NOT TO CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

Serial No. N5189 **NAFO SCR Doc. 05/84**

SCIENTIFIC COUNCIL MEETING – OCTOBER/NOVEMBER 2005

Deriving Quantitative Biological Advice for the Shrimp Fishery in Skagerrak and Norwegian Deep (ICES Divisions IVa east and IIIa)

by

C. Hvingel

Institute of Marine Research
Box 6404, N-9294 Tromsø, Norway

Abstract

A previously used method for assessing the shrimp resource in Skagerrak and Norwegian Deep was investigated. The biomass dynamic model used to describe stock variability lack feedback mechanisms and may in some instances be unstable. Available data series of stock size, recruitment, predation and catch used for fitting the model were found not to be informative.

A model based on these data cannot estimate management parameters such as Maximum Sustainable Yield and fishing mortality and thus its predictive capability is low.

The data did, however, indicate a long period of stable stock size in a stable environment of catch and predation. This information is used to estimate the relative location of the stock on a logistic stock-production curve. The risk that the stock had been overexploited (catches above *MSY* and stock below the optimal biomass level, B_{MSY}) or below the stock biomass limit reference point, B_{lim}, was by use of Bayesian inference quantified to be low, less than 9% for the period 1990-2005.

The stock may likely sustain larger catches than the current level of around 13 000 tons given that the environmental settings remain stable. However, increases in the exploitation level should be carefully planned and designed to provide more information to help estimate the productive capability of the stock. Management should be ready to respond to new information e.g. by reducing catches. This approach could be founded in a multi-annual adaptive management plan.

Introduction

The stock has previously been assessed by Virtual Population Analysis (VPA) (Megrey, 1989) by applying standard ICES software packets to the age distributions of the catches. Ageing was done by modal analyses of their estimated length distributions. Commercial catch rates or abundance indices from the Norwegian survey (Hvingel, 2005a) was used for tuning. However, this method performed poorly and was therefore replaced by a biomass dynamic model in 2001 (Anon., 2004a).

This model relied on data from the survey. The survey series was, however, discontinued after 2002 (Hvingel, 2005a) and the model was therefore not updated in 2003 and 2004 and stock projections were not made. Furthermore, the assessment working group did not seem satisfied with the model (Anon., 2004): “the Working Group has taken notice of the problems and criticism of the simple SPP model used” and provides in the report a 4-bulletpoint list of disadvantages. However, the criticism is imprecise and leaves some confusion in where exactly the shoe pinches.

The purpose of this paper is to investigate the suitability of the biomass dynamic model hitherto used in this assessment and to derive quantitative statements of stock status in the context of the Precautionary Approach.

Investigating the assessment model currently used

The model currently used is a process equation describing the hypotheses of how the stock varies, and a data link function giving the hypotheses of how the data relate to the process equation:

$$\begin{aligned} &\text{Process:} \quad B_{t+1} = \alpha B_t - C_t + \beta R_t - \delta D_t \\ &\text{Data link:} \quad U_t = qB_t + \varepsilon_t \end{aligned} \qquad \text{(eq. 1)}$$

where the subscript t indexes year, B is shrimp biomass, C is catch, R is observed recruitment, D is observed biomass of predators, and U is an observed index of shrimp biomass from the Norwegian survey (Hvingel 2005a). α, β, δ and q are model parameters to be estimated along with initial biomass B_0, and ϵ_t, an error term Normally, independently and identically distributed with mean 0 and variance σ_ε^2. A similar model has been used for assessing shrimp in offshore Icelandic waters (Stefánsson et al. 1994)

Model behaviour and its predictive properties may not be optimal for the assessment for several reasons. In the model predation rate, δ, is independent of prey biomass, while stock biomass, B, has no limits. With no feedback based on biomass, the model risks being unstable: for example, if the biomass went below some critical threshold, unremitting predation could quickly drive it to extinction, or if it went above a critical upper limit, predation and catch could become insignificant and the stock run off to infinity. Stochastic behaviour is not included, but if it was, it would likely make the model even more unstable (Hvingel, 2005b).

However, a bigger problem for the assessment might be the level of information regarding stock dynamics contained in the data series. The variability of the two explicit components of mortality, catch and predation, have been low in the time series (Fig. 1A and 1C) – and without trend. The CVs (standard error/mean) of the annual values are 10% for the catches and 20% for the index of predator biomass, which is at or even lower than the within-year variation typically estimated for such data.

