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A Provisional Assessment of the Shrimp Stock off West Greenland in 2008

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 2005, and has since decreased, in 2008 apparently quite sharply. 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 by this model at about 144 000 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 110 000 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 is still doing so, 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 is small, and the index is still below its average.

Introduction

The stock of 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 a 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-t intervals from 90 000 to 140 000 tons under assumptions that the cod stock, allowance made for a restricted overlap with shrimp distribution, remains at an average level from the most recent 3 years—22 000 t—or at 40 000 t. 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 (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_ν^2 .

The model synthesised information from input priors (Hvingel and Kingsley 2002) (Fig. 3) and the following data: a 21-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; Bergström 2007; Ziemer and Siegstad 2008); 4 series of CPUE indices spanning, between them, 1976 through 2008 and unified into a single series by a separate model; a 54-year series of catches by the fishery (Hvingel, 2004; Hvingel and Kingsley, 2002); a 54-year series of cod biomass estimates (Hvingel and Kingsley, 2002; Storr-Paulsen and Wieland, 2004, 2005; Sünksen 2008); 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 for the biomass indices were:

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

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[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 the current year’s analyses were carried out with *m* fixed at 2. This greatly speeds up the model-fitting process.

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

The catch rate ($CPUE_{,t}$) and survey ($surv_t$) indices were scaled to the biomass index by their catchability constants, q_c and q_s. Their error terms, ω 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 2008 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 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 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:

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

The model was fitted by Bayesian methods, the integration being carried out by Markov Chain Monte Carlo sampling. The sampling was burnt in for 20 000 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.

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 (Sünksen 2008).

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, b).

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,

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[2] as a test, the model was 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.

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 survey estimates of cod biomass (Sünksen 2008). 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 2008b).

Data from the annual West Greenland trawl survey (Ziemer and Siegstad 2008) 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). The precision parameter for the research trawl survey index was equivalent to an error CV of about 18%; 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 error-variance estimates were generally negatively correlated with one another, as a good fit to one series tends to entrain a worse fit to others. In particular the process error was negatively correlated with the errors of the fits to all the input series—if the modelled biomass trajectory fits closely to the input data the process error has to increase—and the errors of the fits to the CPUE and the survey series were negatively correlated—the CPUE series and the survey series did not always agree well and the model had to decide which to follow more closely. The cod predation terms had large error CVs. The main predation term had an error CV of nearly 40%, and the precision estimate for the 4-year Grunwald predation series was nearly 75%. 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.

Assessment Results

The *MSY* of 144 000 t is less uncertain than estimates of recent years, and in general the good model fit lends credibility to this estimate. The model estimates that the stock is some 30% above its *MSYL* at the start of 2008, but decreasing, with a median estimate of 28% above *MSYL* at the end of 2008.

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, but the median estimate of predation increased to about 10 000–30 000 tons in recent years owing to the recent increase in the estimated cod biomass, even after allowances for the different 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 0.6-1.0 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 2008, with projected catches about 132 000 tons, is 0.87, with a 30% risk that it exceeds 1.

The median estimate of the maximum annual production surplus, available equally to the fishery and to the cod (*MSY*) was estimated at 144 000 tons. In keeping with the generally good fit of the model, the estimate is fairly good, with upper and lower quartiles at 130 000 and 163 000 tons (Table 3). The most likely value is estimated to be near 139 000 t.

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 2009, with an 'effective' cod stock at 22 000 tons, are estimated to be:

	Catch option ('000 tons)					
Risk of:	90	100	110	120	130	140
falling below B_{MSY} end 2009 (%)	16.8	18.1	19.3	20.9	22.0	23.0
falling below B_{lim} end 2009 (%)	0.1	0.1	0.1	0.1	0.2	0.1
exceeding Z_{MSY} during 2009 (%)	5.5	10.7	18.2	28.4	38.2	47.5

and with an 'effective' cod stock at 40 000 t

	Catch option ('000 tons)					
Risk of:	90	100	110	120	130	140
falling below B_{MSY} end 2009 (%)	18.6	19.9	20.9	21.7	23.3	25.3
falling below B_{lim} end 2009 (%)	0.1	0.1	0.2	0.1	0.1	0.2
exceeding Z_{MSY} during 2009 (%)	14.2	22.4	31.3	41.9	50.1	58.9

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

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

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 several orders of magnitude less than 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 mean of recent estimates of 'effective' 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. Six levels of annual catch were investigated: 90 000, 100 000, 110 000, 120 000, 130 000 and 140 000 tons (Figs 6–8).

