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A Provisional Assessment of the Shrimp Stock off West Greenland in 2010

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 CPUE 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 147 000 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.

The present assessment estimates the stock to have been in worse state at the end of 2009 than the projections made in that year's assessment, and projects a slight deterioration in stock status by the end of 2010.

Projections from the modelling showed that catches up to 125 000 tons/yr are not likely to drive the stock below B_{MSY} in the short term. However, the distribution of the fishery over 13 statistical areas contracted between 2003 and 2005, and the distribution of survey catches over 6 survey zones contracted from 2003 to 2007; neither has since increased.

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 (Canadian Shrimp Fishing Area (SFA) 1). 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 105 000 to 145 000 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—5 or 10 000 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.

Cod stocks in West Greenland continue to fluctuate, but at very low levels, and there are no signs of a maintained increase in the stock. The stock-dynamic model used in the assessment allows for flexible and comprehensive consideration of possible developments of the cod stock, but the uncertain evolution of the stock in recent years gives no direction for investigations of its future development.

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 23-year (1988–2010) 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 et al. 2010); 4 series of CPUE indices spanning, among them, 1976 through 2010 (Kingsley, 2008a; Hammeken Arboe and Kingsley, 2010b); and unified into a single series by a separate model (Hvingel and Kingsley, 2002); a 56-year series of catches by the fishery with corrections for past overpacking (Hvingel, 2004; Hammeken Arboe and Kingsley 2009b); a 56-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, 2010); 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).

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

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 2010b).

Catch data were updated from available sources, including logbooks, STATLANT 21A, and quota reports from Greenland and Canadian sources (Hammeken Arboe and Kingsley 2010a). 2010 catches for the Greenland fishery were projected from the first 6 months’ logbook catches and the average proportion caught in the first 6 months of previous years. However, in 2009 there had been more intense fishing in the second half of the year and the standard projection had been a serious underestimate (Hammeken Arboe and Kingsley 2010a). Industry observers told us that this pattern was likely to be repeated in 2010, so the standard projected catch was replaced by an estimate similar to that for 2009. Canadian catches had been zero in 2008 and were very small in 2009, but we were told that the Canadian fleet was once again fishing in SFA1 in 2010, and an estimate of 4500 t due to an industry observer was included in the total projected catch for 2010 (Hammeken Arboe and Kingsley 2010a). We assumed that the EU quota of 4000 tons would, as in other years, be fished out.

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 et al. 2010). 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:

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

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

The catch rate ($CPUE_{,t}$) and survey ($surv_t$) indices were scaled to 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 2010 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.

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, 2010b). 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 et al. 20010) 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); parameter estimates and their uncertainties are, overall, very similar to values estimated in the 2009 assessment. Most of the error CV parameters were slightly less than in 2009. The median estimate of the precision parameter for the research trawl survey index was equivalent to an error CV of about 20½%; 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 recent large excursions of the survey series, compared with a more orderly progression of the CPUE series, incline the model to assign it a large error variability. The precision parameter for the unified CPU series was about equivalent to an error CV of 3½% and the process variation was about 9%, 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 42%, and the CV estimate for the 4-year Grunwald predation series was 54%. 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 147 Kt. The model fit in the present year's assessment is slightly tighter than in the previous few years and the uncertainty in parameter estimates slightly 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 147 000 t is uncertain; the e.c.v. of the mean is 34% and the relative interquartile range 24%. The distribution of the estimate is highly skewed and the most likely value for the MSY is estimated at 129 000 t. This implies that all values between 147 000 and 129 000 t, as well as some values *less* than 129 000 t, are more likely than 147 000 t. The median estimate of stock size at start of 2010 was 18% above B_{msy}; this value had been projected at 28% above B_{msy} in the 2009 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 occasional slight increases in cod abundance have been noted in research trawl surveys in West Greenland, but have not been maintained. The present assessment estimates that cod consumed only about 1500 tons of shrimp in 2004; median estimates of predation increased to about 32 000 t and 21 000 t in 2006 and 2007 owing again to an increase in survey estimates of cod. But even after allowances for the different distributions of cod and shrimp, cod has become less abundant 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 1.4 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, if accompanied by significant predation are forecast to bring biomass ratio down (Fig. 4). The median estimate of the Z-ratio for 2010, with catches projected at 138 500 tons, is 0.92, with a 37% risk that it exceeds 1.

The present assessment estimates the stock to be in a worse state than the 2009 assessment did. The 2009 assessment projected that relative biomass (B/B_{msy}) at the end of that year would be 128%; in 2010 we estimate that it was only 117%. In 2009 we projected that year's removals at 65% of Z_{msy}, but in 2010 we estimate 84%[3]. The principal reason is that catches in 2009 were 26 000 tons higher than our projection[4], but the modelled stock trajectory also reflects a small increase in the effective cod stock and projected catches for 2010 that are higher again than the recorded catches in 2009. The present assessment does not expect a big deterioration in stock status to end 2010 (1.16, 0.92) from where we now estimate that it was at the end of 2009 (1.17, 0.84).

