Ecosystem dynamics and fisheries management in the Barents sea

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The Barents Sea is one of the richest fishing and hunting grounds in the world. For the past several centuries fishing, as well as hunting of marine mammals, have played an important role in the function and dynamics of the ecosystem in this area. In the early period the fisheries were purely coastal, based on top predators, and had a minor effect on ecosystem dynamics compared to natural variation. When the offshore fisheries started to extend the effort in the Barents Sea the impact on the state of the fish stocks and on the ecosystem as a whole began to increase rapidly. Presently the large-scale fisheries is one of the main factors determining the state and dynamics of the ecosystem in the Barents Sea. On the other hand, ecosystem factors strongly affect stock development, and may so have serious consequences for the fishery. Abrupt changes in the ecosystem could produce stronger effects on the stocks than regulated fisheries.

The need for an ecosystem approach to fisheries management is widely recognized now. Implementation of this in the Barents Sea is a great challenge, and presently we are only taking the first steps in this direction. The Barents Sea is shared between Norway and Russia, and the two countries have a mutual interest in a rational management of the fish stocks. Therefore, the major studies on development of the ecosystem approach to fisheries management in the Barents Sea are conducted through joint projects of the Institute of Marine Research in Norway (IMR) and the Polar Research Institute of Marine Fisheries and Oceanography in Russia (PINRO).

In the history of harvest of the Barents Sea one can identify several periods with respect to ecosystem consequences and development of the fishery management. A sharp reduction in abundance of marine mammals was the first pronounced large-scale change in the Barents Sea ecosystem induced by human harvesting activity. As a result of unregulated hunting the stocks of right whales were extinct, or almost extinct, around 1800-1850. The walrus stock was depleted so that hunting became unprofitable (Nakken 1998). Management measures were introduced in order to limit the catch. However, they were too late.

The over-exploitation of demersal fish stocks was the second large-scale disturbance in the Barents Sea ecosystem caused by fisheries. With a steady increase in fishing effort from the 1950s, signs of over-exploitation of cod, haddock, redfish and Greenland halibut became apparent. Technical management measures were introduced in order to limit the catches and to restore the depleted stocks. These measures had some positive effect, but didn't achieve the stable healthy state of these stocks for the future.

The third important event in the history of the fishery in the Barents Sea is related to expansion of harvesting from the top predators to intermediate trophic levels. Large-scale fisheries of capelin, polar cod and shrimp were developed in the Barents Sea in 1970-1980. Due to these changes, the influence of the fishery on the Barents Sea ecosystem increased because capelin, polar cod and shrimp played an important role as a key intermediate links in the food web. The expanded fishery demanded further development of its management. In

1975-1980 a fishery management system that included both total allowable catch (TAC) and various technical means for protection of juveniles was introduced in the Barents Sea. However, this management system was mainly based on a single-species approach and didn't take into account ecosystem considerations.

During the last decades exploitation of all main commercial species in the Barents Sea generally corresponded to a maximum allowable level. Under these circumstances the importance of an ecosystem component in the fisheries management increased greatly. This related to a threat to the ecosystem stability as response on non-adequate management measures. This danger is especially increased when too hard fisheries pressure coincides with adverse impact on stock from the environment. Such situation was observed in the Barents Sea in the middle of the 1980's. The most notable event was the collapse of the capelin stock that had a drastic effect on higher trophic levels. The dramatic fluctuations in the Barents Sea ecosystem in the 1980s stimulated both intensified research in the Barents Sea ecosystem and understanding of the need to adopt new management measures aimed at evaluation of ecosystem effects and consequences. In the 1990s major attention has been given to the development of multispecies approach. Since the beginning of the current century the ecosystem approach has been given the highest priority.

The first step to include ecosystem considerations into the fishery management advice is to identify those ecosystem mechanisms responsible for the major natural fluctuations in recruitment, growth and natural mortality of commercial species. This theoretical model should be simple enough to correspond to the existing monitoring system that should provide necessary ecosystem information for making management advice.

