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A Provisional Assessment of the Shrimp Stock off West Greenland in 2007

by

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Abstract

The West Greenland Stock of *Pandalus borealis* was assessed from indices of biomass and biomass density based on catch and effort data from commercial fishing fleets and a research trawl survey, catch data, and information on stock demographics and 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, survey and catch data and includes a term for predation by Atlantic cod, using available series of cod biomass.

Results from the modelling were that the stock biomass has increased since the early 1990s, reached its highest level in 2006, and is now probably decreasing. 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}). However, the stock-dynamics model appears to pay more attention to CPUE series than to survey data as indices of biomass, although the CPUE data used is more properly regarded as an index of density in fished areas than as truly an index of biomass.

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 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 from the modelling showed that catches of 140 000 tons/yr are not likely to drive the stock below B_{MSY} in the short term. However, this finding is tempered by the observation from the analysis of fisheries logbooks that the distribution of the fishery has apparently been contracting since the late 1990s, and that a survey estimate of the number of small shrimps, an index of near-future recruitment to the fishable stock, has been below average since 2003 and in 2007 reached a record low level.

Additional modelling with truncated series of CPUE data. When the CPUE series was stopped at 2003, omitting years in which CPUE stayed high while survey biomass estimates steadily declined, the model results were more pessimistic about both MSY and about the present state of the stock.

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 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 (five-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 assumptions that the cod stock, allowance made for a restricted overlap with shrimp distribution, remains at its current level or at a higher level estimated for 2006, 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 relative to the current stock size. The possible effects of a cod resurgence on the future trajectory of the shrimp stock are therefore of interest. The stock-dynamic model used in the assessment allows for flexible and comprehensive consideration of possible developments of the cod stock, but only limited investigations have been carried out for 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', *v* are normally, independently and identically distributed with mean 0 and variance σ_v^2 .

The model synthesised information from input priors (Hvingel and Kingsley 2002) (Fig. 3) and the following data: a 19-year series of a survey biomass index of shrimp ≥17 mm CL (Wieland *et al*., 2004; Wieland and Bergström, 2005; Bergström 2007); 4 series of CPUE indices spanning 1976 through 2007 (Kingsley 2007c); a 52-year series of catches by the fishery (Hvingel, 2004; Hvingel and Kingsley, 2002; Kingsley 2007z); a 52-year series of cod biomass estimates (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004, 2005; Sünksen 2007); and a short series (4 years) of estimates of the shrimp biomass consumed by cod (Hvingel and Kingsley, 2002) based on stomach analyses (Grunwald, 1998) (Table 1; Fig. 1). The data link functions of the biomass indices were:

[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.

$$CPUE_{c,t} = q_c P_t \exp(\omega_c) \ \text{, for } \ t \in (t_1, t_2, ,..., ..N-1)\text{, } \ CPUE_{c,N} = q_c P_N \exp(1.5\omega_c)$$
$$surv_t = q_s B_{MSY} P_t \exp(\kappa) \ \text{, for } \ t \in (2,3,..,..N)\text{, } \ surv_1 = q_s B_{MSY} P_1 \exp(1.5\kappa)$$

The catch rate ($CPUE_{c,t}$) and survey ($surv_t$) indices were scaled to the biomass index by their catchability constants, q_c and q_s. Their error terms, ω_c and κ, are assumed normally, independently and identically distributed with mean 0 and variance σ_c^2 and σ_κ^2. The standard error for 2007 for the CPUE indices that extend that far 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). The first year of the survey was also 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 ($kg \cdot kg^{-1}$) 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, was 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 40 000 iterations and then run for 18 000 000, every 300th being retained. Of the resulting 60 000 iterations, every 20th was used in the final calculations giving sample sizes of 3000.

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 and to a higher value estimated in 2006 by a German trawl survey in West Greenland (Sünksen 2007).

A substantive difference in data analysis from previous years was the treatment of the data on catches and effort and of the resulting CPUE indices. The data that was input to the standardisation of the recent Greenland fishery included a wider range of statistical areas for both the coastal and offshore fleets, so that some areas were included in both analyses. Furthermore, the four series of annual standardised values—the historical 'KGH' series, the two recent Greenlandic series, and the Canadian series for SFA1—were not combined in a separate step but were input to the stock-dynamic model as though they were 4 independent indices of biomass. The assessment model then estimated a separate catchability and a precision for each CPUE series, as well as for the survey series.

The separate input of the 4 CPUE series made it evident that they did not agree with each other as well after 2003 as before, and it was also evident that they did not agree with survey data that showed a continued and drastic decline in stock biomass from 2003 to 2007. As noted elsewhere, CPUE does not in itself measure biomass, only density in fished areas. Therefore, results were also calculated for the data sets with the CPUE series truncated to include only the range where mutual agreement between the CPUE series, and also between them and the survey series, was good; i.e. values only up to 2003. Results were also calculated for the survey series only, with no CPUE data included.

Previous experience appeared to show that the model was sensitive to the estimates of the historical trajectory of the cod stock. An investigation led to a revised treatment in the stock-dynamic model of Grunwald's (1998) experimental data on how many shrimps get eaten by cod, and the revised model was found to be less sensitive to changes in the historical cod series (Kingsley 2007b).

Recent survey data, as well as the present distribution of fishing, showed that densities of shrimp in southerly areas have decreased in recent years. Cod biomass estimates from the most recent surveys have increased, but survey results also show that cod has a more southerly distribution on the West Greenland fishing grounds and shrimp, now, a more northerly one, the overlap between the two species therefore being restricted and the use simply of total stock biomasses of the two species as an index of their interaction perhaps an over-simplification Storr-Paulsen et al. 2006. In the present assessment, the cod stock biomass used has been the 'effective' series of Wieland () Table 1, updated with recent survey estimates of cod biomass (Sünksen 2007). The low spatial overlap values of recent years have been used to modify recent high cod biomass values toward more modest 'effective' values.

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 (Kingsley 2007c).

Data from the annual West Greenland trawl survey (Bergström 2007) on numbers in pre-recruitment year-classes of small shrimp gave information on the likely future development of the stock.

Results, Model Performance

The model fitted well to the the observed data series (Fig. 2). Precision parameters, which are indices of the quality of the fit, were similar to their intrinsic estimates. The precision parameter for the research trawl survey index was equivalent to an error CV of about 17%. The average error CV for the survey series, calculated from the survey data itself, is about 14%, but that reflects only within-survey sampling error and underestimates the true total uncertainty of the survey. The precision parameters for the Greenland CPU series were about equivalent to error CVs of 8–9%, except for the Canadian series in the small area of SFA1, which had a CV near 17%. The process variation was also about 9%. The cod predation terms had much higher error CVs. The main predation term had an error CV of about 40%, and the precision estimate for the 4-year Grunwald predation series was about 88%. It would appear from this that the cod predation term in the state-dynamic equation may be taking up a lot of the slack in fitting the transfer from one year's biomass to the next, and that the direct predation data is probably not contributing much to the model. Kingsley (2007x) found that the model could be fitted without using the Grunwald data.

Some parameters pairs were highly correlated (Table 3). The major parameters of stock size and productivity—*K* and *MSY*—were positively correlated. Both were negatively correlated with Z_{msy}, but as would be expected, *K* had a much larger negative correlation with *Z* than *MSY* did. The catchability of the survey series had uniform correlations—about 0.24—with those of all the CPUE series, but the catchabilities of the different CPUE series had correlations up at the 0.99 level with one another. A difference between the survey series and the CPUE series was also evident in the correlations of their catchabilities with the main stock parameters, *MSY* and *K*; the survey series catchability was negatively correlated with them, and positively correlated with Z_{msy}, and vice versa for the CPUE series catchabilities.

