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On the Possibility of Using Bayesian Approach to Assess the Northern Shrimp (*Pandalus borealis*) Stock in the Barents Sea and Spitzbergen

by

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Abstract

This document describes the first attempt to apply the Bayesian framework for making quantitative assessments, predictions, and risk analysis of shrimp (*Pandalus borealis*) stock in the Barents Sea and Spitzbergen.

Biomass dynamic models based on the logistic function, with an explicit term for cod predation were used to describe shrimp population dynamics. Biomass indices from a research survey and standardised commercial catch-per-unit-effort series, catch, cod predation estimates and "priors" of model parameters provided information to the models. A Bayesian approach was used to construct a "posterior" distribution of likelihoods of possible values of model parameters and derived variables relevant for developing management advice. The estimate of biomass by the model correlates well with the indices of abundance for survey and catches per effort. Calculated relative indices of biomass and the rate of stock exploitation show that in 1982-2005, the stock status was not critical and, in the majority of cases, it was in the zone of stable status of the stock. Conducted analysis shows the possibility of using Bayesian approach to estimate population dynamics and determine TAC of the Northern shrimp from the Barents Sea and Spitsbergen.

Introduction

Bayesian's theorem and mathematical approaches using the theorem started to be applied in fishery biology in the beginning of 1990s. At present these models are widely used to describe the status of stocks, to forecast and estimate the reference points for marine mammals, fish and invertebrates. The models have been successfully adapted for the stocks of the Northern shrimp, Canadian salmon, the South African anchovy, whales of the Suborder Mystacoceti, Pacific halibut, Pacific herring and others. The estimates of the stock status and forecasts made by this method have been supported by different scientific organizations including ANTCOM, FAO, NAFO, NEAFC, ICES.

The goal of this paper is to estimate the possibility of using this method in order to describe the population dynamics and to determine TAC for the Northern shrimp from the Barents Sea and Spitsbergen areas.

Method

The model was based on systems analysis, which used the state-space method. This method allows us to link the time-series of the observed indices with non-observed absolute abundance and biomass, to take into account the errors in methods and observations. Besides, the approach is quite flexible to create the models of stock dynamics and data-stock relationship. The Bayesian approach production model for the Northern shrimp stocks was described for the first time in the paper by Hvingel and Kingsley (2006).

The logistic model of population growth as a sample was used for mathematic realization of the biomass dynamics (Pella and Tomlinson, 1969):

$$B_{t+1} = B_t - C_t - V_t + \lambda MSY \frac{B_t}{K}\left(1 - \left(\frac{B_t}{K}\right)^{m-1}\right), \qquad \lambda = \frac{m^{\frac{m}{m-1}}}{m-1}$$

where B_t is the stock biomass in year t, MSY is the value of the instantaneous maximum sustainable yield rate, C_t is the catch taken by the fishery, V_t is the predation by cod in year t, and m is a parameter describing the shape of the "stock-recruitment" curve.

The algorithms of calculation, modelling and diagnostics have been realized in the Win BUGS v.1.3 software (www.mrc-bsu.cam.ac.uk/bugs; Gilks *et al*., 1994).

The model uses the two series of the biomass indices: the standardized index of catch per unit of effort ($CPUE_t$) in the Russian shrimp fishery in 1982-2005 and the index of biomass ($surv_t$) obtained from the results of the Norwegian surveys in 1982-2004. Index-real biomass ratio is expressed through catchability coefficients q_c and q_S respectively. It is taken that ω and k errors of observations are lognormally distributed, the biomass has a relative value ($P_t = B_t/B_{MSY}$) and the distribution of data is of the form:

$$CPUE_t \sim q_c B_{MSY} P_t \exp(\omega_t),$$

$$surv_t \sim q_S B_{MSY} P_t \exp(k_t)$$

The data on shrimp catch and mortality associated with cod predation were taken from the reports of NAFO/ICES Pandalus Assessment and Arctic Fisheries Working Groups (Aschan, Bakanev, 2005; Anon., 2005). It is taken that the data on catch are considered as reliable and included into the model with the absence of error and the discards of shrimp if they exist are minor. The observation errors for mortality associated with cod predation is lognormally distributed.

Results

The calculations of stock dynamics with the use of Bayesian's approach require the choice of priors, i.e. estimated or taken distributions of prior probabilities of the unobserved values (Fig.1). The distributions of a priori probability of value parameters when there is a lack of data (for instance, in modelling the majority of marine populations) may have a significant influence on a posteriori distribution and, respectively, change the results of calculations. The a priori distribution for *MSY* was described with the help of prior with the uniform distribution in logarithmic scale between log (100 000) and log (1 000 000). The lower limit in 100 000 t was chosen with the allowance for minimally estimated catch due to both fishing and cod predation as well as based on the most pessimistic estimate of the stock production capacity under the minimal density of the commercial stock. The upper limit was chosen arbitrarily and has a quite high value not to cross with a posterior distribution.