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 is still relatively high, even after the high catches 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 an equally high biomass, and survey results since 2003 have shown a steadily declining and steadily more concentrated stock (Kingsley 2008c; Ziemer and Siegstad 2008). 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. However, numbers at age 2 have increased in 2008 after six years of downward trend, which is slightly encouraging (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				1.748
1977	144.5	51.6				1.565
1978	170.3	42.3				1.226
1979	145.6	42.8				1.107
1980	163.4	55.9				1.345
1981	110.4	53.8				1.264
1982	98.8	54.3				1.628
1983	61.7	56.2				1.428
1984	37.8	52.8				1.338
1985	25.0	66.2				1.433
1986	19.6	76.9				1.495
1987	282.1	77.9				1.650
1988	297.3	73.6	223.2			1.199

[4] Wieland and Storr-Paulsen (2004) updated by Sünksen (2008)

[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
1989	149.1	80.7	209.0	213.7	470.9	1.061
1990	9.9	84.0	207.0	27.8	184.1	1.000
1991	1.6	91.5	146.0	2.7	19.8	1.005
1992	0.3	105.5	194.2	0.8	2.9	1.099
1993	0.2	91.0	216.5			1.083
1994	0.1	92.8	223.1			1.076
1995	0.1	87.4	183.2			1.215
1996	0.1	84.1	192.1			1.270
1997	0.1	78.1	167.1			1.230
1998	0.1	80.5	244.3			1.420
1999	0.1	92.2	237.3			1.605
2000	0.4	98.0	280.3			1.741
2001	1.2	102.9	280.5			1.647
2002	0.6	135.2	369.5			1.978
2003	0.9	130.2	548.3			2.119
2004	1.6	142.2	528.3			2.373
2005	1.9	154.6	479.5			2.480
2006	32.2	154.7	437.5			2.403
2007	22.1	139.6	334.1			2.446
2008	13.2	131.6	262.4			2.129

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 (2007)
Max.sustainable yield	153	46	130	144	163	139	161
Carrying capacity	2355	2360	1427	1780	2417	1493	2854
Max. sustainable yield ratio (%)	16.0	4.9	12.9	16.3	19.2	16.5	10.6
Survey catchability (%)	33.3	14.7	22.9	32.5	43.0	32.1	20.4
CPUE catchability	1.8	0.7	1.4	1.6	2.0	1.6	
$P_{50\%}$	5.4	3.5	3.4	4.7	6.5	4.4	
O_{max}	3.0	0.3	2.8	3.0	3.2	3.0	
CV of process (%)	9.7	2.1	8.3	9.6	11.0	9.6	9.0
CV of survey fit (%)	18.7	3.2	16.4	18.3	20.6	18.1	17.1
CV of CPUE fit (%)	3.8	1.4	2.8	3.5	4.5	3.4	
CV of predation fit (%)	45.4	27.9	23.6	41.4	61.1	39.4	29.7
Start biomass ratio	0.91	0.18	0.78	0.89	1.02	0.88	

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	9.1	21.1					-11.1	32.4	-37.4	-27.6	54.0
Carrying capacity	11.6	7.9	6.4		17.1		6.7	23.2	-50.6	-60.8	
Max. sustainable yield ratio	-18.1		-10.6		-24.9		-22.1	-6.4	79.2		
Survey catchability	-17.4		-6.9		-35.9		-38.1	33.2			
CPUE catchability		17.4			-22.6		-51.1				
$P_{50\%}$	9.6				30.9	15.9					
O_{max}											
CV of process		-36.1	-11.9								
CV of survey fit			-8.6								
CV of CPUE fit											
CV of predation fit	10.2										

[1] those over 5%

Table 4. 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 22 000 tons or 40 000 tons.

