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A Provisional Assessment of the Shrimp Stock off West Greenland in 2009

by

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Abstract

The West Greenland Stock of *Pandalus borealis* was assessed from indices of biomass density based on catch and effort data from commercial fishing fleets, biomass from 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 2005, and has since decreased. Biomass appears still to be above its maximum sustainable yield level (B_{MSY}) and mortality by fishery and cod predation is below the value that maximizes yield (Z_{MSY}). However, the stock-dynamics model appears to pay more attention to the 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 this year by this model at somewhere near 148 000 tons. However, as the stock is estimated by the model to be above its MSY level and therefore less than maximally productive, and is also preyed on by cod, catches less than this are predicted to be associated with decreasing stock biomass.

Projections from the modelling showed that catches up to 120 000 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 contracted 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 for since 2003 and in 2007 reached a record low level. An increase observed in 2008 was small, and the index returned in 2009 to its second lowest observed level.

Introduction

The stock of the northern shrimp (*Pandalus borealis*) off West Greenland is distributed in NAFO Subarea 1 and the eastern margin of NAFO Div. 0A. The shrimp stock within this area is assessed as one unit. A Greenlandic fishery exploits the stock in Subarea 1 (Divs 1A–1F); a Canadian fishery has been restricted to Div. 0A since 1981.

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 document 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 annual catches at 10 000-ton intervals from 100 000 to 140 000 tons under assumptions that the cod stock, allowance made for a restricted overlap with shrimp distribution, remains at a level similar to those of the recent years—10 or 20 000 tons. The associated risks of transgressing reference parameters maximum sustainable yield levels of biomass (B_{MSY}) and mortality (Z_{MSY}), as well as a precautionary limit set at 30% of B_{msy} were estimated.

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, but have not been maintained, the most recent survey, in 2009, showing yet another collapse in the stock. The possible effects of a cod resurgence on the future trajectory of the shrimp stock are nonetheless of some 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 (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 an 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 22-year series of a survey estimate of the ‘fishable’ (i.e. at least 17 mm CL) stock biomass index (Wieland *et al*., 2004; Wieland and Bergström, 2005; Ziemer and Siegstad 2009); 4 series of CPUE indices spanning, among them, 1976 through 2009 (Kingsley, 2008a; Hammeken Arboe and Kingsley, 2009b); and unified into a single series by a separate model (Hvingel and Kingsley, 2002); a 55-year series of catches by the fishery with corrections for past overpacking (Hvingel, 2004; Hammeken Arboe and Kingsley 2009b); a 55-year series of ‘effective’ cod biomass estimates (i.e. allowance made for the imperfect overlap of the two stocks) (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004, 2005; Sünksen 2009); 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 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

1 earlier 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 recent, and this, years’ analyses have been carried out with *m* fixed at 2. This greatly speeds up model fitting.

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 (Sünksen 2009).

The four available CPUE series were unified in a separate step, applying assigned weights based on an estimate of the areas fished by the different fleet components. The resulting unified series gives much weight to the historical 'KGH' fleet from the early days of the fishery and in more recent times to the offshore fleet of large trawlers. Logbook data was corrected for earlier overpacking and associated underreporting before calculating the standardised CPUE index for the Greenland offshore fleet: for data from 2003 and earlier, 15% was added to reported catches of 'large' shrimp and 42% to catches of 'small' and 'unsorted' (Kingsley 2008a; Hammeken Arboe and Kingsley, 2009b).

Catch data were updated from available sources, including logbooks, STATLANT 21A, and quota reports from Greenland and Canadian sources. 2009 catches were projected from the first 6 months' logbook catches and the average proportion caught in the first 6 months of the previous 6 years. However, we were informed that the fishery had developed differently this year from previous years, with relatively more intense fishing in the second half of the year. A higher 2009 projected catch was therefore also run, and provisional statistics for this case are given in Appendix A.

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 in some recent surveys increased from the very low levels that prevailed throughout the 1990s, but survey results also showed that cod had a more southerly distribution on the West Greenland fishing grounds and shrimps, 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 (2005) Table 1, updated with recent, and recently revised, survey estimates of cod biomass (Sünksen 2009). The low spatial overlap values of recent years have been used to modify recent cod biomass values toward more modest 'effective' values.

The data link functions for the biomass indices were:

$$CPUE_t = q_c P_t \exp(\omega) \;, \text{ for } \; t \in (t_1, t_2, ,..,..N-1) \,, \;\; CPUE_N = q_c P_N \exp(1.5\omega)$$

$$surv_t = q_s B_{MSY} P_t \exp(\kappa) \;, \text{ for } \; t \in (2,3,..,..N) \,, \;\; surv_1 = q_s B_{MSY} P_1 \exp(1.5\kappa)$$

The catch rate ($CPUE_{,t}$) and survey ($surv_t$) indices were scaled to the biomass index by catchability constants q_c and q_s. Their error terms, ω and κ, were assumed normally, independently and identically distributed with mean 0 and variance σ_c^2 and σ_κ^2. The standard error for 2009 for the CPUE index series 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 possible 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 predation estimates from Grunwald (1998) were associated with a separate short series of cod biomass estimates that she had used in her calculations, but were related by the same predation function and the same parameter values[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:

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

The model was fitted by Bayesian methods, the integration being carried out by Markov Chain Monte Carlo sampling. The sampling was burnt in for 50 000 iterations and then run for 60 000 000, every 600th being retained. Of the resulting 100 000 iterations, every 10th was used in the final calculations giving sample sizes of 10 000.

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 (Hammeken Arboe and Kingsley, 2009b). The assessment also refers to indices that summarise survey information on the distribution of the stock (Kingsley, 2008b).

Data from the annual West Greenland trawl survey (Ziemer and Siegstad 2009) 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 observed data series (Fig. 2), but less well than in 2008. The median estimate of the precision parameter for the research trawl survey index was equivalent to an error CV of about 21%; 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 probably underestimates the true total uncertainty of the survey. The precision parameter for the unified CPU series was about equivalent to an error CV of 3½% and the process variation was about 9½%, indicating that the model could fit a biomass trajectory very closely to the CPUE series, even at the cost of a slightly worse fit to the stock-dynamic equation. The cod predation terms had large error CVs. The main predation term had median estimate error CV of 44%, and the precision estimate for the 4-year Grunwald predation series was 53%. 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 (2007) found that the model could be fitted without using the Grunwald data.