The main feature of the Barents Sea ecosystem is large fluctuations in environmental conditions. Dynamics of the ecosystem is governed by the inflow of Atlantic water masses, which determines distribution, recruitment success and growth of the main commercially important species. Historically, there have been large variations in the climate conditions, with switching between warm and cold regimes. This scheme of large-scale environmental changes can be used today as a conceptual basis for inclusion of climate-stock relations in fishery management.

Another important element of the ecosystem approach to fisheries management is trophic relations. Consumptions by the main predators in the Barents Sea ecosystem – cod, harp seal and minke whale are all subject to ongoing monitoring investigations, and therefore have a potential for inclusion in the management advice.

The fishery management in the Barents Sea is conducted through the Joint Russian-Norwegian Fishery Commission, which is a political body at the governmental level and which acts based on advice from the International Council for Exploration of the Sea (ICES). Currently the stocks, although they strongly interacting, from the Barents Sea are treated in several assessment working groups at the ICES. (Figure 1). Today the AFWG is considered the main body of the ICES in regard to implementation of ecosystem considerations into stock assessments and to the fishery management in the Barents Sea.

The current and expected state of the Barents Sea ecosystem has been considered routinely at the AFWG since 2002. Last years the informational basis for this was the "Joint PINRO/IMR report on the state of the Barents Sea ecosystem". This report summarized and analyzed ecosystem monitoring information for evaluation of the current situation, making projections and putting the knowledge into operational use. Jointly, IMR and PINRO have developed long time series for main components of the Barents Sea ecosystem, including climate, plankton, benthos, fish, marine mammals and sea birds. Furthermore, there are time series on species interactions – particularly on the diet of Northeast Arctic cod and on influence of the climate on recruitment of commercial species of fish.

AFWG	WGWIDE	WGPAND	WGHARP
Cod *Haddock* *Saithe* *Deep-sea redfish* *Golden redfish* *Greenland halibut* *Capelin*	*Herring* *Blue whiting*	*Shrimp*	*Harp seals*

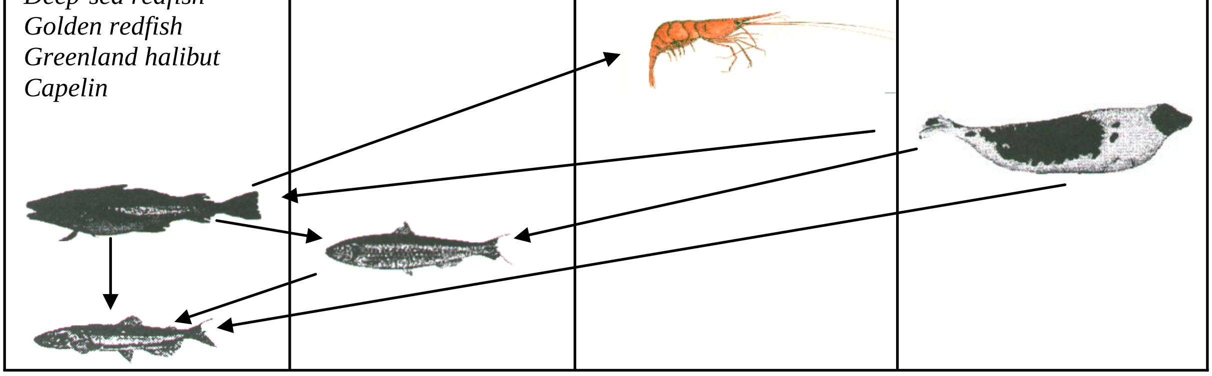

Figure 1. ICES Working Group responsible for the stock assessments and management advice for the commercial species in the Barents Sea. AFWG – Arctic Fisheries Working Group, WGWIDE – Working Group on Wideliy Distributed Stocks, WGPAND - Pandalus Assessment Working Group, WGHARP - ICES/NAFO Working Group on Harp and Hooded Seals. The arrows show interspecies interactions.

