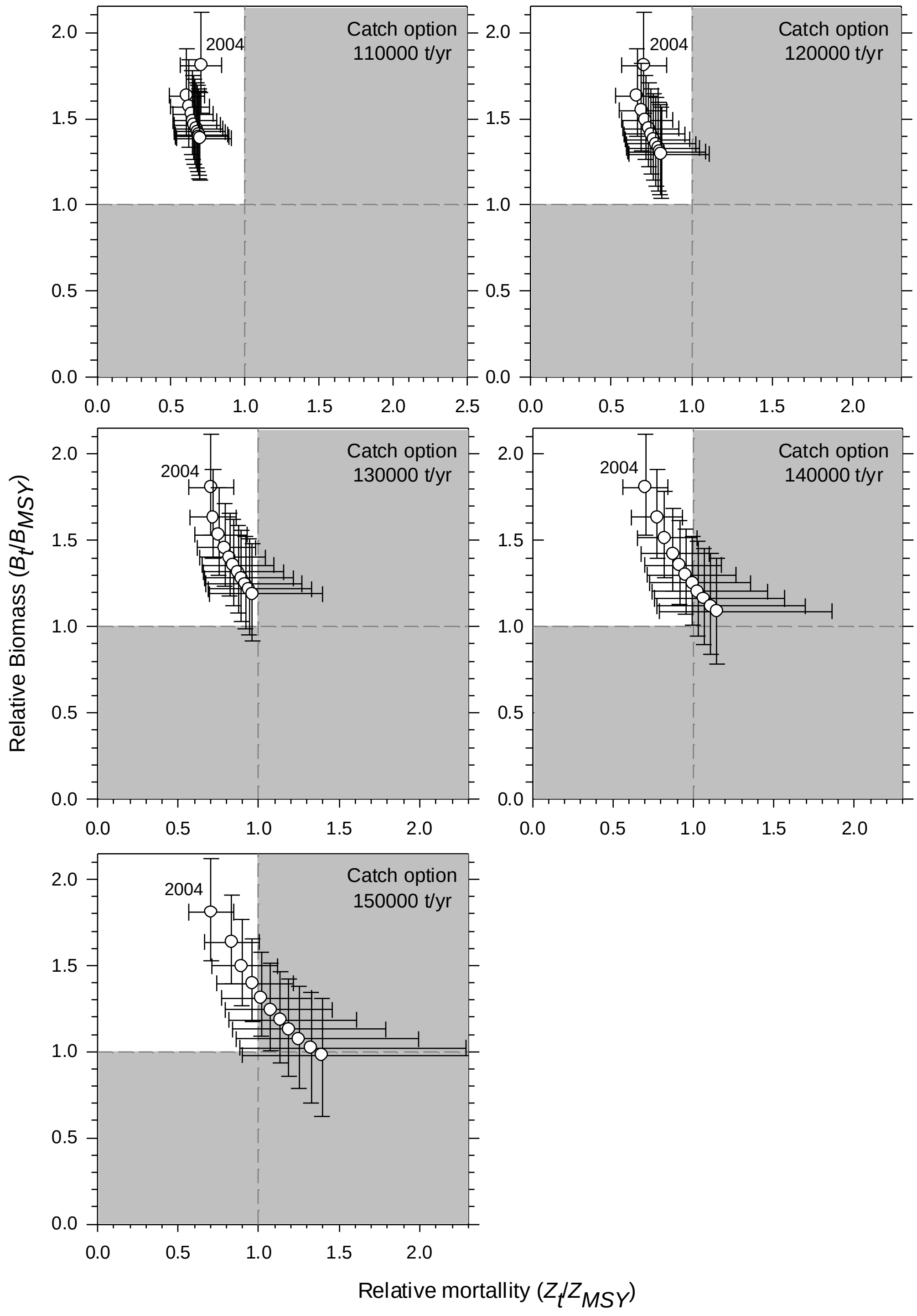

Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2004-2014 quantified in a biomass (B/B_{MSY})-mortality (Z/Z_{MSY}) continuum. Dynamics at 110, 120, 130, 140 and 150 thousand tons of fixed annual catch levels are shown as medians with error-bars at the 25th and 75th percentiles. Dashed lines indicate level of biomass and mortality at *MSY*.