The maximum catch of shrimp in the Barents Sea and Spitsbergen areas was registered in the mid-1980s and amounted to somewhat less than 130 000 tons and, in that period, the shrimp mortality because of cod predation was estimated at 150-440 thousand tons, i.e. the total catch of shrimp per annum could be 280-570 thousand tons. Lower limit of *K* shows the maximal total catch. The upper limit could be hardly determined. Nevertheless when using some information this index may be limited from the unreal extra high value. It is taken into consideration for the upper limit of *K* that the maximal high densities ever registered during the survey with regard for catchability (Berenboim *et al*., 1986) reached 0.1 kg/m^2. If we assume that the area of stock distribution corresponds to that one of survey (176 229 km^2) about the two thirds of which have no commercial value and, respectively, where the probability of the occurrence of shrimp with maximal density is extremely small, the upper limit of *K* may reach on the order of 6 000 thousand tons. Taking into account the results of the previous stock dynamics study with the aid of production models where the estimated total biomass varied within 1 000-2 400 thousand tons (Berenboim, Korzhev, 1997) and the exploitation rate was considered as sparing, it may be assumed that, in this case, the carrying capacity could be 1 000-2 400 thousand tons (if we assume that the biomass approximately corresponded to B_{MSY}). Based on these assumptions we estimated prier for *K* as having gamma distribution ($K\sim dgamma(2.0,001)$) with a median of 1 700 thousand tons with the limits of distribution (P=95%) from 250 thousand tons to 6 000 thousand tons.

Catchability coefficients q_c and q_S scale the biomass indices for survey and catches per effort to absolute abundance of biomass. A prior information about these values is practically absent, so, the "expert" priors with lognormal distribution $\ln(q_c)$~U(-15,1) and $\ln(q_s)$~U(-10,1), where U is a uniform distribution, were used.

There is no a prior information about the m shape parameter for the Barents Sea shrimp metapopulation. However prior for m must be informative since it is a coefficient determining B_{MSY}/K ratio. To convert B_{MSY}/K ratio to m index the approximating function was used. M-curve as B_{MSY}/K function in the interval of $0.37<B_{MSY}/K<0.6$ was described by the function $m=a*\exp(b*P_{MSY}^c)$ with corresponding values of a (0.1817), b (5.1174) and c (1.0938) (Hvingel and Kingsley, 2006).

To estimate the accuracy of data description by the model a comparative analysis of observed values and their calculated distributions has been made. The residuals between observed and calculated values in each iteration step were determined. The summary statistics of distribution of these residues shows that the data are described quite well by calculation values. The slight trend in residuals of Norwegian survey index is not observed (Fig. 2).

The estimate of biomass by the model correlates well with the indices of abundance for survey and catches per effort (Fig. 3). Maximal stable catch with allowance for cod predation amounted to 370 thousand tons with biomass B_{MSY} equaled to 2 200 thousand tons and K equal to 4 500 thousand tons. Calculated relative indices of biomass and the rate of stock exploitation show that in 1982-2005, the stock status was not critical and, in the majority of cases, it was in the zone of stable status of the stock (Fig. 4). The risk-analysis showed that with the cumulative probability of exceeding MSY was equal to 30% the catch of shrimp with an allowance for cod predation that may reach 300 thousand tons (Fig. 5, 6).

Thus, conducted analysis shows the possibility of using Bayesian approach to estimate population dynamics and determine TAC of the Northern shrimp from the Barents Sea and Spitsbergen.

The model requires further evaluation, and may benefit from the inclusion of the new ecosystem survey shrimp indexes. Joint Russian-Norwegian ecosystem surveys have been carried out since 2004. Data from this survey series are currently being analysed. The preliminary results from the surveys shows that shrimp biomass steadily increased from 2004 to 2006 (Table 1, Fig.8).