The median estimate of the *MSY* was 162 Kt, slightly higher than the 159 estimated in 2006. Most stock-dynamic parameters had higher standard deviations and wider distributions than those estimated in 2006.

Assessment Results

Estimates of the parameters governing the modelled predation by cod on the shrimp stock changed little between previous assessments and the 2007 update. The assessment model estimates that the stock is still above its MSY level.

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—median estimate 106 000 t in 1987 and 102 000 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 3 300 tons of shrimp in 2004, but the median estimate of predation increased to about 16 900 tons in 2005 and 96 700 tons in 2006 owing to the recent increase in the estimated cod biomass, even after allowances for the distinct distributions of cod and shrimp.

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 0.6-0.9 times B_{MSY} and mortality 0.6-0.9 times Z_{MSY}. A brief return of high cod stocks in the late 1980s caused a short episode of high mortality, 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 1.3 times B_{MSY}. This corresponds to high catch rates and high survey estimates of biomass in the mid-2000s. Associated with an increase in the cod stock and high catches in 2005–6, 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 of the Z-ratio for 2007, with projected catches about 135 000 tons, is 0.89, with a 38% risk that it exceeds 1; however, the high level of predation by cod estimated for 2006 entailed a Z-ratio in 2006 of 1.4 and a 76% chance of exceeding 1 (Fig. 4).

The median estimate of the maximum annual production surplus, available equally to the fishery and to the cod (*MSY*) was estimated at 162 000 tons, not very precisely estimated, with upper and lower quartiles at 136 000 and 202 000 tons (Table 3).

Given the likelihood that the stock is now above B_{msy}, the risk that it will fall below this level within the next year is low. Risks[2] associated with five possible catch levels for 2008, with an ‘effective’ cod stock at 32 200 tons, are estimated to be:

	Catch option ('000 t)				
Risk (%) of:	110	120	130	140	150
falling below B_{MSY} (end 2008)	27.9	28.5	28.7	29.6	30.2
falling below B_{lim} (end 2008)	0.8	0.8	0.8	0.8	0.7
exceeding Z_{MSY} (during 2008)	19.0	26.9	33.5	40.7	47.3

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

Corresponding risk levels estimated in the 2006 assessment, with cod biomass at 22.7 Kt, were:

	Catch option ('000 t)				
Risk (%) of:	110	120	130	140	150
falling below B_{MSY} (end 2008)	9.55	9.65	10.55	11.7	13.05
falling below B_{lim} (end 2008)	0	0	0	0	0
exceeding Z_{MSY} (during 2008)	2.65	6.55	12	18.45	23.25

When the CPUE series were truncated, the corresponding risk levels estimated, again with the cod stock biomass at 32.2 Kt, but only for 130-Kt catches, were:

	Catch option ('000 t)				
Risk (%) of:	110	120	130	140	150
falling below B_{MSY} (end 2008)			38.4		
falling below B_{lim} (end 2008)			1.5		
exceeding Z_{MSY} (during 2008)			62.3		

With no CPUE data, only survey data, under the same conditions as for the shortened CPUE series, the risk levels were:

	Catch option ('000 t)				
Risk (%) of:	110	120	130	140	150
falling below B_{MSY} (end 2008)	20.4	21.1	21.6	21.6	22.7
falling below B_{lim} (end 2008)	0.7	0.9	0.9	0.8	1.0
exceeding Z_{MSY} (during 2008)	24.0	27.7	34.7	40.1	45.3

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.

5-year projections of stock development were made under the assumption that the cod stock will remain at the highest of recent estimates of 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 150 000 tons (Fig. 6, 7 and 8). When associated with a 32 200-ton biomass of cod, all entailed 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. However, the fishery has become increasing concentrated (Fig. 10), so CPUEs that indicate high densities in the fished areas do not necessarily translate to very high biomess, and the most recent survey estimates have also shown a smaller and more concentrated stock. The assessment model does not take the distribution of the fishery into account, but considers CPUE in fished areas to be a linear index of stock biomass, and may therefore under present conditions be overly sanguine in its evaluation of stock status. The stock composition also gives cause for concern: numbers at age 2 are at a record low level (Fig. 9).

Modelling with the CPUE series truncated at 2003 estimated a lower MSY, 136 Kt instead of 162, and greater risks of transgressing precautionary limits at all times and all catch levels. However, this could be regarded as a worst-case scenario, as the data points removed were those for which the CPUE series, in opposition to the survey data, had been persistently optimistic as to stock status. When the survey data was used alone, with no CPUE data at all,

Effects of different selections of data series.

The model initially run, using 4 different CPUE series, could be considered as giving too much credence to recent CPUE values that apply to a period when the fishery, and the stock, appear to be concentrated and CPUEs therefore apt to overestimate biomass relative to periods when the fishery was more widely distributed. The model was therefore run also with CPUE series truncated at 2003 and with CPUE data omitted from the inputs.

When the CPUE series were truncated by omitting the years for which they disagreed with each other and with the survey series, the model achieved more precision in its estimations. Without the recent years' CPUE points that were relatively lower than the survey, relative biomass—pretty much the same, up to 2003, as it was with full CPUE data—was estimated higher in 2004–5, but then decreased in step with the falling survey index. The model estimated a lower MSY at 136 Kt., and although estimates of the present state of the stock were not very different from those based on all the CPUE data, predictions for future years were more pessimistic than when the full CPUE series were used.

When the survey series was used alone as the only biomass index series, the model estimated a greater process error, to accommodate the survey variability, while the survey variability itself was estimated lower. Recent biomass levels, relative to Bmsy, were estimated higher than when CPUEs were included, and the MSY was between the value estimated with full CPUE series and that from shortened CPUE series. Risk levels for short-term predictions were similar to those obtained when the full CPUE series were used, therefore more optimistic that when the CPUEs were truncated. Longer-term predictions are more optimistic for biomass projections, because of the higher estimate of the present state of the stock, but more pessimistic for mortality predictions because the MSY estimate is lower and it is therefore easier to transgress the limit mortality.

MSY estimated in 2006—159 Kt—was close to the 161 Kt estimated in 2007, but perhaps because the catches used in 2006 were lower the 2006 assessment was more optimistic about the current state of the stock. The future predictions were therefore also more optimistic; more so about future biomass than about future mortality. Mortality predictions must be considered in the light of the 2006 predictions' having been made with a cod stock assumed constant at 22.7 Kt where 33.2 Kt was assumed in 2007. 5-year projections made in 2006 were more optimistic about both biomass and mortality than those made in 2007 with any selection of data.

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 5) and are low.

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Table 1. Input data series for stock-dynamic assessment model.