The stock is now estimated above B_{msy}, and the risk that it will fall below this level within the next year is not high. Risks[5] associated with five possible catch levels for 2011, with an 'effective' cod stock at 5 000 tons, are estimated to be:

5 000 t cod	Catch option ('000 tons)				
Risk of:	105	115	125	135	145
falling below B_{msy} end 2011 (%)	26.6	27.8	28.4	30.2	31.4
falling below B_{lim} end 2011 (%)	0.3	0.3	0.3	0.4	0.4
exceeding Z_{msy} during 200101(%)	7.6	15.1	24.8	35.2	46.4

[3] this *drastically* changed perception does not extend further back in time. In 2009 we estimated removals in 2008 at 85% of Z_{msy} and year-end relative biomass at 127%; in 2010 these estimates for 2008 are 88% and 122%.
[4] not an isolated occurrence. In six years 2004–2009 projected catches for the current year were underestimates by 4.5–26.1 Kt, averaging 14.4 Kt.
[5] 'risk' in this document includes all three of uncertainty of knowledge, uncertainty of prediction, and uncertainty of outcome.

and with an 'effective' cod stock at 10 000 t:

10 000 t cod	Catch option ('000 tons)				
Risk of:	105	115	125	135	145
falling below B_{msy} end 2011 (%)	27.4	28.2	29.5	31.2	31.7
falling below B_{lim} end 2011 (%)	0.3	0.3	0.3	0.3	0.3
exceeding Z_{msy} during 200101(%)	10.2	18.7	29.2	40.1	50.2

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 would significantly increase shrimp mortality could be established in two ways: either by a slow rebuilding process or by immigration of one or two large year-classes from areas around Iceland, as in the late 1980s. The question of cod predation is bedevilled by the difficulty of foreseeing the evolution of the stock and 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.

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: 105 000, 115 000, 125 000, 135 000 and 145 000 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 over 13 statistical areas started to decrease, but they appear stable over the most recent years (Fig. 11).

Survey indices, based on six survey zones, show that the stock continued to contract until 2007 (Fig. 11; Ziemer et al. 2010). The most recent survey result estimates a fishable biomass that is at 59% of its 2003 peak and 13% over the series mean (Table 1).

The present assessment based on the existing modelling approach estimates a stock still slightly over B_{msy}, although reduced by several years of large catches, and large carrying capacity. CPUE remains relatively high, even after the high catches of the past decade, but now seems to be decreasing. The fishery is 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[6]. The contraction of the fishery between 2003 and 2005 does not seem to have continued. 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. It might therefore under present conditions be overly sanguine in its evaluation of stock status.

The number of small shrimps in the stock, estimated by the trawl survey, peaked in 2001 and then apparently decreased continually until 2007. It has since apparently stayed below the series mean.

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.

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[6] The indices used are based on a coarse division of the grounds into 13 statistical areas and could conceal wider distribution or more diligent searching at finer scales.

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. Shrimp in Subareas 0 and 1: Input data series for stock-dynamic assessment model.

	Effective cod biomass[7]	Catch	Survey index of fishable biomass	Predation estimate[8]	Cod-stock estimate[9]	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				1.458
1977	144.5	51.6				1.393
1978	170.3	42.3				1.119
1979	145.6	42.8				1.018
1980	163.4	55.9				1.212
1981	110.4	53.8				1.147
1982	98.8	54.3				1.446
1983	61.7	56.2				1.282
1984	37.8	52.8				1.21
1985	25	66.2				1.297
1986	19.6	76.9				1.342
1987	282.1	77.9				1.613
1988	297.3	73.6	223.2			1.175
1989	149.1	80.7	209.0	213.7	470.9	1.028
1990	12.2	84.0	207.0	27.8	184.1	1
1991	2.1	91.5	146.0	2.7	19.8	0.9805
1992	0.4	105.5	194.2	0.8	2.9	1.076
1993	0.3	91.0	216.5			1.058
1994	0.1	92.8	223.1			1.054
1995	0	87.4	183.2			1.19
1996	0.1	84.1	192.1			1.238
1997	0.1	78.1	167.1			1.203

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

[8] Grunwald (1998).

