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Modelling Approach For Evaluating Of Natural Mortality Variation Caused By Cannibalism In The Barents Sea Cod

by

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Session C: Natural mortality variation in populations and communities

ABSTRACT

Cannibalism is an important population mechanism to control cod abundance in response to environment variations. The estimates of the Barents Sea cod cannibalism calculated on the basis of the quantitative analysis of stomach content have been available since 1984. Based on these estimates the quantity of juveniles consumed by cod significantly varies from year to year and depends on abundance and age composition of adult cod, juvenile abundance, as well as the stock size of capelin as a main food item. Using multispecies STOCOBAR model the attempt to extend the time series of data on cod cannibalism on the basis of the accessible historical data on capelin abundance, cod commercial stock and water temperature since 1973 has been made. The dependence of rate of cod natural mortality due to the cannibalism on capelin stock size in the Barents Sea under different temperature and cod stock was analysed applying scenario modelling. The aspect of improvement of cod harvest control rule based on obtained findings is considered.

Key words: Barents Sea, cod, cannibalism, ecosystem approach, model, natural mortality.

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INTRODUCTION

Cannibalism is an important population mechanism to control cod abundance in response to environment variations. Although the young cod is a prey item for many predators in the Barents Sea the cannibalism put major contribution into the natural mortality of the Northeast Arctic cod at age 1-3 (Dolgov, 1999; Bogstad et. al, 2000). Mortality of juvenile cod induced by cannibalism may greatly impact on the year-class strength. Thus, in 1986-1988, when the capelin stock was low, cannibalism reduced the 1985- and 1986 year-classes, which were very abundant as 0-group and which abundance became much lower than average at age 3 (Hylen et. al., 2008).

Many investigations were devoted to study of cannibalism in the Northeast Arctic cod and this is widely represented in literature (Bogstad et. al., 1994; Yaragina et. al., 2009). The field observations of cod feeding on own juveniles were started in the Barents Sea in the 1930s (Zatsepin and Petrova, 1939). The interest to study of cannibalism in cod stock increase significantly in the mid-1980s when the joint PINRO/IMR research programs on multispecies interactions in the Barents Sea were initiated (Filin et. al, 2008). Recently the both institutes annually have been performing cod consumption estimations of key prey species, including young cod. These estimations are based on the joint PINRO/IMR database on cod stomach content (Dolgov et al., 2007). To calculate cod food intake evacuation model and cod numbers by age from VPA assessments are also applied (Bogstad and Mehl, 1997). Another source of information on cod cannibalism in the Barents Sea is the data on qualitative analysis of cod stomach content. These time series have been available since 1947. The observed data demonstrate significant year-to-year changes of cannibalism rate in the cod stock of the Barents Sea. The analysis of the historical data showed that the cannibalism in the Northeast Arctic cod was at a high level from 1947 to 1965 and then again in the mid-1990s (Yaragina et. al., 2009).

Although many studies focused on cannibalism in the Barents Sea cod the reasons behind the inter-annual variability of cod cannibalism are not entirely clear. As the observed data demonstrate the level of cannibalism in cod stock is the most sensitive to fluctuations in the capelin stock size. The proportion of cod in cod stomachs increases under the low capelin abundance. However these links may be disturbed in dependence on changes in the cod stock state, temperature conditions and availability of alternative food. That caused different cannibalism rate in the cod stock during the three collapses of capelin stock in the Barents Sea that occurred over the last three decades (Gjoseter et. al., 2009).

Since 1995 quantitative estimations of cod consumed by cod have been used by AFWG ICES in the cod stock assessment (Yaragina et. al., 2009). This allows to improve the stock-recruitment relation. However the existing harvest control rules for the Northeast Arctic cod based on spawning stock biomass only and they do not take the cannibalism effect on stock size regulation into account.

The main aim of this paper is an attempt to use the cod-ecosystem coupled model STOCOBAR for the study of cannibalism in the Northeast Arctic cod. The following tasks are intended to be performed:

- to get alternative estimations of cod consumed by cod by adjusting model to historical data since 1984, when the quantitative cod stomach data are available;
- to perform back calculations of cod consumption by cod for 1973-1983 when capelin stock assessments are available but quantitative data on cod stomach content are lacking;
- to test the relationship between the cod cannibalism rate and the cod stock state as well as the capelin stock size using scenario modeling.

MATERIAL AND METHODS

STOCOBAR model is used as an analytical tool in this study. This model simulates stock dynamics of cod in the Barents Sea, taking fishery, trophic interactions and environmental influence into accounts (Filin, 2007).The simplest version of the model species composition that includes cod as a predator and two categories of its prey items: capelin and "other food", was applied in this study

There are different approaches to simulation of cod and capelin dynamics in the model. The cod stock dynamics in the model is described through the imitation of the main biological processes in the cod population such as: growth, feeding, maturation, recruitment, natural mortality (including cannibalism) and fishing mortality. Unlike the cod, the capelin stock projections as well as the temperature projections in the model are based on statistical approach only. These projections include both deterministic and stochastic components. Formation of the replicate sets of input data for cod prey species and temperature scenarios that used in STOCOBAR runs is based on stochastic distributions and statistical relations derived from observed data. The historical data are split into several sets. For example, if a warm period is assumed, the temperature values are drawn with equal probability from the available historical data, which are higher than chosen criterion. The input capelin stock dynamics scenario uses the assumption that the capelin stock size depends concurrently on the cod stock size and the capelin stock size in the previous years according to the observed data. In this case, historical replicates are drawn with equal probability from the two corresponding set of replicates and then the average value is calculated.