						CPUE indices			
	Effective cod biomass[3]	Catch	Survey index of fishable biomass	Predation estimate[4]	Cod-stock estimate[5]	KGH	Offshore[6]	Coastal[6]	Canada SFA1[6]
1955	1819.1	6.1							
1956	1524.0	6.1							
1957	1342.7	6.1							
1958	1224.2	6.1							
1959	1130.8	6.1							
1960	1216.0	6.1							
1961	1194.7	6.1							
1962	982.9	6.1							
1963	876.7	6.1							
1964	870.9	6.1							
1965	897.3	6.1							
1966	837.0	6.1							
1967	769.4	6.1							
1968	577.3	6.1							
1969	395.8	6.1							
1970	253.8	10.5							
1971	224.8	11.6							
1972	185.9	11.9							
1973	114.9	15.5							
1974	84.5	27.0							
1975	68.6	46.5							
1976	136.4	61.4				1.66			
1977	149.0	51.6				1.56			
1978	166.0	42.3				1.23			
1979	142.1	42.8				1.11			
1980	158.2	55.9				1.34			
1981	111.6	53.8				1.27			
1982	102.7	54.3				1.61			
1983	63.0	56.2				1.42			
1984	38.9	52.8				1.34			
1985	25.7	66.2				1.43			
1986	20.4	76.9				1.49			
1987	287.5	77.9				1.79	0.4499		-0.0537
1988	300.8	73.6	223.2			1.47	0.1456	0.1245	-0.0418
1989	138.7	80.7	209.0	213.7	470.9	1.09	0.0534	-0.1134	-0.1065
1990	7.9	84.0	207.0	27.8	184.1	1.00	0.0000	0.0000	0.0000
1991	1.3	91.5	146.0	2.7	19.8		-0.0207	-0.0992	-0.1796

[3] Wieland and Storr-Paulsen (2004) updated by Sünksen (2007).

[4] Grunwald (1998).

[5] the estimate of cod stock biomass associated with Grunwald's estimate of predation.

[6] logged values.

	Effective cod biomass[3]	Catch	Survey index of fishable biomass	Predation estimate[4]	Cod-stock estimate[5]	CPUE indices KGH	Offshore[6]	Coastal[6]	Canada SFA1[6]
1992	0.3	105.5	194.2	0.8	2.9		0.1035	-0.0236	-0.0448
1993	0.3	91.0	216.5				0.0353	0.0053	-0.0402
1994	0.1	92.8	223.1				0.0436	-0.0702	-0.3683
1995	0.0	87.4	183.2				0.1515	-0.0354	-0.2567
1996	0.1	84.1	192.1				0.1615	0.0283	-0.4096
1997	0.1	78.1	167.1				0.1254	0.0316	-0.1066
1998	0.0	80.5	244.3				0.2520	0.1682	-0.3194
1999	0.1	92.2	237.3				0.3906	0.2874	-0.1083
2000	0.4	98.0	280.3				0.4642	0.4713	0.1281
2001	1.2	102.9	280.5				0.4202	0.4122	0.2296
2002	0.6	135.2	369.5				0.5822	0.6331	0.3836
2003	0.9	130.2	548.3				0.6620	0.6380	0.5061
2004	1.6	142.2	528.3				0.8380	0.4950	0.2072
2005	1.9	154.6	479.5				0.8839	0.4876	0.2459
2006	32.2	154.7	437.5				0.8679	0.5522	0.5363
2007	8.7	135.2	334.1				0.8908	0.6224	

Table 2a. Summary of estimates of selected parameters from Bayesian fitting of a surplus production model, using all available data.

	Mean	S.D.	25%	Median	75%	Median (2006)
MSY (Kt/yr)	182.7	79.6	136.8	161.2	204.3	159
K (Kt)	4989.0	5671.0	2107.0	3158.0	5569.0	2854
Z_{msy} (%)	10.8	4.9	7.2	10.6	14.1	
q_s	0.224	0.136	0.116	0.204	0.310	0.208
$q_{(KGH)}$	2.13	1.37	1.38	1.75	2.38	
$q_{(Offshore)}$	1.95	1.20	1.29	1.63	2.17	
$q_{(Coastal)}$	1.73	1.06	1.14	1.44	1.92	
$q_{(SFA1)}$	1.41	0.86	0.94	1.18	1.57	
$P_{50\%}$	2.6		1.8	2.3	3.0	2.52
O_{max}	3.0	0.3	2.8	3.0	3.2	3.00

Table 2b. Summary of estimates of selected parameters from Bayesian fitting of a surplus production model, with CPUE data series truncated at 2003.

	Mean	S.D.	25%	Median	75%	Median (2006)
MSY (Kt/yr)	150.2	58.01	122.8	136.5	158.4	159
K (Kt)	2504	2563	1434	1819	2532	2854
Z_{msy} (%)	0.15	0.04802	0.1203	0.1505	0.1828	
q_s	0.3438	0.1407	0.2479	0.3358	0.4376	0.208
$q_{(KGH)}$	2.007	1.31	1.418	1.698	2.129	
$q_{(Offshore)}$	1.83	1.178	1.314	1.554	1.919	
$q_{(Coastal)}$	1.706	1.099	1.225	1.466	1.793	
$q_{(SFA1)}$	1.386	0.9114	0.9935	1.183	1.469	
$P_{50\%}$	5.301	3.562	3.122	4.724	6.504	2.52
O_{max}	2.985	0.3174	2.777	2.982	3.208	3.00

Table 2c. Summary of estimates of selected parameters from Bayesian fitting of a surplus production model to catch, predator and survey data only, CPUE data series omitted.

	Mean	S.D.	25%	Median	75%	Median (2006)
MSY (Kt/yr)	169.4	92.75	117.7	150.8	200.4	159
K (Kt)	4588	3940	2133	3382	5512	2854
Z_{msy} (%)	10.5	6.239	6	9.569	14.27	
q_s	0.1826	0.1244	0.08723	0.1556	0.246	0.208
$P_{50\%}$	9.994	10.85	3.865	6.934	11.74	2.52
O_{max}	2.977	0.3106	2.764	2.973	3.192	3.00

Table 2d. Summary of estimates of selected parameters from Bayesian fitting of a surplus production model, 2006 assessment.

	Mean	S.D.	25%	Median	75%
MSY	172	50.15	134.6	159	198.7
K	3211	1513	1836	2854	4519
Z_{msy} (%)	12.61	4.895	8.893		15.67
q_s	0.2248	0.1222	0.1244	0.208	0.2995
$P_{50\%}$	2.558	0.7619	2.047	2.52	2.99
O_{max}	3.003	0.09859	2.936	3.00	3.07

Table 3a. Estimated coefficients of variation[1] (%) for the fits of input data series to the model and of derived process parameters.

	Mean	Median
Process	9.1	9.0
Predation (fitted)	39.7	29.7
Predation (data)	86.2	75.2
$q_{(Survey)}$	17.5	17.1
$q_{(KGH)}$	10.3	9.8
$q_{(Offshore)}$	7.9	7.8
$q_{(Coastal)}$	8.1	7.9
$q_{(Canada\ SFA1)}$	16.6	16.2

[1] i.e. reciprocal of the square root of the log-normal precision parameter

Table 3b. Estimated coefficients of variation[1] (%) for the fits of input data series to the model and of derived process parameters, when CPUE series are truncated at 2003.

	Mean	Median
Process	8.8	8.6
Predation (fitted)	35.0	29.8
Predation (data)	84.6	74.8
$q_{(Survey)}$	16.6	16.3
$q_{(KGH)}$	9.4	8.9
$q_{(Offshore)}$	5.1	5.0
$q_{(Coastal)}$	4.9	4.8
$q_{(Canada\ SFA1)}$	16.7	16.1

[1] i.e. reciprocal of the square root of the log-normal precision parameter

Table 3c. Estimated coefficients of variation[1] (%) for the fits of input data series to the model and of derived process parameters, when CPUE series are omitted.

	Mean	Median
Process	17.5	17.1
Predation (fitted)	35.2	24.4
Predation (data)	86.6	74.8
$q_{(Survey)}$	9.5	9.0

[1] i.e. reciprocal of the square root of the log-normal precision parameter

Table 3d. Estimated coefficients of variation[1] (%) for the fits of input data series to the model and of derived process parameters; values from 2006 assessment.

