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ECOSYSTEM DYNAMICS AND OPTIMAL LONG-TERM HARVEST IN THE BARENT SEA FISHERIES

Proceedings of the 11th Russian-Norwegian Symposium
Murmansk, 15-17 August 2005

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PREFACE

The 11th Russian-Norwegian Symposium entitled “Ecosystem dynamics and optimal long-term harvest in the Barents Sea fisheries” took place in Murmansk, Russian Federation, 15-17 August 2005. The organizers of the Symposium were the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia, and the Institute of Marine Research (IMR), Bergen, Norway. The Symposium was held pursuant to the decision of the intergovernmental Joint Russian-Norwegian Fisheries Commission.

The history of such international symposia dealing with different aspects of scientific basis for fisheries management in the Barents Sea dates back to 1983. They are held every two years. The list of titles of the 10 symposia that have been already held is given on the reverse side of the cover to this volume.

In 1983-1989, only scientists from PINRO and IMR participated in such symposia. Afterwards, representatives of fishing industry and national management bodies joined them. The most representative was the 10th Symposium, which made an analysis of life cycles and management measures for different stock units of those Barents Sea species (cod, capelin, Greenland halibut, red king crab, northern shrimp and seals) that also inhabit other areas of the World Ocean, such as waters of Greenland, Iceland, Faeroe Islands, Canada and Alaska.

The organizers of the 11th Symposium hope that these Proceedings will contribute not only to deeper understanding of the problems facing all the participants of the fishery – managers, scientists and fishermen but also to the search of practical ways for solution of these problems.

In this regard we express our deep appreciation to authors for their notably interesting contributions, to participants of discussions, co-chairs of theme sessions and also extend our gratitude to all PINRO employees involved with the Symposium.

Co-conveners V. Shibanov, Å. Bjordal

Murmansk, Bergen. September 2005

OPENING ADDRESS

by

Vladimir Shibanov

Research Director, Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia

Ladies and gentlemen, time has come to open the 11th Russian-Norwegian Symposium. I am a Russian Co-Chair of the Steering Committee for this forum. From the Norwegian side Dr Åsmund Bjordal is a Co-Chair.

I would like now to make a brief introduction of the participants of this Symposium. It is attended by Director of the Department for Food, Fisheries and Agriculture of the Government of the Murmansk Region Dr Vyacheslav Zilanov. I am delighted to welcome heads of delegations from research institutions, Director of the Institute of Marine Research Dr Tore Nepstad and Dr Boris Prischepa, Director of PINRO. The Symposium is also attended by representatives of the fishing industry of Russia and Norway. I am also glad to welcome representatives of the diplomatic circles, Consul General of the Kingdom of Norway in Murmansk and a representative of the Murmansk office of the Russian Ministry of Foreign Affairs, who also considered it important to attend our symposium.

Over the past years our symposium has evolved from being just a bilateral event into a truly international forum. And it is my pleasure to welcome a representative of ICES, Dr Poul Degnbol.

The history of these symposia is closely related to the history of management of fish stocks in the Barents Sea by the Joint Russian-Norwegian Fisheries Commission. The first symposium was held in 1983. After that it was decided that such symposia would be organized every second year and address more specific issues or topics. For instance, the 1983 symposium was dedicated to the biology of the Barents Sea cod, while the next one focused on studies of the Barents Sea capelin. Over 22 years of the history of these symposia a variety of topics was addressed including such as “Specific features of the impact of hydrographic conditions on the dynamics of commercial stocks” in 1986, the biology of such important species as herring and blue whiting was reviewed in 1989. Moreover, in addition to discussing the biology of separate stocks the symposia gradually moved on to focusing more on studies of the Barents Sea ecosystem. For example, the impact of recruitment dynamics variation on the status of commercial stocks was discussed in 1994. Issues relating to the Barents Sea ecosystem were on the agenda of symposia held in 1991, 1999 and 2003. Selectivity of fishing gear as a basis for refining the fisheries regulations for the Barents Sea was under review at the 2001 symposium. At the last symposium held in Norway in 2003 we were given the opportunity to learn from experience gained by institutes of other countries in studying stocks in the North Atlantic and Pacific oceans similar to our stocks in the Barents Sea. And it seems to me, that that experience is of particular interest as we see an increased number of representatives of the fishing industry and management participating in our symposia.

Moving on to the topic of this symposium I would like to say, that it in full measure mirrors the tendencies in contemporary fisheries science. The need for an ecosystem approach to the management of marine biological resources is being generally recognized nowadays.

Knowledge and experience available today suggest that when devising a fishery management strategy failure to take due account of ecosystem mechanisms behind formation of fish production in a water body may undermine the effectiveness of fisheries. This is of particular importance for our Barents Sea as this area is situated in the zone of active interaction of waters of different origin, which is the reason for a high volatility of its ecosystem under varying climatic conditions.

I presume, we can be talking for long about this and a considerable part of presentations will be dedicated exactly to these questions, but as a Co-Chair, I would first like to briefly tell you about our programme. In the next two days we will listen to 19 plenary presentations and have the opportunity to look into 12 posters. So, the programme we have ahead is quite substantial.

OPENING STATEMENT

by
Vyacheslav Zilanov

Member of the Government of the Murmansk Region, Director of the Department for Food, Fisheries and Agriculture of the Murmansk Region, Russia

MURMANSK REGION – AN IMPORTANT FISHERIES AND STRATEGIC INDUSTRIAL REGION IN THE NORTHWESTERN RUSSIA

Dear Co-Chairs of the 11th Russian-Norwegian Symposium, Dr Boris Prischepa, Dr Vladimir Shibanov, Director General of the Fisheries Directorate of Norway, Dr Tore Nepstad and Dr Åsmund Bjordal.

Dear representatives of the Consulate General of the Kingdom of Norway in Murmansk, reprsentatives of the Ministry of Foreign Affairs of the Russian Federation, Federal Agency for Fisheries, fishing industry of the Murmansk region and Northern basin, dear colleagues from Russia and Norway, friends.

It is my great pleasure on behalf of the Government of the Murmansk region, Governor of the Murmansk region Yuri Evdokimov to cordially welcome you here on the Murmansk soil, in the hero-titled city of Murmansk, in connection with the opening of the Russian-Norwegian Symposium, a very important event for the fishing industry and all of the scientific community. I avail myself of the opportunity now, particularly knowing that for many of our Norwegian colleagues this is their first visit to the Kola land, to briefly introduce our region to you and then be back again to the topic of the Symposium.

The Murmansk region is a young region within the Russian Federation. It was established on 28 May 1938. The area of the Murmansk region is 144.9 km^2. It is mainly located beyond the Arctic Circle. Its west-east extent is 550 km and north-south 440 km. The population of the Murmansk region is 872 000 people, 92% are townspeople. I would like to refer you to that the second big, in terms of population size, region in the world after Murmansk region, which also lies beyond the Arctic Circle, Alaska, has a population of no more than 600 000 people. Among large towns in the Murmansk region mentioned in the first place should be Murmansk (329 000 people), Apatity (64 000), Severomorsk (54 000) and Monchegorsk (51 000). Three administrative territorial districts of the region located in the central part and coastal areas of the Kola Peninsula (Lovozero, Kola and Kovdor) are the areas, where communities of the First Nations of the North, Sami people, live. Murmansk region is very important strategically for the Northwestern Federal Okrug. First of all, this is due to specific geopolitical position of the region, unique, in terms of composition and amount, mineral and biological resources. Besides, important also is an outlet to the ocean and ice-free sea harbour.

Northern shipping route is a national transport main line. It begins at Murmansk, northern gates to Russia, which is a starting point of the sea transit along the Northern shipping route.

Murmansk is a capital of the trans-polar region, where a fleet of nuclear vessels was created, which continues to successfully perform its duties today.

Industry forms the basis of the economy of the region. It constitutes 41.6% of the gross regional produce. 25% of the population is employed in the industry. Mining industry makes up 55% in the total industry and the fishing industry 15.6% (Fig.1). Murmansk region plays an important role in the overall Russian production. Every 6^{th} ton of fish products is produced in our region. We produce 100% of the Russian production of concentrated apatite, 80-100% of mica and other minerals. Moreover, the region produces nepheline – 100%, nickel – 45%, cobalt – 26%. As you can see the contribution of the Murmansk region into production of a number of important mineral and biological resources is quite outstanding (Fig.2).

During the process of economy reformation in the Murmansk region overall industrial output underwent significant changes, and in 1994-1996 it was at a minimal level. However, in recent years the production has been growing. The biggest growth against 1996 has been noted for the non-ferrous metallurgy, ferrous metallurgy and chemical industry. Over the past years food industry, and fishing industry in particular, has been showing an increasing trend (Fig.3). The structure of industrial production in the period of transition from directive planning to market economy underwent considerable changes. In Fig. 4 the year of 1990 is given as a reference year. The figure shows, that at that time the fishing industry, and the food industry as a whole, which made up 34.6%, played a key role in the economy of the region. In recent years in the process of reformation its proportion declined to account for 15.6%. At the same time non-ferrous metallurgy, ferrous metallurgy and energy production as well as chemical industry have been growing). This is, in the first place, linked to increased focus on the international market. Presently according to statistics for 2004 (Fig.4) non-ferrous metallurgy is the first important industry in the region (28.3%), second is energy production (21.1%), third fishing industry (15.6%) and fourth chemical industry (15.2%).

The Government of the Murmansk region has defined the strategy of development of the area up till 2015, to include the following main objectives:

- improving and developing industrial and market infrastructure;
- diversification of production, creation of new businesses and promoting modern technologies;
- better use of raw materials and promoting production of more sophisticated products;
- promoting cost-effective and less energy consuming production with improved ecological parameters;
- re-equipment, reconstruction and modernization of production.

The main goal the region has set for itself is to enhance competitiveness of the regional economy and to improve socio-economic situation for the population of the Murmansk region. All this is of equal relevance to the fishing industry, which is one of the key industries in the region.

There are 241 fishing vessels registered at the Murmansk fishing harbour, which are owned by companies of the Murmansk region, of them 35 large vessels (average age – 22.7 years), 163 medium-size vessels (average age 21.3 years) and 43 small vessels (average age 18 years). In addition 160 small-sized vessels are engaged in the coastal fishery, they land all their catch for processing on land.

Yearly catch by companies of the Murmansk region varies from 530 000 to 650 000 t being dependent on the amount of quotas allocated and fishing conditions, and the production of fish products is 440 000-460 000 t per year. About 60% of fish products are supplied to the domestic market and up to 40% to the international market. Currently the fishing industry is being reformed with the aim of enhancing its competitiveness and effectiveness.

The fishing industry will continue to be a key industry in the Murmansk region in the future, as it plays an important role in the development of the region and well-being of its population. Therefore, it is a great honour for me to be among you today. Particularly, in the light of that I am the only person in the Russian delegation, who was among initiators of this forum. This year marks 30 years since conclusion of the Agreement between Russia and Norway on cooperation in fisheries and setting up of the Joint Russian-Norwegian Fisheries Commission.

Everything that has been done so far refers to the management of individual stocks, individual species. And this has yielded tangible results. And for this best thanks to Russian and Norwegian scientists on behalf of fishers of the Northern basin and the Government of the Murmansk region, and for that you are doing everything for conservation and enhancement of fish stocks in the Barents Sea. It is natural, that there were successes deserving respect on the road we had walked together. However, there were also not quite flawless decisions taken. But such imperfect decisions inspire us to do everything for the Barents Sea, one of the most productive waters in the ocean, to continue to be ecologically clean and its biological resources to be harvested in a sustainable manner and to the benefit of fishing industry and the population of Russia and Norway. Besides, we wish also be sure that the advice you provide will indeed allow us continue successful fishing in a long-term perspective.

Moving from a single-species management of living marine resources in the Barents Sea to the ecosystem approach requires not only drawing on scientific and fisheries information already available, but also taking into account socio-economic implications of its application to the fisheries management. In the light of this the fisheries community of the Murmansk region and the whole Northern basin have the right to expect that the industry will only benefit from using such an approach and its implementation will be gradual taking into account traditional nature of the fisheries and their inertance.

I would like now on behalf of the Governor of the Murmansk region Yuri Evdokimov, Government of the Murmansk region to wish the Symposium every success in its work on our Kola soil. We hope that you will not only exchange scientific ideas and come to productive conclusions, but will also have the opportunity to enjoy our still summerly, however turning into autumn weather and the hospitality, which our city and our land can offer.

It is very important to us that your working at this Symposium is fruitful. Best luck to you and thank you for attention.