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

	Effective cod biomass[7]	Catch	Survey index of fishable biomass	Predation estimate[8]	Cod-stock estimate[9]	CPUE
1998	0	80.5	244.3			1.39
1999	0.1	92.2	237.3			1.567
2000	0.4	98.0	280.3			1.687
2001	1.2	102.9	280.5			1.613
2002	0.7	135.2	369.5			1.926
2003	1	130.2	548.3			2.061
2004	1.7	149.3	528.3			2.307
2005	2	156.9	479.5			2.406
2006	35.7	157.3	437.5			2.332
2007	24	144.2	334.1			2.361
2008	6.4	152.7	262.4			2.426
2009	2.4	135.3	255.5			2.086
2010	4.4	138.5	321.1			1.965

Table 2. Shrimp in Subareas 0 and 1: Summary of estimates of selected parameters from Bayesian fitting of a surplus-production model.

	Mean	S.D.	25%	Median	75%	Est. mode	Median (2009)
Max. sustainable yield	157	47	132	147	167	128	148
B/Bmsy, end current year (proj.)	1.17	0.33	0.97	1.16	1.37	1.13	1.28
Z/Zmsy, current year (proj.)	0.92	0.29	0.75	0.92	1.09	0.91	0.65
Carrying capacity	2785.5	2404.5	1675.5	2122.5	2939.5	796.5	1922
Max. sustainable yield ratio (%)	13.8	4.4	10.8	13.9	16.7	14.1	15.5
Survey catchability (%)	29.2	13.2	19.9	28.0	37.5	25.5	30.9
CPUE catchability	1.7	0.8	1.1	1.6	2.2	1.5	1.8
$P_{50\%}$	4.8	3.1	2.9	4.1	5.8	2.9	4.5
O_{max}	3.0	0.3	2.8	3.0	3.2	3.0	3
CV of process (%)	8.9	2.0	7.5	8.9	10.2	8.9	9.4
CV of survey fit (%)	20.8	3.4	18.4	20.5	22.8	19.8	21.2
CV of CPUE fit (%)	3.8	1.5	2.7	3.6	4.7	3.2	3.6
CV of predation fit (%)	44.5	32.4	16.8	42.2	63.4	37.5	44.4
Start biomass ratio	0.92	0.19	0.78	0.90	1.03	0.87	0.89

Table 3. Shrimp in Subareas 0 and 1: Selected[1] correlations (%) between model parameters.

	Start biom .ratio	*CV pred*	*CV s*	*CV cpu*	*CV proc*	*Omax*	*P50%*	*Qc*	*Qs*	*MSY ratio*	*K*
Max.sustainable yield	8.1	22.0					-17.1	-27.8	-27.7	-26.9	61.1
Carrying capacity	12.0	5.9	6.0		16.6			-51.5	-51.2	-63.0	
Max. sustainable yield ratio %	-16.9		-9.2		-27.7		-23.5	83.1	82.7		
Survey catchability (%)	-15.7	5.4			-35.5		-41.0	99.4			
CPUE catchability	-15.9	5.5			-35.8		-41.3				
$P_{50\%}$	7.6				29.4	17.3					
O_{max}											
CV of process (%)		-38.0	-27.1								
CV of survey fit (%)			-10.4								
CV of CPUE fit (%)											
CV of predation fit (%)	8.3										

[1] those over 5%

Table 4. Shrimp in Subareas 0 and 1: Risks (%) of exceeding limit mortality in 2015 and of falling below B_{msy} or limit* biomass at the end of 2015

Catch (Kt/yr)	Prob. biomass < B_{MSY} (%)		Prob. biomass< B_{lim} (%)		Prob. mort > Z_{msy} (%)	
	5 Kt	10 Kt	5 Kt	10 Kt	5 Kt	10 Kt
105	17.9	19.8	0.2	0.2	5.6	7.8
115	22.3	24.4	0.2	0.3	13.1	17.4
125	27.7	30.5	0.3	0.3	24.6	29.7
135	33.7	36.8	0.4	0.3	38.1	44.1
145	39.9	41.9	0.5	0.6	50.5	55.9