	Mean	Median
Process	11.2	11.6
Predation (fitted)	30.6	29.7
q_s	15.4	15.2
q	8.4	8.2

[1] i.e. reciprocal of the square root of the log-normal precision parameter

Table 4. Selected[1] correlations (%) between model parameters; full CPUE data series.

	O_{max}	$P_{50\%}$	$q_{(SFA1)}$	$q_{(Coastal)}$	$q_{(Offshore)}$	$q_{(KGH)}$	$q_{(survey)}$	Z_{msy} (%)	K
MSY		-16.6	48.2	48.2	48.2	48.0	-29.9	-25.2	55.0
K			33.7	33.5	33.6	33.1	-51.5	-63.4	
Z_{msy} (%)		-12.9	-13.1	-12.9	-13.1	-13.5	79.4		
q_{survey}		-33.3	24.5	24.8	24.7	24.2			
$Q_{(KGH)}$		-48.1	99.1	99.3	99.3				
$Q_{(Offshore)}$		-48.2	99.7	99.9					
$Q_{(Coastal)}$		-48.2	99.7						
$Q_{(SFA1)}$		-48.0							
$P_{50\%}$	11.9								

[1] those over 10%

Table 5a. Risks (%) of exceeding limit mortality in year 5 and of falling below *MSYL* or limit* biomass at the end of year 5 of different catch rates, with 'effective' cod stocks assumed constant at 33 200 tons or 9 000 tons

Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass<B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt
110	27.4	22.7	0.5	0.5	19.3	8.2
120	29.1	24.7	0.7	0.5	28.0	14.8
130	33.1	28.4	0.7	0.5	36.9	22.8
140	36.8	31.7	1.0	0.6	45.4	31.2
150	40.5	35.3	1.2	0.7	53.1	41.3

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

Table 5b. Risks (%) of exceeding limit mortality in year 5 and of falling below *MSYL* or limit biomass at the end of year 5 of 130 000-t catches, with 'effective' cod stocks assumed constant at 33 200 tons, estimated from input data including CPUE series truncated at 2003.

Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass<B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt
110						
120						
130	53.0		0.7		71.6	
140						
150						

Table 5c. Risks (%) of exceeding limit mortality in year 5 and of falling below *MSYL* or limit* biomass at the end of year 5, with 'effective' cod stocks assumed constant at 32 200 tons, estimated using survey data only

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Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass<B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt	32.2 Kt	9.0 Kt
110	26.0		1.8	#N/A	27.9	#N/A
120	29.8		1.9	#N/A	35.1	#N/A
130	31.6		2.3	#N/A	41.2	#N/A
140	34.0		2.4	#N/A	47.3	#N/A
150	36.4		3.3	#N/A	52.1	#N/A

Table 5d. Risks (%) of exceeding limit mortality in year 5 and year 10 and of falling below *MSYL* or limit* biomass at the start of year 5 and year 10, with 'effective' cod stocks assumed constant at 22 700 tons, estimated in 2006.

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	11.7	18.0	0.0	0.3	11.5	18.4
130	13.2	21.6	0.0	0.6	18.3	24.4
140	16.8	27.5	0.0	1.4	26.0	33.4
150	18.6	31.0	0.1	2.7	33.4	39.8

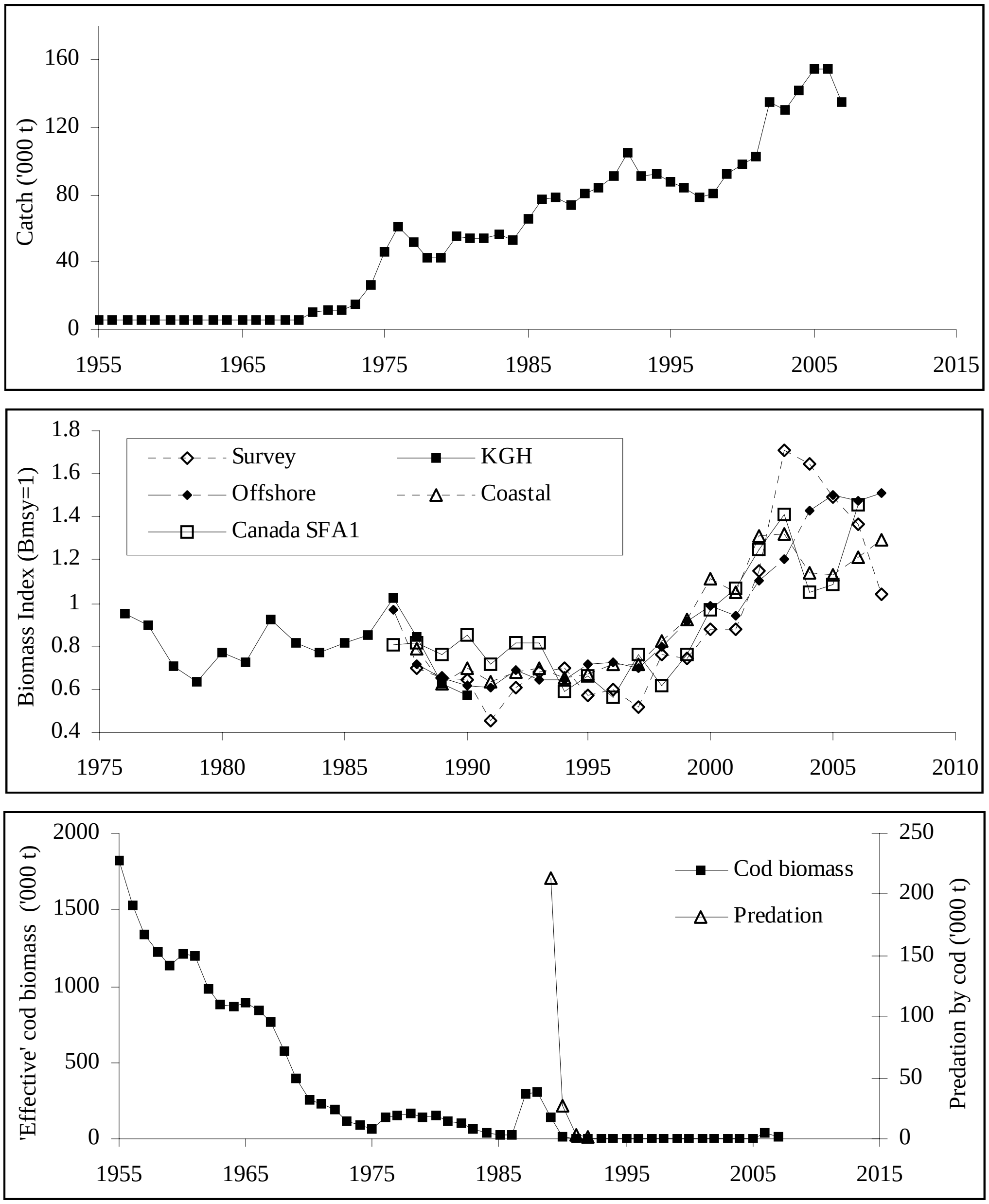


Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model. Catch by the fishery; shrimp fishable biomass density indices (shrimp≥17 mm CL) based on standardised commercial catch rates (CPUE-index) and research surveys; biomass estimates of cod and a four-year series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