The model parameters are estimated by fitting the simulated data to the observed data on cod body weight and length, cod maturation ogive and fatness (hepatosomatic index) as well as a cod diet. Minimization of the square of discrepancies between simulated and observed data using Solver option in Microsoft Excel spreadsheets is used.

The following historical data were used to estimate the parameters of the model:

- abundance-at-age of cod in the beginning of the year;
- individual weight-at-age of cod in the stock in the beginning of the year;
- length-at-age of cod in the stock in the beginning of the year;
- mean annual weight-at-age of cod in catch;
- annual age based coefficient of cod fishing mortality;
- cod maturation ogive in the beginning of the year;
- cod fatness (hepatosomatic index) by age at the end of year;
- mean annual temperature on the Kola Section;
- capelin stock biomass in the beginning of the year;
- quantitative composition of cod stomach content;

- annual estimates of total cod biomass consumed by cod calculated in PINRO and IMR from data on cod stomach content using gastric evacuation rate and number of cod by age .

Data on capelin stock biomass and cod maturity, mean weight-at-age, abundance, consumption, fishery mortality coefficients and the fishing selection pattern were taken from ICES AFWG report 2009. The capelin stock assessments on 1 January were used not only for tuning the model but also for creating future capelin scenarios. Annual temperature data averaged for 0-200 m on the Kola Section for the period since 1951 to 2009 were used for development of the temperature scenarios for the simulations. These data were taken from PINRO hydrographic database. For the model parameterization also used were PINRO database on cod hepatosomatic index and joint PINRO/IMR database on cod stomach content.

The model is capable of modeling cod from age 1. It takes cod numbers for ages 4 and older on 1 January from ICES AFWG assessments as the input historical data for tuning the model and then models cod numbers at ages 1, 2, and 3 with cannibalism. The model tuning includes the following calculation scheme when it performs the estimations of cod number consumed by cod and abundance indices of cod at age 1-3. At the first stage the portion in cod rations of young cod as well as capelin and “other food” is taken as equal to the corresponding values from the observed data on cod stomach content. The numbers (abundance indices) of cod at age 1-3 are found by back calculations from available number of cod at age 4 and cod number consumed by cod. Then these estimates of young cod abundance are applied for assessment of the prey suitability indices for cod, which allow to simulate cod diet based on data on prey stock biomass. At the second stage the cod numbers at age 2, 3 and 4 are calculated forward from its numbers at age 1. These calculations are performed including the cod numbers consumed by cod, which are estimated using simulated cod diets. The number of cod at age 1, which is obtained at the first stage, is used as a starting point. The final values of cod number at age 1 are set by adjusting them to get the agreement with available data on cod number at age 4.

To evaluate the impact of temperature, cod and capelin socks on the cannibalism rate in the Northeast Arctic cod the scenario modeling approach was used. 5 model runs with 200-year simulated period were performed. The alternation of cold, moderate and warm periods was introduced in the temperature scenario. This may be regarded as a deterministic component in the long-term year-to-year dynamics of water temperature. The values of temperature for cold, moderate and warm periods were randomly selected from the historical data, and this reflects the stochastic component in the annual temperature variability. In our study the cold periods included temperature less then 3,6 C°, the warm periods had temperature more than 4,2 C° and the temperature ranged from 3,6 C° to 4,2 C° for the moderate periods. The duration of each of these periods were established to be equal to 3±2 year

The capelin stock dynamics scenario was developed taking into account the revealed relationship between the changes in cod and capelin stocks (Figure 1). The available historical data demonstrate that probability of appearance of large capelin stock is much higher if cod spawning stock in the previous year was lower then 400 thousands tones. Therefore, we set scenario for capelin stock dynamics on the basis of random selection of values from the historical data step by step, according to the cod spawning stock biomass calculations in the model. A relationship between successive capelin stocks in the historical time-series was used also in the scenarios of capelin stock dynamics (Figure 2).
The modified Ricker recruitment equation (Cook and Heath 2005), which incorporates temperature, was used to couple the cod spawning stock biomass and recruitment at age 1. Uncertainties associated with the recruitment were implemented by including residuals in the simulated data. The variability in the recruitment was derived from the relationship between

historical spawning stock biomass and the number of recruits at age 1 for 1984-2007. A fixed exploitation pattern, which corresponded to that one in 1990 was applied in the simulations. The cod harvest control rule that based on Fpa = 0,70 (averaged for 5-10 age, F_{bar}) and Bpa = 460 000 was applied in the model.

RESULTS AND DISCUSSION

The STOCOBAR estimates of the biomass of cod at age 1-5 consumed by cod in 1973-2006 in comparison with those ones obtained in PINRO and IMR using a traditional method (stomach content data and gastric evacuation model) are represented in Figure 3. A reasonable consistency between the two kinds of estimates is observed. Both approaches show a close dynamics of cannibalism in the Northeast Arctic cod stock since 1984. However according to STOCOBAR the level of the cannibalism in the cod stock in the Barents Sea in 1995-1997 was less than that one resulted from the traditional estimations. At the same time STOCOBAR estimates of cod consumption by cod in 1989-1990 and in 2004-2006 are higher then those ones calculated by the traditional method. Nevertheless the STOCOBAR estimates of cod consumption correlate well with the estimates that are calculated routinely in PINRO and in IMR, the correlation coefficients are 0,921 and 0,926 correspondingly. The correlation coefficients between the STOCOBAR estimates and the routine estimates by IMR are even some what higher than between PINRO and IMR estimates that are based on the same methodological approach.

According to our model assessments in 1973-1983 the level of cannibalism in the Northeast Arctic cod was relatively low (Figure 3). This supports the findings from the analysis of the qualitative data on cod stomach content for that period (Yaragina et. al., 2009). Good feeding conditions due to a large capelin stock probably caused a low cod consumption of own juveniles in the 1970s. Cod and capelin stocks dynamics as well as the temperature fluctuation in 1973-2009 are shown in Figure 4.

