Appendix 13

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on

Optimal long-term harvest in the Barents Sea Ecosystem

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The joint PINRO-IMR project for estimation of optimal long-term harvest in the Barents Sea Ecosystem was adopted at the 33rd session of the JNRFC. According to the mandate, in the first stage (2005-2007) the studies were focused at a scientific assessment of maximum sustainable yield of NEA cod. This work should be based on an analysis of the population dynamics of cod and take into account this species interaction with other species, which influence the yield from the cod. The assessments have to include all ecosystem elements available for evaluation, i.a. natural and man-made effects on reproduction, growth and survival.

Below the main findings from the first stage of the joint Research Programme are summarized. This includes quantitative evaluation impact of ecosystem variables on cod growth, recruitment, fecundity, skipped spawning and cannibalism along with the overall status of the assessment of cod long-term yield. Capelin abundance and temperature are identified as the main ecosystem factors that influence cod stock dynamics.

Growth of cod

Correlation analysis of the time series 1946-2004 showed that for all age groups except age 6 there were statistically significant relations between cod weight at age and stock size of the adjacent age groups. Sea temperature (Kola section) was significant for ages 4-7 and 13+. The available time series (1973-2004) for capelin biomass was significant for ages 3-6. The cod weight tended to increase with capelin biomass and temperature, and to decrease with cod abundance (density dependant growth). On this basis weight at age was modeled as a function of the weight at age for the same cohort in the previous year and the significant parameters mentioned above.

With this growth model the simulation results show reduced yield and stock size at low fishing mortality, compared to simulations with fixed weights at age.

Cod cannibalism

The stomach sampling of cod has shown that cannibalism is an important source of mortality for young cod (in some years up to age 4). Cannibalism mortality depends on the abundance of large cod and the availability of other food, where capelin is the most important. The abundance of age 1-3 cod indicated by the survey indices and the abundance of young cod in cod stomachs are

well correlated. An inverse relationship between mortality induced by cannibalism and capelin abundance was found. Cannibalism was at a high level from 1947-1965 and then again in the mid-1990s. The high level of cannibalism in the mid-1990s was comparable to that observed in the 1950s.

Simulations where cannibalism is modeled as a direct function of the biomass (or abundance) of adult cod, show a cyclic stock development; -a large stock of adult cod graze down the young cod, which later leads to a low stock of adult cod, which again improves the survival of young cod, and so on. The cycles in these simulation results are much more regular than experienced in the stock history. At a given fishing mortality the average effect over many simulations may still be realistic. A recent formulation of the EcoCod model estimates natural mortality of ages 0-2 as a function of capelin and temperature, while natural mortality of ages 3-5 is modeled as function of the biomass of older fish. This gives a less regular cyclic pattern, more similar to the experienced history. In all cases models assuming a natural mortality depending on the cod biomass give lower yield and biomass at low fishing mortality, compared to calculations where cannibalism is assumed to be independent of the cod biomass.

Skipping of spawning by cod

Skipped spawning could be considered as a rapid response of cod to unfavorable feeding conditions in the ecosystem. Implementation of this mechanism in the model of the stock dynamics will permit to increase its realism. Skipped spawning could have important implications for the estimation of spawning stock biomass and egg production because a significant portion of the mature population may not participate in the spawning.

In addition to the historical data joint studies PINRO and IMR in 2005-2007 have identified potential skipped spawning in Barents Sea cod. The methods used were visual (gonad staging) and histological techniques. There has been a comparison between the visual staging of gonads undertaken at PINRO and IMR along with a comparative study on histological techniques. The techniques are comparable. The two laboratories estimated similar levels of skipped spawning. The staging methods were compared with histological methods and gave similar results. The former allows a large number of fish to be processed, especially at sea, and the latter provides a more precise but expensive and time-consuming estimate.