The availability of necessary ecosystem information is only one of the needed items for implementation of an ecosystem approach to management. Another needed element is the development of appropriate methods and instruments for incorporating of ecosystem information into stock assessment and existing harvest control rules.

Presently we have the following methods and tools for implication of ecosystem information in fisheries management in the Barents Sea, which are used or have potential for application at the AFWG:

1. Qualitative estimations of ecosystem impact on population parameters of commercial species
2. Statistical model
   - Recruitment of cod, capelin, herring
   - Growth of cod, capelin
   - Natural mortality (cannibalism) cod, haddock
3. Multispecies models
   - EcoCod
   - Bifrost
   - Gadget
   - STOCOBAR
4. Numerical models for simulation the drift of eggs and larvae of cod, capelin and herring
5. Inclusion of data on cod predation into stock assessment of cod and haddock.

6. Inclusion of data on cod predation into estimation of TAC for capelin

The most simple method is the qualitative analysis that contain the expected qualitative estimations of influence of the main ecosystem parameters on population parameters of commercial species. The overall effect summarizes the influence of all ecosystem factors and is expressed as high, medium or low value of stock parameters compared with their long-term levels. The advantages of this approach in compare with quantitative methods that it is able to use all kind of ecosystem information.

The main method for inclusion ecosystem information into stock assessment and fisheries management advice is through mathematic modeling. The most common method is the use of regression models.

The other kinds of models are simulation models that incorporate both species interactions and environmental influence. Development of complex multispecies models designed to improve fisheries management in the Barents Sea based on species interactions stated in the mid 1980s. At the first stage, the work was focused on models that included maximum number of species interacting through to their trophic relations. This approach was used in IMR to develop such models as MULTSPEC, AGGMULT and SYSTMOD (Tjelmeland and Bogstad, 1998; Hamre and Hatlebakk, 1998). In PINRO this approach was employed for development of the MSVPA model (Korzhev and Dolgov, 1999). All these models can give quantitative characteristics of commercial species interactions in the Barents Sea and can be useful to solve some theoretical problems of multispecies harvest management. However, the use of these models for practical tasks concerning fisheries management is limited by a high level of uncertainty in calculations, due to assumptions employed in the models and incomplete data, which are needed for the estimation of model parameters. Therefore, since the second part of the 1990s more simple, in structural sense, models have been prioritized. Benefits of multispecies models include: improved estimates of natural mortality and recruitment; better understanding of stock-recruit relationships and variability in growth rates; alternatives views on biological reference points.

The separate group of model consist of drift models. This kind of models has been used to simulate the drift of cod, capelin and herring larvae in the Barents Sea in order to find their dispersion area. Parameters in the model such as the location of spawning area, time of spawning and vertical distribution of eggs and larvae, as well as temperature, salinity and current information, are based on historical data and recent field observations. Simulations of the drift routes are performed by means of tracers representing the fish larvae.

One of the main directions in using ecosystem information for improvement of management advice is prognosis of stock dynamics. In spite of many theoretical studies in this field our possibility for producing prognosis for the stock dynamics based on ecosystem information that can be used in management recommendations is restricted. Considering AFWG as an example we can see that in 2007 only 3 prognoses on stock parameters that directly included ecosystem data was available these. These were the following:

- Prediction of growth rate of cod by STOCOBAR model;
- Prediction of cod recruitment by regression models;
- Expected stock parameters of cod and capelin based on qualitative analysis of ecosystem impact.

So presently we have obvious inconsistency between the amount of regularly collected ecosystem information and application of this information in fisheries prognoses for management advice. In future attempts need to be taken to improve this situation.

Along with short- and medium term prognosis of stock dynamics much interest is in long-term projections of stock dynamics that take into account expected changes in ecosystem. In this regard the most interesting are influences on stock of the expected warming in the Barents Sea and the increasing in abundance of marine mammals.