To analyze the impact of capelin abundance and the cod stock size on the cannibalism mortality rate in the Northeast Arctic cod at age 1-3 we used both the historical estimations and the scenario modeling. Cod mortality rates due to cannibalism at age 2 and 3 calculated for the period 1984-2006 show a positive correlation with the cod fishable stock biomass, although these statistical links are weak (Figure 5). No links of the cod cannibalism rate at age 1 with fishable stock size were revealed from the STOCOBAR estimations based on the observed data on cod stomach content. The results from the scenario modelling confirm the lack of the significant links between the cannibalism level and fishable cod stock biomass. A weak positive relationship was found for age 2 only. The model analysis of the relationship between the cod cannibalism rate and its spawning stock showed a moderate link for age 3 only. In this case, the results were the same as for the period of the historical observations on cod stomach content as for the scenario modeling (Figure 6).

The model analysis demonstrates a significant relationship between capelin stock biomass in the Barents Sea and the level of cannibalism in the Northeast Arctic cod. This is seen from both the historical simulations and the scenario modeling (Figure 7). The relative number of cod consumed by cod substantially decreases as the capelin stock size increases. This is obvious especially if the capelin stock biomass exceeds 3 million tons. Following the model the correlation between capelin stock size and cod mortality caused by cannibalism at age1 is stronger then at age 2 and 3.

A relationship between the inter-annual changes in the temperature in the Barents Sea in 1984-2006 and the model estimates of cannibalism rate in the Northeast Arctic cod for this period are shown in Figure 8. Statistically significant links were not revealed. However the obtained results support the assumption that cod mortality at age 1 due to cannibalism has a tendency to decrease in the warm yeas. The explanation of this may be related with more wider spatial dispersion of cod larvae and fry in the Barents Sea in the warm years in comparison with the cold ones. This assumption couldn't be tested by using STOCOBAR scenario modeling because our model is not able to simulate temperature-dependent spatial distribution of the cod. However the STOCOBAR simulations demonstrate the apparent increase in cod cannibalism under the warming scenarios in the Barents Sea with the expected temperature increments at 1-4º C. It was shown in our previous studies (Filin, 2009). The reason behind this is a simulated rise in the total cod consumption owing to larger body weight of adult cod (as a result of temperature-dependent growth acceleration) and changes in the metabolic rates.

In the management aspect it is interesting to evaluate the ratio between the estimates of the biomass of cod consumed by cod and yield. According to the ecosystem approach this parameter may be considered as a candidate to the additional reference points in the cod fishery management. In Figure 9 the estimates of this parameter derived from STOCOBAR scenario modeling are plotted against the corresponding values of the capelin stock biomass. One can see a clear negative tendency in changes of this parameter as capelin stock size increases. This is explained by the decrease of the cannibalism mortality in the cod stock while the fishing mortality does not change depending on the capelin stock size. Since the cannibalism is an adaptive mechanism of the population regulation in response to the changes in the ecosystem it would be reasonable to take it into account in the fishery regulation if we want to introduce the ecosystem approach. To implement these considerations into the Northeast Arctic cod management are needed more detailed investigations on cod cannibalism, including the modeling approach.

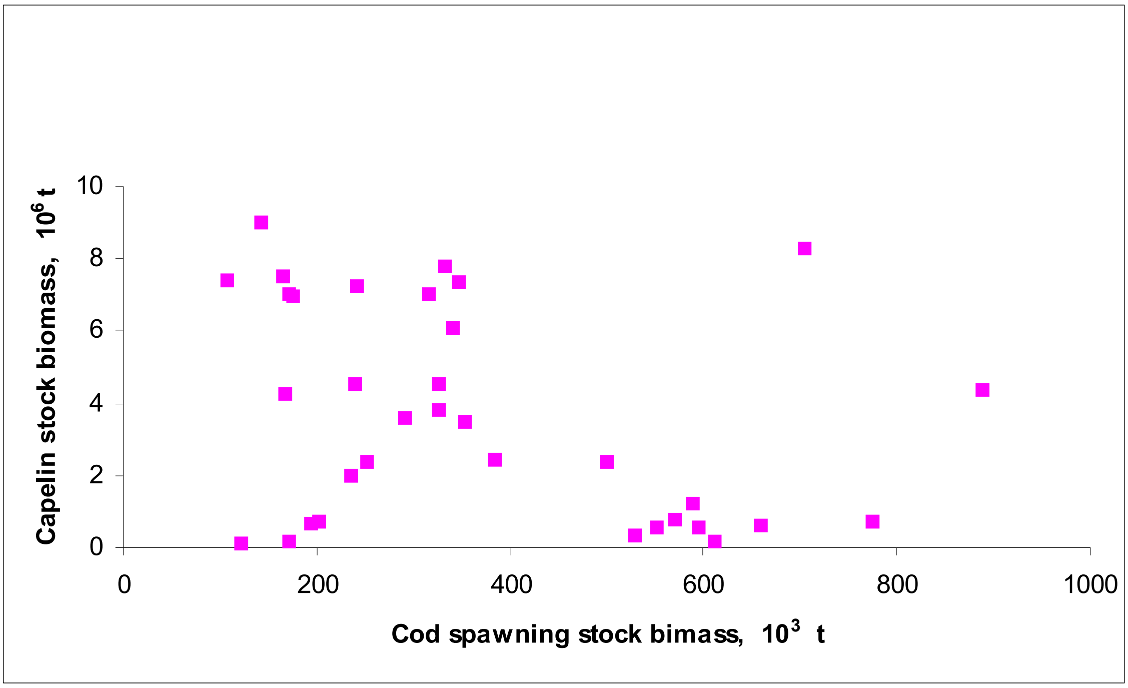

Figure 1. Relationship between capelin stock biomass and cod spawning stock biomass in year before (observed data for 1972-2007).