Some parameter 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. Since the *MSY* was estimated with only a moderate uncertainty, the *MSY* ratio ($Z_{msy} = MSY//B_{msy}$) was negatively correlated with carrying capacity *K*, but it was also negatively correlated with MSY itself, which was unexpected.

The median estimate of the *MSY* was 144 Kt, similar to estimates obtained in 2007 when CPUE series were truncated in 2003 (i.e. using only logbook data uncorrected for overpacking) or when only survey data was used. The model fit in the present year's assessment is tighter than in the previous few years and the uncertainty in parameter estimates lower.

[2] in 2008, as a test, the model had been allowed to fit a multiplier to the cod biomass series that Grunwald used to calculate total consumption; its median estimate was close to 1 and the uncertainty large, so this modification to the model was not retained.

Assessment Results

The median *MSY* of 148 000 t is uncertain; the e.c.v. of the mean is 34%. The distribution of the estimate is highly skewed and the most likely value for the MSY is estimated at 126 000 t. This implies that values between 148 000 and 126 000 t, as well as some values *less* than 126 000 t, are more likely than 148 000 t. The median estimate of stock level at start of 2009 was 27% above *MSYL*; this value had been projected at 26% above *MSYL* in the 2008 assessment.

The model estimated the yearly consumption of shrimp by cod to be relatively constant between about 30 and 100 000 tons all the way from 1957 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 modelled consumption estimates to increase dramatically—median 191 000 t in 1987 and 95 000 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. 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 only about 1500 tons of shrimp in 2004; median estimates of predation increased to about 31 000 t and 21 000 t in 2006 and 2007 owing again to an increase in survey estimates cod biomass, even after allowances for the different distributions of cod and shrimp, but have declined again in the most recent years.

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 0.6-1.0 times B_{MSY} and mortality 0.7 to 1.2 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 increased and is modelled to have reached 1.5 times B_{MSY} in 2004, while annual median *Z*-ratio has been stable at levels estimated at 0.6–0.1, i.e. below the value that maximises yield. Associated with an increase in the cod stock and high catches in 2005–06, mortality is modelled to have increased; future high catches accompanied by significant predation are forecast to bring biomass ratio down (Fig. 4). The median estimate of the Z-ratio for 2009, with projected catches about 108 000 tons, is 0.65, with a 3½% risk that it exceeds 1.

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[3] associated with five possible catch levels for 2010, with an 'effective' cod stock at 10 000 tons, are estimated to be:

	Catch option ('000 tons)				
Risk of:	100	110	120	130	140
falling below B_{msy} end 2010 (%)	15.4	16.8	17.4	18.1	19.9
falling below B_{lim} end 2010 (%)	0.3	0.3	0.2	0.2	0.2
exceeding Z_{msy} during 20010 (%)	3.0	6.7	12.6	21.4	30.9

and with an 'effective' cod stock at 20 000 t

	Catch option ('000 tons)				
Risk of:	100	110	120	130	140
falling below B_{msy} end 2010 (%)	16.7	17.8	18.7	19.4	20.6
falling below B_{lim} end 2010 (%)	0.2	0.2	0.2	0.2	0.2
exceeding Z_{msy} during 20010 (%)	6.7	11.9	20.8	29.5	39.6

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, and recent signs of increase have not been maintained. A large cod stock that

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

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 uncertainty as to the overlap between two species. 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. 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.

5-year projections of stock development were made under the assumption that the ‘effective’cod stock will remain at levels consistent with recent estimates, 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: 100 000, 110 000, 120 000, 130 000 and 140 000 tons (Figs 6–8).

Shrimps in West Greenland spread more widely after 1990 and the fishery extended into more southerly areas. However, after about 1997 the proportion of the catch taken in the most southerly areas started to decrease and the ‘latitude index’ of the survey biomass increased. After 2003 indices of the breadth of distribution of the stock started to decrease, but they appear stable over the most recent years.

The present assessment based on the existing modelling approach indicates a B_{msy} greater than half of the carrying capacity K, and is also estimating large stocks and large carrying capacity. This is probably because CPUE still remains relatively high, even after the high catches of the past decade. However, the fishery is now more concentrated than in 1992–2003 (Fig. 10), so CPUEs that indicate high densities in the fished areas do not necessarily translate to an equally high biomass; survey results estimate a stock biomass that is 47% of its 2003 peak and, like the fishery, more concentrated (Fig. 11; Ziemer and Siegstad 2009). 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. Numbers at age 2 have been at low levels for the last 5 years, so recruitment prospects remain poor (Fig. 9).

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.

	Effective cod biomass[4]	Catch	Survey index of fishable biomass	Predation estimate[5]	Cod-stock estimate[6]	CPUE
1955	1919.1	6.1				
1956	1592.7	6.1				
1957	1392.9	6.1				
1958	1258.3	6.1				
1959	1212.6	6.1				
1960	1287.3	6.1				
1961	1263.1	6.1				
1962	1051.3	6.1				
1963	911.2	6.1				
1964	898.1	6.1				
1965	950.2	6.1				
1966	889.2	6.1				
1967	797.4	6.1				
1968	578.1	6.1				
1969	389.7	6.1				
1970	244.9	10.5				
1971	218.7	11.6				
1972	191.9	11.9				
1973	115.4	15.5				
1974	84.7	27.0				
1975	68.2	46.5				
1976	132.5	61.4				1.745
1977	144.5	51.6				1.561
1978	170.3	42.3				1.226
1979	145.6	42.8				1.109
1980	163.4	55.9				1.342
1981	110.4	53.8				1.263
1982	98.8	54.3				1.628
1983	61.7	56.2				1.427
1984	37.8	52.8				1.338
1985	25	66.2				1.432
1986	19.6	76.9				1.494
1987	282.1	77.9				1.658
1988	297.3	73.6	223.2			1.201
1989	149.1	80.7	209.0	213.7	470.9	1.053
1990	12.2	84.0	207.0	27.8	184.1	1.000
1991	2.1	91.5	146.0	2.7	19.8	1.004
1992	0.4	105.5	194.2	0.8	2.9	1.101
1993	0.3	91.0	216.5			1.083
1994	0.1	92.8	223.1			1.078
1995	0	87.4	183.2			1.218
1996	0.1	84.1	192.1			1.269
1997	0.1	78.1	167.1			1.234
1998	0	80.5	244.3			1.429
1999	0.1	92.2	237.3			1.612
2000	0.4	98.0	280.3			1.746

[4] Wieland and Storr-Paulsen (2004) updated by Sünksen (2009).