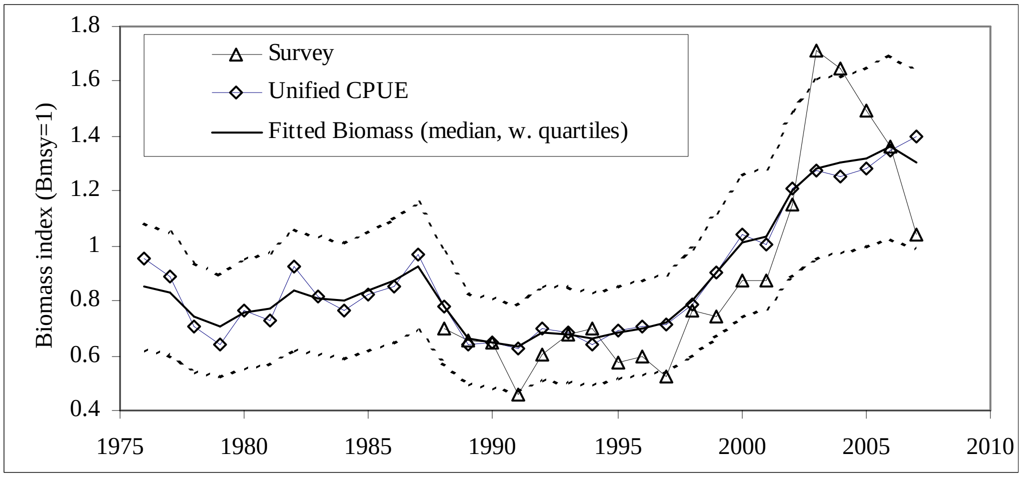


Fig. 2a. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices.

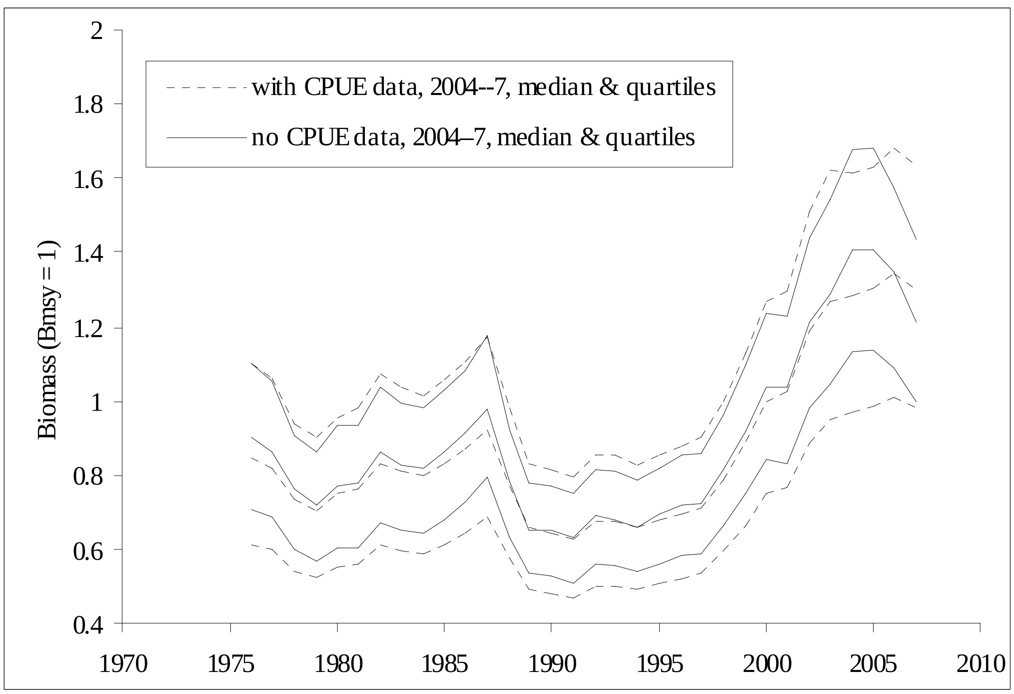


Fig. 2b. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices; effect of truncating CPUE data at 2003 on estimated relative biomass trajectory.

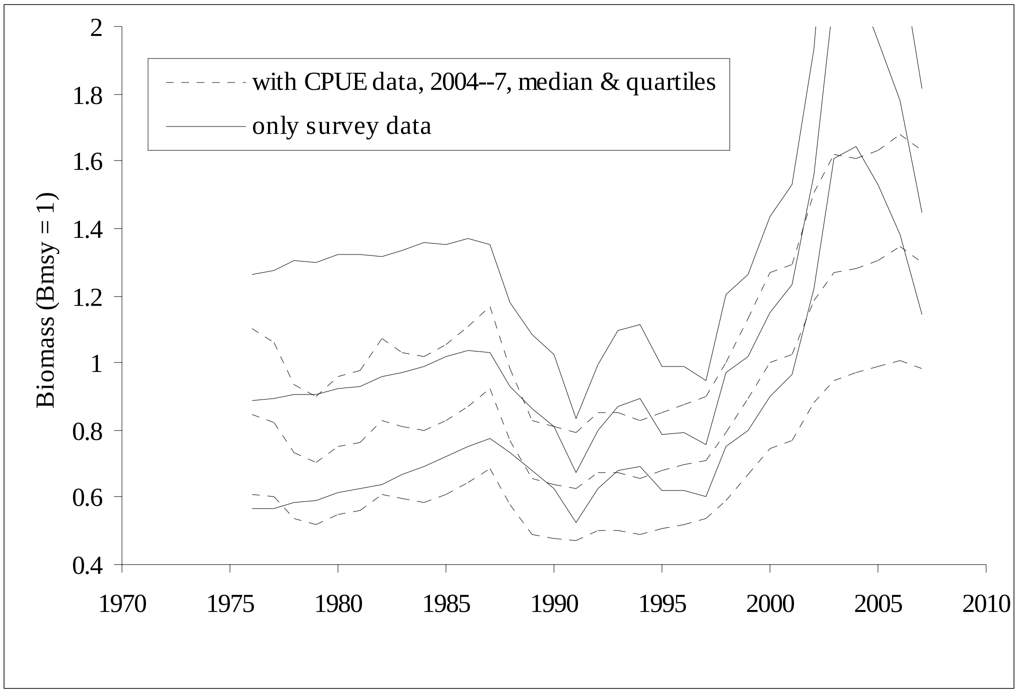


Fig. 2c. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices; effect of omitting all CPUE data on estimated relative biomass trajectory.