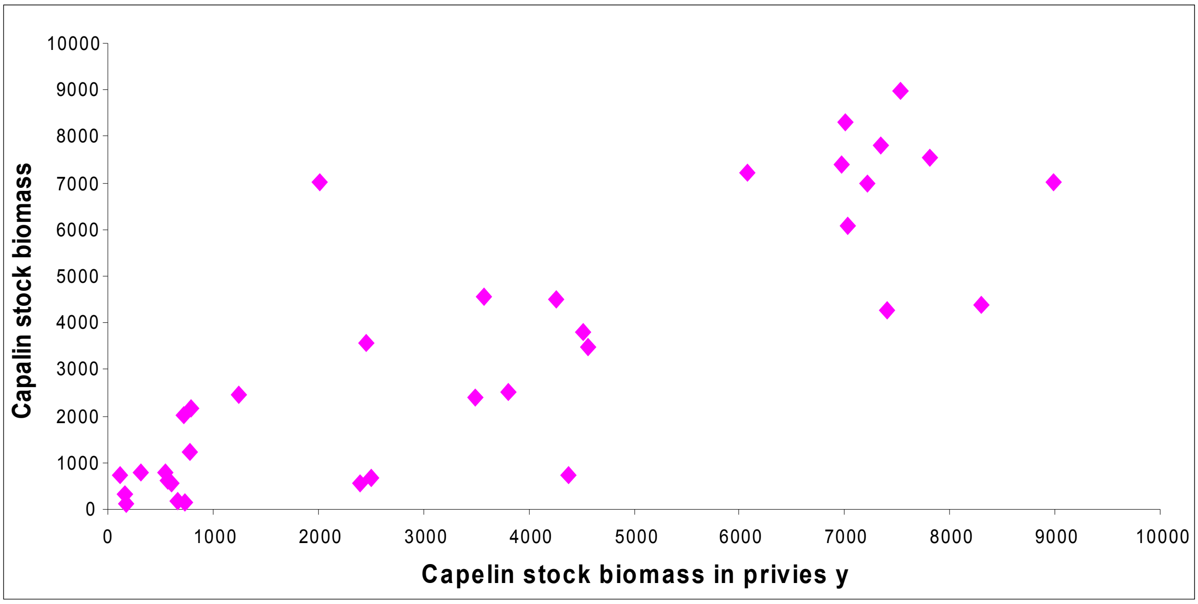

Figure 2.Relationship between successive capelin stocks in the historical time-series (1972-2007).

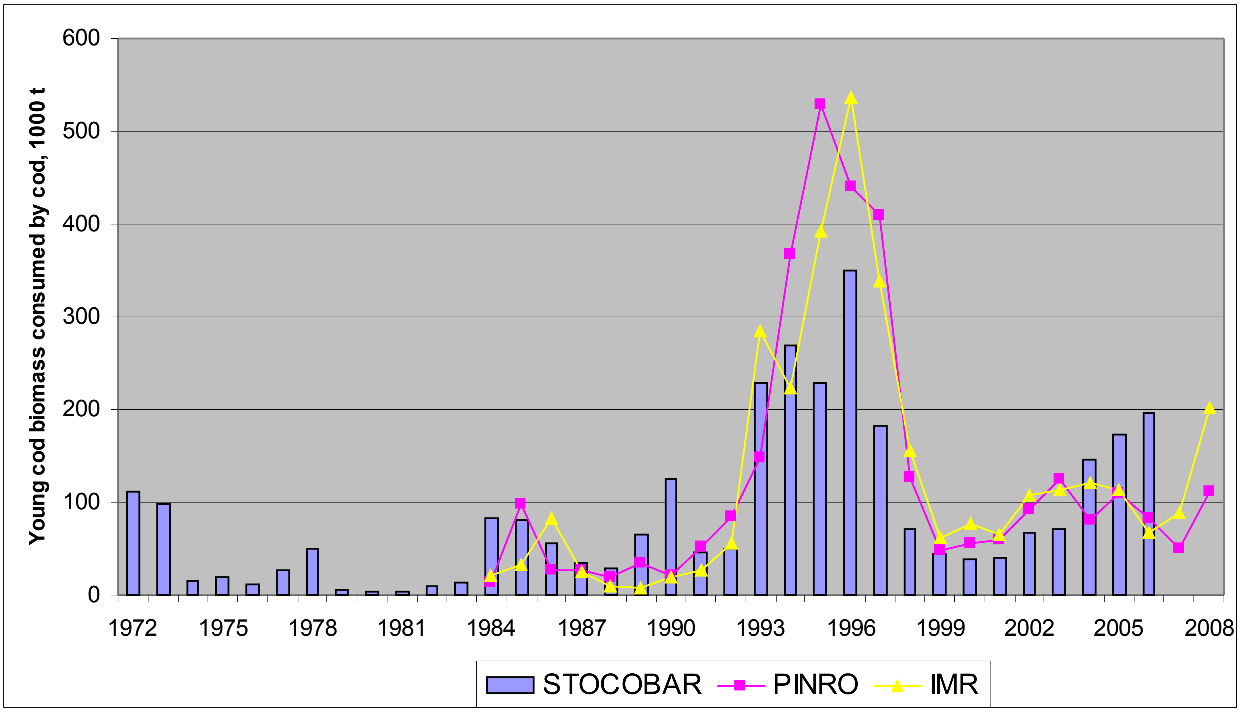

Figure 3. Estimates of the biomass of cod consumed by cod calculated in PINRO and IMR from data on cod stomach content, gastric evacuation rate and the number of cod by age (AFWG 2009) in comparison with STOCOBAR estimations based on prey abundance, simulated cod growth rate and the number of cod by age.