[5] Grunwald (1998).

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

	Effective cod biomass[4]	Catch	Survey index of fishable biomass	Predation estimate[5]	Cod-stock estimate[6]	CPUE
2001	1.2	102.9	280.5			1.653
2002	0.7	135.2	369.5			1.979
2003	1	130.2	548.3			2.119
2004	1.7	149.3	528.3			2.375
2005	2	156.9	479.5			2.478
2006	35.7	157.3	437.5			2.398
2007	24	144.2	334.1			2.430
2008	6.4	152.7	262.4			2.498
2009	2.4	108.8	255.5			2.149

Table 2. Summary of estimates of selected parameters from Bayesian fitting of a surplus production model.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2008)
Max.sustainable yield	159	54	133	148	168	126	144
Carrying capacity	2584	2764.5	1526	1922	2642	598	1780
Max. sustainable yield ratio (%)	15.3	4.7	12.2	15.5	18.5	15.8	16.3
Survey catchability (%)	31.6	14.0	21.7	30.9	40.4	29.3	32.5
CPUE catchability	1.9	0.8	1.3	1.8	2.4	1.7	1.6
$P_{50\%}$	5.0	2.9	3.1	4.5	6.2	3.3	4.7
O_{max}	3.0	0.3	2.8	3.0	3.2	3.0	3
CV of process (%)	9.3	2.3	7.8	9.4	10.8	9.5	9.6
CV of survey fit (%)	21.6	3.6	19.1	21.2	23.6	20.4	18.3
CV of CPUE fit (%)	3.8	1.6	2.6	3.6	4.7	3.0	3.5
CV of predation fit (%)	46.6	33.1	18.5	44.4	66.3	40.1	41.4
Start biomass ratio	0.91	0.19	0.77	0.89	1.03	0.85	0.89

Table 3. Selected[1] correlations (%) between model parameters.

	Start biom. Ratio	*CV pred*	*CV cpu*	*CV surv*	*CV proc*	*Omax*	*P50%*	*Qc*	*Qs*	*MSY ratio*	*K*
Max.sustainable yield	9.2	24.8					-12.5	-32.5	-32.3	-29.9	57.1
Carrying capacity	10.8	7.4			13.9			-47.2	-47.0	-58.1	
Max. sustainable yield ratio	-17.0		-9.5		-24.9		-21.7	81.8	81.3		
Survey catchability	-16.1				-37.1		-41.9	99.3			
CPUE catchability	-16.2				-37.4		-42.2				
$P_{50\%}$	7.6	-9.7			33.7	17.1					
O_{max}											
CV of process		-45.5	-23.1								
CV of survey fit			-10.2								
CV of CPUE fit											
CV of predation fit	9.6										

[1] those over 7%

Table 4. Risks (%) of exceeding limit mortality in 2014 and of falling below *MSYL* or limit* biomass at the end of 2014

Catch (Kt/yr)	Prob. biomass < B_{MSY} (%)		Prob. Biomass < B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	10 Kt	20 Kt	10 Kt	20 Kt	10 Kt	20 Kt
100	10.5	12.6	0.2	0.2	3.2	6.9
110	13.8	17.6	0.2	0.2	7.1	14.5
120	17.2	22.3	0.2	0.3	15.3	25.5
130	23.6	28.1	0.2	0.2	26.6	38.6
140	28.3	33.8	0.3	0.2	40.2	50.6

* limit biomass is 30% of B_{msy}

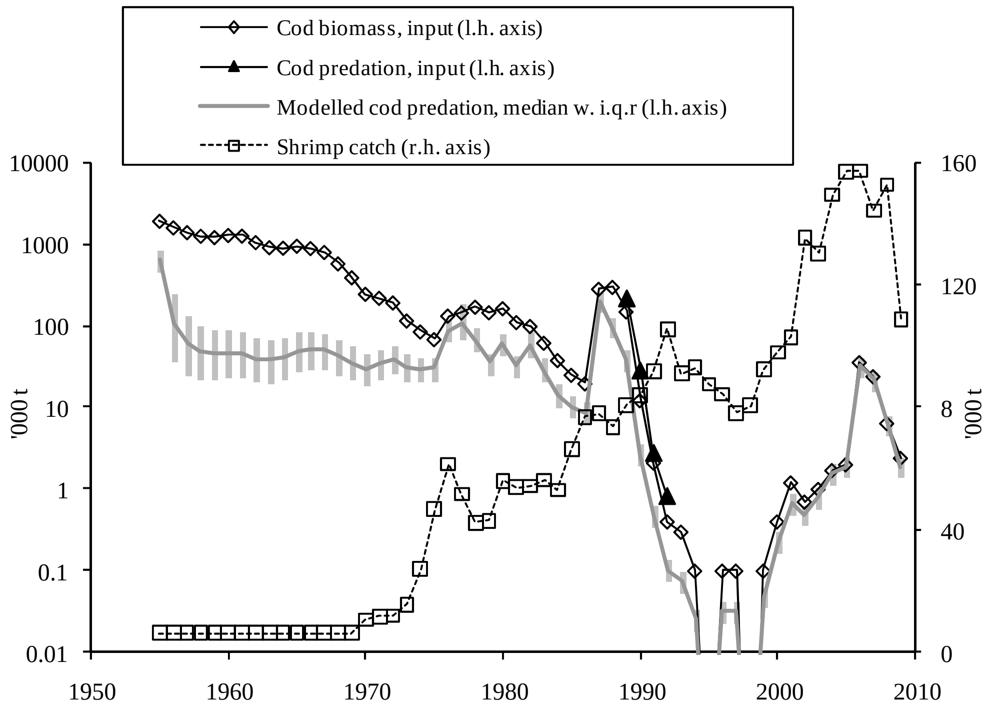


Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model, and cod predation estimated by the model.