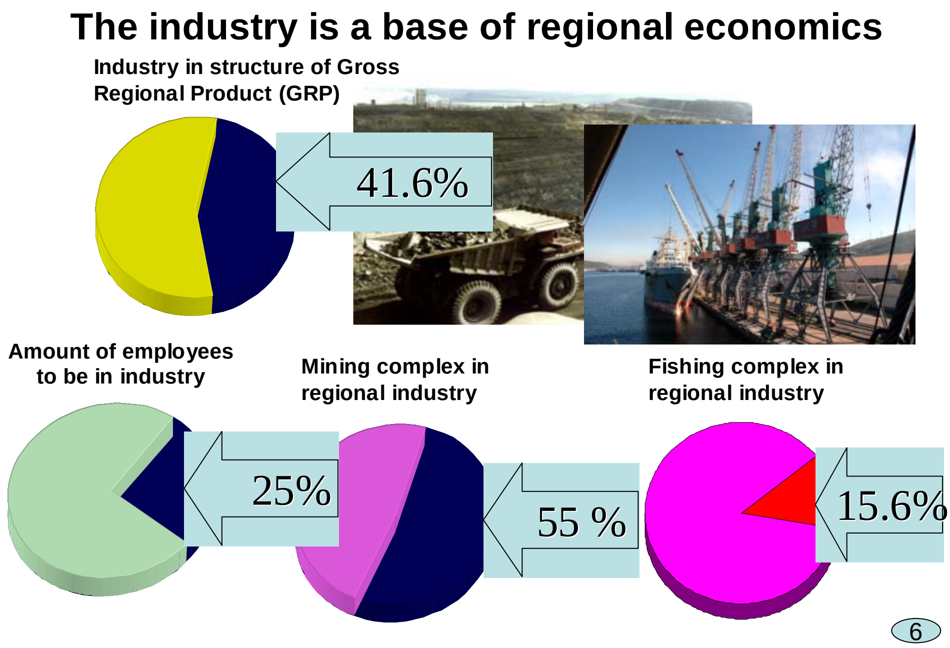


Fig.1. Key industries in the Murmansk region

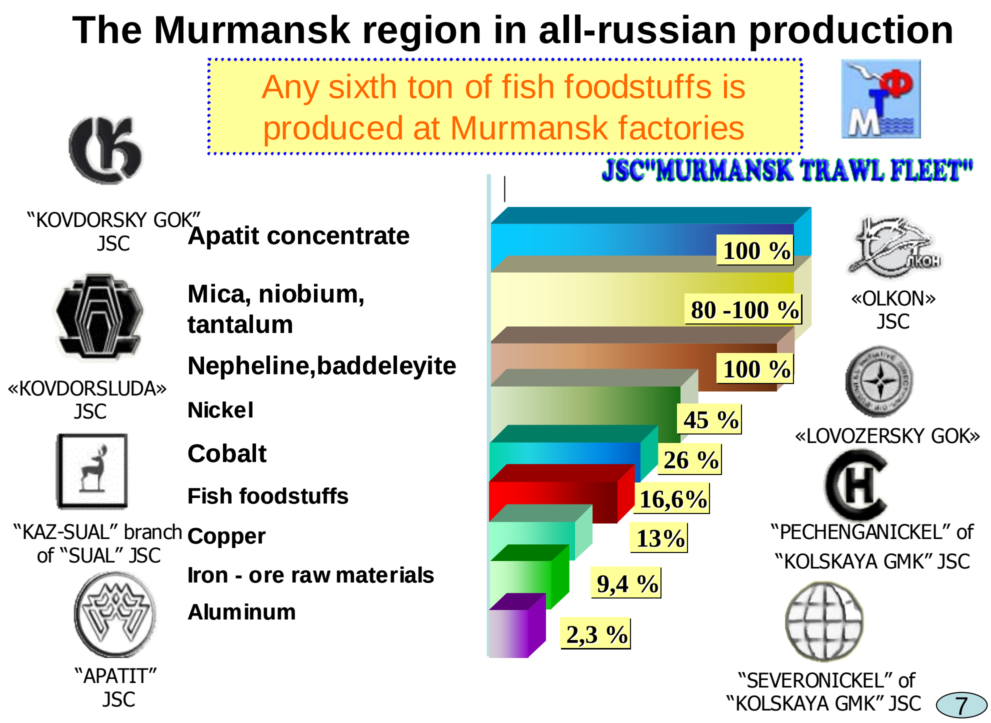


Fig.2. The Murmansk region's share in All-Russian production

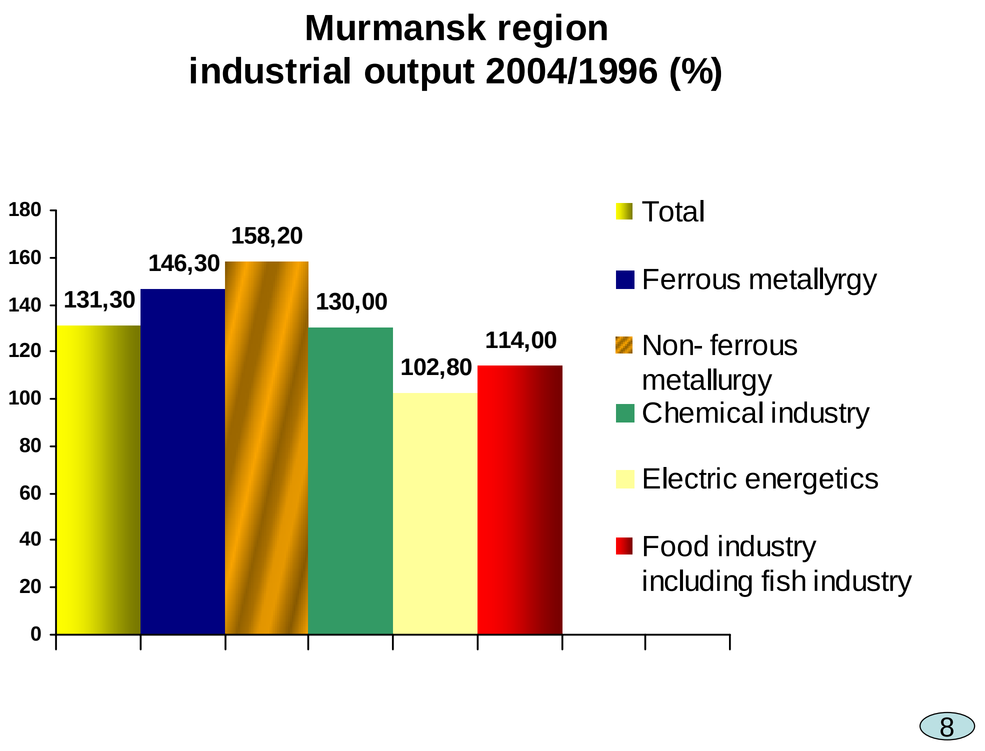
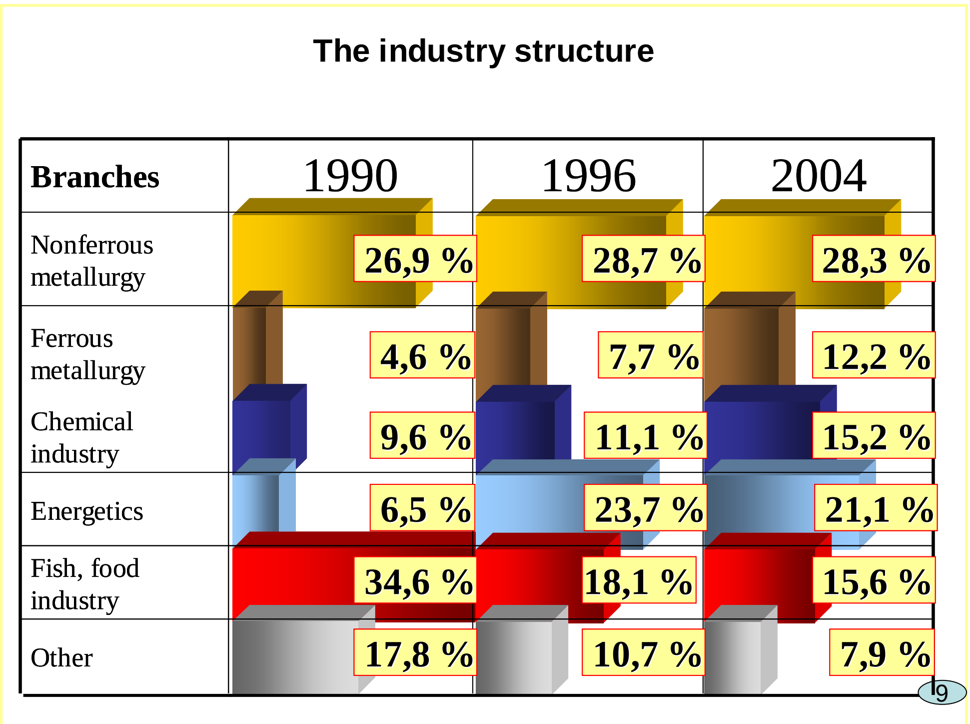


Fig.3. Murmansk region industrial output 2004/1996 (%)



Branches	1990	1996	2004
Nonferrous metallurgy	26,9 %	28,7 %	28,3 %
Ferrous metallurgy	4,6 %	7,7 %	12,2 %
Chemical industry	9,6 %	11,1 %	15,2 %
Energetics	6,5 %	23,7 %	21,1 %
Fish, food industry	34,6 %	18,1 %	15,6 %
Other	17,8 %	10,7 %	7,9 %

Fig.4. The industry structure in the Murmansk region

OPENING STATEMENT

by

Sergey Andreev

Head of the International Division, Russian Federal Agency for Fisheries, Moscow, Russia

First of all, I wish to express my appreciation and gratitude to the Co-Chair from the Russian side, Mr V Shibanov, and Co-Chair from the Norwegian side, Mr Å Bjordal for the invitation to attend this very important and prominent Russian-Norwegian forum. We all know how important fisheries are for the economy of Norway and northwestern Russia. We are also well aware of the importance of cooperation between our countries. The gist of international cooperation is in that it is cooperation among people, and it was, is and should be to the benefit of the people of Russia and Norway.

This year is a significant year for the relations between Russia and Norway in the area of fisheries. It marks a 30-year anniversary of effective joint work under the fisheries agreement concluded between Russia and Norway.

Invaluable contribution to the development of good neighbourly relations between our countries in the fisheries was, in the first place, made by scientists of PINRO and IMR. And, in the first place, it is cooperation within the Joint Russian-Norwegian Fisheries Commission.
From the very first minutes of work of this forum clearly seen is an important role, which the Government of the Murmansk Region, diplomats, scientists and managers play in promoting this development. It is on joint efforts and implementation of plans worked out through our cooperation that the final result of this cooperation depends.

On behalf of the Russian Federal Agency for Fisheries I would like to wish this forum every success in the hope that it will become a new milestone in not only taking decisions, but also in defining approaches to address the challenges we have before us.
Thank you for your attention.

OPENING STATEMENT

by

Peter Gullestad

Director, Directorate of Fisheries, Bergen, Norway

It’s a great honour for me to greet the symposium on behalf of the Joint Russian-Norwegian Fisheries Commission. This year is the 30-year anniversary for the establishment of the Commission. Or at least it is 30 years since the agreement between the USSR and Norway on establishment of the Commission was signed. And throughout all these years it is correct to say that the scientific co-operation between Norway and Russia has been not only an important part of the work of the Commission. It has been the cornerstone. So, as to the successes and failures of the Commission I think science contributed largely to the successes, and only to very few of its failures. On a day like this, I shall be nice and say that science contributed to the successes, and leave the failures.

In recent years together we have achieved quite a lot. We have managed to put in place what I would call the first generation of management strategies and harvest control rules for important fish stocks. We have implemented the precautionary approach. And two years ago the Commission gave the scientists the task to look into the long-term optimal harvest strategies of the stocks in the Barents Sea. It also means including the ecosystem approach into our work. And this symposium is, as I understand it, an important step on our way forward. We will take stock of and summarize our achievements so far in this programme. I very much look forward to learning where we are at this stage. If I were to point out one challenge in particular with regard to where we need new knowledge and better understanding, I would say that it is to get marine mammals into the ecosystem approach and fisheries management. For the important fish stocks we have management strategies in place that can be adjusted in the future based on new knowledge. But with regard to marine mammals, and harp seals in particular, we don’t have any strategies so far on how to include them into an ecosystem approach. This is both a scientific challenge, and a political one.

Speaking of challenges, there are two serious challenges to our co-operation that I have to address in this opening speech. The first is that next year we will be in the sad position to “celebrate” the 10-year anniversary of the problems concerning the conduct of scientific cruises of Norwegian research vessels in Russian waters. In my view these obstacles represent a gross neglect of the common and long-term interest of the Russian and Norwegian fisheries sectors. Let us hope that these problems are solved in the near future so that we can delete this frustrating item for good from our common agenda.

The second and most fundamental and pressing challenge to our co-operation is, however, the ongoing extensive illegal fishery for cod in the Barents Sea. This criminal activity, which has the potential not only to ruin the cod stock, but also to severely damage our otherwise good and close co-operation was on the agenda when Prime Minister Bondevik met with President Putin in Moscow in May. Two weeks ago I attended the meetings between our Minister of Fisheries and Coastal Affairs Svein Ludvigsen and the Russian Minister of Agriculture and Fisheries Aleksey Gordeev in Norway where this issue was on top of the agenda. And I must say that I am much more optimistic about the future now that this issue has drawn the attention at the very high level. I think that Mr. Gordeev showed that this is a problem we decisively have to solve together. It should not be the case that criminals are the ones who profit from our joint management and conservation efforts, and that those who are not criminals, namely most of our fishermen, are the ones who suffer.

When looking at the programme of this symposium and the thorough preparations done by our host, I am convinced that it is going to be a success. I am looking forward to listening to all the speakers during these two days that surely will enlighten us all. Good luck and thank you for your attention.

INVITED PAPER

ICES ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

by

Poul Degnbol

Chair of the ICES Advisory Committee on Fishery Management (ACFM), Copenhagen, Denmark

The international basis for an ecosystem approach

The WSSD Implementation Plan (UN 2002) stated that actions are required at all levels to '*Encourage the application by 2010 of the ecosystem approach, noting the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem and decision 5/6 of the Conference of Parties to the Convention on Biological Diversity'*.

This plan confronts us with a range of issues to be addressed with some urgency given the short time horizon provided. The first is to identify what an ecosystem approach means in conceptual and operational terms. An important part of the latter is to identify the institutional requirements for implementation and how these requirements can be met.

Intergovernmental organisations have developed initial approaches and guidelines to an ecosystem approach. FAO has, on basis of consultations in Reykjavik (FAO 2001), developed guidelines as part of its guidelines for responsible fisheries (FAO 2003). ICES has developed guidelines to support the European Marine Strategy (ICES 2005).

ICES has started a process to provide its advice within the framework of an ecosystem approach. This is based on the WSSD Implementation Plan, the FAO guidelines and the outcomes of the dialogue meeting with clients and stakeholders in Dublin 2004 (ICES 2004).