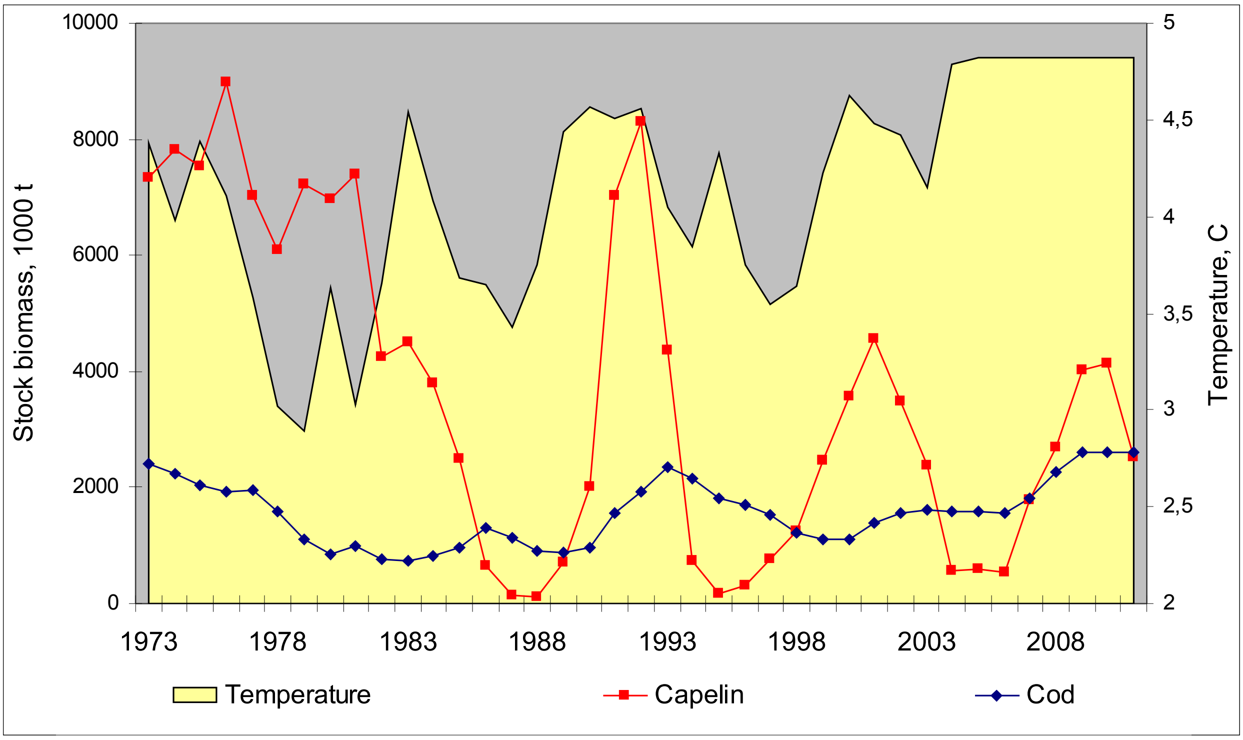

Figure 4. Variations in the annual water temperature on the Kola Section, capelin stock biomass and cod fishable stock biomass (age 3+) at the beginning of the year in the Barents Sea, 1973-2009.