The recruitment series (Fig. 1D) supposedly being a main determinant of future stock size do have periods with trend as do the survey biomass indices (Fig. 1B), and some correlation between these two variables is noticeable. Part of this is likely a year-effect of the survey, but neither this correlation (Fig. 2A) nor the one between recruitment and the stock in the following year (Fig. 2.B) is significant (P >0.17). However, a correlation between the recruitment and survey biomass two years later (Fig. 2C) was (P <0.01).

As expected the catches could not be found to correlate with either the biomass of recruits or the 2+ group (Fig. 3A and 3B). The Biomass of predators did not correlate with recruitment (Fig. 4A and 4B), but showed a positive correlation with the biomass of the 2+ group in the same year (P <0.05) (Fig. 4C). Again some year effect of the survey might be to blame. With a one year lag (Fig.4D) the correlation is still positive but not significant (P =0.12).

Finally the variables were analysed together using a General Linear Model (GLM) of the form:

$$B_t = u + B_{t-1} + C_{t-1} + R_{t-1} + D_{t-1} + e \qquad \text{(eq. 2)}$$

where B is the index of biomass of age group 2+, u is the intercept, C is the landings (C_{t-1} is 0.25*landings in year t-1 + 0.75*landings in year t because the survey is conducted in the autumn), R is recruitment (biomass index of age 0 and 1), D is the index of predator biomass taken as a sum of the estimated survey biomass of 20 different fish species, e is an error term and t indexes year. Input data series were based on Anon., 2004. Neither the individual main effects or their interactions nor the model were significant:

The GLM Procedure. Dependent variable: B_t

Source	DF	SS	MS	F Value	Pr > F
Model	4	0.61293030	0.15323257	1.17	0.3698
Error	13	1.70678162	0.13129089		
Corrected Total	17	2.31971192			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
B_{t-1}	1	0.00066142	0.00066142	0.01	0.9445
C_{t-1}	1	0.18905529	0.18905529	1.44	0.2516
D_{t-1}	1	0.10855779	0.10855779	0.83	0.3797
R_{t-1}	1	0.03947770	0.03947770	0.30	0.5927

Parameter	Estimate	SE	t Value	Pr > |t|
Intercept	-.7528493398	0.91479585	-0.82	0.4254
B_{t-1}	0.0226627544	0.31929325	0.07	0.9445
C_{t-1}	0.0000828340	0.00006903	1.20	0.2516
D_{t-1}	0.5387551394	0.59248620	0.91	0.3797
R_{t-1}	0.1286604984	0.23463166	0.55	0.5927

In conclusion: the hypothesis of how the stock varies as represented by the assessment model (eq. 1) lacks biological realism and might in some instances be unstable. The perturbation history of the stock is badly suited for extracting information on how the fishery and predation affect the stock. Neither of the explanatory variables used in the model correlate with the stock biomass in the following year. Thus the model cannot be used to make predictions.

For extracting information on exploitation level (fishing mortality) the model relies on the ability to estimate absolute biomass. As there is no information on absolute consumption by predators the stock size can be scaled only by the catch series. As this series has low variability and no correlation with stock size absolute stock biomass cannot be estimated.

An alternative model

The stock has since the mid 1980s experienced a relatively stable environment of predation and exploitation (Fig. 1A and 1C) and have itself remained relatively stable (Fig. 1B). This indicates that the stock can sustain the current level of exploitation. With such information in the data it is with a few assumptions still possible to quantify the risks of the stock being overexploited (catches above *MSY* and stock below B_{MSY} (biomass that gives *MSY*)) or outside safe limits (=below B_{lim}, a limit reference point for stock biomass).

Assume that the production curve of the stock is dome shaped, e.g. population growth follows a logistic curve and the biomass series therefore can be described by:

$$\text{Process:} \quad B_{t+1} = B_t + rB_t(1-\frac{B_t}{K}) - C_t \qquad \text{(eq. 3)}$$

$$\text{Data links:} \quad U_t = qB_t$$

where r is intrinsic rate of growth (per year), K is carrying capacity; otherwise notation as before. The logistic model deviates from model used previously (eq. 1) in also including a function of density-dependent population growth – and thus adds some biological realism and stability to the model. Predation, although an important source of mortality for shrimp (Hvingel, 2005b and references therein), was not included as an explicit variable because the predation indices do not vary much (see previous section).