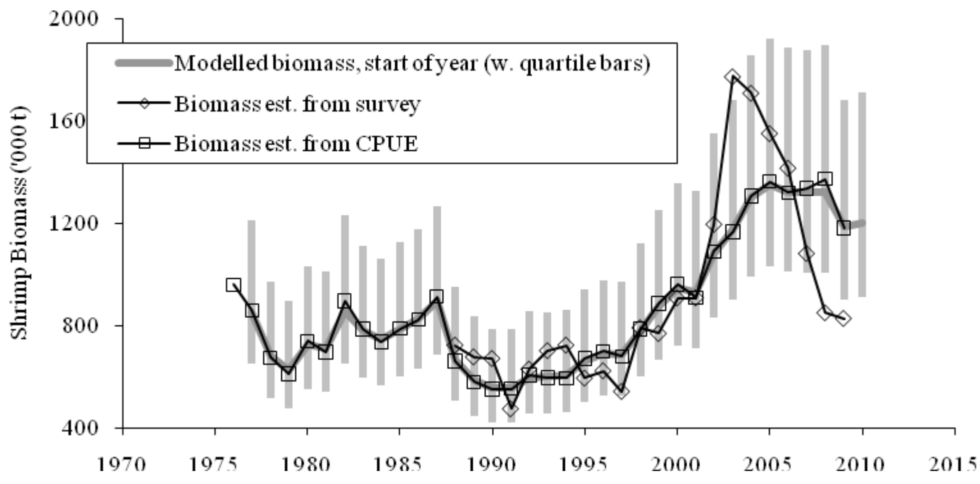


Fig. 2. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2008.

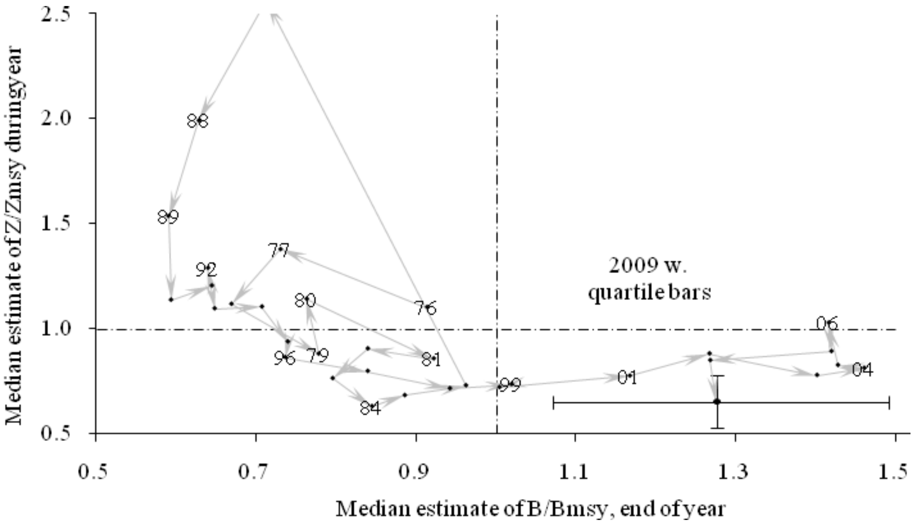


Fig. 3. Shrimp in West Greenland: median estimates of biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1976–2008.

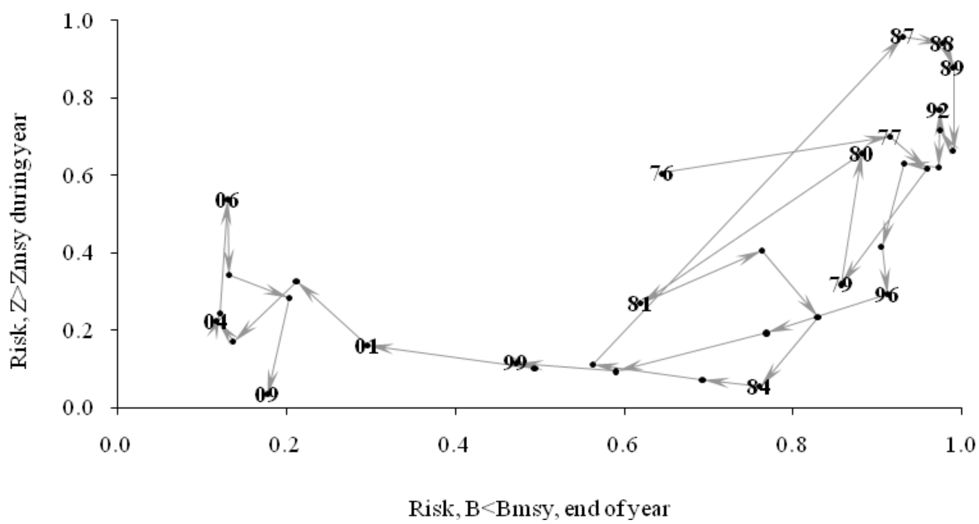


Fig. 4. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{MSY} and that mortality caused by fishing and cod predation has been above Z_{MSY} 1976–2008.

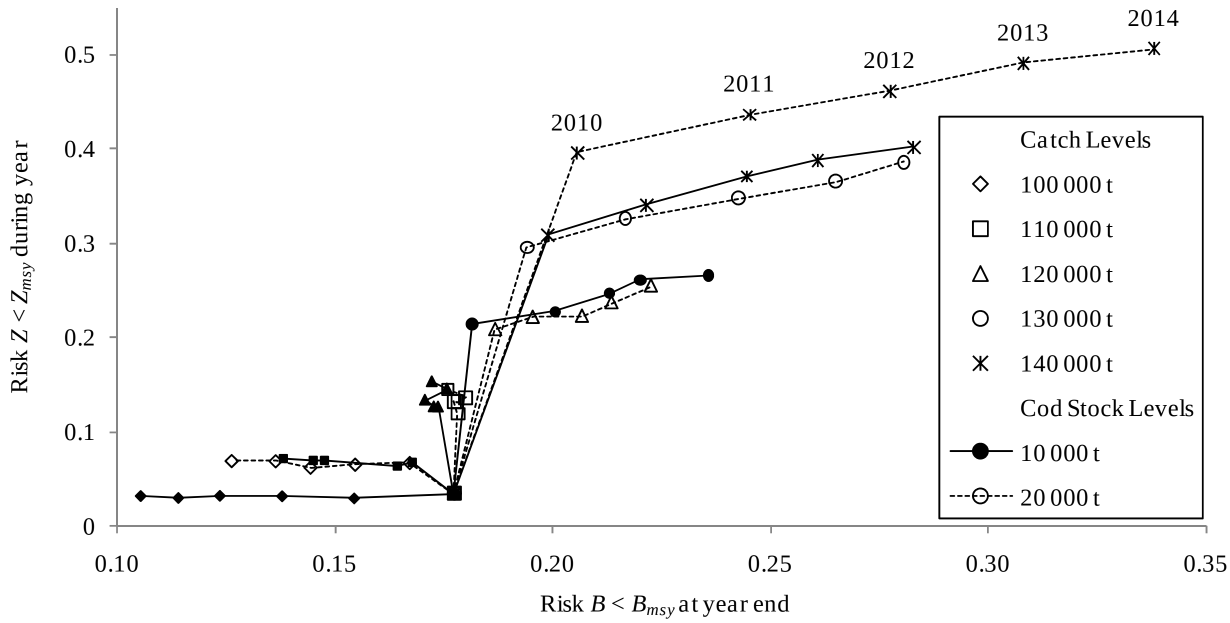


Fig. 6. Joint 5-year plot of the risks of transgressing B_{msy} and Z_{msy} at catch levels 100–140 Kt/yr; with effective cod biomass 10 and 20 Kt