According to the data obtained, the fish skipping spawning are mainly females aged 5-8. This is, most of all, caused by organism energy depletion after 1-2 spawning times, in conditions of low recovery processes in the feeding period. In addition to skipped spawning in females, both PINRO and IMR have evidence of skipped spawning in cod males. At very low stock size, skipped spawning in males could be a problem for egg fertilization.

Conducted studies show a clean distinction between the fatness (hepatosomatic index - HSI) and Fulton's condition factor (K) for maturing and skipped spawners in cod. The values 4.5 % for HIS and 0.8 for K in November/December may be considered as threshold for skipping spawning fish. Below these values the mechanism of preparation to the current spawning does not work because of the low energetic reserves. There was revealed a good correlation between mean fatness (ages 5-8) and mean portion of females with fatness < 4.5. Due to these results at present, skipped spawning can be identified through a combination of 'fatness' (HSI) and condition (K). The joint surveys from August/September, PINRO data time series from November/December and IMR February surveys are available. However one should to take into account that the relationship between fatness and Fulton's condition of an individual is quite noisy, therefore, conversion between condition and HSI will generate uncertainty in any

estimated HSI. It is recommended that in the future HSI is used as a proxy to estimate the proportions of skipped spawners in the cod population.

It was revealed a relationship between capelin stock size and the portion of cod females with low fatness. Under conditions of insufficient capelin availability as prey species, the number of cod that skip spawning increases. However, a formal regression relationship is not available at present. The relationships between capelin biomass and both portion of females HSI < 4.5 was particularly good for the period 1984 to 2006 (absolute value of the correlation coefficient > 0.58), however the relationship was not so good for the preceding years (1973-83).

The obtained results on cod skipping spawning were presented at the ECONORTH conference in Tromsø in 2007.

Cod fecundity

The total egg production (TEP) of Barents Sea cod was estimated from the virtual population (VPA) numbers of mature adults, using age-length keys, estimated relative condition and published fecundity/condition relationships. Over the period 1946 to the present there has been an overall trend of decreasing mean length of mature females, the largest difference occurring between the period before and then after the early 1980s. There has also been a corresponding increase in mean condition of mature females over the whole time series. There was an approximately linear relationship between the spawning stock biomass (SSB) and the estimated TEP with relatively little scatter. However, the variability in TEP at a given SSB is relatively large at low stock sizes.

Individual absolute cod fecundity (IAF) occurred to depend strongly on fish weight, length, liver weight, gonad weight; there are average links of IAF with liver condition indices, Fulton's condition factor, while a weak link with gonadosomatic indices. There are links of IAF of cod at age 6 and 7 with rations (in Kcal) in a pre-spawning year (Yaragina, Dolgov, Kiseleva, 2003). While there is an overall tendency to increase IAF with the number of spawning seasons, significant relationships of IAF of cod at the same age with the number of spawning seasons were not revealed. The closest positive relationship was revealed between individual absolute fecundity and such biological parameters as body and liver weight, fish length and age. There is a weak but reliable relationship between individual absolute fecundity and fatness index.

Growth of Capelin

There was performed the analysis of capelin growth rate dependence on water temperature, indices of atmospheric circulation and stock biomass. Total 66 data series of independent variables for the period of observations from 1971 to 2004 were studied by correlation analysis, using one predictor variable at a time. In accordance with the results obtained at age 1+ the closest positive relationship (correlation coefficient – 0.5) is obtained between the capelin growth rate and water temperature in the central branch of the North Cape Current, in 0-50 m layer, in the third quarter. At age 2+ strong negative relationship (correlation coefficient - -0.67) of the weight growth and biomass of capelin aged 2+ in the previous year has been revealed. A relationship of the growth rate and water temperature and the indices of atmospheric circulation (the greatest coefficients of correlation – from 0.4 to 0.47) has been found for capelin at the age older than 2+.