As the uncertainty of absolute stock size is huge biomass is dealt with on a relative scale to cancel out the uncertainty in q (Hvingel and Kingsley, 2005). Relative biomass $P_t = B_t/B_{MSY}$, this implies that $K = 2$ and $P_{MSY} = 1$. Observation and process error was implemented simultaneously using a state space framework:

$$\text{Process:} \quad P_{t+1} = \left(P_t - \frac{C_t}{B_{MSY}} + rP_t\left(1-\frac{P_t}{2}\right)\right)\cdot \exp(\nu_t) \qquad \text{(eq. 4)}$$

$$\text{Data links:} \quad U_t = qB_t \exp(\beta_t)$$

The 'process errors', v, and observation errors, β, are normally, independently and identically distributed with mean 0 and variance σ_v^2 and σ_β^2. Bayesian inference was used to estimate probability distributions of model parameters following the approach of Hvingel and Kingsley (2005). Similar models have been applied to the shrimp fisheries off West Greenland (Hvingel and Kingsley, 2005; Hvingel, 2004; Anon., 2004b).

Low-information or reference priors were given to MSY, q, K, P_1 and σ_v as there was little or no information on what their probability distributions might look like. MSY was given a generously wide uniform prior between 0 and 150 000 tons. The catchability q were given a distribution uniform on a log scale as a reference prior (Hvingel and Kingsley, 2005). A similar distribution was used for K between 1 and 665 000 tons (The upper limit corresponds to about 11g or about 5-10 shrimp per m^2 over the survey area of 57 300 km^2 which by shrimp experts is considered to be high). The prior for the stock size in the first year, P_1, was uniform 0 to 2. The prior distributions for the error terms associated with the biomass indices were assigned inverse gamma distributions (the gamma distribution, G(r,μ), is defined by: $\mu^r x^{r-1} e^{-\mu x}/\Gamma(r)$; x>0). Estimates of the variance of survey biomass estimates 1984—2002 was not available. CVs of the 2004-2005 survey values were 30% (Hvingel, 2005a) but are probably over-estimated due to the fixed station design. Observation error was therefore given an inverse gamma distribution with a mode at 0.2, comparable to the CVs found in the Greenlandic shrimp survey (Wieland *et al*., 2004).

Results

As expected absolute scale of stock biomass and production (Fig. 5) could not be determined with any precision. However, the model is quite certain that the stock has been larger than B_{msy} (P = 1) and indeed above the limit reference of P = 0.3 (The limit reference point for stock size, B_{lim}, for a logistic production curve is 30% B_{msy} (Shelton, 2004)) (Fig. 6). The uncertainty of the relative stock size are big for all years but increases after 2002 as these values are model predictions due to missing survey data (Fig. 6).

The risk of the stock being below B_{msy} is between 1.5 and 8.2% and and even smaller, 0.1–2.2% for being below B_{lim} for the period 1990–2005. The risk of the fishing mortality being above F_{lim} was not estimated due to the inability to estimate the full distribution of MSY, however, an index of harvest rate (landings/estimated median biomass) (Fig. 7) has shown a declining trend since the late 1980s. The risk table are as follows:

Year	p(B<Bmsy)	p(B<Blim)	p(F>Flim)	p(C>MSY)
1990	8.2%	0.2%	Declining trend ↓	1.6%
1991	5.4%	0.1%		2.4%
1992	4.1%	0.1%		2.5%
1993	3.7%	0.1%		1.7%
1994	3.4%	0.1%		2.4%
1995	3.0%	0.1%		3.2%
1996	2.4%	0.1%		4.6%
1997	2.0%	0.1%		4.8%
1998	2.2%	0.1%		2.0%
1999	2.1%	0.1%		1.3%
2000	2.2%	0.1%		1.4%
2001	1.7%	0.1%		1.7%
2002	1.5%	0.1%		2.3%
2003	6.4%	1.0%		2.2%
2004	5.1%	1.2%		2.2%
2005	7.7%	2.2%		1.6%

Estimated series of median stock size relative to the reference points are shown in Fig. 9.