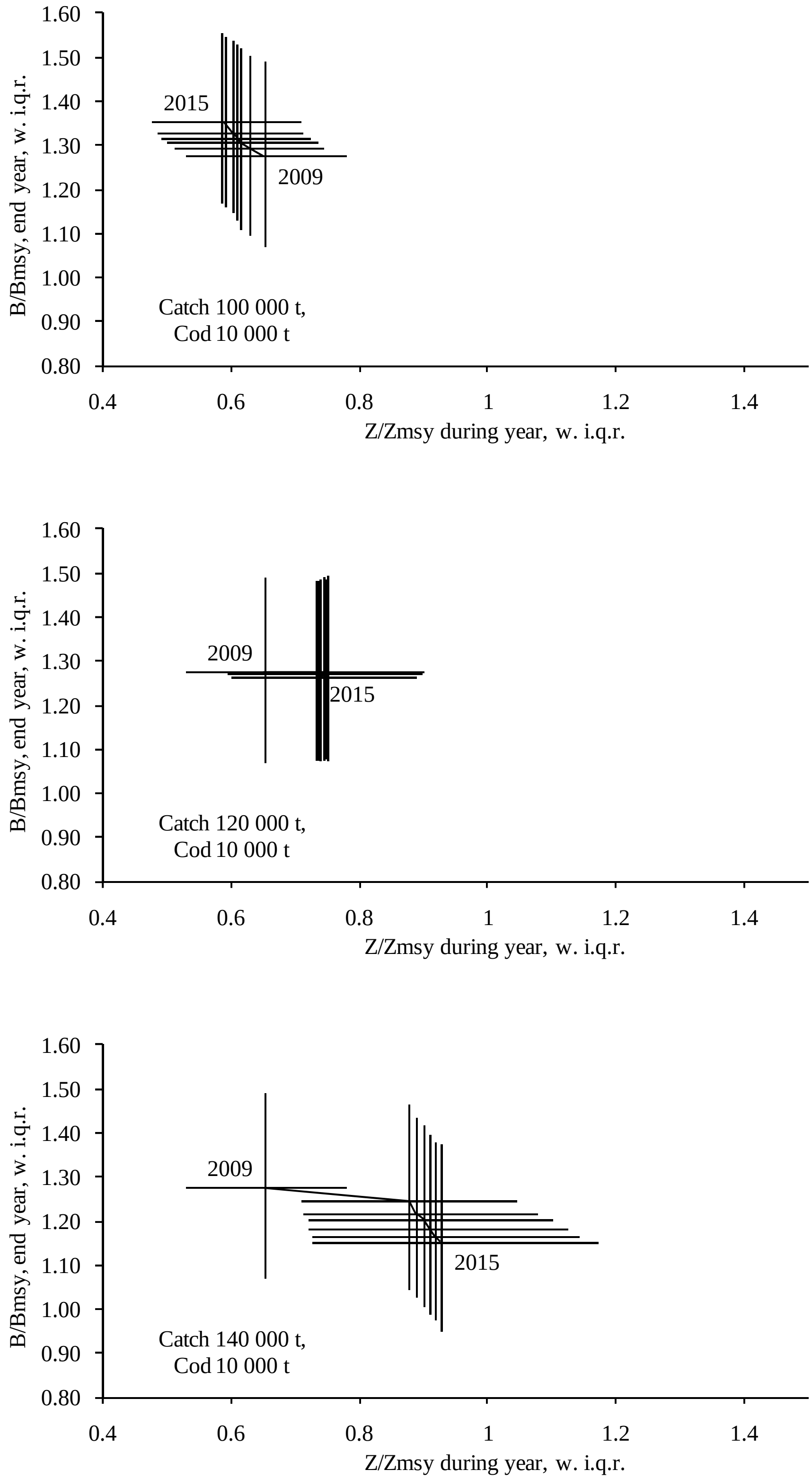


Fig. 7. Shrimp in Subareas 0 and 1: projections of stock development for the period 2009-2015 with effective cod biomass assumed at 10 000 t: median estimates with quartile error bars.