* limit biomass is 30% of B_{msy}

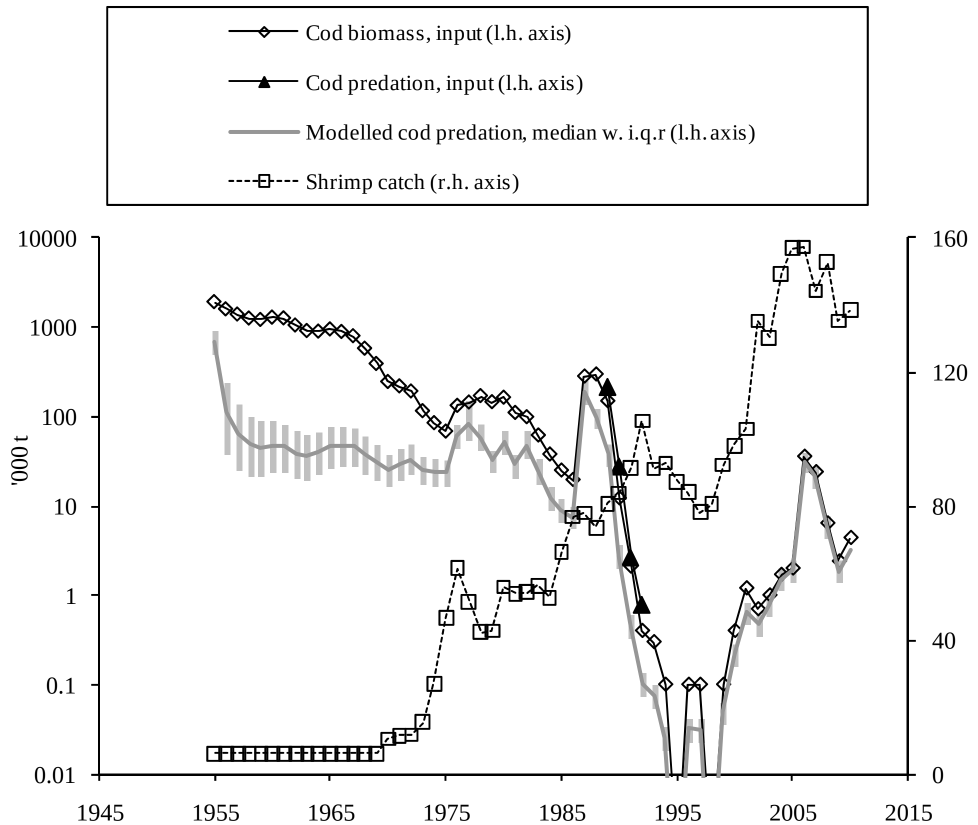

Fig. 1. Shrimp in Subareas 0 and 1: data series providing information for the assessment model, and cod predation estimated by the model.

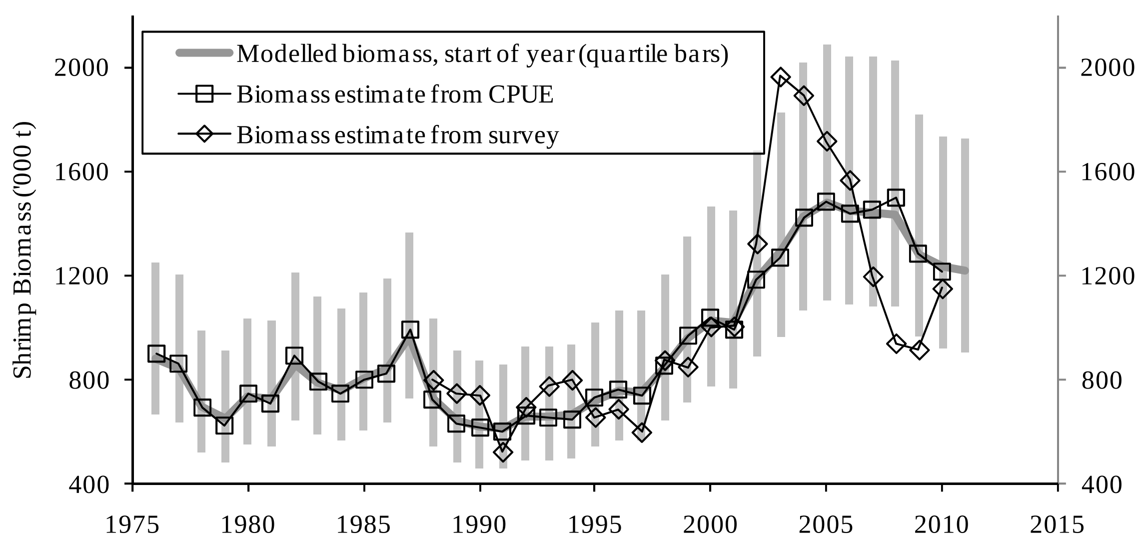

Fig. 2. Shrimp in Subareas 0 and 1: modelled shrimp standing stock fitted to survey and CPUE indices, 1976–2010.