Institutional consequences

An ecosystem approach to oceans management has far-reaching consequences for the management institutions as it implies normative, cognitive and regulatory changes.

The normative changes include an inclusion of new and multiple objectives in management. New types of knowledge need to be included in the basis for management decisions relating both to the immediate resources for utilisation and other biota and ecosystem functioning. Regulatory changes are required not just because the scope is expanded but more fundamentally because the complexities of marine ecosystems are such that management cannot be based on predictions of outcomes. Fisheries management must more than ever be adaptive, a learning system rather than a system assuming a predictable and direct link between actions and outcomes.

The institutional implications include that processes must be developed for reconciliation of multiple and often conflicting objectives. This must be based on inclusiveness with participation of many types of stakeholders. Other institutional implications are that decision processes must be able to handle uncertain and complex information and that the regulatory framework for implementation must be adaptive.

These institutional implications are such that all countries will be on a steep learning curve in the development of an ecosystem approach.

The starting point is an identification of the objectives for en ecosystem approach – why is an ecosystem approach required in the first place? Various definitions of an ecosystem approach have been provided. The WSSD Implementation Plan refers to the Convention of Biological Diversity decision 5/6 (Convention on Biological Diversity 2000) which defines an ecosystem approach as '*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Thus, the application of the ecosystem approach will help to reach the three objectives of the Convention: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilisation of generic resources.' And 'It recognises that humans, with their cultural diversity, are an integral component of many ecosystems.*' This definition is thus firmly based on the concept of sustainable development with the users as the core concern of management. Other definitions which have been put forward in the debate are less clear about this balance and include statements referring to restoration of natural structure and function or even restoration of virgin ecosystems. The latter has been associated with the concept of 'ecosystem based management', setting the ecosystem and not the users at the center and ultimately leading to some goal of designer ecosystems. This interpretation of the concept of 'ecosystem based management' as opposed to an 'ecosystem approach' is for instance presented by Garcia et al 2003. In the international debate there is clearly a need for clarification of the objectives and the first step in an identification of the normative basis for the implementation of an ecosystem approach is therefore to establish that it must be based on the concept of sustainable development and the corresponding principles as expressed in CBD decision 5/6. Within this understanding an ecosystem approach does not add anything fundamentally new in terms of objectives, but an ecosystem approach is necessary because we have realised that human life and the development of human societies can only be sustainable in the longer term if we understand and act in accordance with our dependence on healthy ecosystems to support us.

EAF – requirements for knowledge and scientific advice

An ecosystem approach implies an immense expansion of the types of functions and processes which must be considered in management decisions and thus of the scope of knowledge required. One of the early attempts to identify the challenges to knowledge was the Ecosystem Advisory Panel to the US Congress (1999). It summarised these challenges by stating that the ability to predict ecosystem behaviour is limited, that ecosystems have real thresholds and limits which, when exceeded, can effect major system restructuring, that once thresholds and limits have been exceeded, changes can be irreversible, that diversity is important to ecosystem functioning, that multiple scales interact within and among ecosystems, that components of ecosystems are linked, that ecosystem boundaries are open and that ecosystems change with time. This complexity means that an ecosystem approach to management can no longer be based on predictive knowledge about outcomes. Fisheries management has generally been based on a real or perceived ability to predict outcomes.

However, this approach cannot be extended to ecosystem concerns. There are several reasons for this but ultimately there will be economic limitations – the costs to produce knowledge and to implement management explode if the requirement for understanding, precision and implementation efficiency is to be maintained while the complexity of issues to be addressed increases and a larger group of stakeholders with diverse interests are to be accommodated in the management institution. It is therefore necessary to accept that management decisions cannot be based on knowledge which traces the implications of management through all the diverse processes in the ecosystem and predicts outcomes on that basis. Possible outcomes are at best predictable with very large uncertainty and more often than not only on a qualitative basis. Management decisions must at any time be based on the available knowledge about specific interactions but cannot assume understanding of all the linkages in an ecosystem. Instead of attempting to predict systemic outcomes management work adaptively using signposts about the system state which are generalised indicators which represent ecosystem health without pretending to grasp all the details or capture all possible outcomes. Work is ongoing to identify such indicators but there is still a long way to go before there is an operational knowledge basis for an ecosystem approach to management which also includes considerations of overall ecosystem health.

The consequence of this is that the implementation of management must change in two ways. One is that management must be inclusive of users, both in terms of defining objectives and in terms of identifying and accepting the knowledge base for management decisions. Both objectives and knowledge must be considered valid if management decisions are to have any legitimacy. These principles are also stated in Decision 5/6. Another important consequence is that implementation must be based on an adaptive approach. When outcomes can only be predicted qualitatively or with large uncertainty the only option is to operate through an adaptive or learning mode and refine management in the course of implementation based on realised outcomes. This is recognised by Decision 5/6 which states that '*The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning. Ecosystem processes are often non-linear, and the outcome of such processes often shows time-lags. The result is discontinuities, leading to surprise and uncertainty. Management must be adaptive in order to be able to respond to such uncertainties and contain elements of "learning-by-doing" or research feedback. Measures may need to be taken even when some cause-and-effect relationships are not yet fully established scientifically.*'

In summary we can conclude that an ecosystem approach will imply a range of important institutional changes: that clearer objectives based on sustainable development must be developed, that a knowledge base which can address the complexities by using soft predictability needs to be developed, that implementation must be through an adaptive approach and the decision processes must be inclusive of a wide set of stakeholders and suitable to reconcile multiple objectives and interests.

This emphasis on process is also the basis for the technical guidelines regarding an ecosystem approach which presently are being finalised by FAO. The guidelines recognise the lack of experiences with implementation and intend to start a process of learning rather than to define universal solutions.

Implementation of EAF

So far there has been limited experience with implementation of en ecosystem approach. FAO (2003) and ICES (2005a) have developed principles and guidelines, both of which are of a fairly general nature to be refined on basis of actual experience.

FAO (2003) recommends in its guidelines that fisheries management under EAF should respect the following principles:

- fisheries should be managed to limit their impact on the ecosystem to the extent possible;
- ecological relationships between harvested, dependent and associated species should be maintained;
- management measures should be compatible across the entire distribution of the resource (across jurisdictions and management plans);
- the precautionary approach should be applied because the knowledge on ecosystems is incomplete; and
- governance should ensure both human and ecosystem well-being and equity.

The ICES (2005) guidelines propose the following principles:

- Management should be based on a shared Vision and requires stakeholder engagement and participation;
- Planning and management should be integrated, strategic, adaptive, and supported by unambiguous objectives and take a long-term perspective;
- The geographic span of management should reflect ecological characteristics and should enable management of the natural resources of both the marine and terrestrial components of the coastal zone;
- The management objectives should be consistent with the requirement for sustainable development and reflect societal choices. They should address the desired quality status of the structure and dynamic functions of the ecosystem;
- Management should be based upon the precautionary principle, the polluter-pays principle, and the prevention principle. Best Available Technologies (BAT) and Best Environmental Practices (BEP) should be applied;
- Management should be supported by coordinated programmes for monitoring, assessment, implementation, and enforcement and by peer-reviewed scientific research and advice and should make the best use of existing scientific knowledge.

At the dialogue meeting in Dublin 2004 (ICES 2004) on an ecosystem approach to marine management there was agreement between the scientific community, policy makers and stake holders that an ecosystem approach should be developed and implemented in an incremental manner. This means that at any time the best information available should be utilised, operationalised and transformed into management while research is going on to expand the knowledge bases. This is in contrast to an approach which would wait for implementation until some holistic approach which simultaneously considers and addresses all interlinkages in the ecosystem has been developed.

For fisheries advice the incremental approach starts from the present advisory setup, based on single stock assessments. The assessments and the advice will increasingly incorporate knowledge on environmental interactions and fisheries impacts on the ecosystem. The ecosystem approach is not new in this respect. Ecosystem considerations have already for several years been incorporated in a number of cases where the interactions were known and there was sufficient information to operationalise this knowledge. An example is the advice regarding Barents Sea capelin where the basis for the advice has included a criterion that a minimum biomass should remain after fishing to sustain the cod stock which depends on the capelin stock for food. What is new is therefore not the concept but that the work to incorporate ecosystem interactions into assessments and advice is now done systematically. Specialised study and working groups which actively search the knowledge base for information on interactions and which communicate with assessment working groups regarding implementation in assessments are in operation and from and including the advice for 2006 the results of this process will be reflected in the ICES advice.

The format of advice has been change so that it from 2004 was given on an ecosystem basis. From 2005 ecosystem considerations will be included incrementally wherever knowledge becomes available in three areas:

- Regarding the impact of the ecosystem on fish populations – in stock assessments (growth, natural mortality, recruitment).
- Regarding the importance of fish populations to other components of the ecosystem as food, predator or as a component in biodiversity – when limit reference points are identified.
- Regarding the impacts of fisheries on the ecosystem – when advising on acceptable fishing mortality, effort or gears.

In the longer term advice will include considerations about overall ecosystem health, but indicators in this regard have not yet been operationalised to the extent that they can be used as a basis for fisheries advice.

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Theme Session 1: DYNAMICS OF THE BARENTS SEA ECOSYSTEM

PRINCIPLES OF THE ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

by

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Introduction

The main body in the management of the fisheries in the Barents Sea is the Joint Russian Norwegian Fisheries Commission (JRNFC). In the later years there has been a changing landscape of fishery management policy and this has been reflected in the work of the commission. In 2001 JRNFC set down an expert group to work out a "Basic document regarding the main principles and criteria for long term sustainable management of living marine resources in the Barents and Norwegian Seas." The main recommendations from that study has been implemented into long term management plans for the Northeast Arctic cod and capelin stocks and a management plan for Northeast Arctic haddock is in progress. The long term management plans, which have been evaluated by ICES to be in accordance with the precautionary approach in fisheries, represent a mayor step forward, moving the aim from the short term view of the quota for next year to a view of a long term harvest and stock development. This long term view makes it possible to ensure a better balance between fishing effort and resource availability.

A new element in this changing landscape of fishery management policy is the "ecosystem approach ". What is the ecosystem approach? Does this represent a completely new direction for the management of fisheries in the Barents Sea? Is the tradition working set up for the JRNFC relevant with regard to the ecosystem approach to fisheries management? Is the commission's latest years emphasis on the long time management plans relevant for incorporating the ecosystem approach in the management of the fisheries of the Barents Sea? The ecosystem approach is variously defined, but principally put emphasis on a management regime that maintains the health of the ecosystem alongside appropriate use of the marine environment, for the benefit of current and future generations (Jennings, 2004).

The question on the ecosystem approach to fisheries management in the Barents Sea has so far not yet been discussed in detail in JRNFC. However, in 2003 a mandate was given to the "Basic Document" expert group to "make a scientific assessment of optimal harvest (maximum sustainable yield) from the most important commercial species in the Barents Sea…The assessments shall include all ecosystem elements available for evaluation, i.e. natural and man-made effects on reproduction, growth and survival." Here JRNFC gives a clear signal that ecosystem parameters should be included in the scientific assessments. This should be regarded as a step towards an ecosystem approach.

The aim of the present contribution is to review the present management status with regard to the ecosystem approach, and to review some aspects which could be considered on the way towards a more extended ecosystem approach in the management of the living marine resources in the Barents Sea.

An example: is there an ecosystem approach to the management of the northeast arctic cod?

In June 2006 ICES released an advice for TAC for Northeast Arctic Cod for 2006 of 471 000 tonnes. This advice will be the basis for discussion at the 34th meeting of JRNFC in November 2005. If this advice is adopted as part of the management of Northeast Arctic cod for 2006 it may be reasonable to ask if JRNFC has introduced an ecosystem approach in the management of the living marine resources.

Some people will argue that this advice has not a basis in the ecosystem approach. This is mainly because the assessment of the cod is made on basis of single stock population model and technique (XSA, VPA). They will argue that before you can have an ecosystem approach the fish stock assessments have to be made on the basis of a large holistic model taking into account as many ecosystem parameters as possible (temperature, plankton, prey and predator species etc).

We feel that this is not a constructive starting point for an implementation of the ecosystem approach to management of living marine resources. We should look at the present TAC advice as a step forward in the way toward an ecosystem approach. It is true that the assessment is made on basis of a single stock population, but the quota is now, unlike previously, chosen on the basis of a long term management plan. In the development of the management plan historical data on stock development and ecosystem data have been an important factor. Further, the management of the cod cannot be seen isolated from other management measurers made by JRNFC. The quota for cod has to bee seen in connection with the quota for the capelin fishery. Here the commission has accepted that the consumption of capelin by cod is taken into account when the TAC for capelin is set. Thus the trophic levels (i.e. ecosystem structure and function) is kept intact. Other management measures have been introduced by the JRNFC such as closing areas of the shrimp and bottom trawl fishery if large amounts of cod fry is recorded in the catches, In addition sorting grids in bottom trawl allowing undersized fish to escape from the trawl have been introduced. These measures reduces the impact on the ecosystem due to the fishing practices.

Thus several elements have been introduced by JRNFC that point toward an ecosystem approach in management of the living marine resources. We feel that the correct approach in the way towards a more fully ecosystem approach would be an extension and systematization of these elements, and a gradual introduction of other elements. Some of these elements are discussed in the chapters below.

Scientific assessment and prognoses

Within the field of modelling, assessments and prognoses a move towards ecosystem approach can take place within the following:

- More extensive use of ecosystem information in the population parameters applied in assessment
- Expansion of the multi-species models from the capelin-cod connection already in use

Ecosystem information in population parameters, assessment models and prognoses

The following principles should be taken into account in this work:

1. A principle of the ecosystem likelihood at the assessment of the stocks status;
2. A principle of the ecosystem correspondence at the fisheries prediction
3. A principle of the ecosystem stability at the calculation of TAC and substantiation of the fishery strategy
4. A principle of minimization of attendant ecosystem disturbances during fishery.