Catch (Kt/yr)	Prob. biomass < B_{MSY} (%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	22 Kt	40 Kt	22 Kt	40 Kt	22 Kt	40 Kt
90	12.5	18.6	0.1	0.2	5.3	15.2
100	15.9	22.8	0.1	0.1	10.8	25.5
110	20.7	28.5	0.2	0.3	20.6	38.4
120	25.6	35.6	0.2	0.2	32.5	50.4
130	32.7	41.3	0.3	0.4	47.2	61.2
140	38.1	47.7	0.5	0.9	58.0	69.9

* limit biomass is 30% of B_{msy}

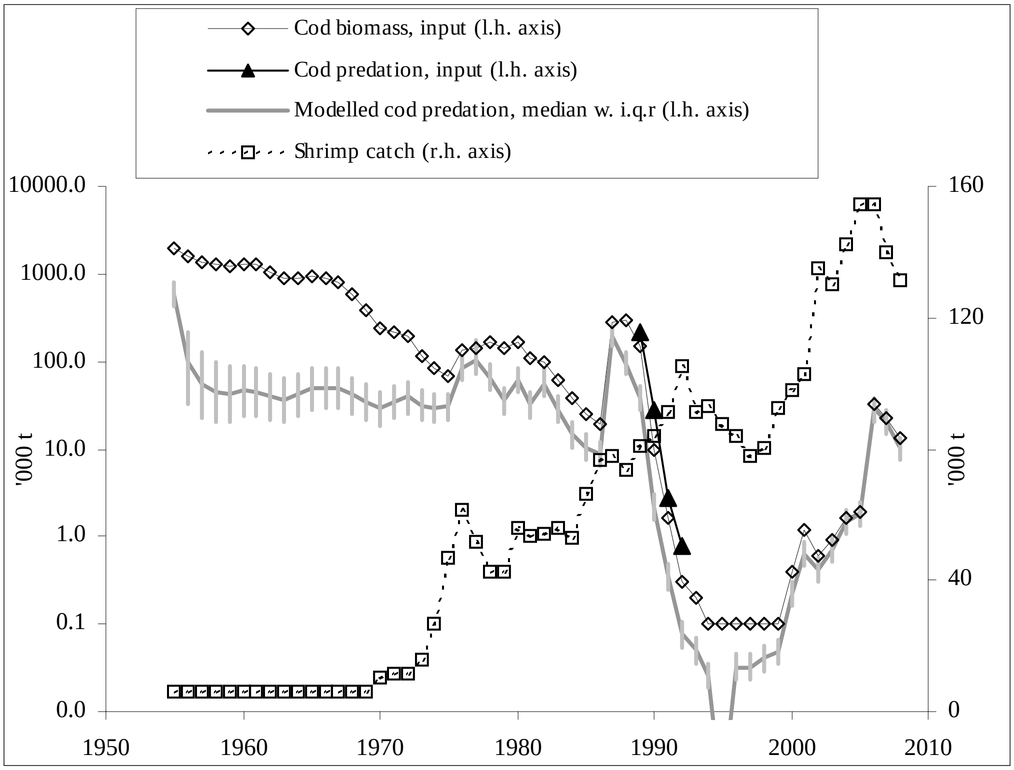


Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model, and cod predation estimated by the model.