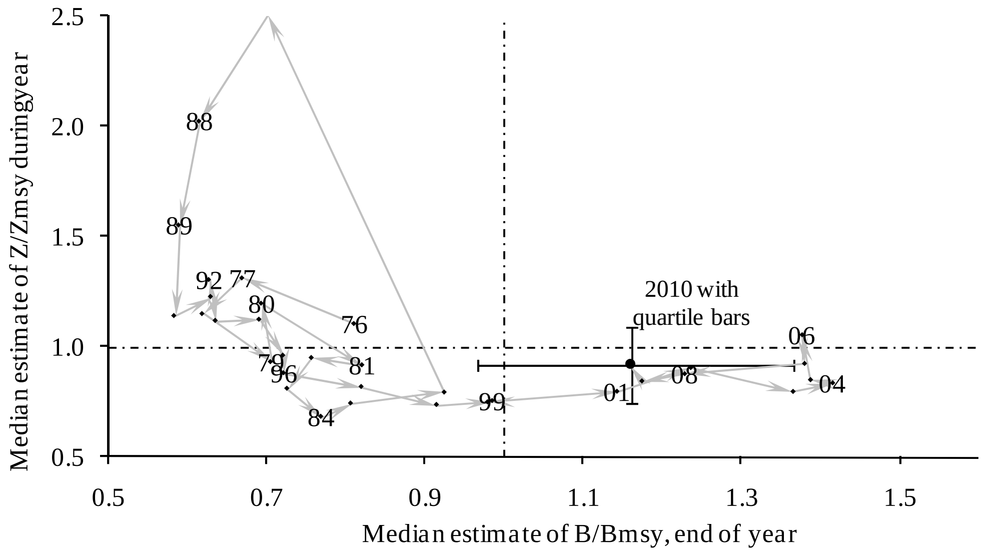

Fig. 3. Shrimp in Subareas 0 and 1: median estimates of biomass-ratio (B/B_{msy}) and mortality-ratio (Z/Z_{msy}) 1976–2010.

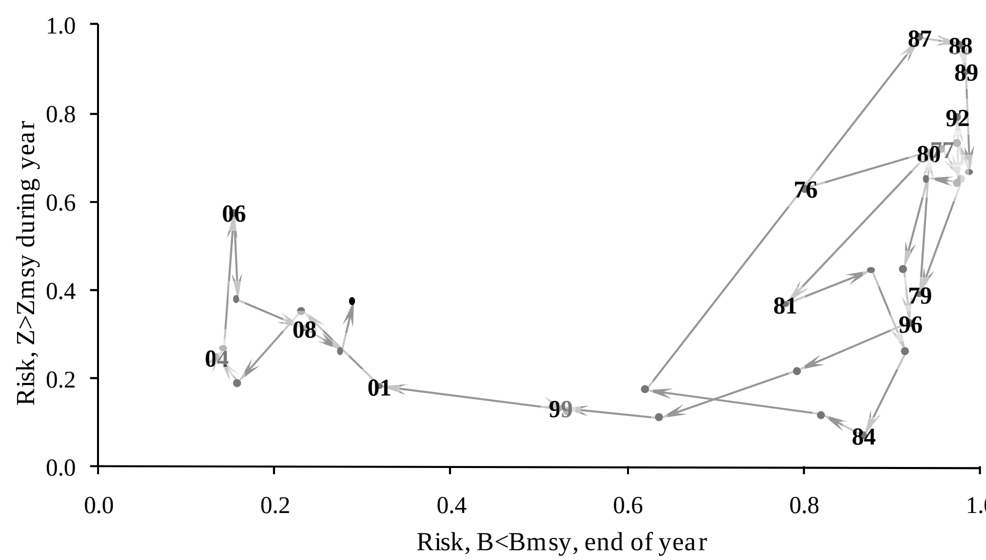

Fig. 4. Shrimp in Subareas 0 and 1: annual likelihood that biomass has been below B_{msy} and that mortality caused by fishing and cod predation has been above Z_{msy} 1976–2010.