As the productive potential of the stock remains unknown an evaluation of different future catch options could not be made.

Discussion

The choice of upper limits of the priors for *K* and *MSY* has a small influence on the calculated risk values. If they are increased the risk values tend to increase slightly, and decline if they are reduced. However, the truncation was chosen so that higher values would be unlikely and the calculated risks may in this respect therefore be considered to be conservative.

Berenboim *et al.* (1980) estimated a catchability of 0.173 by calibrating trawl catches to the results of a photo survey. If this is chosen as basis for an informative prior by giving *q* a lognormal distribution with a median of 0.173 and a variance of 0.3 (Fig. 8) the estimated posterior distribution of *K* would be tighter; however *MSY* can still not be determined as the data have not "explored" that region of the production curved yet. With this prior the risks calculated in the first model run (see text table above) remain largely unchanged.

The stock may likely sustain larger catches than the current level of around 13 000 tons given that the environmental settings remain stable. However, increases in the exploitation level should be carefully planned and designed to provide more information on stock dynamics and to help estimate the productive capability of the stock. It should be kept in mind that an increased exploitation could affect catch rates negatively and might also lead to lower mean size of shrimp in the catch. Management should be ready to respond to new information e.g. by reducing catches. This approach could be founded in a multi-annual adaptive management plan.

References

ANON. 2004a. Report of the Pandalus assessment working group. *ICES C.M. Doc*., 2005/ACFM:05, 74 p.

ANON. 2004b. Scientific Council Reports 2004. *NAFO,* 203 p.

BERENBOIM, I. B., A. YU. LYSY, and L. I. SEREBROV. 1980. On distribution, stock state and regulation measures of shrimp (*Pandalus borealis* Kroeyer) fishery in the Barents Sea. *ICES C.M. Doc.*, 1980/K:**15**. 18 p.

HVINGEL, C. 2005a. Results of the Norwegian bottom trawl survey for northern shrimp (*Pandalus borealis*) in Skagerrak and the Norwegian Deeps (ICES Div. IIIa and IVa) in 2004—2005. *NAFO SCR Doc.*, No. 82, 8 p.

HVINGEL, C. 2004b. An assessment of the shrimp stock off West Greenland, 1970-2004. *NAFO SCR Doc.*, No. 76. 15 p.

HVINGEL, C. 2005b. Construction of biological advice for the management of a northern shrimp fishery – the West Greenland example. Doctorial Thesis, Doctorial thesis. Greenland Institute of Natural Resources, Nuuk, Greenland /Norwegian College of Fishery Science, University of Tromsø, Norway, 82 p.

HVINGEL, C., and M. C. S. KINGSLEY. 2005. A framework to model shrimp (*Pandalus borealis*) stock dynamics and quantify risk associated with alternative management actions, using Bayesian methods. *ICES J. Mar. Sci.*, **62**: 00-00.

MEGREY, B. A. 1989. Review and comparison of age-structured stock assessment models from theoretical and applied points of view. *Am. Fish. Soc. Symp.*, **6**: 8-48.

SHELTON, P. A. 2004. Report of the NAFO study group on limit reference points, Lorient, France, 15-20 April 2004. 72 p.

STEFANSSON, G., U. SKULADOTTIR, and G. PETURSSON. 1994. The use of a stock production type model in evaluating the offshore Pandalus borealis stock of north Icelandic waters, including the predation of northern shrimp by cod. *ICES C.M. Doc.*, No. 1994/K:25, 13 p.

WIELAND, K., P. KANNEWORFF, and B. I. BERGSTRÖM. 2004. Results of the Greenland Bottom Trawl Survey for Northern Shrimp (*Pandalus borealis*) off West Greenland (NAFO Subarea 1 and Division 0A), 1988-2004. *NAFO SCR Doc.*, No. 72, 31 p.