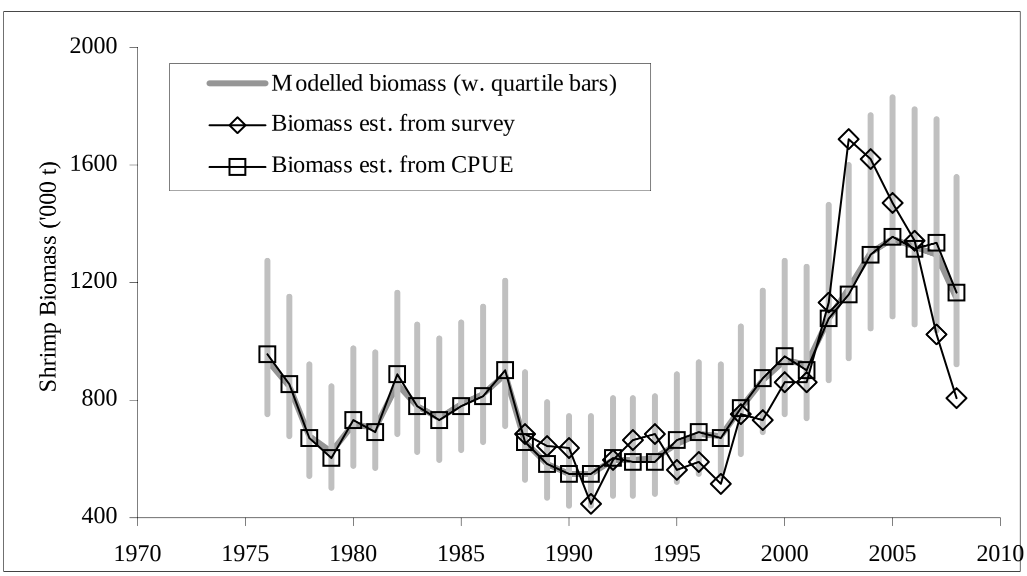


Fig. 2. Shrimp in West Greenland: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2008.

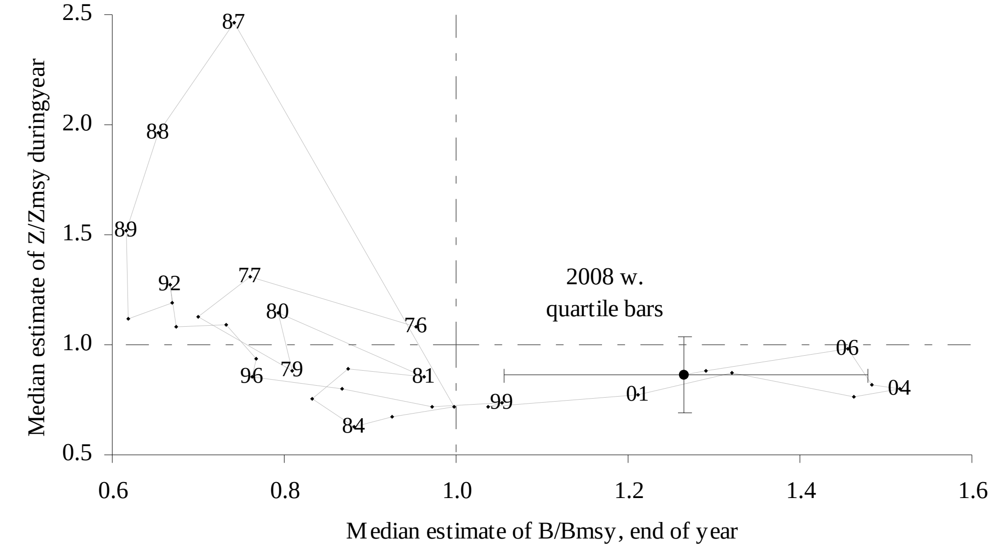


Fig. 3. Shrimp in West Greenland: median estimates of biomass-ratio (B/B_{MSY}) and mortality-ratio (Z/Z_{MSY}) 1976–2008.