1) We understand the principle of the ecosystem likelihood as the usage of the ecosystem characteristics for determination of the reliability of the obtained stock estimates and population parameters of the commercial species. For example, high growth rate of cod in the Barents Sea should correspond to the heightened heat content of waters or to a higher biomass of the capelin stock. High estimates of capelin abundance should be proved the same way by the increased content of this species in the stomachs of the predators. A situation cannot be realistic when the calculated consumption of a species by a predator exceeds the existing estimates of this species population biomass.

Realization of a principle of the ecosystem likelihood suggests in the practice of the fisheries investigations two approaches to the introduction of ecosystem data into the process of the stock status assessment: either to use directly the ecosystem characteristics in the assessment models as the input data at the determination of its parameters or to consider them as a criterion of reliability of the obtained estimates of the stock status.

Quite a many models have been developed for assessment of a stock size with the use of some elements of the ecosystem approach, trophic relations mainly. The example is a method of multi-species virtual/population analysis, on the basis of which the multi-species models are developed for the North, Baltic and Barents Seas. Elements of a relationship predator-prey are included either into various production models. Such models are developed in particular for shrimp biomass assessment in the Barents Sea and in Icelandic waters accounting data on consumption of shrimp by cod. There are also the other examples. However, the multi-species approach is not widely used at the stock assessments, since the modern models are imperfect, and they have a high demand to an input data, that is often difficult to realize at practice.

Using ecosystem parameters as a criterion of reliability of the obtained estimates of the stock status, it is necessary to be guided by the following ideas:

- Interrelations of all elements of the ecosystem;
- Uncertainty in estimates of populations and ecosystem parameters:
- Flexibility of the ecosystem relationships;
- Relativity of our knowledge of both the functioning of the ecosystem and a role of the discussed species in it;

The simplest way of analysis of the ecosystem correspondence between the available data on stock status is the expert assessment. The application of the formalized approach for such a kind of analysis requires the development of the corresponding models.

2) A principle of the ecosystem correspondence at the prediction of the stock dynamics should be understood as conformity of the projected of the stock status with the expected changes of the ecosystem parameters, basing on the existing of knowledge of the interrelation between the ecosystem characteristics and population parameters of the fishing species. This principle is intuitively evident; nevertheless proper attention is not always paid to it. The objective reason for that is the absence or unreliability in many cases of the projected estimates of the expected dynamics of the ecosystem parameters. The example of realisation of the principle for the Barents Sea is the usage at the latest ICES Arctic Fisheries Working Group of the results of analysis of the projected ecosystem situation for the assessment of expected conditions of growth and feeding, natural mortality of recruitment of cod and capelin stocks in the Barents Sea.

3) Under the principle of the ecosystem stability at the substantiation of the fisheries strategy we understand the conservation of the balanced correlation of the populations of commercial species connected between each other by trophic relationships. Breaking of the formed trophic relations in connection with the sudden increase of the predator abundance or reduction of abundance of its main food object is quite usual for the boreal ecosystems, however, it is always a destabilizing factor for the ecosystem structure and function, especially if it concerns the dominating species.

Capelin stock reduction in the Barents Sea as the main food object of cod leads both to the slowing down of cod maturation and to the increase of cannibalism (Ozhigin et al.,1996; Dolgov, 1999). Under the deficiency of the food cod migrate far to the east of the sea, where they feed on polar cod, the important food object of birds and sea mammals (Marine colonial birds…, 1995; Nilssen et al.,1997). Under the reduction of the capelin stock, food migrations of harp seal vary also, and this species predation press on Gadidae increases (Invasion of …, 1998).

Large-scale breaks in the ecosystem cause the fisheries crisis. According to the existing opinions, during the previous century there twice at least was a situation in the Barents Sea, which caused a crisis of fishery (Giske et al., 1998). It was mentioned for the first time in the end of the 19^{th} – early 20^{th} centuries. At that time fishing for cod was reduced. Catches were low, and small fish with low fatness predominated in catches. Besides, a mass invasion of seals to the coast of Norway was observed, and a big number of dead birds were registered. In the 1980's the events have happened similar to those in the end of the 19^{th}-early 20^{th} centuries. A collapse of the capelin stock took place, and stocks of cod, haddock and saithe decreased. From 1977 to 1990, a total year catch in the Barents Sea reduced from 4 mill. t to 0.5 mill. t (Nakken, 1998). A mass invasion of seals was observed off the coast of Norway, a high mortality of sea birds was registered in the Spitsbergen and in the Norway (Vader et al., 1990; Skjoldal, 1990, Blindheim, Skjoldal, 1993).

Therefore, the main task of the ecosystem approach to the management of the stock exploitation should be a development of the fisheries strategy providing a possibility to reduce maximally a probability of arising of the ecosystem large-scale breaks that can result in the decrease of fish productivity.

The main factors destabilizing the marine boreal ecosystems status are the large-scale oceanographic processes independent on the human control. In the Barents Sea, the increase of the influence of the warm Atlantic waters favours as a rule the inflow of zooplankton, increase of the fish growth rate and appearance of their abundant year classes (Dalpadado et al., 2002). A cold period vice versa is characterized by the decrease of the primary bioproduction of the Barents Sea and appearance of poor year classes of commercial fish species.

In the process of the evolution the marine ecosystems existing under the dynamic conditions have acquired an adaptive resistance to the destabilizing influence of the external natural factors. That is why the varying oceanographic conditions are not themselves a reason of crises in the ecosystem, although they change the level of the ecosystem total productivity and fish productivity in particular. The inadequate fishing pressure, which does not consider the dynamics of relationships on the background of climate change, is able in a greater measure to stimulate or accelerate the transference of the ecosystem to the crisis. At the same time, the regulated fishery can play a role of a stabilizing factor for the ecosystem functioning, if it promotes the support of a ratio between the population sizes of predators and their prey species or food competitors within a certain range.

A principle of the ecosystem stability suggested for the management of the exploitation of the marine bioresources contain the two basic ideas:

- For the commercial species connected between each other by the trophic relations there is the optimal ratio of sizes of their populations at which the total catch in the long-term aspect will be maximal;
- For the inter-dependent species dominating in the ecosystem there are limits in the ratio of sizes of their populations, overrun of which is connected with a high measure of risk of crises arising in the ecosystem functioning that can result in a sharp decrease of its productivity.

The first of the items can be considered as a reference point for the multi-species fishery. The second is more significant, since it promotes conditions of the long-term stable exploitation of marine bioresources . Realization of this idea in practical management suggests nor only the account of food requirements of predators in the calculation of TAC, but the regulation of the abundance of the inter-dependent species within the established limits as well. And all species engaged in the fisheries, both the forage species and predators of the high trophic levels, can be objected to the directed regulation of abundance from the ecosystem stability point of view.

Multispecies models as an element of ecosystem approach to fisheries management in the Barents Sea

Multi-species modeling should be treated as an element of the ecosystem approach to the management of living marine resources. It is believed that the first multi-species model based on trophic interactions between species and designed for sea fish stocks assessment and projection was suggested by Riffenburgh in 1969 (Ursin, 1982). The model developed by him combined three species on the Pacific coast of North America: hake, anchovy and sardine. Agger and Nielsen in 1972 adapted this model for the North Sea that is regarded as the first experience of the use of a multi-species model for description of commercial species in the European seas (Ursin, 1982).

For the Barents Sea, purposeful activity towards development of multi-species models destined for optimization of fisheries management has been pursued since late 1980's. In the Bergen Institute of Marine Research (IMR) a MULTSPEC model was developed to describe stock dynamics and trophic interactions in the Barents Sea between cod, capelin, herring, harp seal and Minke whale (Tjelmeland and Bogstad, 1998a). Estimations in the model are done with the time step of 1 month. According to the scheme of areas used in the model, the Barents Sea was divided into 7 areas.

Later on, based on the MULTSPEC model, a model AGGMULT was developed, which was distinguished, first of all, by aggregation of data (Tjelmeland and Bogstad, -1998b). The AGGMULT is spatially non-aggregated model with the time step of 1 quarter. As distinct from the MULTSPEC, the AGGMULT model includes only three species: cod, herring and capelin.

The MULTSPEC and AGGMULT models were designed as analytical instruments for analysis of multi-species fisheries strategies in the Barents Sea. For practical application of the multi-species approach to the estimation of total allowable catch of capelin in the Barents Sea, a simplified version of the multi-species model called Bifrost was developed (Gjøsæter *et al*., 2002). This model does not use the spatial structure of the Barents Sea and includes only two species: capelin as an object of fishery and cod as predator of capelin. Since 1998 ICES with the use of this model and based on acoustic survey data has been estimating annually the total allowable catch (TAC) of the Barents Sea capelin taking into account food requirements of cod (Gjøsæter *et al*., 2002).

Interaction between capelin and Norwegian spring-spawning herring is also a simulation object in the Barents Sea. The Norwegian spring-spawning herring are drifted to the Barents Sea at their early life stages and dwell there for 3-4 years until the maturity. It is reckoned that immature herring in the Barents Sea are able to consume larval capelin largely, thereby affecting adversely the capelin stock (Huse and Toresen, 1995). This, in its turn, has an effect on cod feeding conditions, growth and maturity rates as well as on cannibalism level. To simulate these interactions a model SYSTMOD was designed – a system model of fisheries in the Norwegian and Barents seas (Hamre and Hatlebakk, 1998). In this model there is no division of the Barents Sea into areas. Parameters of recruitment and growth of herring, capelin and cod are related to climate changes. Warm period favors good recruitment and growth of all the species but the appearance in the Barents Sea of rich herring year classes entails massive mortality of larval capelin.

At PINRO, works on multi-species modeling at the first stage were confined to adjustment of MSVPA model to the conditions of the Barents Sea as this model was primarily designed for the North and Baltic seas. In early 1990's, the two-species models, "cod-capelin" and "cod-shrimp" were developed at PINRO (Berenboim et al., 1992; Ushakov, Korzhev, Tretyak, 1992). Further improvement of the model resulted in the eight-species MSVPA model for the Barents Sea designed in the second half of 1990's. In addition to capelin and shrimp, arctic cod, herring and haddock as food items of cod and harp seal and Minke whale as supplementary predators were incorporated in the model (Korzhev, Dolgov, 1999; Multi-species analysis…, 2001). Time step used in the MSVPA model for the Barents Sea is one quarter. The model is not structured spatially, i.e. does not include details of the simulated processes by areas.

Since 1996, PINRO carries out works towards development of a multi-species model based on the use of algorithms formalizing cause-and-effect relations in growth, feeding, maturation, migration, mortality and recruitment in fisheries populations (Filin *et al.,* 2003). The core element of the model being developed is cod as the most extensively studied species of crucial importance not only for fisheries but also for the Barents Sea ecosystem. The model simulates intra-population and inter-species relations of cod and is destined for optimization of multi-species fisheries management in the Barents Sea.

In accordance with the adopted scheme, the model is constructed stage by stage, through creation of separate structural units able to function both as an element within one single model and as an independent model. The first model constructed on the basis of such approach was a CONCOD (CONsumption of COD) model meant for quantitative assessment of feeding and growth of cod in the Barents Sea using data on food supply, temperature and abundance of the cod population as the base (Filin, Gavrilik, 2001). The CONCOD model was further developed into the STRAFICOD (STRAtegy Fishery of COD) model describing implications of different fishing strategies for the cod stock with regard to trophic links between cod and capelin.

In 2001, the first version of a STOCOBAR (STOck of COD in the BARents Sea) was constructed. This model comprised CONCOD and STRAFICOD models. The STOCOBAR model includes seven species as prey to cod such as capelin, shrimp, arctic cod, herring, euphausiids, juvenile haddock and cod. The model is not structured spatially. Time step in the model may be set equal to one year or half a year.

Thus, Russian and Norwegian scientists have accumulated a wealth of experience in constructing multispecies models for commercial species in the Barents Sea. Unfortunately, the majority of the models have not been put to practical use as analytical instruments for stock assessment, projection or TAC estimation. The cause of that may be both shortcomings in the existing models and insufficient opportunities to provide them in full measure with necessary input data.

Elements related to the ecosystem approach that are not traditionally discussed by JRNFC

So far in the present contribution we have discussed how to incorporate ecosystem information in assessment models and how to interrelate several species, thus enabling the mangers to take ecosystem information into account when deciding upon catch quotas. The mandate to the scientists on this field is given in JRNFC 2003 decision on an assessment of optimal harvest including ecosystem information.

However, in implementing the ecosystem approach, JRNFC can expand the traditional field of discussion to also evaluate other elements. A common thought on the ecosystem approach is a transition from traditionally maintaining fish stocks at a healthy to maintaining ecosystem health. This on the background of increased activities in the Barents Sea of shipping, waste disposal and oil and gas exploration. Further, use of certain fishing can have an impact on the environment. It is a world wide growing concern that the fishing operations should allow for the maintenance of the structure, productivity and diversity of the ecosystem on which the fishery depends Two elements, that traditionally have not be dealt with have been pointed out as indicators for ecosystem health and are relevant to the management of fisheries are the following:

- Biodiversity
- Pollution

The ocean floor is increasingly recognized as an important reservoir of marine biodiversity. There are at present planned joint Norwegian /Russian investigations on benthos habitat and species structure in the Barents Sea. The use of certain fishing gears or practise can have a disproportionately harmful ecological impact on species and habitats in some areas. As discussed in the introduction of this contribution there is at present area/time restrictions for certain fisheries in the Barents Sea in order to protect young individuals of commercial fish species. This current measures could easily be expanded to benthos species, and the discussion could also be expanded to included eventual marine protected areas (MPA). MPA can be a useful tool on the way towards an ecosystem approach. The following elements are relevant (Bowman and Stergiou, 2004).