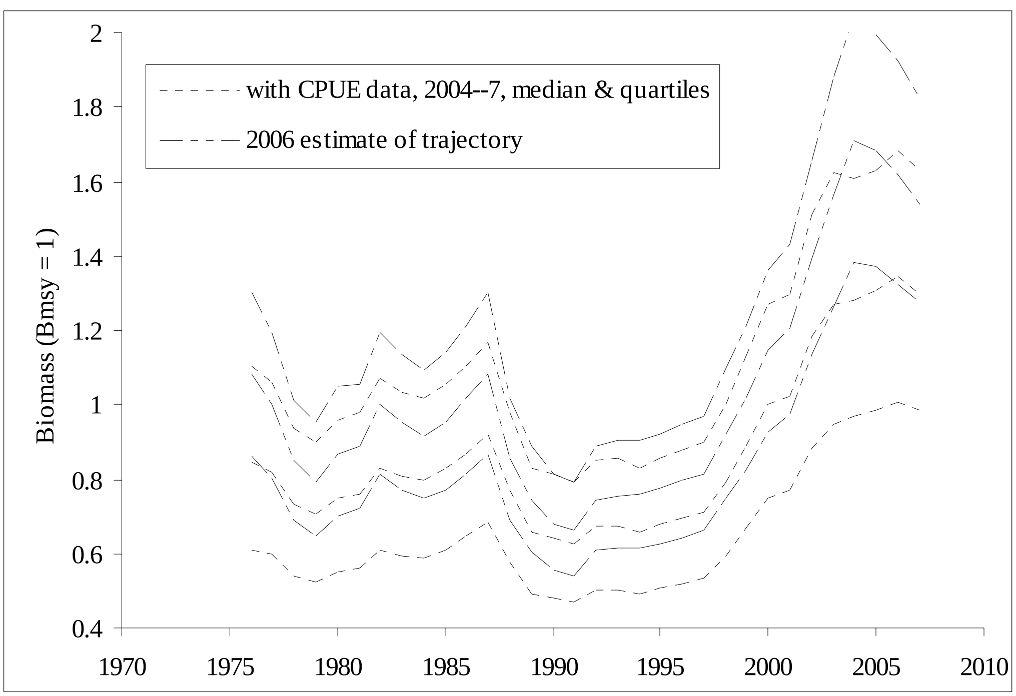


Fig. 2d. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices; comparison with trajectory estimated in 2006 (including one year's projection at 130 Kt catch).

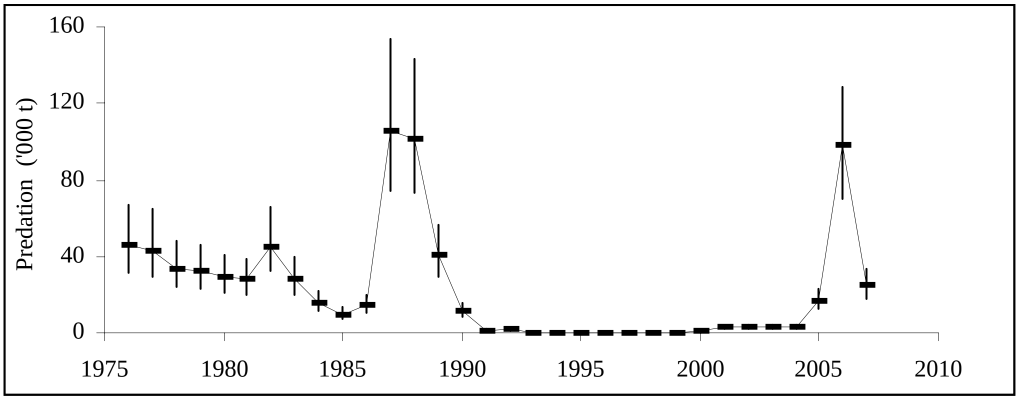


Fig. 3. Shrimp in West Greenland: estimated median consumption of shrimp by cod (quartile error bars) (estimate using full CPUE series).

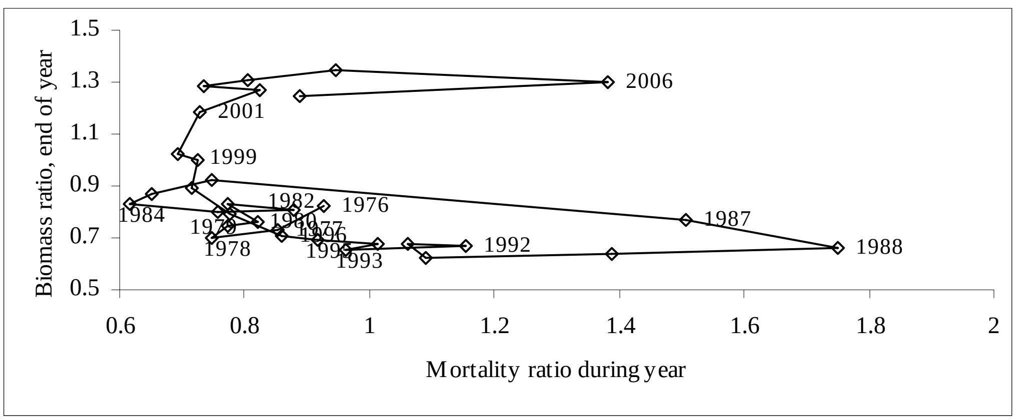


Fig. 4. Shrimp in West Greenland: median estimates of biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1976-2007.

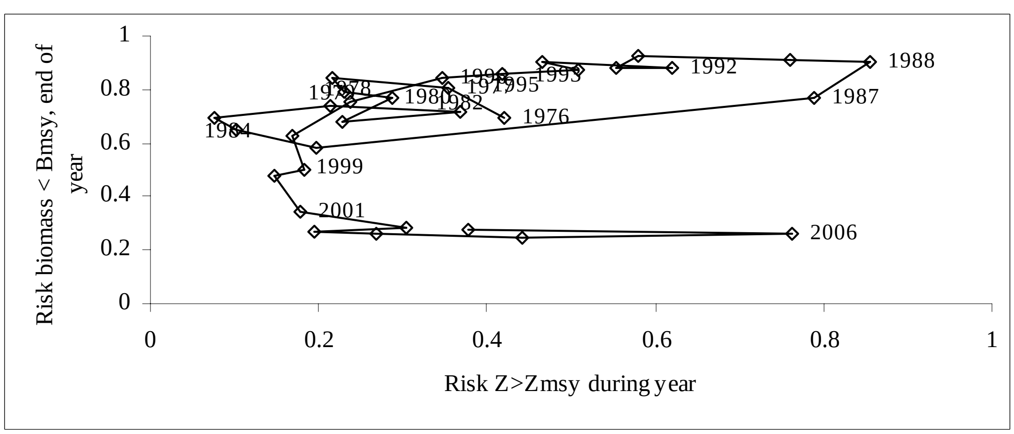


Fig. 5. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{MSY} and that mortality caused by fishing and cod predation has been above Z_{MSY} 1976–2004.

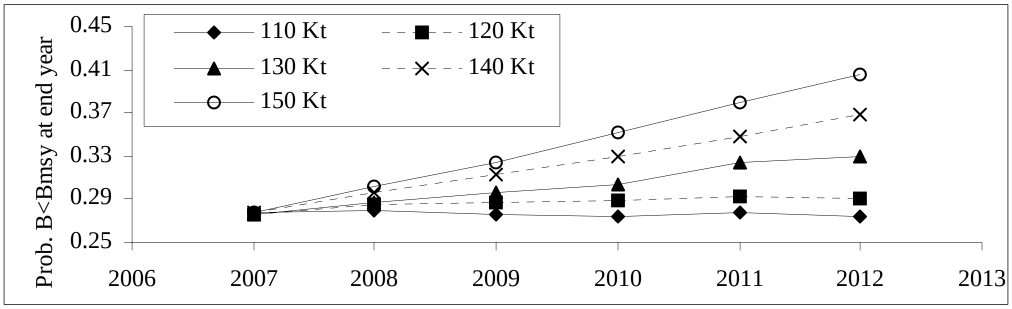


Fig. 6. Risk over 5 years of transgressing B_{msy} at catch levels 110–150 Kt/yr; 'effective' cod biomass 32.2 Kt