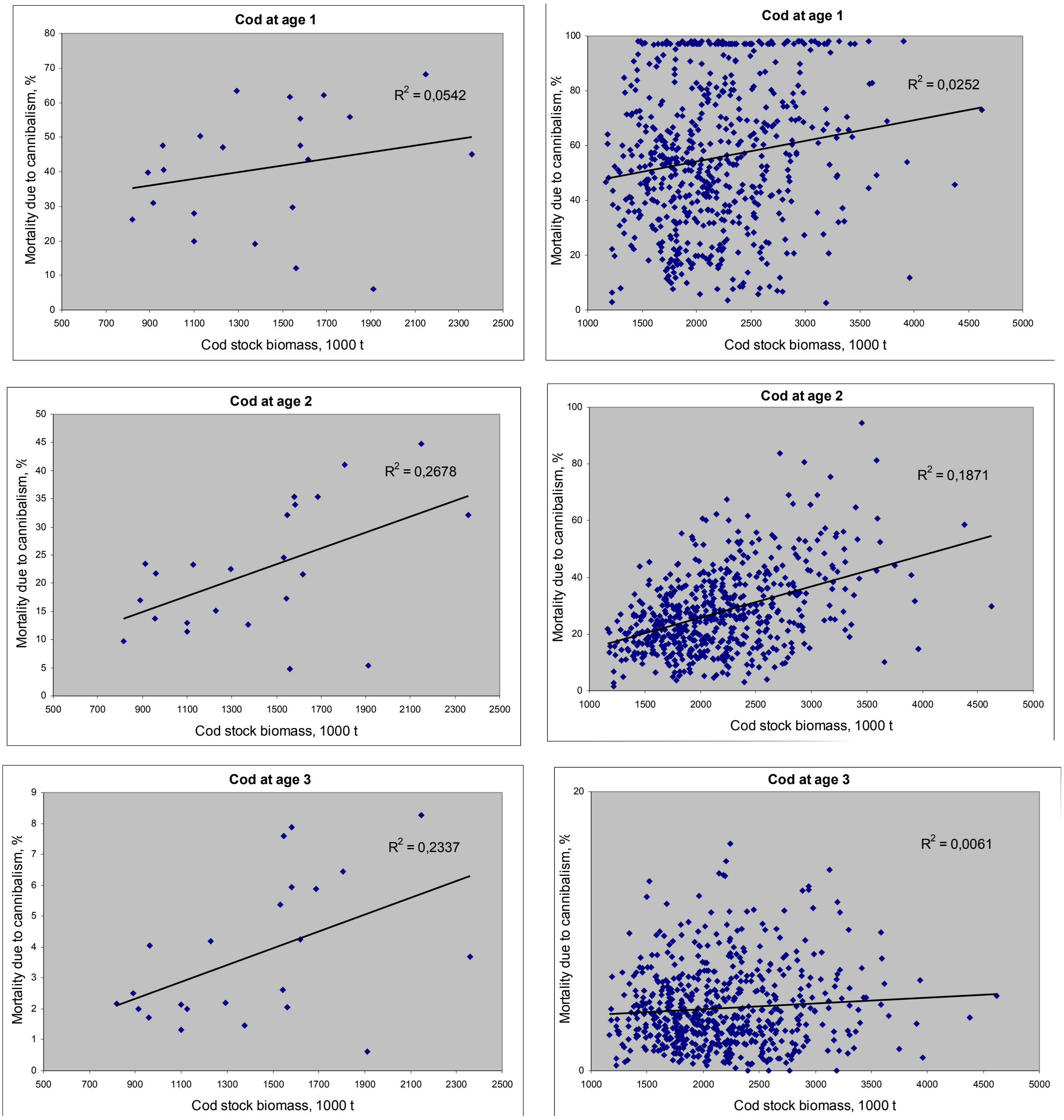

Figure 5. The relationship between cod mortality at age 1-3 caused by cannibalism and cod fishable stock biomass following STOCOBAR model estimation. Left panels are the model output based on the historical data for 1984-2009, right panels are the results from the scenario simulations.

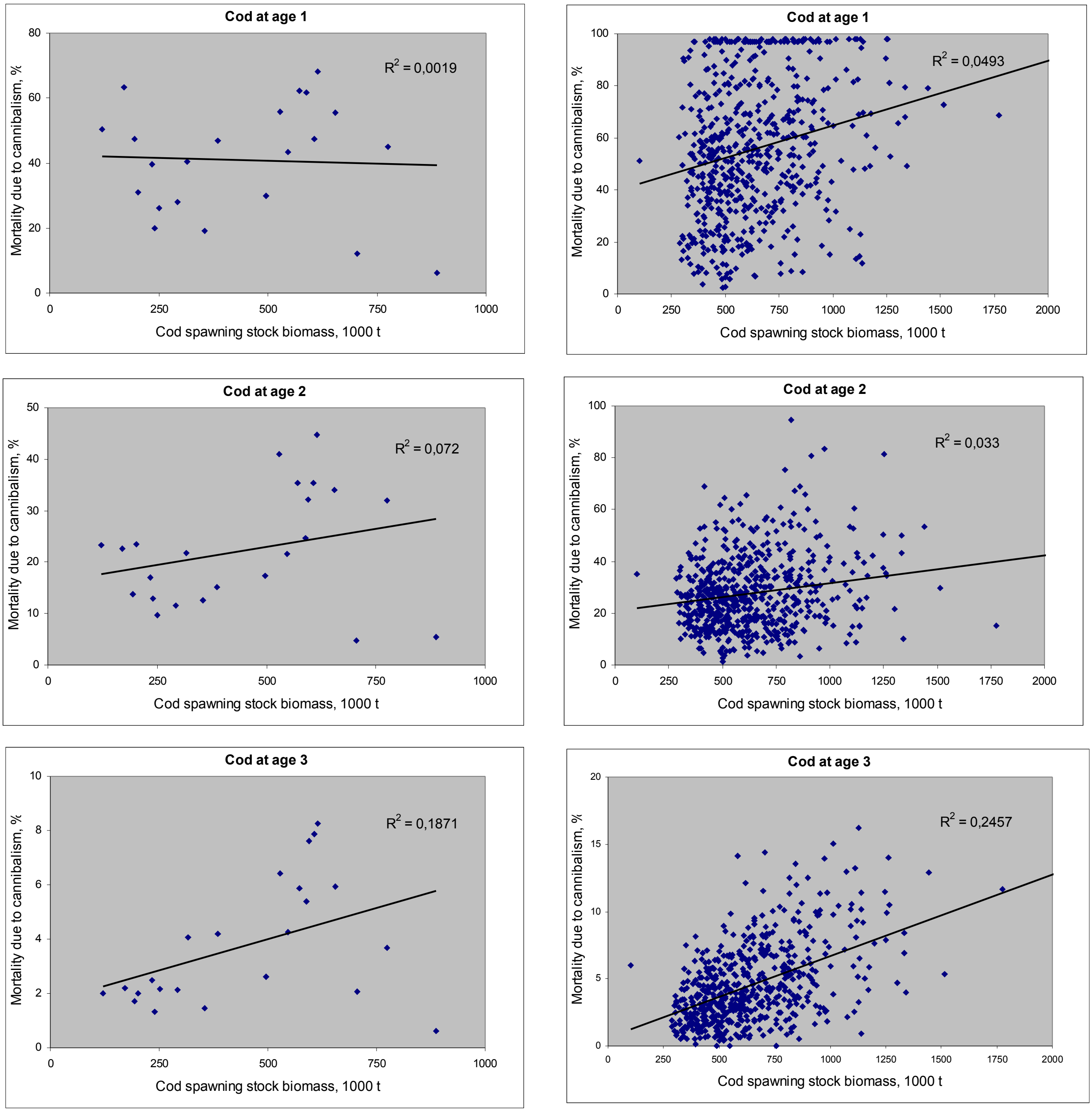

Figure 6. Relationship between cod mortality at age 1-3 caused by cannibalism and cod spawning stock biomass following STOCOBAR model estimation. Left panels are model output based on the historical data for 1984-2009,   right panels are the results from the scenario simulations.