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Table 1. Estimated biomass (thou. tons) and numbers of stations from joint ecosystem survey in Barents Sea and Spitzbergen, 2004-2006

Year	Number of stations	Stock biomass index thou.t
2004	669	215.4
2005	756	363.0
2006	676	400.3

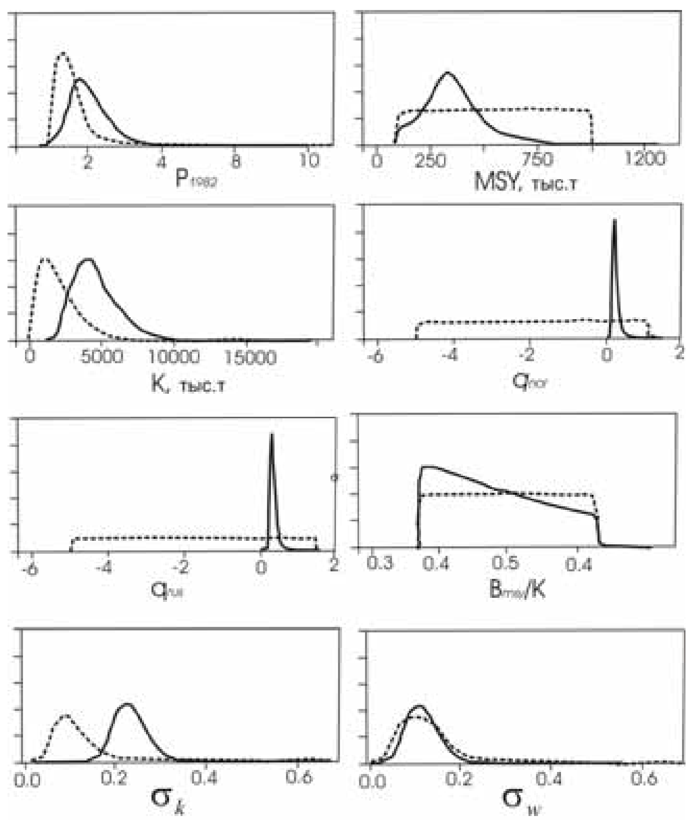

Fig. 1. Prior and posterior probability density distributions of model parameters (symbols are explained in text).

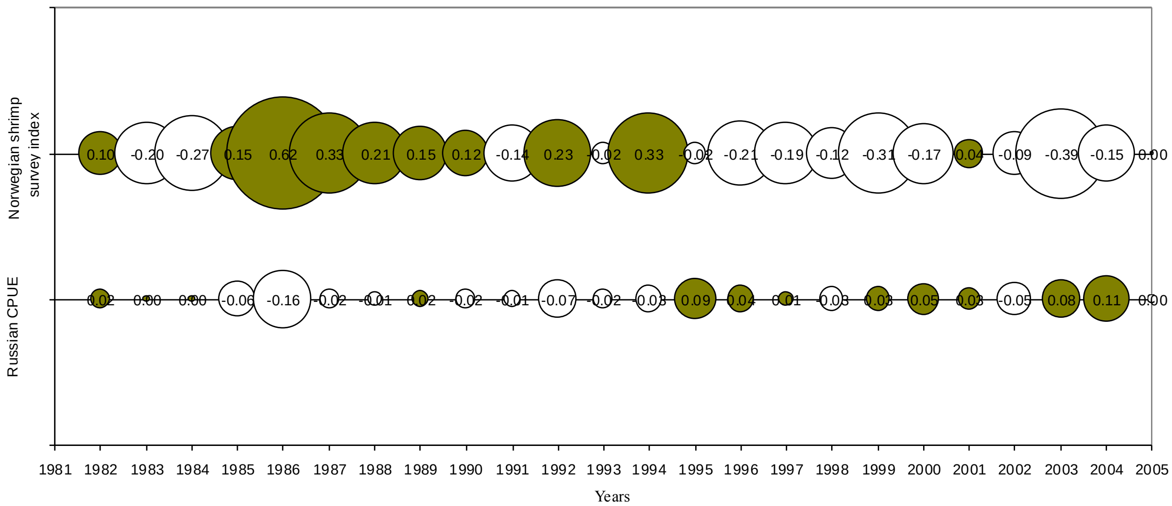

Fig.2. Log catchability residuals for the tuning fleets (Russian CPUE and Norwegian survey index) included in the assessments. Open bubbles represent positive values; filled bubbles represent negative values.