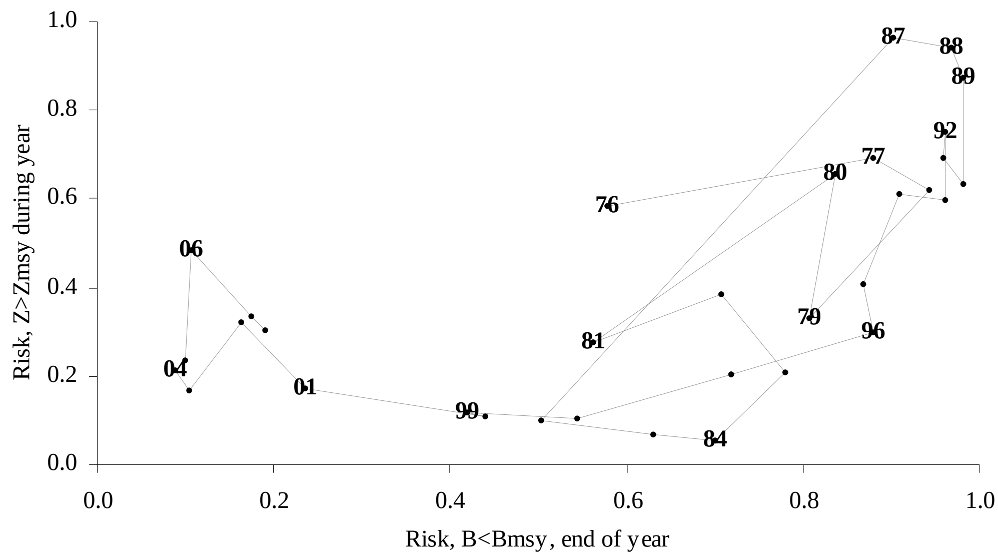


Fig. 4. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{MSY} and that mortality caused by fishing and cod predation has been above Z_{MSY} 1976–2008.

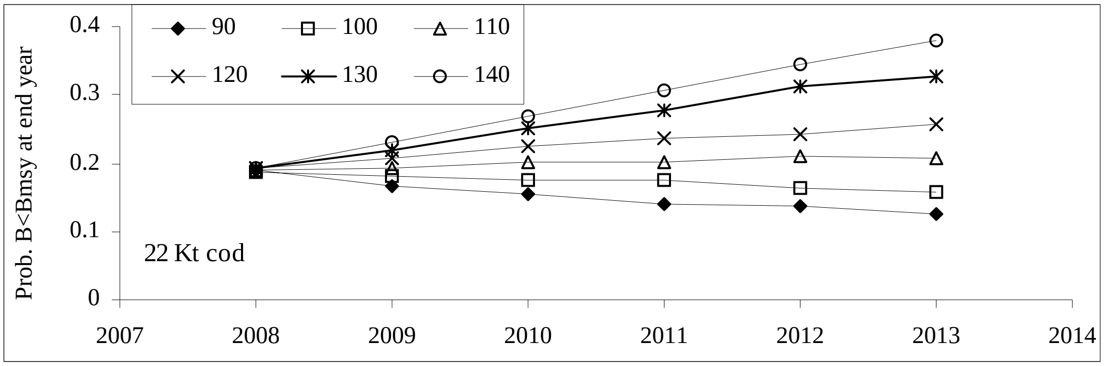


Fig. 6. Risk over 5 years of transgressing B_{msy} at catch levels 90–140 Kt/yr; 'effective' cod biomass 22 Kt