- Rebuilding overexploited fish stocks
- Preserving habitat and biodiversity
- Maintaining ecosystem structure
- Buffering against the effects of environmental variability
- Serving as a control area (population parameters on exploited groups in some areas can be compared).

The fishing industry in the Barents Sea is dependent on a non-polluted Barents Sea when selling the products. At present the Barents Sea is defined as clean. However, on a background of increased activities in the Barents Sea of shipping, waste disposal and oil and gas exploration it is important the development of pollution state is investigated and monitored so a non-polluted state of the Barents Sea can be documented. The competence and responsibility in this field has traditionally been within environmental bodies, but it is important that the monitoring is coordinated with the fisheries management body.

Conclusions

There is no single way to implement the "Ecosystem approach", it depends on historical practices and national, regional and global conditions. We feel that JRNFC has taken important steps on a way to implement an ecological approach when managing the living marine resources of the Barents Sea. Incorporation of ecosystem information and multi-species models in assessments will continue the next years.

A further implementation will probably need extension of the traditional field of discussion from the health and state of commercial fish stocks to the health and state of the Barents Sea ecosystem (of which the commercial stocks represent one element). Pollution and biodiversity could be actual candidates for further analysis with regard to the ecosystem approach. The implementation should be a gradual process where much of the foundations for the theoretical work, investigations and surveys are already set.

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CLIMATE VARIABILITY, FRONTAL ZONES, AND RECRUITMENT TO COMMERCIAL FISH STOCKS IN THE BARENTS SEA

by

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Abstract

This paper describes the ecological mechanism behind the impact of climate variations on the biological and fish productivity in the Barents Sea. An important element in this mechanism is environmental conditions in frontal zones. The highest temperature gradients emerge in the periods of strong interaction between Arctic and boreal ocean systems, under fairly extensive ice coverage in the Barents Sea and, at the same time, increased heat content in Atlantic waters moving into its southern part. Such situation develops with transition from cold to warm climatic conditions in the Barents Sea. When the climate gets warmer, the frontal zones first become more pronounced in pelagic waters, thereafter in bottom waters. The abundance growth of the commonest fish species in the Barents Sea that is cod and capelin is linked to increasing horizontal gradients of temperature in the frontal zones in the Barents Sea. Therefore, at the stage when climatic conditions are getting warmer, favourable conditions develop first for pelagic species (capelin) and then for demersal fish (cod). On the whole, it can be maintained that under transition from cold to warm climatic conditions a particular transitional condition develops in the Barents Sea ecosystem, which plays an important role in its biological production.

Introduction

The Barents Sea is characterized by a good water exchange with the North Atlantic and Arctic oceans and has a number of water masses with different features (Fig. 1) (Loeng, 1991; Ozhigin and Ivshin, 1999). Interaction of these water masses makes quite a vivid picture of frontal zones in the sea (Ozhigin, Ivshin, 1999). It is thought that owing to interaction between the boreal and Arctic waters, the Barents Sea ecosystem is noted for a high level of biological productivity and is rich in aquatic organisms important for the fisheries (Knipovich, 1938; Zenkevich, 1963).

Capelin, the commonest pelagic species, migrate for feeding to the cold Arctic and Barents Sea waters but spawn in the warm coastal waters of the North Norway (Ozhigin and Luka, 1985). Northeast Arctic cod, the most important demersal species, feed and spawn in the warm coastal and Atlantic waters (Maslov, 1968). Both cod and capelin distribution varies depending on climate conditions and related to frontal zones in the periods of feeding and wintering (Ozhigin and Tereshchenko, 1989).

The effect of short-term climate variations on cod recruitment is discussed in several papers. The analysis of abundance of year-classes that appeared in warm and cold years showed that strong year-classes mostly occurred in the Barents Sea in warm years and poor year-classes emerge in the years with negative temperature anomalies (Loeng, 1989; Nilssen and Hopkins, 1992; Ottersen et al., 1994; Ottersen and Loeng, 2000). Sætersdal and Loeng (1984) suggested a hypothesis that reproduction of cod is evolutionary adopted to the spatial variations of feeding area and showed that strong year-classes appear primarily in the periods of transition from cold to warm climatic conditions and in the beginning of warm periods. Nilssen et al. (1994) have found a similar link between cod recruitment and year-to-year variations of temperature. Capelin did not have any significant relationships between recruitment to the fishing stock and climatic variations.

Based on the data collected in 1979-1984 in spring-summer period along the section that goes through Polar front in the central Barents Sea, Rey et al. (1987) and Skjoldal et al. (1987) analysed spring phytoplankton bloom and reproduction of zooplankton in the years that fairly differ in climatic conditions. However, no relationship between parameters of the frontal zone and biological productivity was reviled.

Nowadays there is a following hypothesis (Titov, 2001). The largest increase of horizontal temperature gradients in the frontal zones occurs in the periods with relatively extensive ice coverage in the Barents Sea while heat advection by Atlantic currents is getting stronger. An index indicating sharpening of the Barents Sea frontal zones based on the Barents Sea ice coverage and temperature in the upper 200 m layer of the Kola Section was suggested. On the whole, sharpening of the frontal zones was perceived as an indicator of strength of interaction between the Arctic and boreal oceanic systems. An increase in this index coincides in time with a decrease in oxygen content in the bottom layer in the Kola Section that may be a consequence of higher biological productivity in the photic layer and settling of organic matter to the bottom. Relationships between variations in the above index and strength of capelin and cod year-classes were found to be significant.

The purpose of this paper is to estimate year-to-year variability in characteristics of the frontal zones under the effect of climate fluctuations and to study the relationship between such variability and biological and fisheries productivity of the Barents Sea.

Material and methods

The study is based on temperature data at the surface, 50 and 100 m, and in the bottom layer in July-November 1951-2003 (21 906 stations). In July-November, the ice edge is located to the north of the Polar front, which makes it possible to get a correct estimation of the frontal zone parameters (location and horizontal gradients).

Time series of monthly anomalies of water temperature in the upper 200 m layer (Tereshchenko, 1997, 1999), oxygen saturation (bottom layer) in the Kola section (Titov and Nesvetova, 2003) and ice coverage in the Barents Sea were used (Fig. 2). The anomalies were averaged over the period from July to November and normalized by dividing the average anomalies by relevant standard deviations (σ_i) to get a better comparison of values.

Based on normalized temperature and ice coverage anomalies, the years (1951-2003) were divided into four groups. This grouping was implemented by calculating sums and differences of normalized temperature (T) and ice coverage (IC) anomalies that gave two new time series (T+IC and T-IC) (Fig. 3). Main features of the four groups are as follows:

1) WARM-years are the years with warmer-than-normal water temperature and decreased ice coverage; (T-IC)>0.5σ_1; (1954, 1955, 1957, 1959, 1960, 1970, 1972, 1973, 1983, 1984, 1990, 1991, 1992, 1995, 1999, 2000, 2001, 2002).
2) COLD-years are the years with colder-than-normal water temperature and increased ice coverage; (T-IC)<-0.5σ_2; (1958, 1962, 1963, 1965, 1966, 1967, 1968, 1969, 1971, 1977, 1978, 1979, 1980, 1981, 1982, 1987, 1988, 1993, 1998).
3) WIIC-years are the years with warmer-than-normal water temperature and increased ice coverage; (T+IC)>0.5σ_3; (1951, 1959, 1960, 1964, 1967, 1968, 1969, 1973, 1975, 1982, 1983, 1989, 1990,1991, 1992, 2002).
4) CDIC-years are the years with colder-than-normal water temperature and decreased ice coverage; (T+IC)<-0.5σ_4; (1953, 1955, 1956, 1957, 1965, 1966, 1971, 1972, 1977, 1978, 1979, 1981, 1984, 1985, 1986, 1987, 1994, 1996, 1997, 2001).

It is necessary to emphasize that the WIIC group is comprised by the years in which temperature exceeded its "balance" value typical at a certain ice coverage values. It means that ice coverage in the Barents Sea was larger than normally observed at certain thermal condition.

Initial temperature data was also divided into four groups according to the selected types of years. Since data coverage in some areas of the Barents Sea is not good enough both in space and time, the sea area was divided into "squares" of about 60x60 miles (Fig. 4). Only those "squares" that had at least 100 observations were used to calculate horizontal temperature gradients according to the algorithm described by Ozhigin (1989).

Data on recruitment of Northeast Arctic cod (3+) and Barents Sea capelin (1+) was taken from the reports of the ICES Arctic Fisheries Working Group (ICES, 2003a) and the Northern Pelagic and Blue Whiting Working Group (ICES, 2003b). The data was averaged over the four groups of years listed above.

Results and discussion

Horizontal gradients of temperature were calculated at 0, 50, 100 m and in bottom layer for each group of years. The thermal frontal zones in the Barents Sea, on the whole, were quasi stationary. No differences in location of the zones according to the type of years were revealed. The highest gradients were typical of the Bear Island and Spitsbergen area. Weaker frontal zones were located along the slopes of the Central Bank, Central Basin and the Goose Bank. Fig. 5 shows, as an example, distribution of temperature horizontal gradients in the bottom layer in different types of years since it gives a good general idea about thermal frontal zones in the Barents Sea.

Fig. 6 shows horizontal gradients of temperature (°C/km) at 0, 50 100 m and in the bottom layer averaged over the area having good data coverage and years with different climatic conditions. It can be clearly seen that the highest gradients for all groups of years were typical of 50 and 100 m depths and difference between year types is barely visible. At the surface and in the bottom layer gradients were considerably lower. The most sharpened frontal zones at the surface were typical of WIIC- and COLD-years and in the bottom layer of WARM- and

WIIC-years. However, the difference between average temperature gradients in different types of year at all depths is not statistically significant.

Variations in some parameters of the Barents Sea ecosystem under different climatic conditions are shown in Fig. 7. The top left panel shows estimates of the index describing the relationship between temperature in the pelagic waters (0-100 m) and ice coverage of the sea. This index indicates that the strength of interaction between the Arctic and boreal oceanic systems is strongest in WIIC-years.

Oxygen deficiency in the bottom layer (left bottom panel) is also highest in WIIC-years. Its variations in different types of years can be explained by a change in the settling intensity of organic matter from the pelagic waters to the bottom, which in turn, can depend on variation in primary production in the photic layer.

Curves on the right top panel display variations of water temperature gradient in the frontal zones. In the upper 100 m layer increased horizontal gradients were typical of WIIC- and COLD-years and in the bottom layer of WIIC- and WARM-years.

The right bottom panel shows variations in the strength of cod and capelin year-classes based on estimates of their recruitment. Capelin year-classes of medium and high abundance occurred in COLD- and WIIC-years, correspondingly, while strong year-classes of cod occurred in WIIC- and WARM-years.

The central part of the Figure 7 introduces possible cause-and-effect relationships, which can represent a mechanism of climate variability effect on the recruitment to the main fish populations in the Barents Sea.

Based on the results obtained it is possible to make an idealized representation of the relationships between climate variations, environmental conditions, settling of organic matter and strength of cod and capelin year-classes (Fig. 8).

In cold years, the effect of Arctic system is stronger, ice coverage is wide and heat inflow from the Atlantic is weak. As a result of opposite trends in the effect of oceanic systems, sharpening of the frontal zones and settling of the organic matter to the bottom is at the average level. For capelin as an Arcto-boreal species, such conditions determine the formation of year-classes average in strength. For cod being a northern-boreal species, such conditions in the spawning and nursery areas are unfavourable. Accordingly, year-classes of cod are of low strength.

The transition from cold to warm climatic conditions (WIIC – years) is probably the most productive stage of the Barents Sea ecosystem functioning. All physical, chemical and biological processes show maximum development. Strength of cod and capelin year-classes is the highest.

In warm years, the intensity of ecological processes in the Arctic and boreal oceanic systems is opposite to that in cold years. Correspondingly, for capelin such conditions contribute to formation of average year-classes. For cod, the conditions formed in the spawning and nursery areas are favourable, and thus, abundance of cod year-classes is high like in WIIC – years.

Finally, the weakest interaction between the oceanic systems is presumably typical of the transition from warm to cold conditions (CDIC-years). All physical, chemical and biological processes are most likely slack. In such years, strength of cod and capelin year-classes is low.

Studies of Ponomarenko (1984), Ellertsen et al. (1987), Loeng (1989), Nilssen and Hopkins (1992), Ottersen et al. (1994), and Ottersen and Loeng (2000) have explored relationship between variability in environmental conditions (climate) and recruitment to the main fish stocks (mainly cod, haddock, and herring) in the Barents Sea and made an attempt to understand the causes of occurrence of strong and poor year-classes. These scientists assume that strong year-classes occur in the years with higher-than-normal temperature and vice versa year-classes that appear in cold years are mostly poor. The results of this work prove the conclusions of Sætersdal and Loeng (1984) and Nilssen et al. (1994) that warm years and periods of transition from cold to warm climatic conditions, which means the periods when interaction of Arctic and boreal systems is fairly strong are mostly favourable for occurrence of strong year-classes of cod.

When it comes to capelin, there is no clear conclusion about effect of climate variations on abundance of capelin year-classes in the scientific publications. It might be caused by the fact that capelin changes spawning areas if temperature conditions are significantly altered, which means that spawning areas move eastwards in warm years and westwards in cold years and by doing this capelin follow thermal optimum (2-3 °C) (Ushakov and Ozhigin, 1987). Unlike capelin, cod have permanent spawning areas (ICES, 1994). However, our results show that climate conditions have a certain effect on abundance of capelin year-classes since occurrence of strong year-classes is more like in the transitional from cold to warm years (WIIC).

Conclusions

Hypothesis (Titov, 2001) according to which maximum sharpening of frontal zones occurs in the WIIC-years in general has been advocated.

The lowest oxygen saturation of water in the bottom layer is observed in WIIC-years that may be a consequence of the increased primary production and/or settling of organic matter from pelagic waters to the bottom.