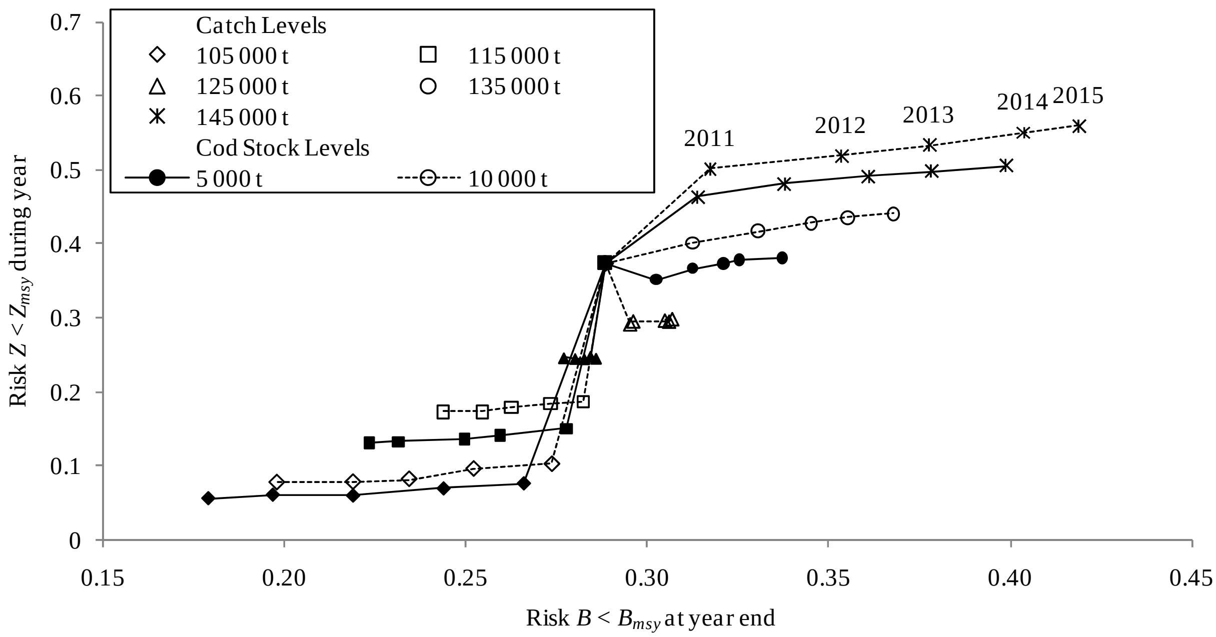

Fig. 6. Shrimp in Subareas 0 and 1: Joint 5-year plot of the risks of transgressing B_{msy} and Z_{msy} at catch levels 105–145 Kt/yr; with effective cod biomass 5 or 10 Kt