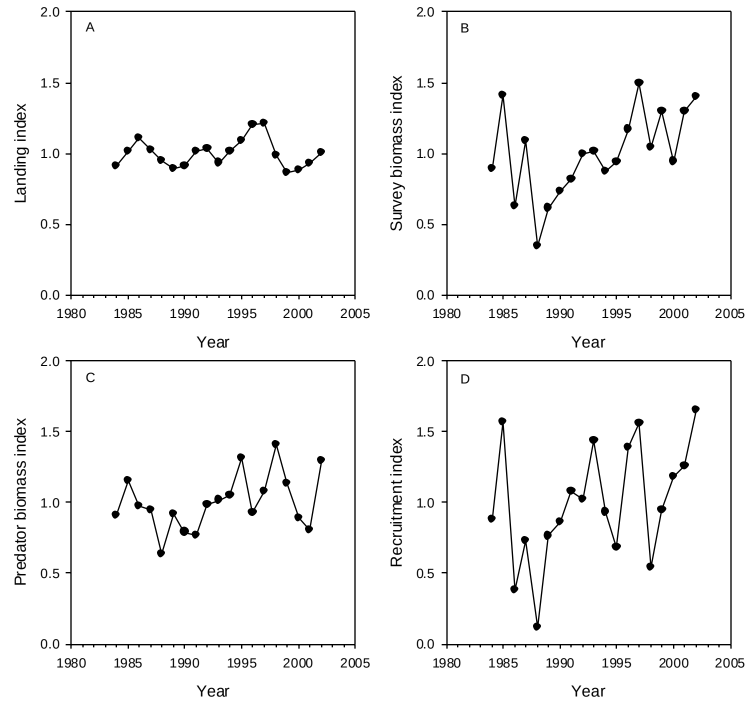

Fig. 1. Time series of landings (A), biomass index of age 2+ (B), biomass index of predators (C) and recruitment biomass index (age 0 and 1) (D) available for the biomass dynamic model used in the assessment of the shrimp stock in Skagerrak and Norwegian Deep. All scaled to their mean (mean=1)

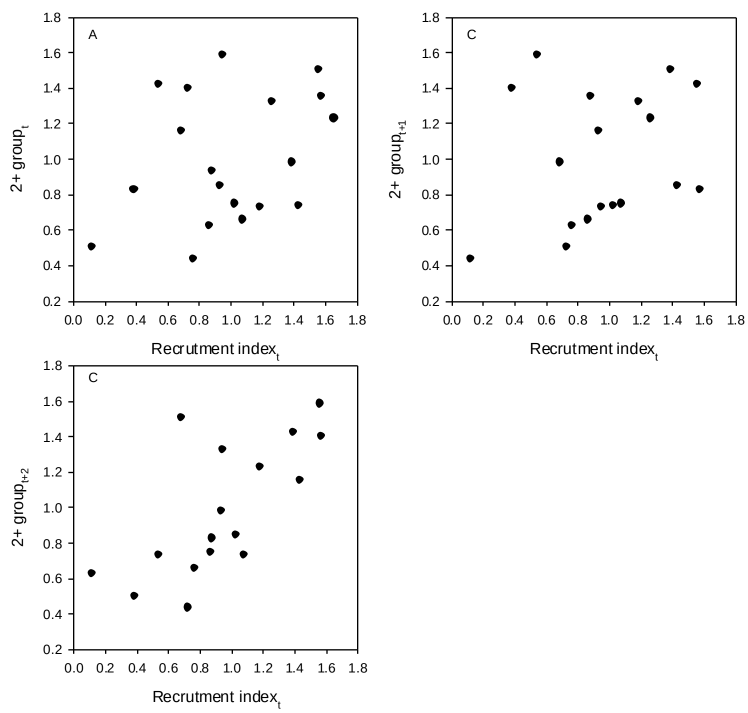

Fig. 2. Index of recruitment (biomass of age 0 and 1 from the survey) *vs.* the 2+ group survey index 0, 1 and 2 years later. The variables were scaled to their means (mean=1).

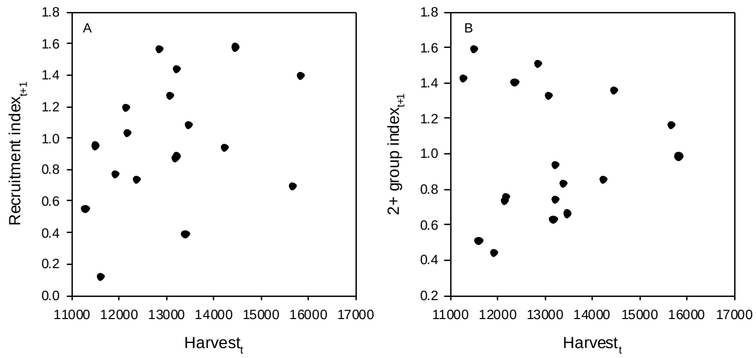

Fig. 3. Harvest (0.25*landing in year t+0.75*landings in t+1) *vs.* survey biomass of recruits (age 0 and 1s) and 2+ group scaled to their means (mean=1).