However, today our possibilities to forecast the consequences of long-term changes in the ecosystem influencing stock dynamics in the Barents Sea are very restricted. This is more limited compared to short- and medium term prognoses. During the last 15 years we didn't achieve any essential progress concerning model analysis of impact of changes in abundance in the main marine mammal species on the state of populations of commercial fish in the Barents Sea. In this question we are still at the same level as in the end 80s - beginning 90-s, when in IMR developed the MULTSPEC model. Due to this model it was for the first time possible to make simulations on the development of cod, capelin and herring stocks under different scenarios changes in abundance of minke whale and harp seals (Tjelmeland and Bogstad 1998). These results showed one interesting feature, which reflects the complexity of the system, that there would be larger gains in average in cod fishery by removing the seals than by removing the whales, despite the fact that whales ate more cod than seals in the model runs. The explanation lies in the indirect effect through the herring-capelin-cod dynamics.

Estimation of consequences of expected climate warming on the state living resources in the Barents Sea at last time have increasing interest. However, in spite of extended studies in this field, today we have mainly qualitative analysis of the possible changes in distribution and state of stocks in the Barents Sea in relation with expected climate changes. According to predictions made by Drinkwater (2005), if temperature increased by 1 or 2ºC above present day values, NEA cod would benefit from increased recruitment. If temperature increased by 3ºC or 4ºC the stock of NEA cod would not see any any further change in recruitment.

Quantitive modeling analysis of change in the state of stocks in the Barents Sea as respons to climate changes is a needed future issue. In this sense multispecies models need to be used. For example the STOCOBAR model (Filin, 2005). Long-term simulation by this model demonstrates that under increasing water temperature in the Barents Sea to 1-4 ºC above present day values both growth rate and rations of cod will be increase. However, relative increment in ration will be overtaking a relative increment in body weight. Discrepancy between relative increments in body weight and rations will grow, as temperature will rise. It follows that under the same abundance role cod, as predator, will increase when temperature will rice. This conclusion is important in an ecosystem aspect, taking into account that cod is one of the main predators in the Barents Sea ecosystem.

Apart from ICES the joint IMR/PINRO study on development of an ecosystem approach to the fisheries management in the Barents Sea are conducted at the request from Norwegian - Russian Fishery Commission. In 2003 the Commission requested IMR and PINRO to evaluate the prospects for long-term yield of commercial species in the Barents Sea taking into account species interactions and the influence from the environment. According to this request the joint IMR/PINRO project on evaluation of optimal long-term harvest in the Barents Sea Ecosystem was initiated. The project is divided into two phases. During the first phase (2005-2007) empirical relations will be used to evaluate prospects for long-term yield of cod. During the second phase (2008-2014) other species will be included.

The results from the work in the sub-projects are incorporated into mathematical models – EcoCod, Bifrost and STOCOBAR- which are used for long-term simulations to test harvesting control rules and associated sustainable long-term catch. EcoCod is a stepwise extension of a single species model for cod to multispecies model where cod growth, maturation, cannibalism and recruitment are modelled on the basis of their correlations with ecosystem factors. In the first phase of the project the EcoCod is set as a main tool for evaluation of optimal F-value for cod from ecosystem prospect. STOCOBAR is used for estimation of consequences of changes in temperature regimes and capelin stock for cod stock size dynamics in the Barents Sea under different harvest control rules.

Results of exploratory runs of EcoCod with dependent growth, maturation and cannibalism of cod from ecosystem driving forces has revealed that fishing mortality must be decreased from the present value in order to achieve maximum long-term yield. On the other hand, the outputs from STOCOBAR demonstrate that under ecosystem shifts connected with sharp changing in temperature or capelin stock size the values of fishing mortality that produced maximum long-term yield is distinguished. According to these results values of the reference points for cod should change depending on ecosystem state in order to achieve maximum long-term yield. So, both models demonstrates that current harvesting regulation for cod in the Barents Sea is not optimal from ecosystem prospects.

The current results do not yet give a definite recommendation to management implementation. At the first stage the attention was focused on construction of concepts and mathematical models as tools that address ecosystem approach to long-term fisheries management in the Barents Sea. The next stage will include estimations of the reliability of model simulations with employing uncertainties and their potential use in management practice.

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