WIIC-years are characterized by the occurrence of strong year-classes of capelin and Northeast Arctic cod, which are the most important fish species.

Sharp frontal zones in the upper 100 m layer and rich cod year-classes are also typical of warm years.

The transition from cold to warm climatic conditions is probably the most productive stage of the Barents Sea ecosystem functioning.

Thus, the strength of interaction between oceanic systems manifesting itself in the sharpening of frontal zones is one of the important factors governing the functioning of the Barents Sea ecosystem.

These results should be considered as preliminary ones since in our work only effect of abiotic factors on recruitment was analysed. Further work will require a more in-depth analysis that will also include biological data.

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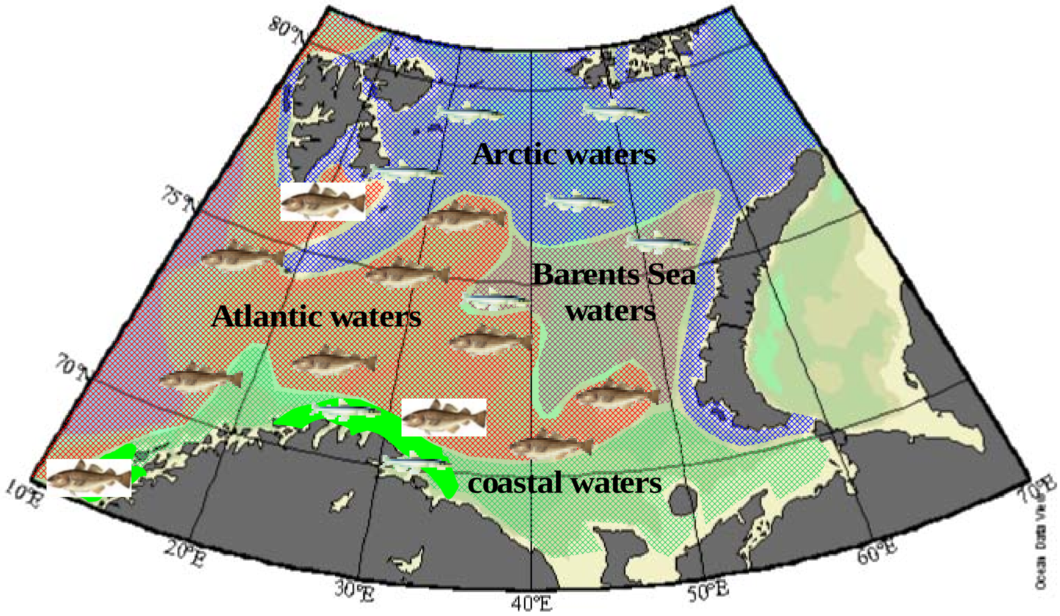

Fig. 1. Water masses in the Barents Sea (after Loeng, 1991). Feeding areas (fishes) and spawning grounds (green) of cod and capelin

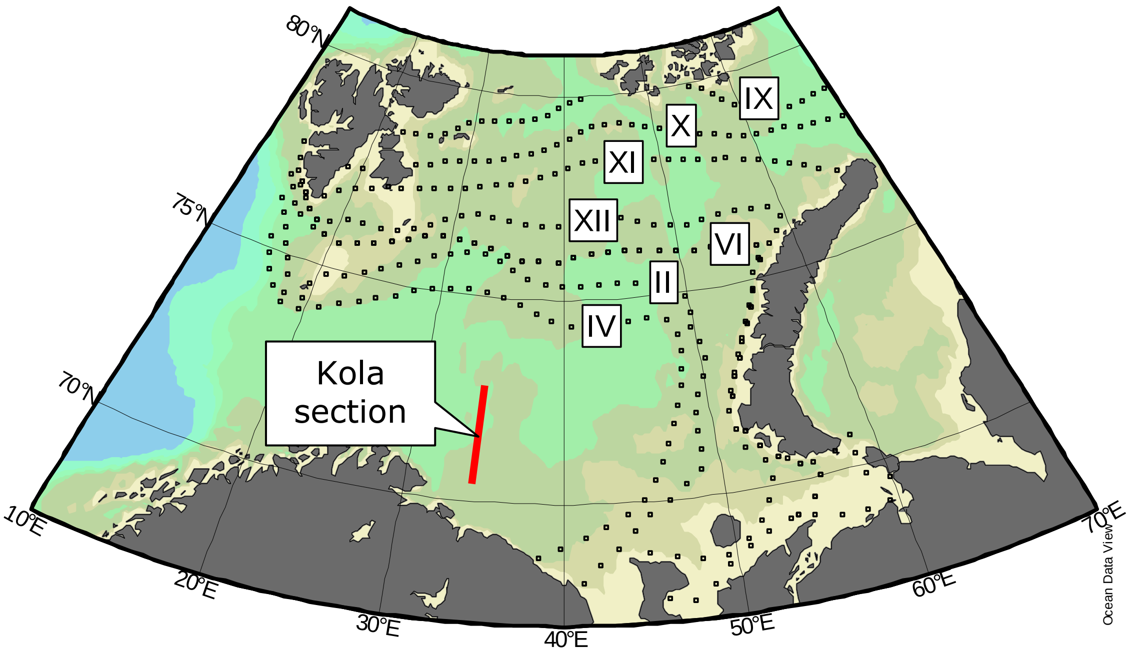

Fig. 2. Ice coverage in different months (PINRO data) and the Kola section location

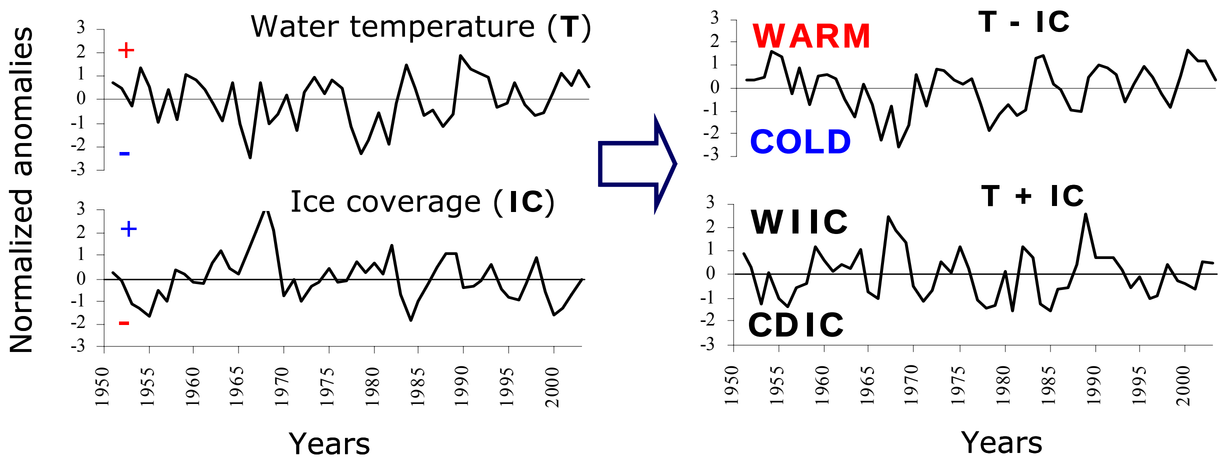

Fig. 3. Time series of normalized anomalies of temperature (T) in the Kola section, ice coverage (IC) in the Barents Sea, difference (T-IC) and sum (T+IC)

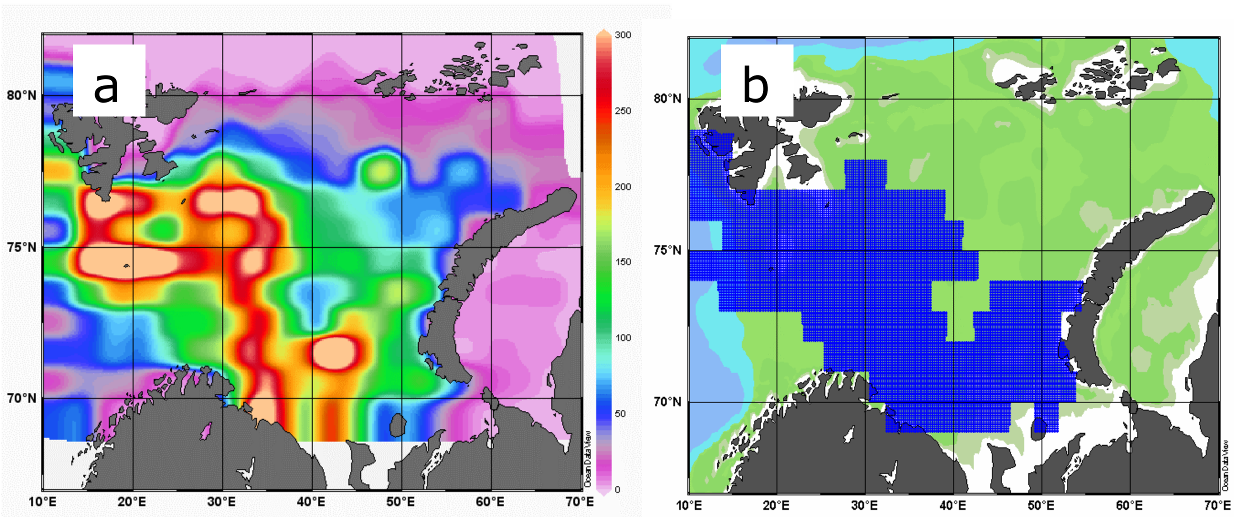

Fig. 4. Density of observations on water temperature in the Barents Sea in July-November of WARM-years (a) and areas that have at least 100 measurements of temperature in a "square" of 60x60 miles (b)

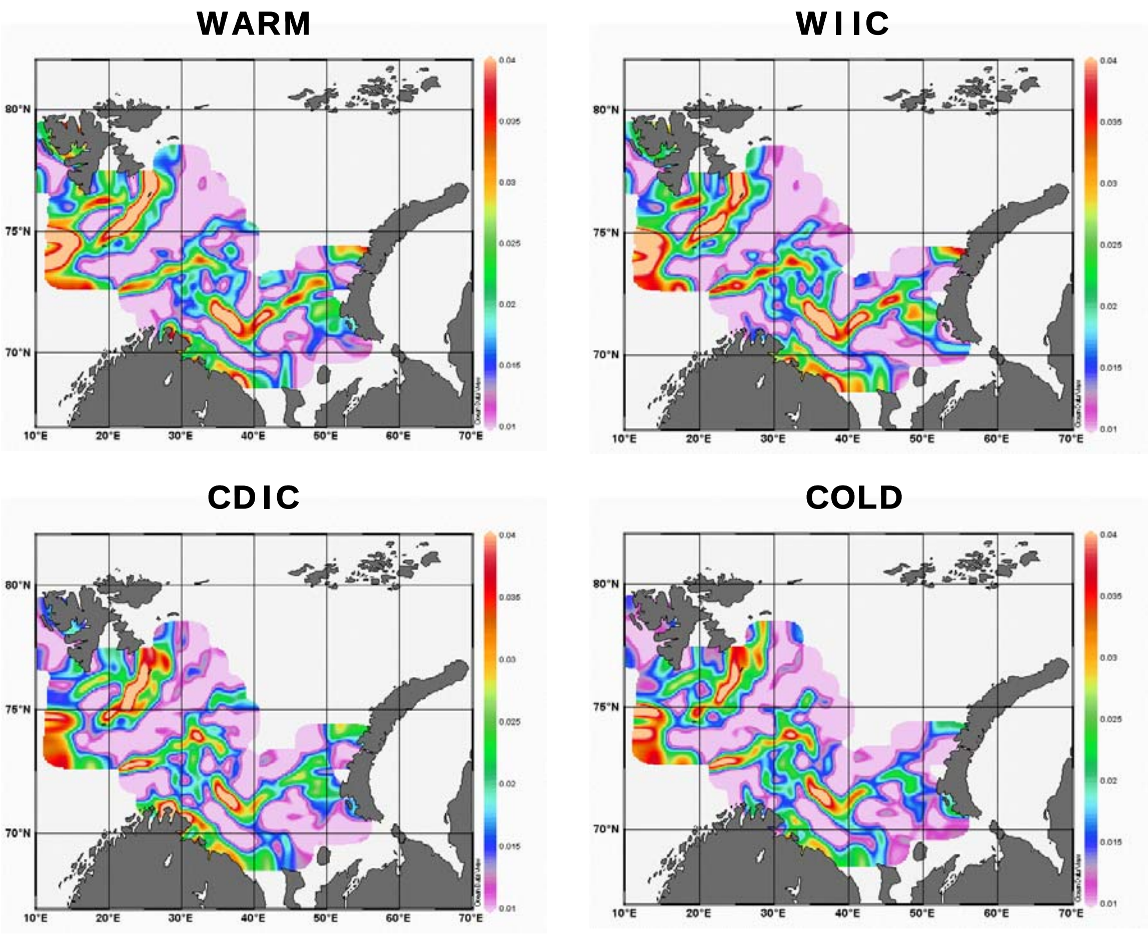

Fig. 5. Temperature gradients (°C/km) in the bottom layer in years that differ in climatic conditions