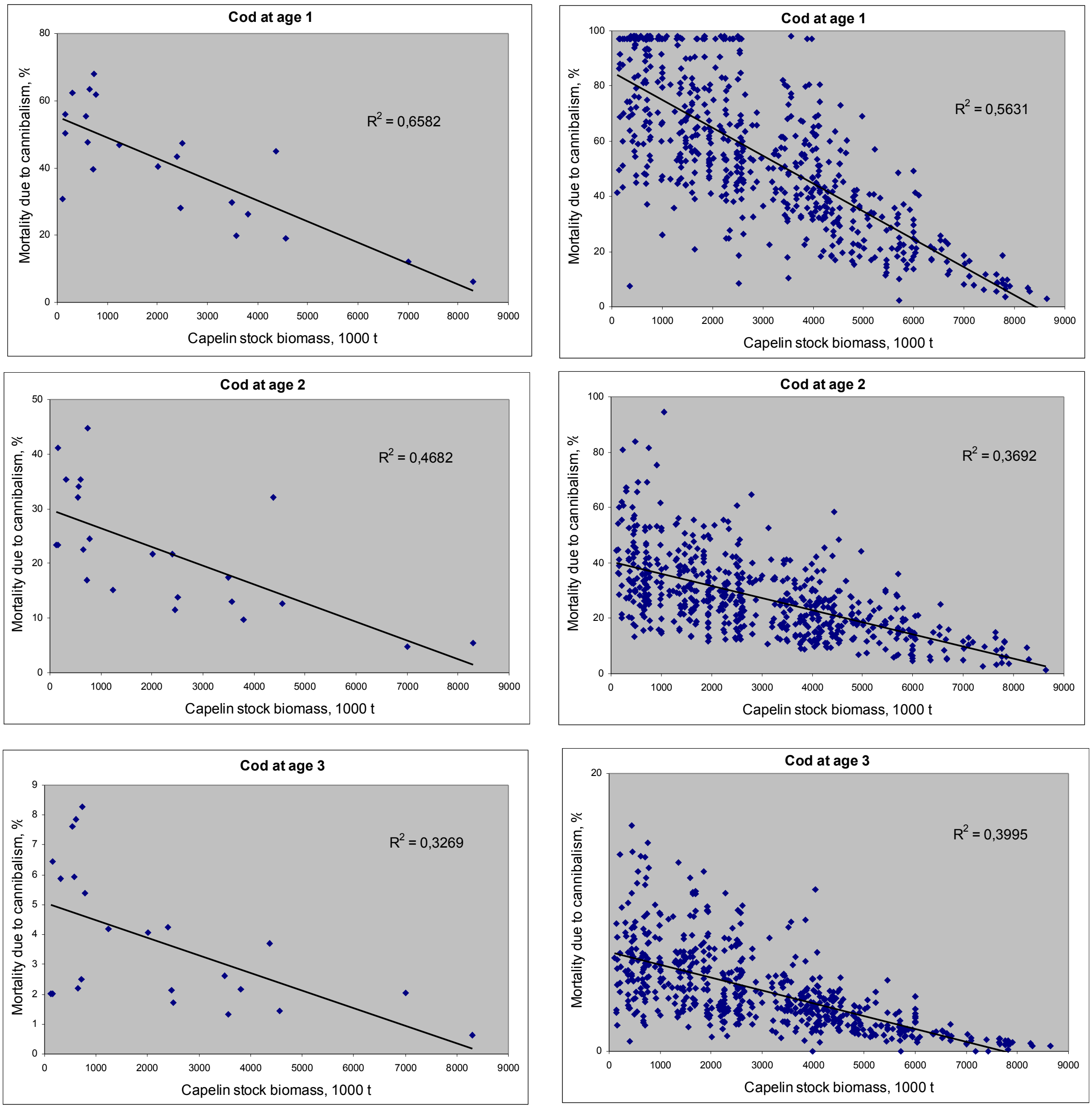

Figure 7. Relationship between cod mortality at age 1-3 caused by cannibalism and capelin stock biomass following STOCOBAR model estimation. Left panels are the model output based on the historical data for 1984-2009, the right panels are the results from scenario simulations