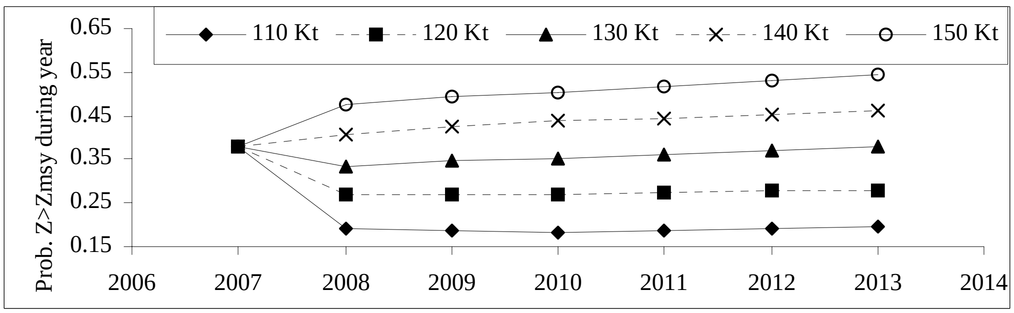
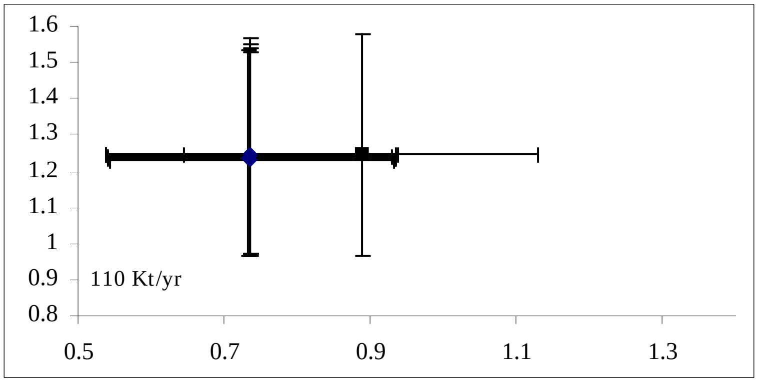
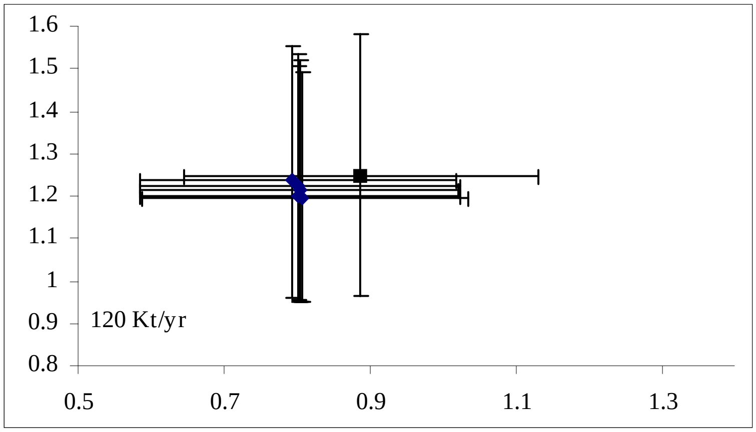


Fig. 7. Risk over 5 years of transgressing Z_{msy} at catch levels 110–150 Kt/yr; effective cod biomass 32.2 Kt.


1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
110 Kt/yr
0.5
0.7
0.9
1.1
1.3


1.6
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0.8
120 Kt/yr
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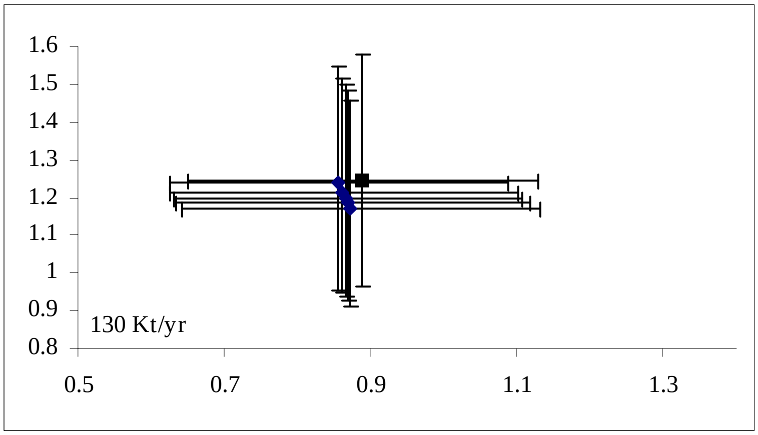
0.9
1.1
1.3


1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
130 Kt/yr
0.5
0.7
0.9
1.1
1.3

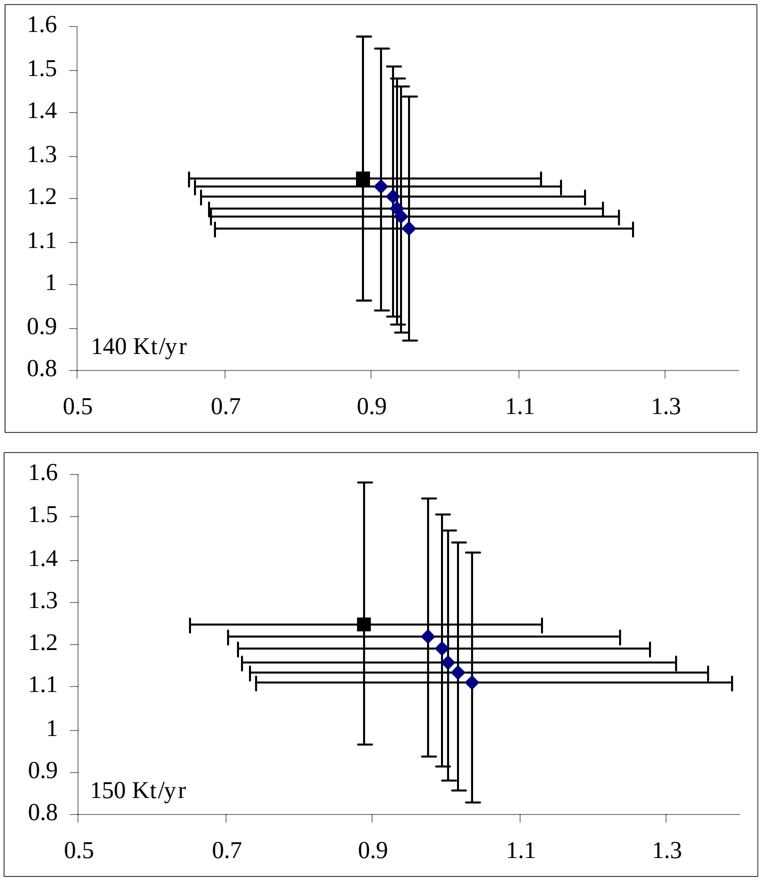


Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2008-2013 plotted as biomass ratio (B/B_{MSY})at end of year *vs* mortality ratio (Z/Z_{MSY}) during year. Estimated stock trajectories at 110–150 thousand tons fixed annual catch levels are shown as medians with quartile error bars.

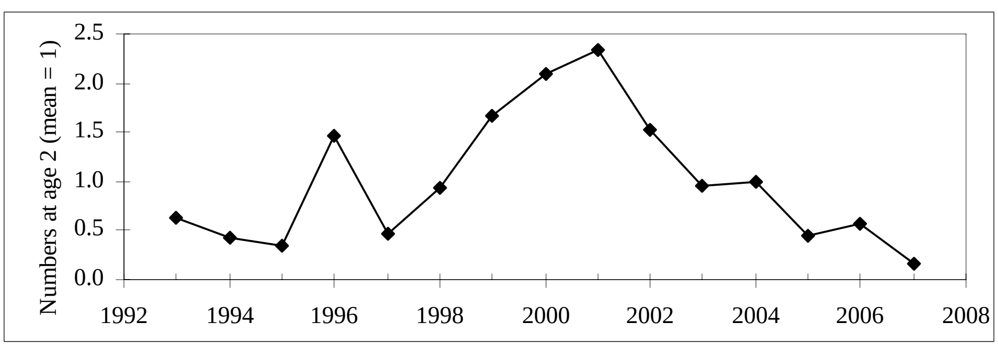


Fig. 9. Shrimp in Subareas 0 and 1: numbers at age 2 from research trawl survey, 1993–2007.