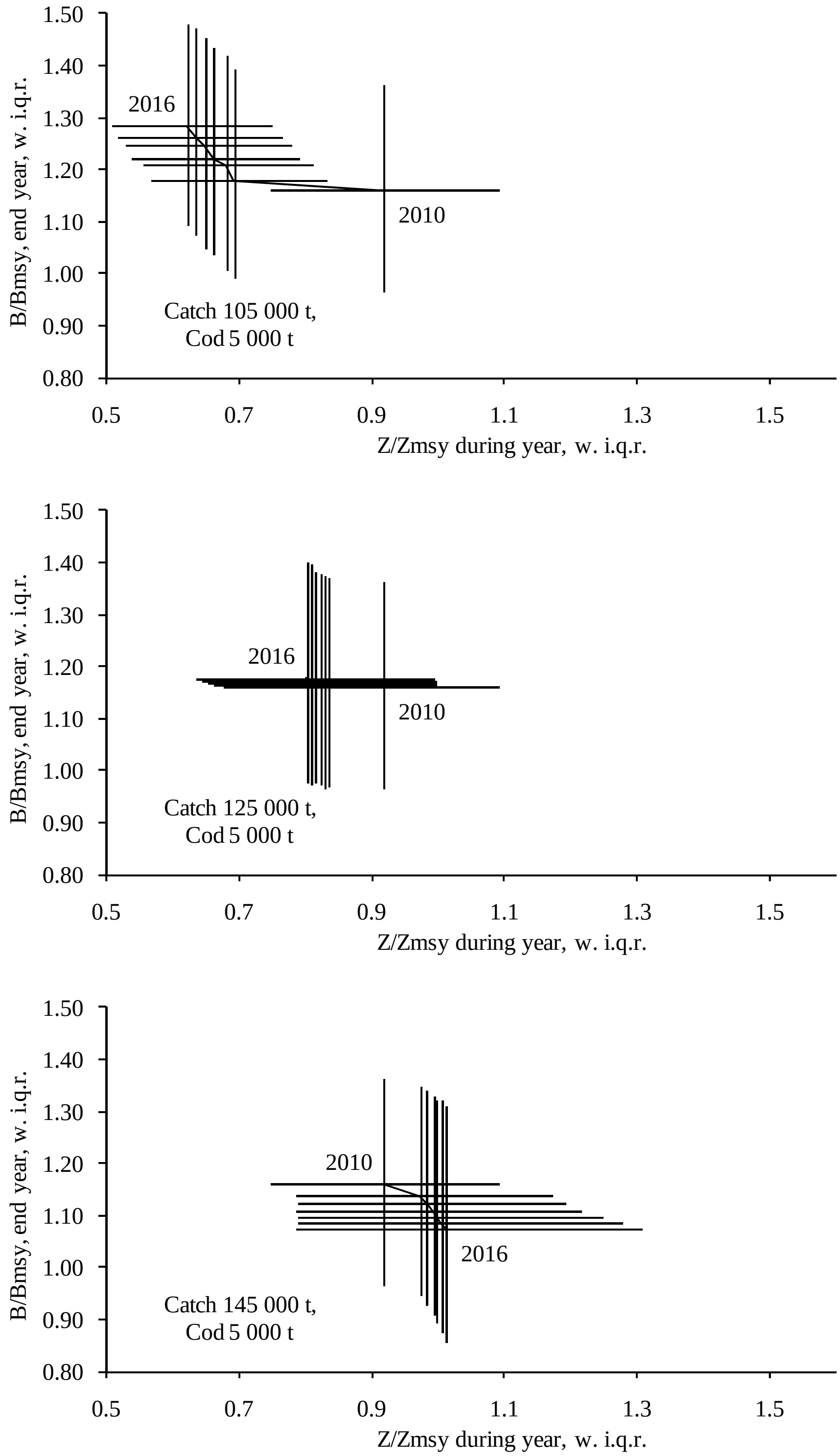

Fig. 7. Shrimp in Subareas 0 and 1: projections of stock development for the period 2010–2016 with effective cod biomass assumed at 5 000 t: median estimates with quartile error bars.

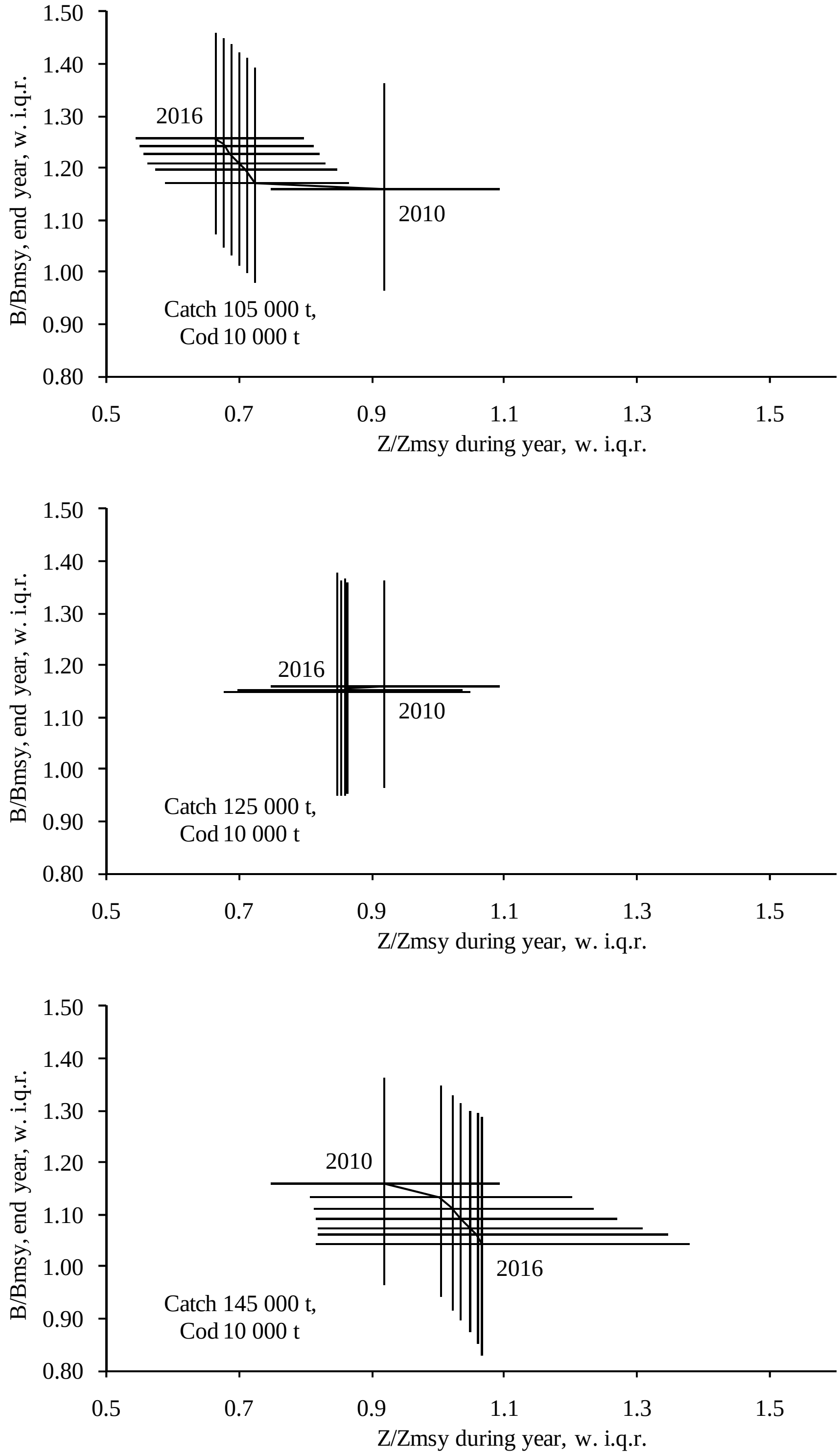

Fig. 8. Shrimp in Subareas 0 and 1: projections of stock development for the period 2010-2016 with effective cod biomass assumed at 10 000 t: median estimates with quartile error bars.