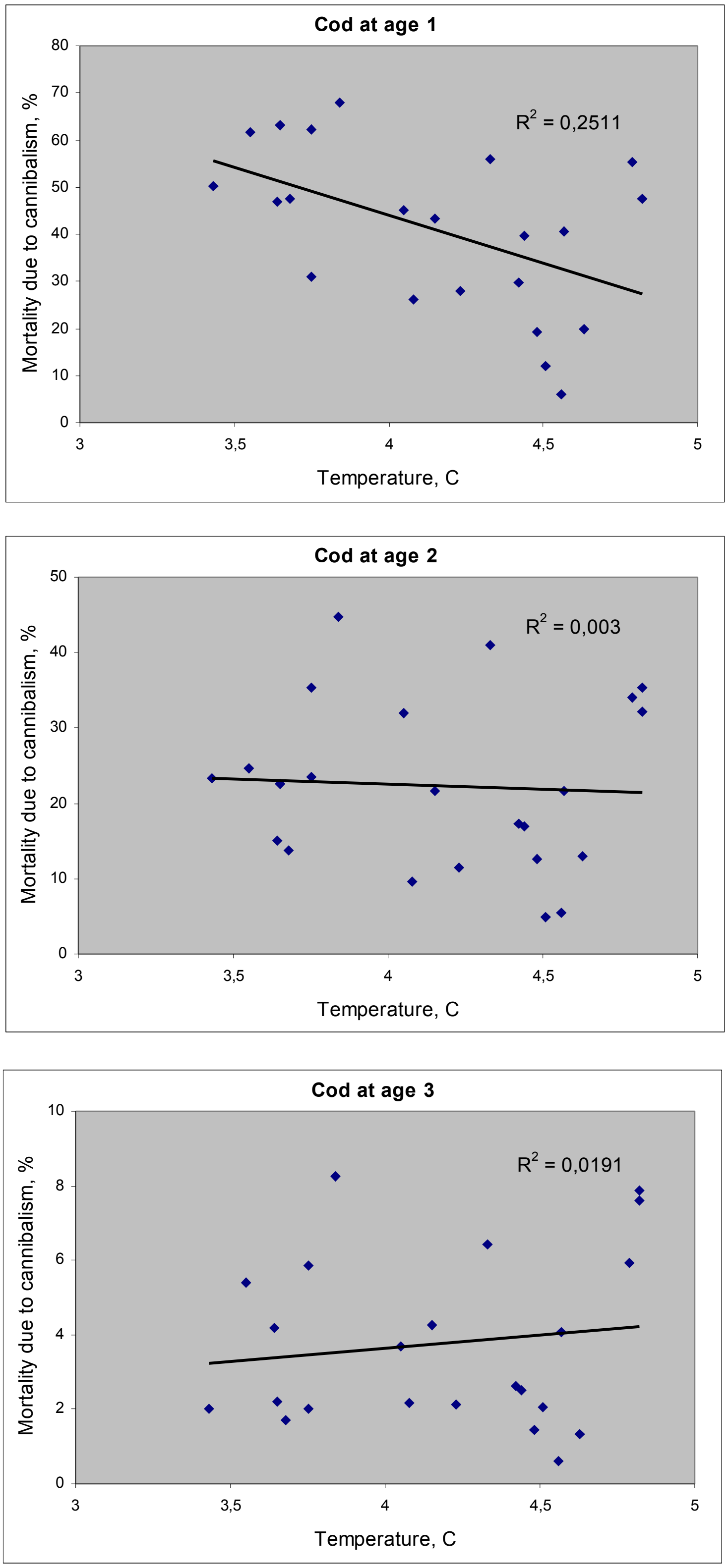

Figure 8. Relationship between cod mortality at age 1-3 caused by cannibalism and annual water temperature following STOCOBAR estimates that based on the historical data for 1984-2009.

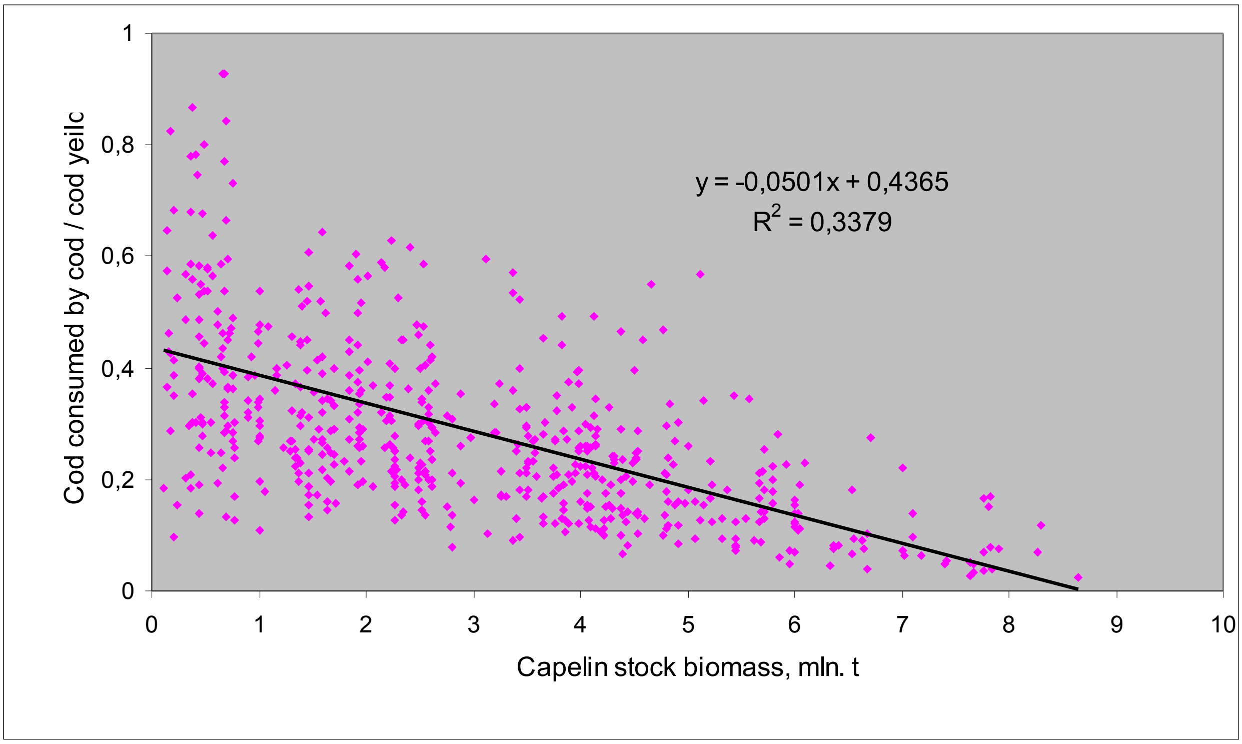

Figure 9. Relationship between ratio of the biomass of cod consumed by cod and cod yield and capelin stock biomass from STOCOBAR simulations.

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