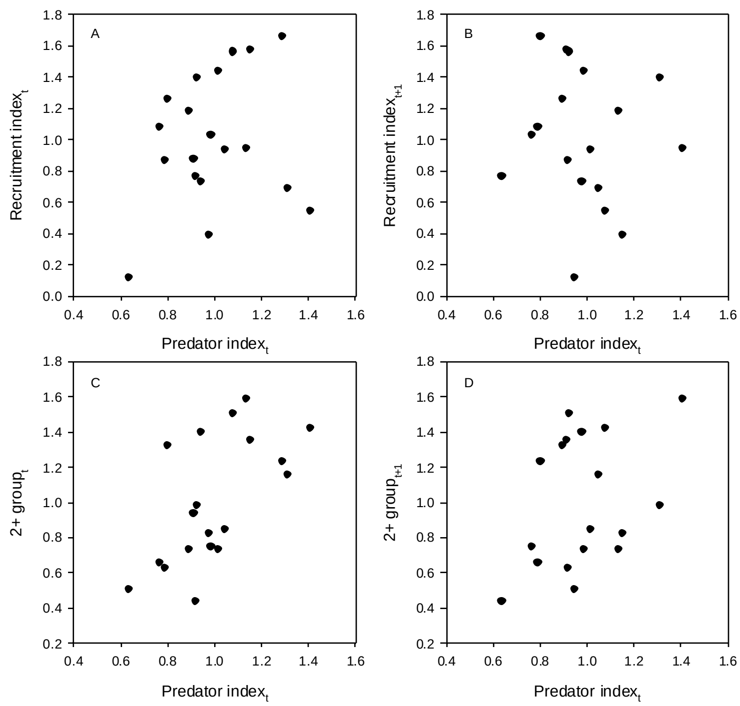

Fig. 4. Predator biomass indices from the Norwegian survey (mean=1) *vs.* the survey recruitment and 2+ group indices in the same and following year (mean=1).

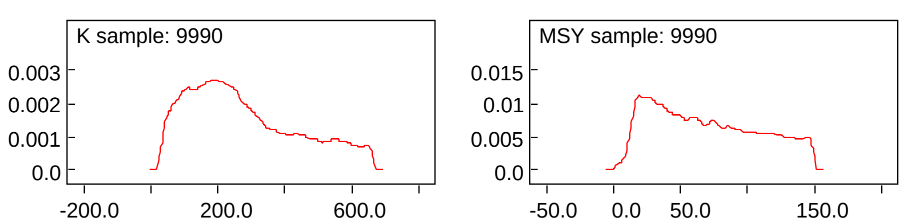

Fig. 5. Posterior probability density distributions of the carrying capacity, K, and maximum sustainable yield, *MSY*, derived by Monte-Carlo-Markov-Chain (MCMC) sampling methods using the model (eq. 4). The scale of the X-axis is Ktons.