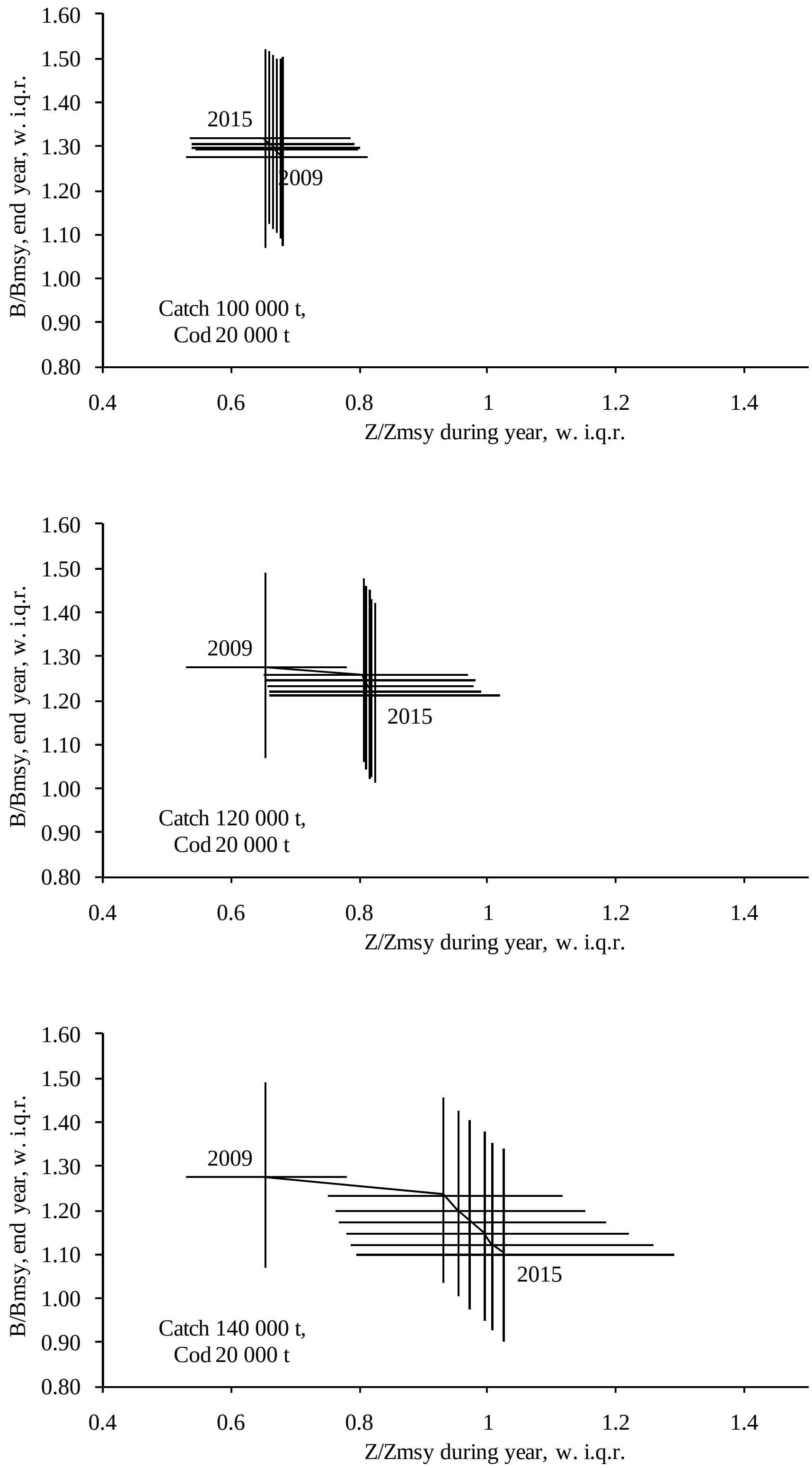


Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2009-2015. Estimated stock trajectories: medians with quartile error bars.

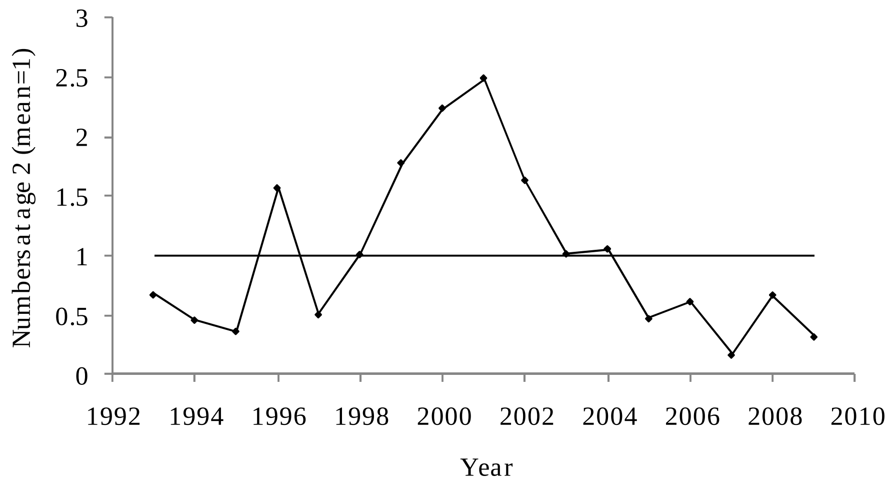


Fig. 9. Shrimp in Subareas 0 and 1: numbers at age 2 from research trawl survey, 1993–2009.

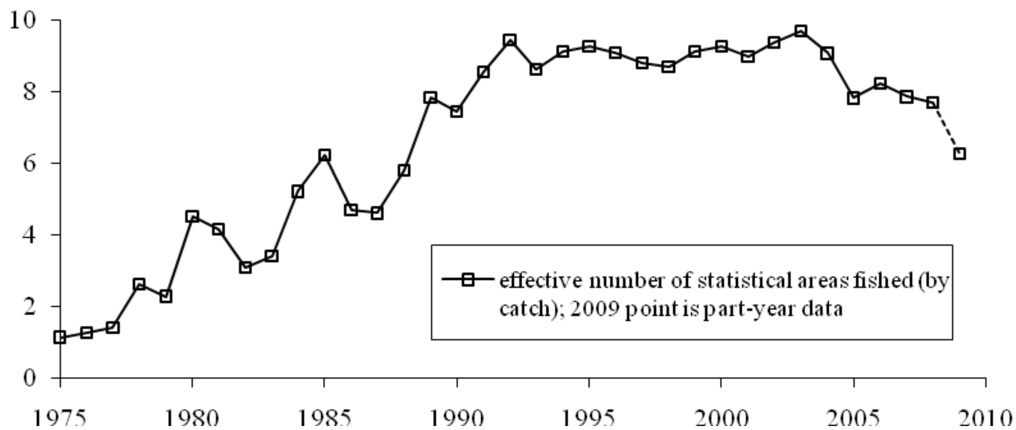


Fig. 10. Shrimp in Subareas 0 and 1: indices of distribution of the fishery from logbook records.

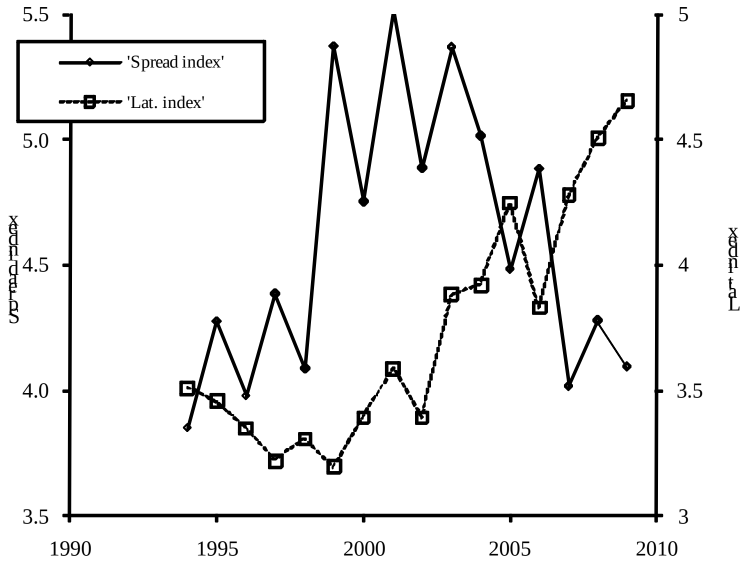


Fig. 11. Shrimp in Subareas 0 and 1: indices of distribution of the survey biomass.