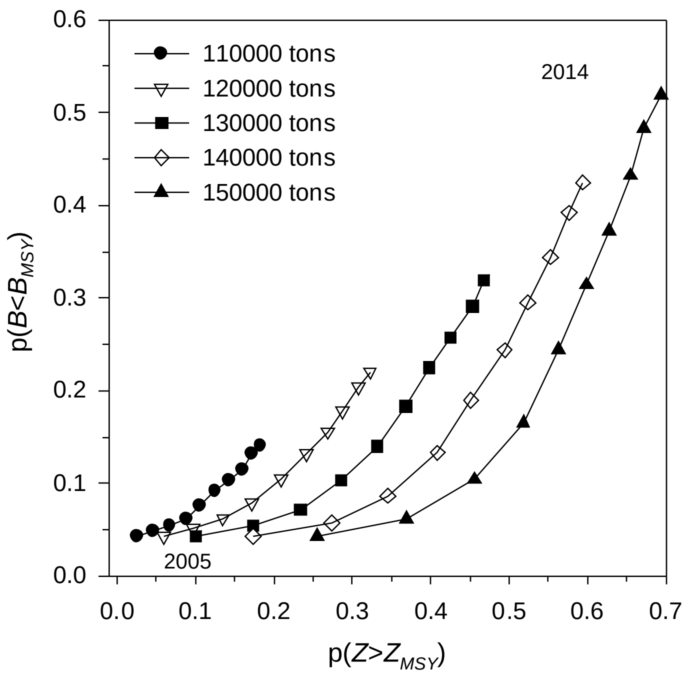

Fig. 9. Shrimp in Subareas 0 and 1: risk of exceeding Z_{MSY} and of driving the stock below B_{MSY} by maintaining optional annual catch levels of 110-150000 tons/yr during the period 2005-2014.

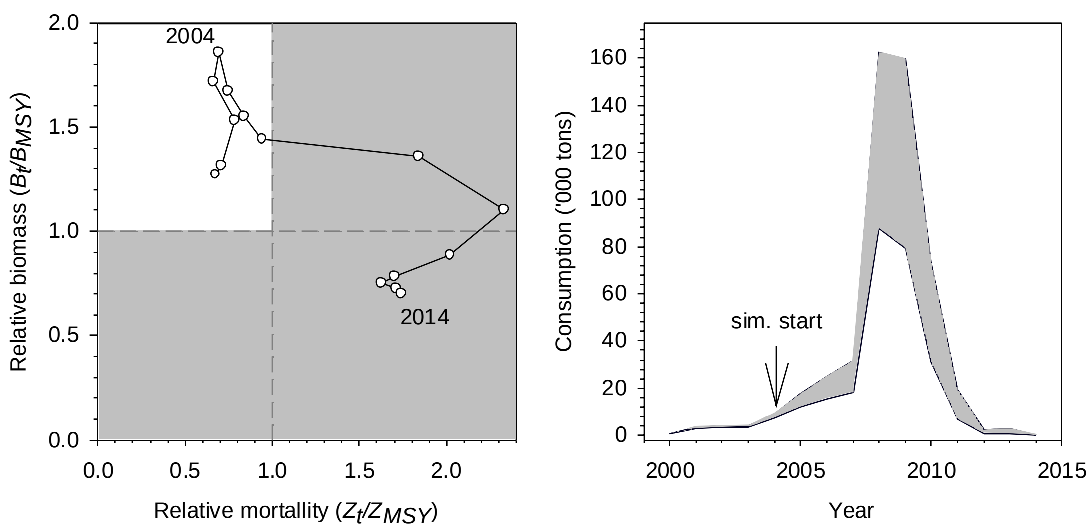

Fig. 10. Simulated annual median biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) (*left*), and consumption of shrimp by cod (*right*) 2000-2014. Assumptions: catch by fishery 130000 tons/yr. Cod biomass in the projected years 2005-2014 is similar to that seen in the 1985-1994 period (see Fig. 1).