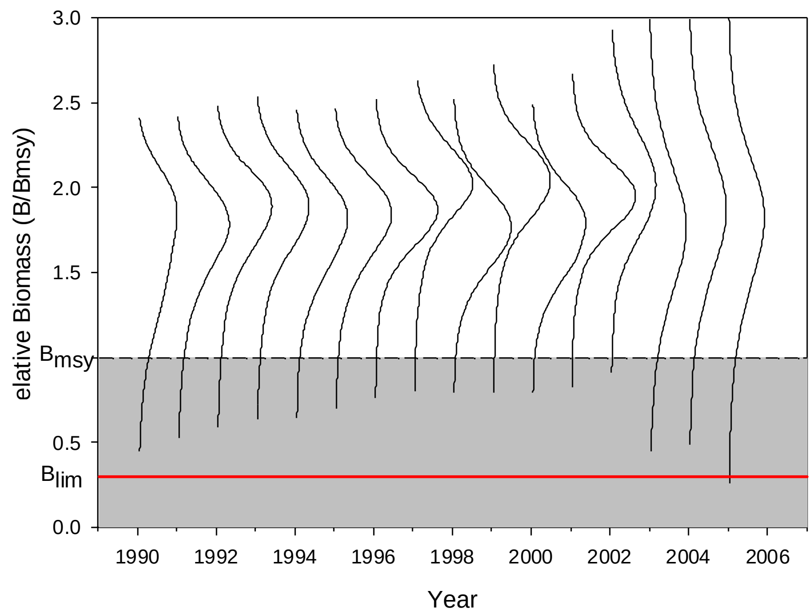

Fig. 6. Posterior probability density distributions of stock biomass (relative to B_{msy}) 1990-2006 derived by applying Bayesian inference and MCMC sampling techniques to a logistic model of shrimp stock dynamics. The 2003-2006 values are predicted due to the lack of standardised survey data after 2002. Red line is a limit reference point.

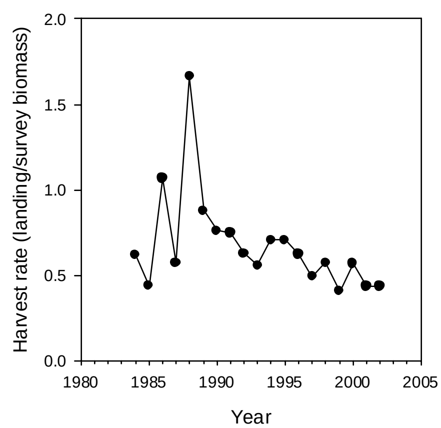

Fig. 7. An index of harvest rate (survey biomass$_t$/0.25*landing$_t$+0.75*landing$_{t+1}$t indxes year).

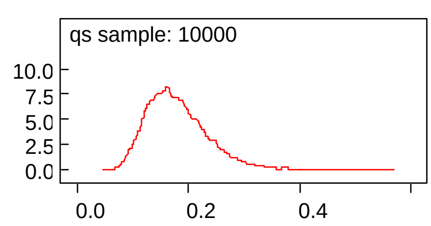

Fig. 8. Alternative informative prior for the catchability, q (scaling survey biomass to real biomass), based on Berenboim *et al.* (1980).

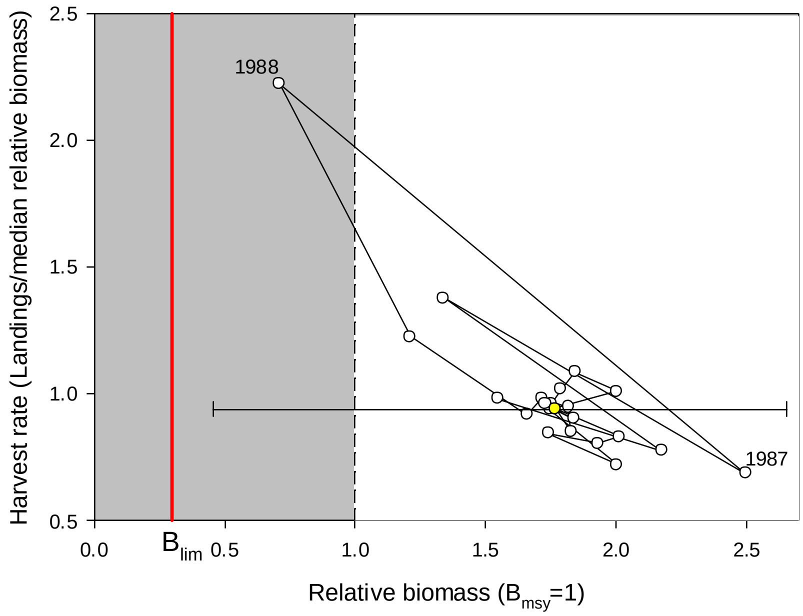

Fig. 9. Shrimp in Skagerrak and Norwegian Deep: Stock dynamics 1984 to 2005 in a fishing mortality/biomass continuum. Points are the median values of estimated biomass and harvest rate. Red line is limit reference point. Error bars for the 2005-value (yellow point) are 95% conf. interval.