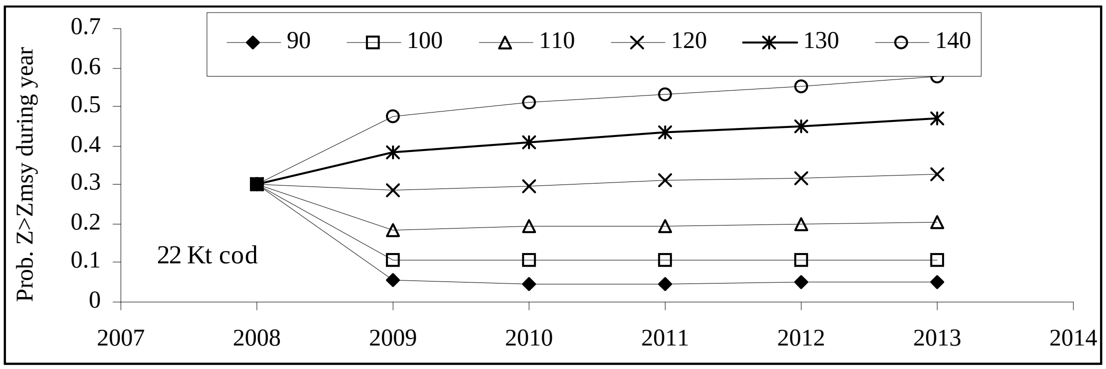
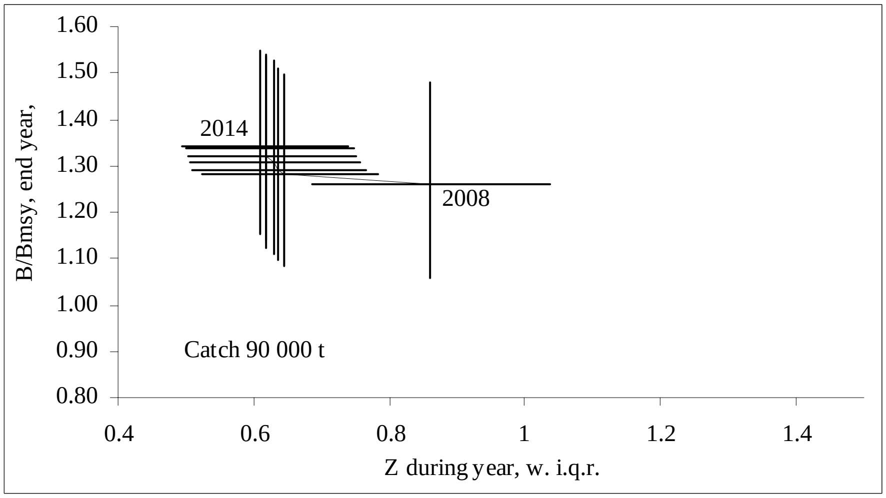
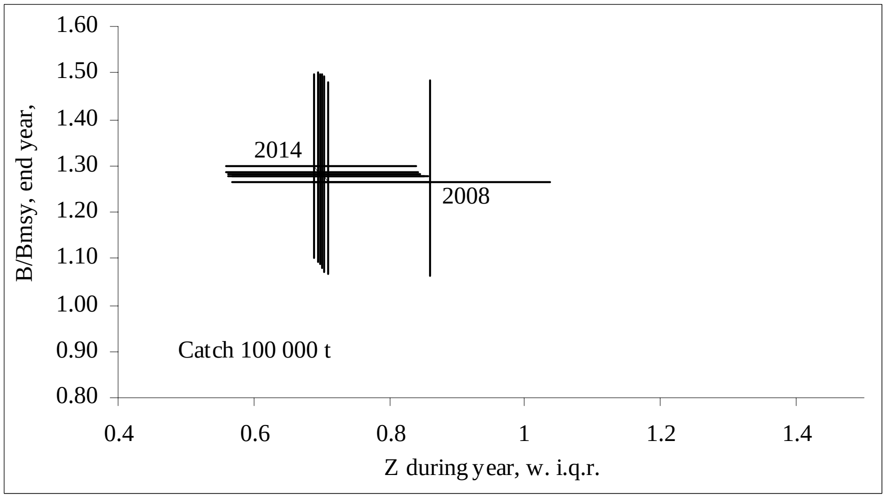
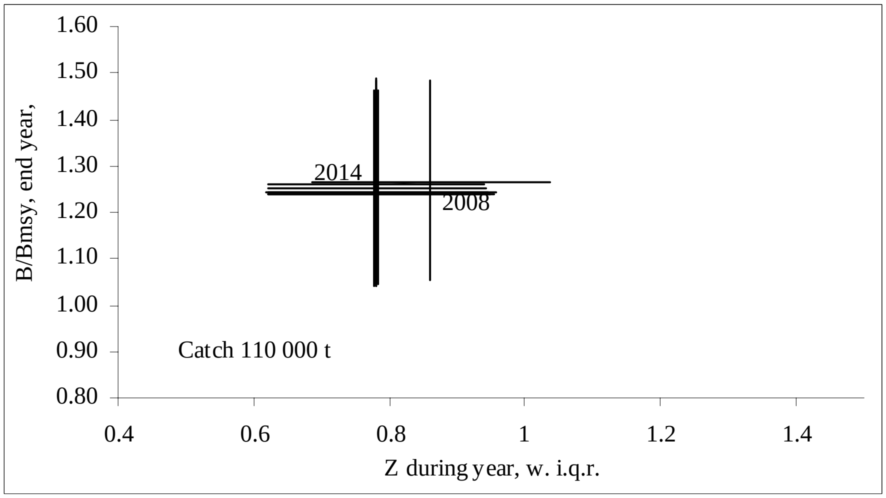


Fig. 7. Risk over 5 years of transgressing Z_{msy} at catch levels 90–140 Kt/yr; effective cod biomass 22 Kt.