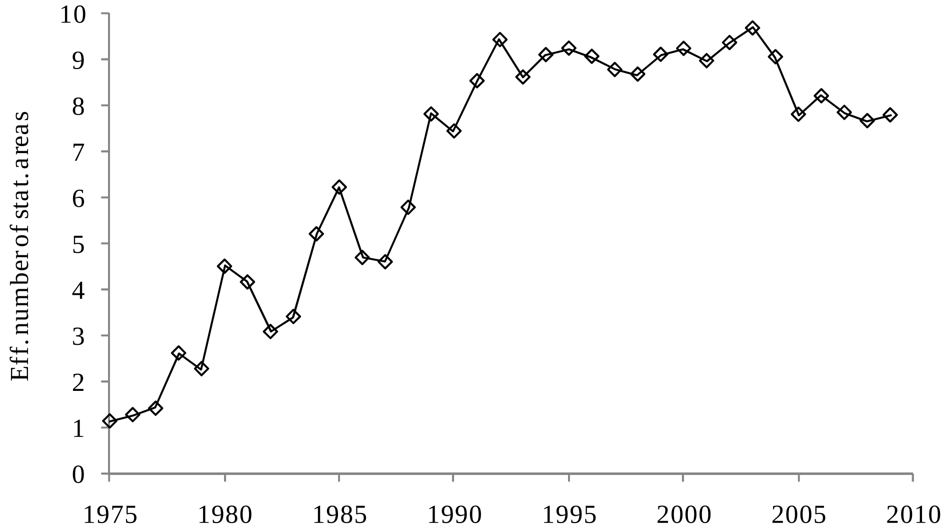

Fig. 9. Shrimp in Subareas 0 and 1: an index of distribution of the Greenland fishery, based on statistical areas, from logbook records 1975–2009.

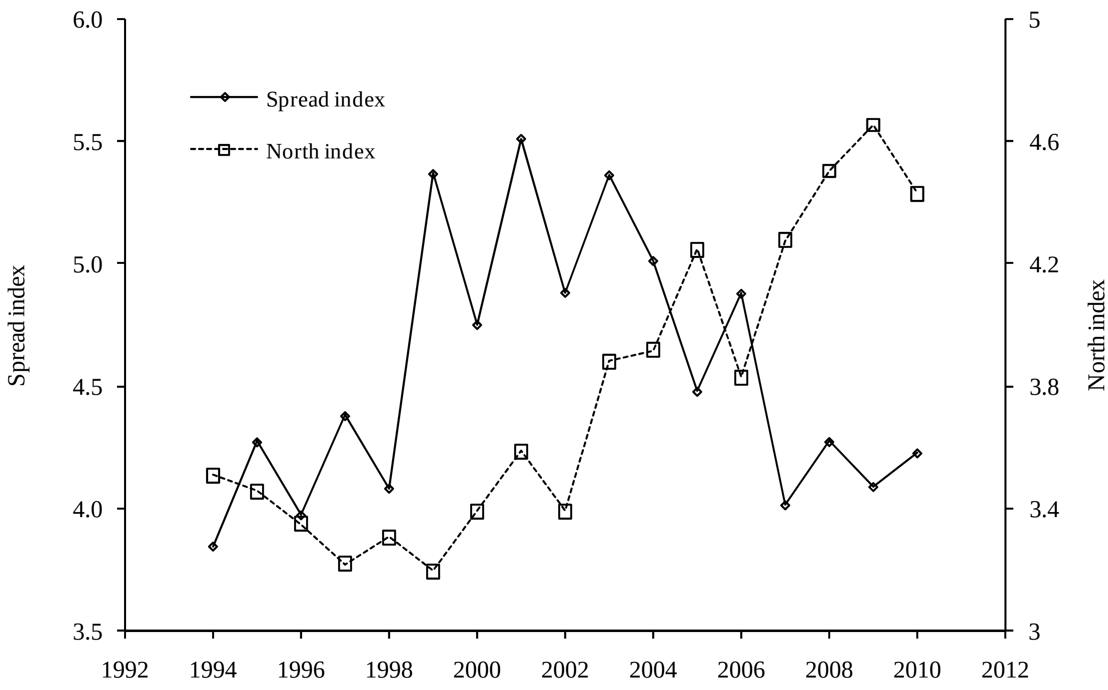

Fig. 11. Shrimp in Subareas 0 and 1: indices of distribution of the survey biomass, 1994–2010.