Appendix: Forecast probabilities for 130 000-t catch in 2009

10 Kt cod stock
Risk table for first future year

	Catch option ('000 tons)				
Risk of:	100	110	120	130	140
falling below BMSY end 2010 (%)	18.9	20.1	20.4	21.5	23.1
falling below Blim end 2010 (%)	0.1	0.1	0.1	0.1	0.1
exceeding Zmsy during 20010 (%)	4.0	8.7	15.2	23.9	34.1

20 Kt cod stock
Risk table for first future year

	Catch option ('000 tons)				
Risk of:	100	110	120	130	140
falling below BMSY end 2010 (%)	19.8	20.9	21.7	22.5	23.6
falling below Blim end 2010 (%)	0.1	0.2	0.1	0.1	0.1
exceeding Zmsy during 20010 (%)	8.4	14.7	22.8	32.5	42.2

5-year risk table, 10 & 20 Kt cod

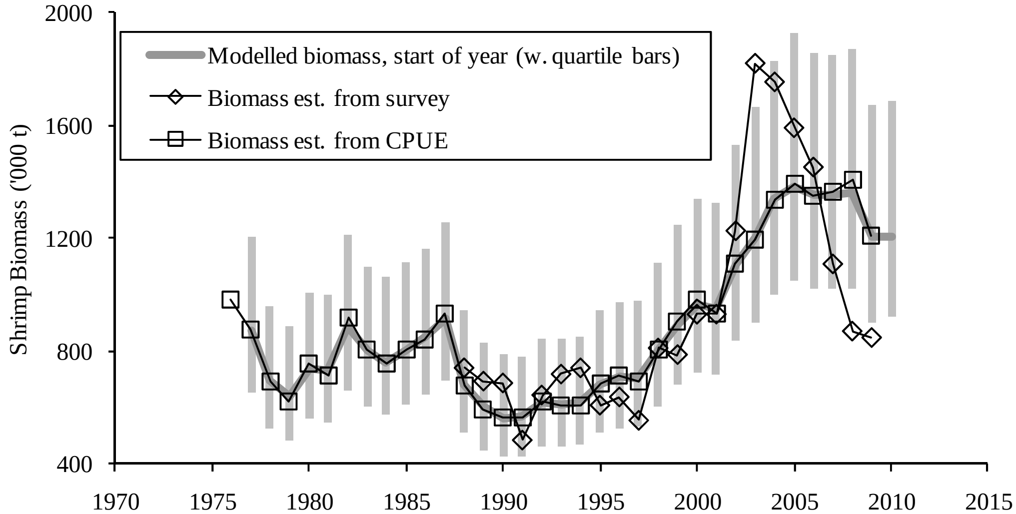
Catch (Kt/yr)	Prob. biomass < B_{MSY} (%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	10 Kt	20 Kt	10 Kt	20 Kt	10 Kt	20 Kt
100	11.2	15.3	0.1	0.2	3.1	7.9
110	15.8	19.3	0.1	0.1	8.2	15.8
120	19.1	23.8	0.1	0.2	16.1	26.4
130	24.0	29.7	0.1	0.1	27.3	39.1
140	30.9	36.3	0.2	0.4	41.6	52.9

10Kt cod projection risk table

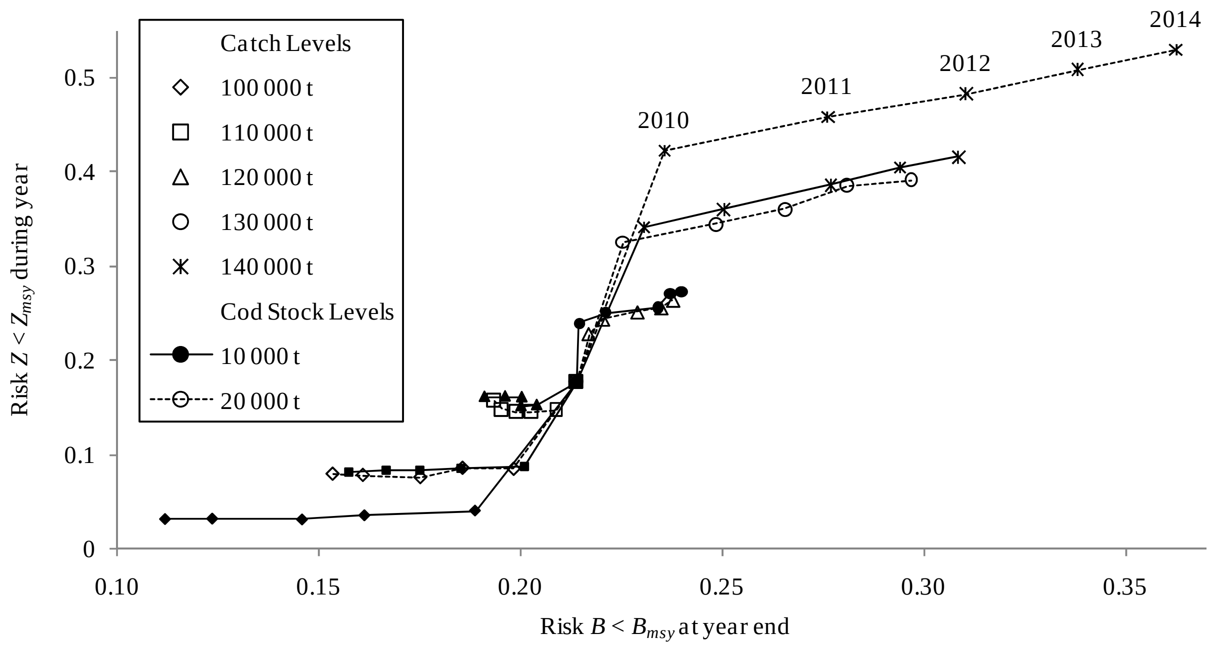
Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	5 yr	10 yr	5 yr	10 yr	5 yr	10 yr
100	11.2	9.2	0.1	0.2	3.1	3.9
110	15.8	12.9	0.1	0.2	8.2	8.5
120	19.1	19.2	0.1	0.6	16.1	17.8
130	24.0	28.1	0.1	0.9	27.3	30.2
140	30.9	37.7	0.2	2.3	41.6	46.0