The coefficients of correlation between length/weight of capelin and euphausid abundance indices were obtained for different areas of the Barents Sea based on macro-plankton survey data

conducted by PINRO. The most statistically significant relationship between these parameters of capelin growth and relative abundance of euphausids in autumn and winter was revealed for fish at age 2. The highest correlation coefficients were related to abundance indices of macroplankton in the eastern Barents Sea. The closest relationships between indices of euphausid abundance and absolute/relative increments in length and weight of capelin were registered in fish at the fourth year of life (age 3+). For younger age groups no statistically significant correlation coefficients were revealed. Based on the obtained calculations, equations of linear regression for estimation of annual relative increments in length and weight of capelin at the fourth year of life were found.

Predation by marine mammals

There are 6 species of the marine mammals that is likely to have significant influence on the dynamics of cod and capelin in the Barents Sea: harp seal, minke whale, humpback whale, white-beaked dolphin, harbor porpoise and white whale. In general the data on fish consumption by sea mammals are scarce. For minke whale and harp seal some amount of stomach data exist, but these are still considered rather uncertain for estimating annual consumption of cod. With current knowledge, the preliminary conclusion is that the estimation of long term yield of cod will not be improved by including sea mammals. Some scenarios could be produced for illustration purposes. There are some ongoing work on quantifying the consumption of capelin by minke whale and harp seal.

Models

During the first stage of the project, several models (EcoCod, CodSim, STOCOBAR and Bifrost) were developed as tools for estimation of long-term yield and optimization of the cod management strategies in the ecosystem aspect. The descriptions of these models are presented on the web-site of the project. All of these models have both advantages and shortcomings. All models satisfactorily describe the necessary biological processes (growth, maturation, cannibalism), however, they treat uncertainties to a different extent.

The current version of EcoCod is an extension of the model CodSim that has been used on first stage of the project to estimate long term yield for NEA cod in a single species approach. The current model version is realized as an Excel spreadsheet model. Current version includes following submodels: cod recruitment, growth, maturation, cannibalism and fishing. The results from “reality check” runs for the EcoCod model demonstrate its ability to simulate cod stock dynamic and fishery in most recent period (1973-2006). Sensitivity tests demonstrate influence of different modeled processes on model outputs. It was concluded that most important factor for estimation of long term yield and corresponding F is the recruitment model.

At the latest project meeting (February 2008) it was concluded that the current version of the model needs further development to improve the estimation long term yield. These developments should include cod-capelin interaction and influence of other species (mainly herring and marine mammals). The plan for future work includes a development of capelin sub-model for EcoCod and work on reconstruction of data on capelin dynamics and cod cannibalism for the whole period since the 1940s. It is believed that these data will allow creating more accurate sub-models for cod recruitment and growth.

Conclusions so far

The preliminary results from EcoCod model in current configuration supports a conclusion made in the first stage of the project using CodSim model. It was shown that the Harvest Control Rule currently used for cod by Joint Russian Norwegian Fishery Commission correspond to a regime providing a long term mean catch close to maximum possible one.

Research Program for the second stage of joint IMR-PINRO project on evaluation of optimal long-term harvest in the Barents Sea Ecosystem (2009-2011)

EVALUATION OF OPTIMAL LONG-TERM HARVEST OF COD AND CAPELIN IN THE BARENTS SEA ECOSYSTEM

Objectives:

i. Quantitative estimations of capelin impact on cod stock dynamics in long-term simulations.
ii. Estimation of long-term yield of cod and capelin under different scenarios of capelin stock dynamics

Description of work:

Model the response of the cod stock on changes in capelin stock size and water temperature. It also includes the effects of fishing. The model will be validated using historical capelin data since 1972. The input data on cod and capelin stock size and biological parameters will be derived from reports of ICES AFWG. A longer time series on the capelin dynamic back to the 1940s will be considered from analysis on the time series of cod stomach sampling. The data on the joint cod stomach content database as well as the temperature observations at the Kola section will be used. Improvement on modelling cod cannibalism and cod recruitment will be an integrated part of the work. Simulations will be based on a stochastic approach.