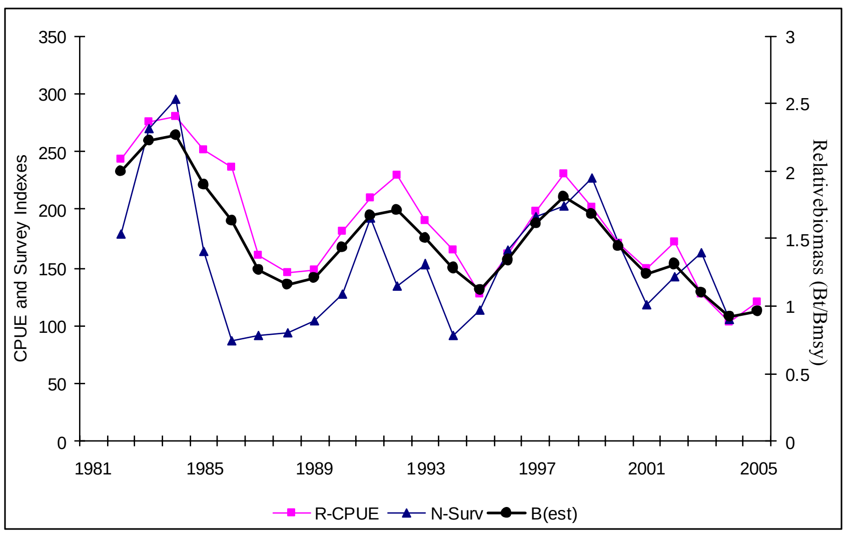

Fig. 3. Comparison of observed and model estimated values: CPUE and survey stock biomass indices.

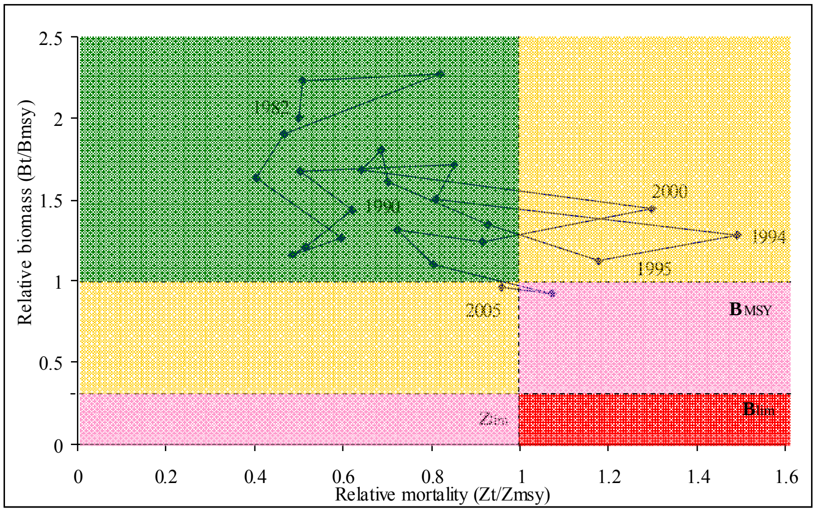

Fig.4. Dynamics of the Northern shrimp stock from the Barents Sea in 1982-2005 by zones of the regulation area with precautionary approach (green area – the zone of stable status of stock).

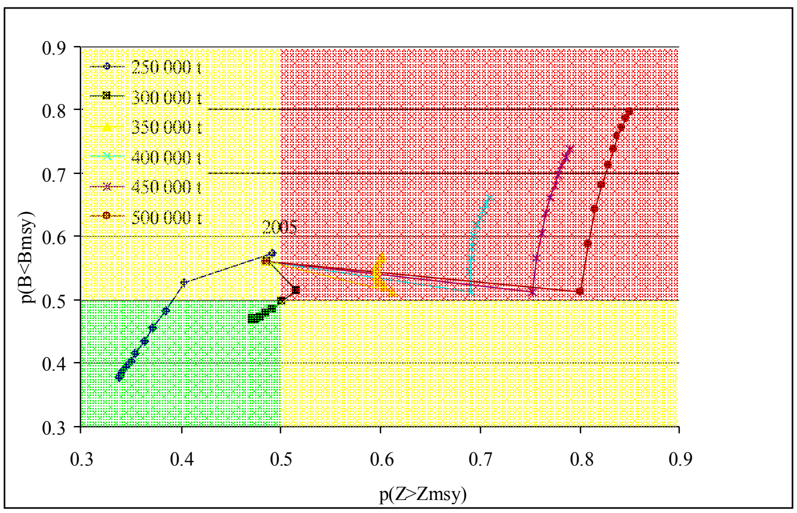

Fig.5. Risk of exceeding *Zmsy* and of driving the stock below *Bmsy* by maintaining optional annual removal levels (catch and cod consumption) of 200 000-500 000 t/y during the period 2005-2015.