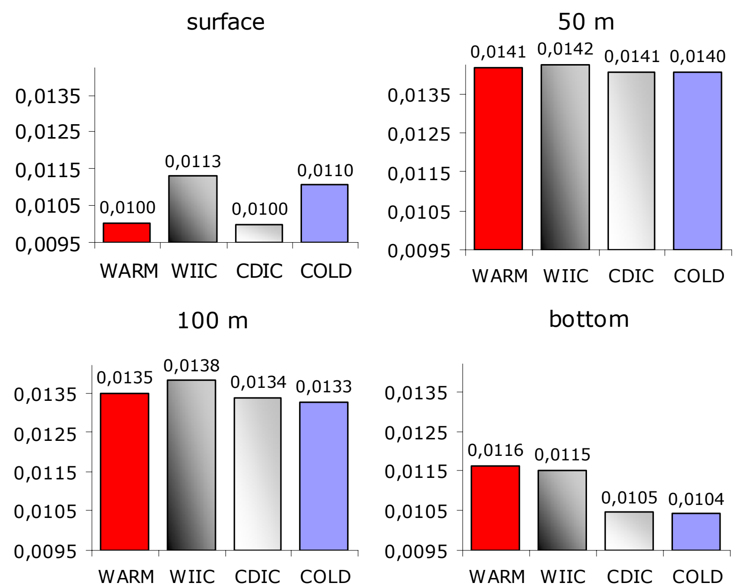

Fig. 6. Temperature gradients (°C/km) at different depths averaged over the study area and years that differ in climatic conditions

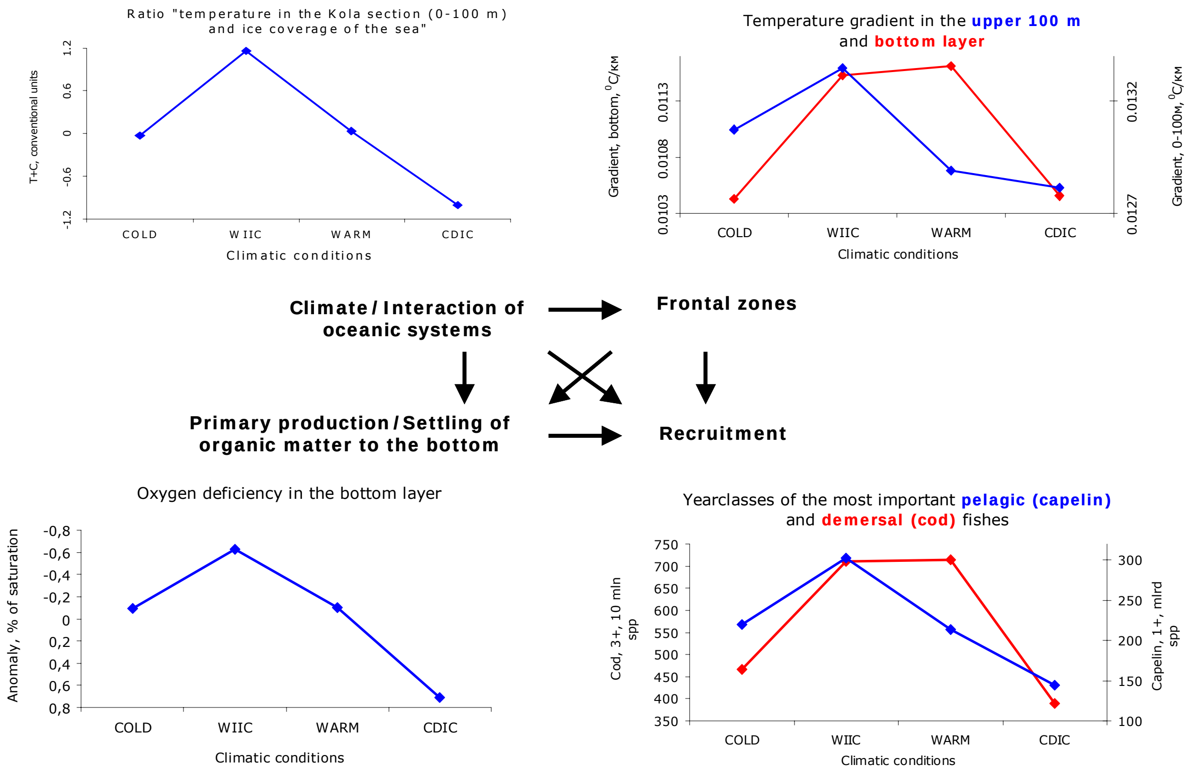

Fig. 7. Presumable cause-and-effect relationships in the Barents Sea ecosystem

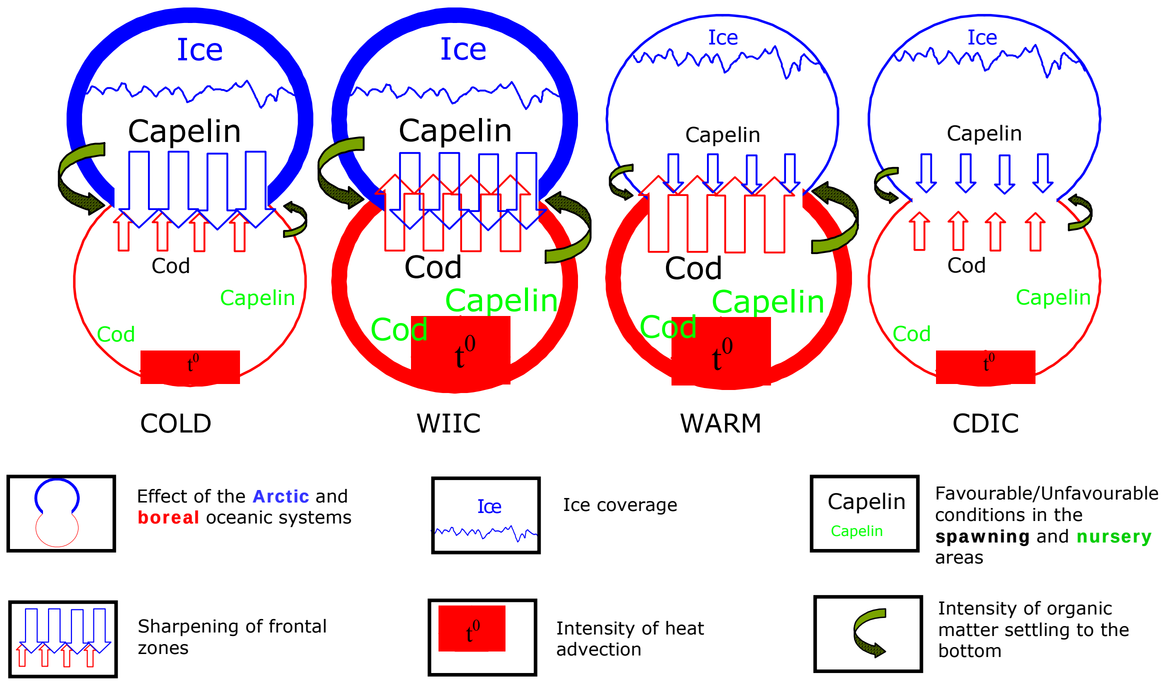

Fig. 8. Idealized representation of the relationships between climate variations, environmental conditions, settling of organic matter and strength of cod and capelin year-classes in the Barents Sea ecosystem

YEAR-TO-YEAR DYNAMICS OF TROPHIC LINKS OF THE MAIN COMMERCIAL FISHES IN THE BARENTS SEA AS INDICATING THE STATE OF ECOSYSTEM

by

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Functioning of the Barents Sea ecosystem is based on the energy transfer in the phytoplankton-zooplankton-pelagic fishes-cod trophic chain. Cod has a broad diet, feeding both on pelagic fishes – capelin, herring, polar cod, as well as seasonal concentrations of juvenile fish, shrimp, euphausiids and hyperiids. By feeding also on benthos (worms, mollusks, echinoderms, bottom amphipods) and other demersal animals including non-commercial fish species, cod is able to exploit a wide variety of the sea's food supply. However, cod predation has a great effect on commercial fish stocks. Abrupt fluctuations in cod food supply have large impact on its feeding behavior and the character of its migrations. Also, prey distribution influences the cod feeding cycle. The cod prey species and groups represent different geographic complexes; therefore, climatic fluctuations influence prey species abundance, distribution, and interactions. The interplay between climate, prey abundance and distribution, and interactions among prey species can be illustrated by the year-to-year dynamics of the historically observed cod feeding. In the end of the cold period in the 1920s, a high consumption of the polar cod was registered (Zenkevich and Brotskaya, 1931). This was connected to a very wide distribution of polar cod. However, in the cold 1960-1970s, due to the stock depression of polar cod (Shleinik, 1973), the polar cod almost completely disappeared from the cods diet. In the warm 1930s, "herring" and "capelin" years were alternating in cod diet (Zatsepin and Petrova, 1939), caused by year class variations and interactions between capelin and herring. Later, when a cold period (the 1960s) coincided with over-fishing of herring, the latter one was replaced by capelin (Ponomarenko and Yaragina, 1985) in the cods diet. In the cold years (the late 1970s-early 1980s), intensive feeding on capelin by cod accompanied by a reduced eastward migration by cod was recorded (Yaragina, 1984). Some of these particularities in cod feeding linked to climatic and hydrographic conditions and the prevalence of typical species (polar cod in the 1920s, herring – in the 1930s) have not been observed later.

When stocks of plankton-eating fish fluctuated, plankton food resources were redistributed between the different predator species. For instance, there was a recorded deficiency of euphausiids in the southern Barents Sea in the early 1950s owing to a considerable increase in the abundance of the main plankton consumers – capelin and cod, as well as the appearance of strong year-classes of herring (Shutova-Korzh, 1960). This deficiency was accompanied by cod starvation during several summer seasons (Grinkevich, 1957). Also there were alternating consumption of capelin and euphausiids by cod according to fluctuations in capelin abundance (Ponomarenko and Yaragina, 1990), and strengthening of food competition between capelin and polar cod for copepods and euphausiids in the northern Barents Sea in the early 1980s (Panasenko, 1990).

The trophic links abruptly changed in the middle of the 1980s, during the catastrophic depletion of the capelin stock coinciding with the increase in the cod stock owing to recruitment of cod from the strong 1983 year-class. Since that period, the cod food supply has been fluctuating, and these fluctuations have been intensified by climatic fluctuations and have led to irregularity in the traditional trophic links.

In this paper we will consider trophic in the Barents Sea by summarizing main findings from Russian studies on cod and capelin diet, condition and distribution, in relation to year-to-year variation in climate and prey abundance and distribution, with particular emphasis on the period from the late 1970s until present.

Material and methods

We used data obtained in the Bear Island-Spitsbergen area (ICES Subdivision IIb) (data from PINRO, literature and archive). These data include cod stomach content from 1984-2004 processed by quantity-weight (47384 ind.) and qualitative (over 400.000 ind.) methods. Capelin data (1979-1980) included 850 stomachs processed by quantity-weight methods and 4400 – by qualitative methods. Percentage by mass (m) (% of the stomach contents mass) and frequency of occurrence (f) (% of feeding fish) were used as feeding indices. Stomach fullness was visually determined using a five-point scale: 0, empty; 1, low fullness; 2, mean fullness; 3, full stomach; and 4, full stomach with walls stretched by food. An index of fullness was calculated as the stomach contents mass divided to the fish mass and multiplied by 10 000. Fish fatness was estimated by standard methods: of cod – by relative weight of liver, of capelin – by fat content in muscles (Lazarevsky, 1955). Distribution of cod and capelin aggregations was analyzed according to the distribution of catch data in the fishery areas. Long-term data were mainly used to estimate stock and distribution of the euphausiids in the Barents Sea (Anon., 1988; Anon., 1996).

Results and discussion

During the last twenty-thirty years significant fluctuations of the pelagic fish stocks were registered in the Barents Sea. Fluctuations were most typical for capelin, which, being the object of fishery, simultaneously served as the main food item for cod and other animals. Therefore, the capelin stock status was more often than other pelagic fish stocks, characterized by negative tendencies. The typical feature was alternating periods of a short-term recovery and a new reduction in the capelin stock (Fig.1). Accordingly, a relative index of cod food supply (the number of capelin per cod) reached 2.500-3.400 in the late 1970s – early 1980s, then significantly fluctuated till 1999 and only rose in periods of short-term capelin stock recovery (Fig.2). The minimal supply of cod by capelin was registered in 1995 (14 capelin per cod). Under those conditions, accessibility of food items for cod became deciding for its condition and migrations. Under periods of capelin deficiency, cod started migrating to the north-west (the Bear Island-Spitsbergen area) more regularly. We shall consider in detail trophic relations of cod and capelin in this area in the previous years and at present.

The cold years: 1976-1982

Despite a high extent of feeding area overlap between cod and capelin, there are certain limits to capelin accessibility for cod connected with temperature conditions. The supply and distribution of food for capelin is also of great importance for cod distribution.

Capelin feeding in the northwestern Barents Sea is related to the start of the season when copepod plankton is forming maximal biomasses. Capelin feeding is also dependent on the distribution of macroplankton. Transported and local species of euphausiids, forming maximal concentrations in the shallows, play an important role in capelin feeding at the beginning of summer, when the processes of plankton reproduction only begin. In some years feeding on euphausiids start already in June-July.

In the cold period (1976-1982), with a north and northeastern distribution of capelin (Røttingen and Dommasnes, 1985), and a favorable state of the capelin population, the food supply for capelin was at a high level. The good food supply was connected to a high density of euphausiids in these years due to combined concentrations of warm and coldwater species (Anon., 1988), low abundance of cod juveniles (the main capelin food competitor) and the existence of older capelin (Ushakov, 2000) which are able to reach the northern borders of feeding area early and use food resources of the arctic fauna. In most cases, the intensive consumption of euphausiids started in early August and was limited to the southern areas. In September-October, the area with capelin feeding on euphausiids widened northward to 76-77ºN, where euphausiids were consumed together with copepods. The copepods, though predominating by frequency of occurrence in capelin stomachs, had lower weight percent in the stomachs than euphausiids. In anomalous cold 1979, feeding on euphausiids was most prolonged in the Hopen Area (Fig.3). To the north of 77ºN, capelin did not feed on euphausiids, but consumed mainly copepods. In moderate 1980, in August-September, capelin having migrated northward to 77-78ºN, fed on euphausiids in the large area from the South Cape Deep to the Perseus Elevation (Fig.4). In 1980, weight percentage of euphausiids in capelin stomachs was very high: 58% in August, 62-96% in September-October, and 89% in November.