20Kt cod projection risk table

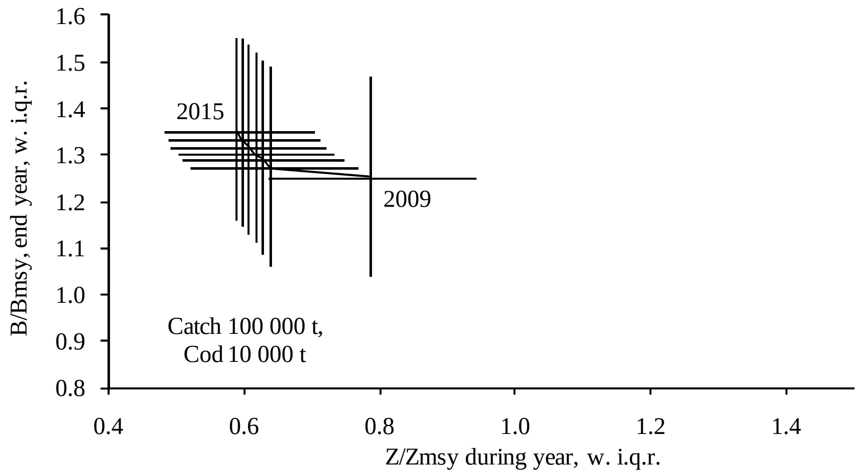
Catch rate (Kt/yr)	Prob. biomass < B_{MSY}(%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	5 yr	10 yr	5 yr	10 yr	5 yr	10 yr
100	15.3	13.4	0.2	0.1	7.9	8.1
110	19.3	19.2	0.1	0.3	15.8	16.4
120	23.8	26.4	0.2	0.8	26.4	29.1
130	29.7	37.0	0.1	1.7	39.1	45.4
140	36.3	47.3	0.4	3.6	52.9	58.6

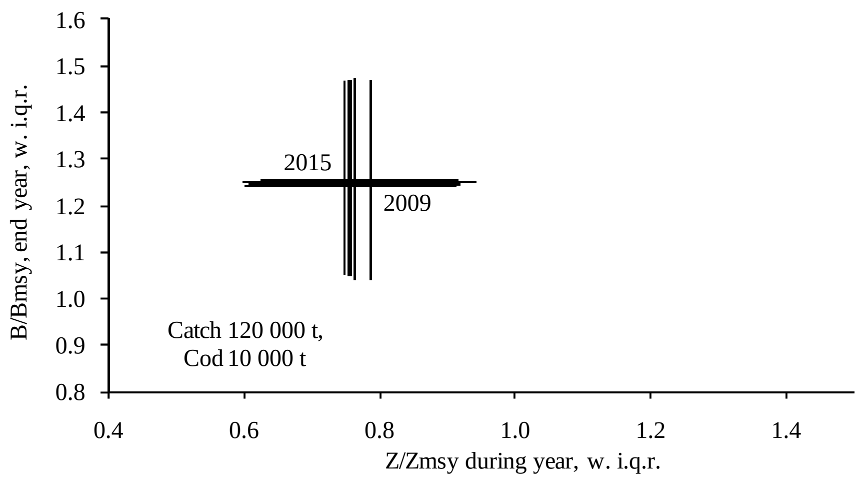


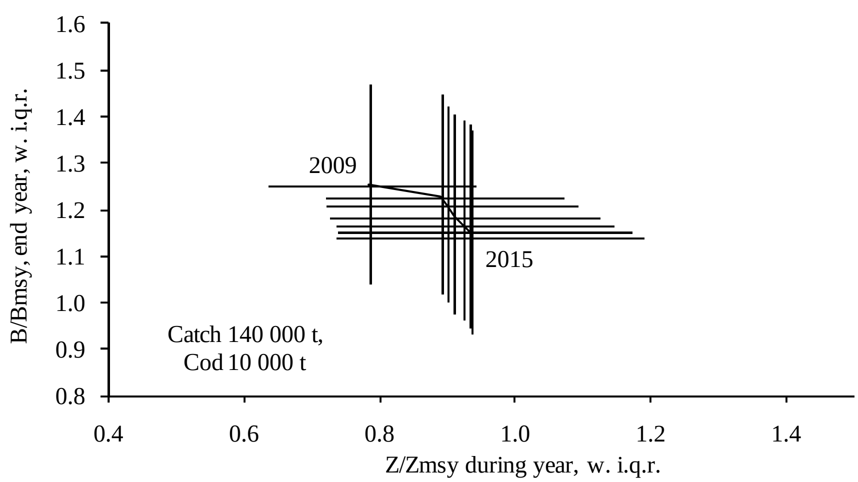
Modelled biomass, start of year (w. quartile bars)
Biomass est. from survey
Biomass est. from CPUE
Shrimp Biomass ('000 t)
2000
1600
1200
800
400
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015



Catch Levels
100 000 t
110 000 t
120 000 t
130 000 t
140 000 t
Cod Stock Levels
10 000 t
20 000 t
2010
2011
2012
2013
2014
Risk $Z < Z_{msy}$ during year
Risk $B < B_{msy}$ at year end
0.5
0.4
0.3
0.2
0.1
0
0.10
0.15
0.20
0.25
0.30
0.35


1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
B/Bmsy, end year, w. i.q.r.
2015
2009
Catch 100 000 t,
Cod 10 000 t
0.4
0.6
0.8
1.0
1.2
1.4
Z/Zmsy during year, w. i.q.r.


1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
B/Bmsy, end year, w. i.q.r.
2015
2009
Catch 120 000 t,
Cod 10 000 t
0.4
0.6
0.8
1.0
1.2
1.4
Z/Zmsy during year, w. i.q.r.


1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
B/Bmsy, end year, w. i.q.r.
2009
2015
Catch 140 000 t,
Cod 10 000 t
0.4
0.6
0.8
1.0
1.2
1.4
Z/Zmsy during year, w. i.q.r.