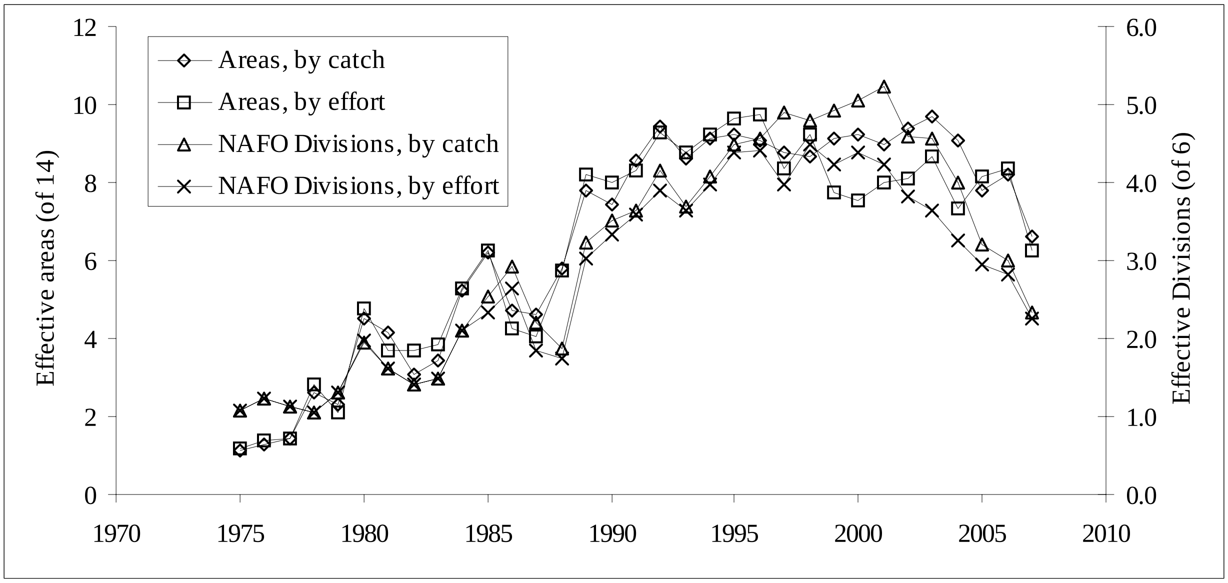


Fig. 10. Shrimp in Subareas 0 and 1: indices of distribution of the fishery from logbook records of catch and effort.

Appendix I

The following additional estimates of risk levels associated with different catch levels and selections of input data were made in the course of the 2007 NIPAG meeting. The associated text was also elaborated at the meeting.

Estimation of Parameters

1. A Schaefer surplus-production model of population dynamics was fitted to series of CPUE, catch, and survey biomass indices. The model included a term for predation by Atlantic cod and a cod biomass series was included in the input data. CPUE data extended back as far as 1976, but survey data only started in 1988. CPUEs were standardized by linearised multiplicative models including terms for vessel effect, month, year, and statistical area; the fitted year effects were considered to be series of annual indices of total stock biomass. Series for the Greenland fishery after the end of the 1980s were divided into 2 fleets, a coastal and an offshore; a series for 1976–1990 was constructed for the KGH fleet of sister trawlers and a series for 1987–2006 for the Canadian fleet fishing in SFA1. Twin-trawl data was included for the recent offshore fleets, a twin-trawl effect being included in the models. The four CPUE series were included separately in the surplus-production model.

While the model used in 2007 was broadly similar to that used in 2006, there were differences of detail that impeded the direct comparison of results. Among them were the use of 4 CPUE series separately in the model, where in 2006 a unified series was constructed in a separate preliminary step, and revised coding for the inclusion of the direct estimates of cod predation (SCR Doc. 07/67). This revision to the coding of the model permitted the use of an 'effective' cod biomass series that allowed for low spatial overlap between shrimp and cod, an alteration advocated in previous assessment meetings but hitherto impeded by the original coding of the model. In previous years a 'total' cod-stock estimate had been used.

Table: Summary statistics of stock dynamics, present stock status, and short-term predictions for 3 different catch levels, estimated from different selections of available data in 2007, and compared with estimates made in 2006.

	1. Full CPUE & Survey		2. Short CPUE & Survey		3. Survey only		4. 2006 Assessment	
	Median	IQR/Med.	Median	IQR/Med.	Median	IQR/Med.	Median	IQR/Med.
MSY	161.2	42	136.5	26	148.7	54	161.4	40
K	3158	110	1819	60	3245	104	3036	88
Zmsy(%)	10.63	66	15.05	42	9.67	76	11.66	58
B/Bmsy(2007)	1.25	49	1.15	40	1.40	49	1.49	37
$P(Z>Z_{msy}$, 2008)								
90 Kt	10.13		*12*		13.10			
110 Kt	18.99		*31*		24.00		2.65	
130 Kt	33.54		62.31		34.67		12.00	

Results obtained from this model were similar to those obtained in the 2006 assessment as regards stock-dynamic parameters, but more pessimistic as regards the present state of the stock—although still estimating it to be above B_{msy}—and short-term predictions.

2. This use of CPUE data could be regarded as giving too much credence to recent CPUE values that apply to a period when the fishery, and the stock, appear to be concentrated and CPUEs therefore apt to overestimate biomass

relative to periods when the fishery was more widely distributed. The model was therefore run with CPUE series truncated at 2003 before the stock contraction became so evident, and also with CPUE data completely omitted from the inputs.

When the CPUE series were truncated by omitting the years for which they disagreed with each other and with the survey series, the model achieved more precision in its estimations. Without the recent years' CPUE points that were relatively lower than the survey, relative biomass—much the same as with full CPUE data up to 2003—was estimated higher in 2004–5, but then decreased in step with the falling survey index. The model estimated a lower MSY at 136 Kt; estimates of the present state of the stock were lower than those based on all the CPUE data and even short-term predictions were much more pessimistic than when the full CPUE series were used. However, this selection can be regarded as setting a bound, on the pessimistic side, of the use of the available data and therefore of the state of the stock, and still estimates an MSY over 130 Kt. Recent estimates of consumption by cod with this data selection were about ¾ tons of shrimp per ton of cod, so a cod-stock prediction of 30 Kt would indicate that an allowance of order 20 Kt from the estimated MSY is needed for sustainability.

3. When the survey series was used alone as the only biomass index series, the model estimated a greater process error while the survey variability itself was estimated lower. Recent biomass levels, relative to B_{msy}, were estimated higher than when CPUEs were included, and the MSY was between the value estimated with full CPUE series and that from shortened CPUE series. Risk levels for short-term predictions were similar to those obtained when the full CPUE series were used, therefore more optimistic that when the CPUEs were truncated.

4. MSY estimated in 2006 was close to the 161 Kt estimated in 2007, but perhaps because the catches used in 2006 were lower the 2006 assessment was more optimistic about the current state of the stock. The future predictions were therefore also more optimistic; more so about future biomass than about future mortality. Mortality predictions must be considered in the light of the 2006 predictions' having been made with a cod stock assumed constant at 22.7 Kt where 33.2 Kt was assumed in 2007.