1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
B/Bmsy, end year,
2014
2008
Catch 90 000 t
0.4
0.6
0.8
1
1.2
1.4
Z during year, w. i.q.r.


1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
B/Bmsy, end year,
2014
2008
Catch 100 000 t
0.4
0.6
0.8
1
1.2
1.4
Z during year, w. i.q.r.


1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
B/Bmsy, end year,
2014
2008
Catch 110 000 t
0.4
0.6
0.8
1
1.2
1.4
Z during year, w. i.q.r.

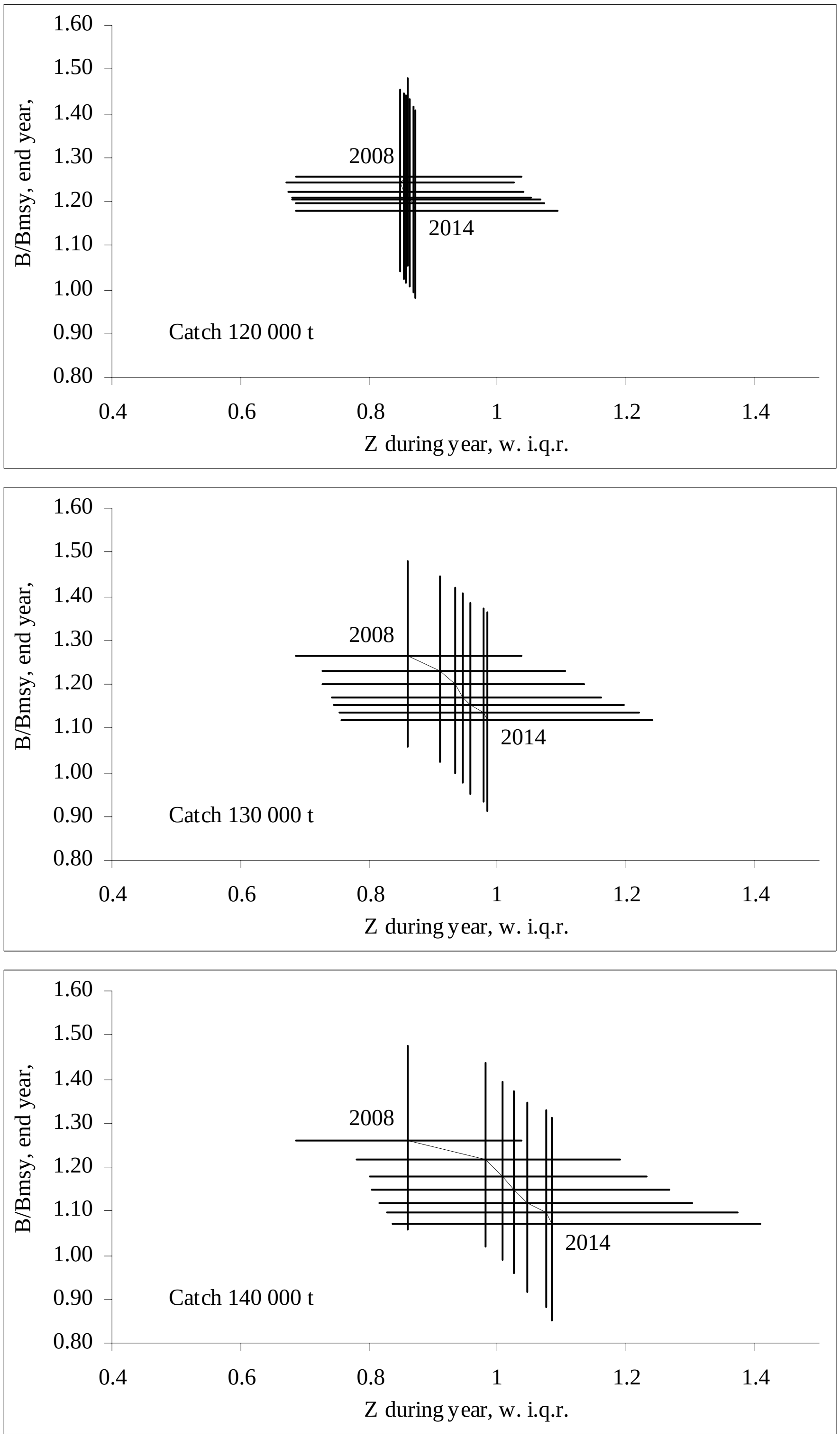


Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2009-2014 plotted as biomass ratio (B/B_{MSY})at end of year *vs* mortality ratio (Z/Z_{MSY}) during year. Estimated stock trajectories at 90–140 thousand tons fixed annual catch levels are shown as medians with quartile error bars.

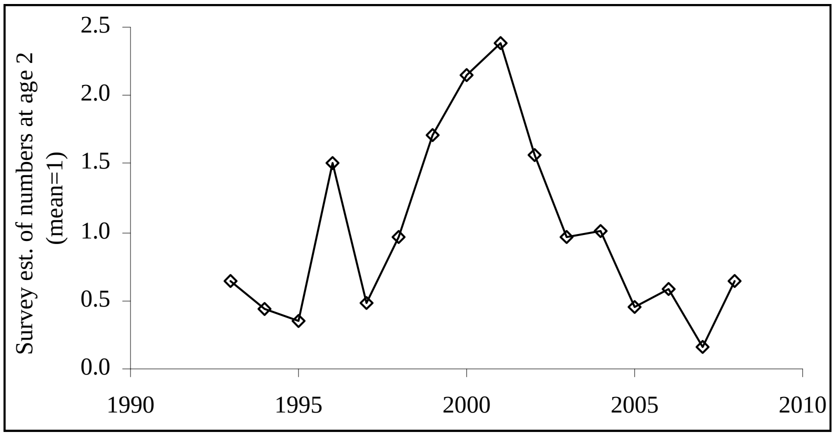


Fig. 9. Shrimp in Subareas 0 and 1: numbers at age 2 from research trawl survey, 1993–2008.

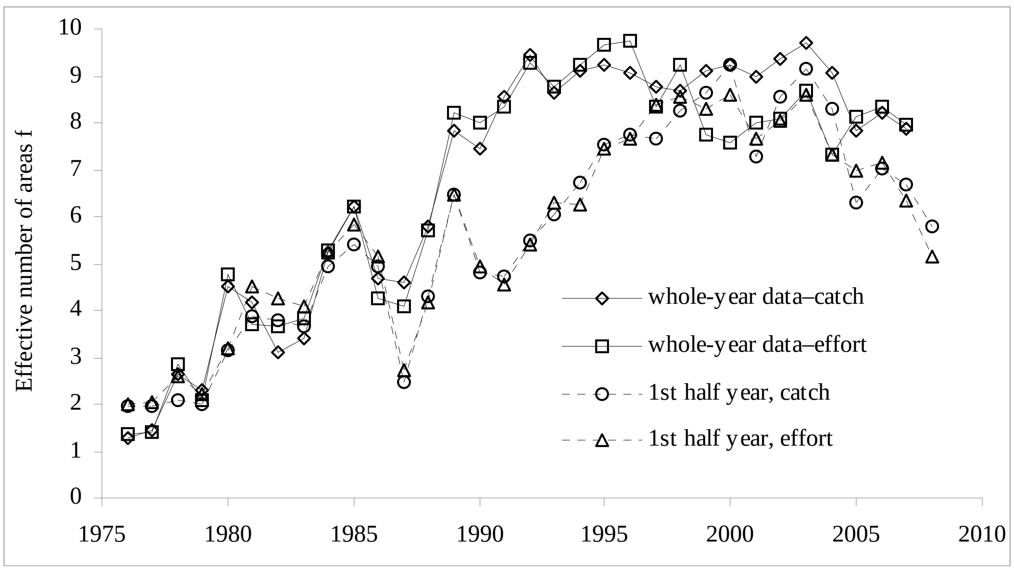


Fig. 10. Shrimp in Subareas 0 and 1: indices of distribution of the fishery from logbook records of catch and effort.