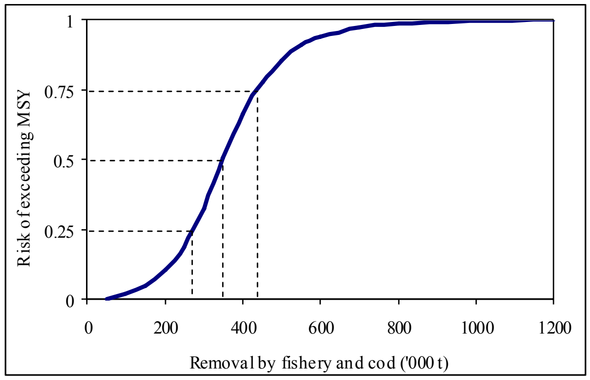

Fig. 6. The cumulative probability of exceeding MSY.

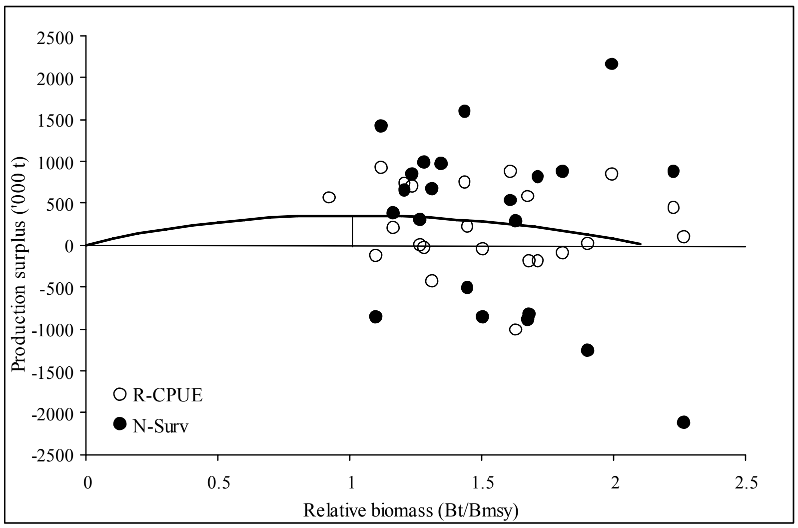

Fig. 7. Ability of model define the stock-production curve: annual stock size estimates calculated directly applying the MCMC-sampled catchabilities to the actual index values, and the corresponding production calculated by subtracting biomass in the current year from biomass in the next, then adding catch and predation. The generalized stock-recruitment curve shown was based on the median of the posteriors of the parameters MSY and m.

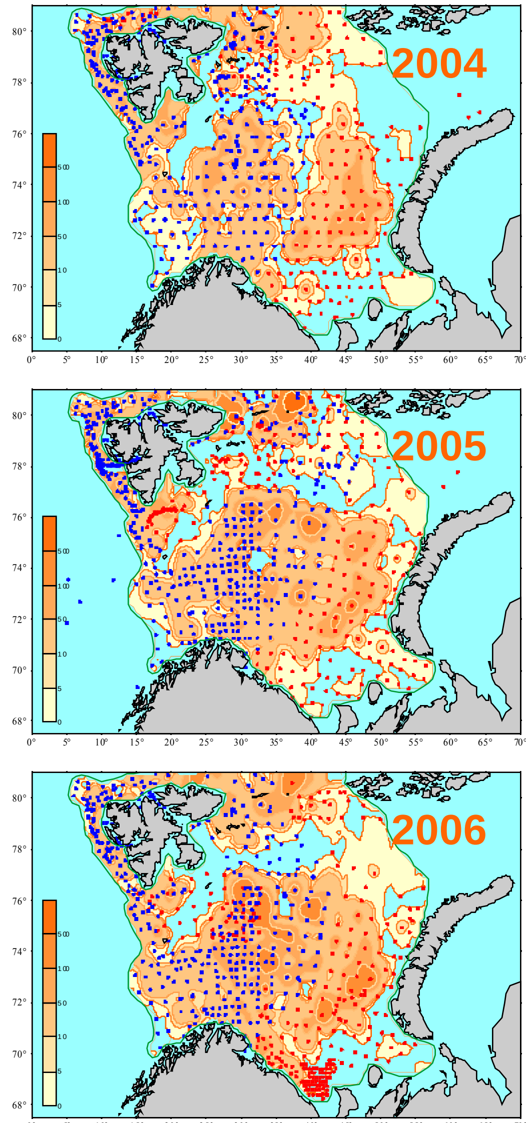

Fig. 8. Shrimp distribution in the Barents Sea according to joint ecosystem surveys conducted in the period August-October, 2004-2006 (red dots – Russian stations, blue dots – Norwegian stations).