In the late 1970s capelin was characterized by a high level of fatness. In 1979, capelin mean fatness reached 12.9% in August, 18.1% in September and 16.7 % in October. This led to mass maturation of capelin (Oganesyan and Dvinin, 1988). In 1980, when the consumption of euphausiids by capelin was highest, capelin growth was the highest too (Gjøsæter, 1985). Capelin year class strength was moderate (1978, 1979) to strong (1976, 1977, 1980) (Anon., 1991). The capelin stock was heavily exploited despite that the stock was reduced already in 1981, owing to a decrease in the spawning stock, a decrease that continued and was particularly strong in 1983-1985 (Ushakov, 2000).

In those years (1976-1982), cod distribution did only to a minor extent overlap with capelin. Taking into consideration that small cod concentrations overlapped with capelin feeding on euphausiids to the north of 76ºN, in both anomalous cold (1979) and normal (1980) years (Fig.5, 6), one could assume that the lack of overlap of main aggregations of capelin and cod was not only caused by the limiting effect of low temperature on cod distribution. Probably another factor was more important, namely that there was a large supply of capelin in the western areas that favored that cod stayed there. It is also known, in that period, that cod had no feeding migrations eastwards. Due to intensive feeding on capelin, cod was characterized by a high fatness – 8-9% (Yaragina, 1984).

General warming with short-term periods of cooling: mid 1980s to late 1990s

With warming of the Barents Sea (the 1980s) and the change of capelin distribution (more south- and westwards) (Røttingen and Dommasnes, 1985) that coincided with the reduction in capelin stock size, cod started moving to the north more actively. Later, capelin stock variations, which, in their turn, were the reasons of the outbursts and drops of euphausiid abundance, had a great influence on the character of cod migrations, together the temperature conditions. In this warm period, the appearance of strong year-classes of cod and haddock was also observed. Thus, the total predation pressure on euphausiids became larger. As a result, in some periods, euphausiid concentrations were sharply reduced in the northwest and copepods started to dominate in capelin feeding.

In the periods of general warming in the Barents Sea, there were some well-pronounced periods of short-term cooling. These periods were radically different than the cold 1970s due to the sharp reductions in capelin abundance. First of all, the abundance of euphausiids increased, approaching the long-term mean in 1986-1988 in northwestern areas and exceeding it by 1.5-2 times in 1996 and 1998 (Anon., 1996). The outbreak of hyperiids abundance (consumers of *Calanus* and occupying the capelin food niche) was even more sudden and further enlarged the food supply of all the fishes (Orlova et al., 2003).

With the unstable supply of main prey species, the role of alternative prey became more important for cod. In the coldest years (1986-1987), when cod distribution was extremely westerly, cod fed on deepwater redfish, hyperiids, polar cod, non-commercial fishes, benthos, as well as shrimp. In less cold years (1996-1997), cod distribution was more southward. In 1996, cod consumed euphausiids from April to July. In the second half of the year cod started to feed intensively on hyperiids at the Perseus Elevation (Fig.7); making up more than 70% by weight in the diet of cod (Orlova et al., 2003) in the III-IV quarters. Despite a small increase in capelin abundance in those years, capelin constituted only 4-8% by weight of cods diet (Table 1). Only in 1998, when cod schools reached 77º30'N (Fig.8), and partly overlapped with feeding capelin aggregations, the percentage of capelin in cod diet rose to 15% by weight. That year, the percentage of shrimp was also high (more than 18% by weight).

In this period, generally warm and with capelin and euphausiids stocks fluctuations, cod migration behavior was not only determined by the environmental conditions and capelin supply, but also by an increase in cod abundance and a increase in percentage of elder fish in the population (Yaragina et al., 1996). The data for 1990-1992 are the most interesting. In those years cod was characterized by a northerly distribution. In the Hopen Area and the Perseus Elevation, large fish reached 78ºN-78º30'N. There, feeding areas of cod and capelin overlapped (Fig.9) leading to a high consumption level of the latter (36% by weight).

Cod fed regularly on shrimp similar to in the cold years (the 1970s). The consumption of shrimps usually was higher in the first half of the year, when capelin consumption was relatively poor (1990, 1992) or capelin was absent in the cod diet (1995). In 1995, the maximum frequency of shrimp occurrence (from 50 to 95%) was registered in the first half of the year, leading to more than 60% by weight (Orlova et al., 2003). The area of cod feeding on shrimps was, mainly, limited to western areas (Fig. 10) and, as shrimp was the main food item, when the local shrimp stock decreased after cod predation, large concentrations of cod migrated from area to area. Cod fed on shrimps in the Western Deep, on the slopes of the Bear Island and in the Hopen Area (April-June 1995) for the longest period. Later, in the year cod consumed shrimp regularly, but in smaller amounts, and euphausiids (August-September, November 1995), hyperiids (September-November 1995), and other invertebrates was important in cods diet this year. The weight percentage of shrimp in the cods diet made up over 11% in 1995 (Table 1).

Polar cod consumption by cod should be considered since the polar cod has a special importance in the annual life cycle of cod. Usually, consumption of polar cod by cod is connected with the final stage of cod feeding when water temperature decreases, and when cod growth finishes and the process of intensive accumulation of fat starts. Long-term data show large variability in the role of polar cod in cod feeding (Orlova, Oganin and Tereshchenko, 2001). In the second half of the 1990s, the consumption of polar cod by cod rose. This was caused by the reduction in capelin abundance and cooling of the Barents Sea. The consumption of juvenile polar cod by cod did not exceed 1-2% by weight, and for adult polar cod, it amounted to 14%. In the northwest, where cod fed on adult polar cod from the "western" component, the portion of the latter by weight reached 8% (Orlova et al., 2003).

The present: 1999-2004

The period from 1999 to 2004 was characterized by considerable reconstructions of the ecosystem structure of the Barents Sea. This was connected with stable warming and small increase in the stock size of most commercial species (Fig.1). The increase in capelin stock size was especially significant due to the appearance of strong year-classes in 1997-1999 and closed fishery in those years that led to an increase in percentage of older fish in the stock. In 2002-2003, capelin were distributed in the northern areas including the area of Frantz Josef Land, where capelin already in September fed on Atlantic and arctic species of copepods, euphausiids and hyperiids. Capelin reached a high fatness comparable to the one in the 1970s. However, in the following period, the stock was reduced again and, in 2004, it was 6 times lower compared to the maximum value in 2000 and 2001. In 1999-2004, the polar cod stock size also increased and the portion of mature fish in the population rose. This lead to an increase in the area of polar cod distribution. At the same time, in the Barents Sea, the immature herring abundance increased due to the appearance of moderate and strong year-classes (Krysov, 2002). Besides the Barents Sea traditional species, mass migration of blue whiting from the Norwegian Sea was observed. This was caused by the growth of its abundance owing to the appearance of strong 1999-2000 year-classes (Belikov et al., 2004).

In the considered years (1999-2004), euphausiids abundance was high despite an increase in plankton eater abundance due to the increase in warm-water species, especially *Meganyctiphanes norvegica* transported from the Norwegian Sea (Drobysheva et al., 2003).

On that background, new predator-prey interactions were formed. However, the main factor influencing fish feeding conditions, as before, was the abundance of the main prey species. The role of hydrographic conditions influencing overlap between predators and their potential preys was even more important than before.

The most favorable conditions for cod-feeding on capelin were in 1999-2002. In 1999, cod fed on capelin already in the cod wintering grounds in northwest. In that year, intensive capelin feeding was recorded from May-June to October (Fig.11), where capelin frequency of occurrence reached 65-90%. As a result, this year the maximum annual value of capelin in cod feeding was observed out of the years 1984-2004 – about 60% by weight (Table 1). In 2000, when the capelin stocks was at its maximum (over 4 x 10^6t), cod started feeding on capelin early (in February), however, the main consumption took place later (July-October), with a maximum level of feeding in the Hopen Area and the Perseus Elevation. Shorter feeding period of capelin compared to the previous year, led to lower level of consumption (about 19% by weight). In the other years (2001-2002), variation in accessibility of capelin and duration of capelin consumption in some areas caused fluctuations in capelin consumption (19-31% by weight, Table 1).

Despite the reduction in capelin abundance, the biomass of capelin consumed by cod was extremely high, amounting to 1.43-2.38 x 10^6t and remaining to be at the high level in 2003 and 2004 (Fig.12). Those values significantly exceeded the capelin catch (14 times in 1999, the other years, 3-4 times).

The area of polar cod feeding by cod expanded and extended from West Spitsbergen to the Perseus Elevation and Frantz Josef Land (Fig.13). Polar cod made up 6-18% by weight in northern areas, this was higher than in the southern part of the sea, where juvenile polar cod were consumed. In 2004, when capelin abundance decreased, in some areas (Perseus Elevations, Zuidkap Deep, Western Spitsbergen) polar cod practically substituted capelin in the diet of cod or was consumed by cod at the same level as capelin. That caused food competition strengthening between capelin and polar cod for food resources.

A wide distribution of blue whiting in the Barents Sea led to an increase in food competition between blue whiting and cod. In the Bear Island-Spitsbergen area, large blue whiting fed on capelin, polar cod and juvenile cod (these prey species amounted to 25-65% by weight in October-December 2003), as well as on euphausiids and hyperiids (Belikov, Sokolov and Dolgov, 2004). Fish were mostly consumed by blue whiting in West Spitsbergen, Bear Island Bank, and South Cape Deep, in areas with concentrations of feeding cod.

The blue whiting itself also started to occur more often in the cod diet. The widest distribution of blue whiting consumption by cod was recorded in 2002 (Fig.14), corresponding to the maximal biomass of blue whiting in the Bear Island-Spitsbergen area (around 145 x 10^3t). As a result, blue whiting made up about 10% by weight in the annual diet of cod, in the other years, it varied from 3% to 14% (Table 1).

Herring was not important in cod feeding in the Bear Island-Spitsbergen area. However, due to the shift of cod wintering borders eastwards, cod influence on concentrations of herring wintering in the central, coastal southeastern and even eastern areas strengthened. Mostly, it showed itself in 2003, when a high level of herring consumption was recorded from January to July, and then it was resumed in September (Fig.15). However, in that year, the portion of herring in the annual diet of cod did not exceed 9% by weight (Table 1).

Cod fatness changed according to the seasonal succession and the intensity of consumption of capelin and other important prey species. The prey species differ in accessibility and calorie content; capelin has high calorie content (2 kcal/g in raw weight), while the other abundant prey species (microplankton crustaceans, shrimps, polar cod) hardly reaches1 kcal/g. According to the significance of capelin in annual dynamics of cod feeding, the years from 1984 to 2004 can be grouped into two groups, characterized by the level and seasonal variations in cod fatness. The first group included the years with capelin percentage by weight of 15% and more in the cods diet (1984, 1990-1992, 1998-2000). In most cases, after a small reduction in fatness in May-July, an abrupt rise (to 8-9%) was registered in August-October and the level was high until December (Fig.15). The second group involved the years with percentage of capelin of less than 15% (1986-1988, 1993-1997).

In 2001-2003, with low level of capelin consumption, cod fatness was corresponding to that one of the second group of years. In January-July 2003, cod fatness value did not exceed 4-6% and, in August-September, it was reduced to 4-5%. Only in September, in the areas where cod fed on capelin, fatness steadily increased to 7-7.8%.

In 2004, cod from the Hopen Area had higher fatness even in December.

Conclusions

Structural changes in pelagic (plankton, nekton) communities of the Barents Sea and the interactions of the main commercial fish species caused different efficiency of the Barents Sea ecosystem functioning. From time to time, fishery made a significant contribution to the trophodynamics that, on the background of climatic variations had catastrophic consequences. It is exemplified by the disappearance of the Atlanto-Scandian herring, falling out of the ecosystem and cod diet for a long period (the late 1960s-early 1980s).

In the cold period (mid-1970s-the early 1980s), the conditions were favorable for capelin. Good conditions for feeding, a high rate of growth and reproduction provided a large capelin stock. This had several causes. With high capelin abundance, cod was provided well with capelin and did not make long migrations and was concentrating in the western areas. It resulted in a main separation of the feeding areas of cod and capelin in the northern areas and, respectively, a weak predator pressure by cod on capelin. The lack of the main food competitors of capelin also had a favorable effect on capelin feeding conditions. Fatness of both capelin and cod was high.

Over-fishing of capelin led to a collapse in the mid-1980s. With a low total abundance and an abrupt reduction in the proportion of older fish in the population, capelin did not use the feeding resources in the northern areas. Capelin deficiency, in its turn, conditioned poor feeding of cod and an increase in the consumption of euphausiids and hyperiids, i.e. cod and capelin became food competitors. In this period, where cod fed intensively on macroplankton, the food chain was short, and due to the low calorie content of e crustaceans, feeding on crustaceans could not compensate the cod energy consumption. As a result, cod fatness was low (less than 3%). Only in some periods, when capelin abundance recovered, the ecosystem came to the normal functioning regime (1990-1992) based on the ecologically efficient interactions of the key species: euphausiids (copepods) – capelin – cod.

In the stable warm period (1999-2004), plankton-eater food supply was stabilized because of a higher transport of warm-water euphausiids (and copepods, probably) and their wide distribution in the Barents Sea area. Also, the opportunity for fish using the food resources from the northern areas increased. Plenty of zooplankton favored migration and a wide distribution of blue whiting and polar cod, which increased in abundance in the Barents Sea. At the same time, in some local areas, the feeding areas of capelin and polar cod, as well as cod and blue whiting overlapped leading to the increased food competition being acknowledged in some cases by low fatness of those fish species.

Negative consequences for cod of food competition were compensated by a wide distribution in the warm years and a high accessibility of capelin and polar cod, as well as of herring wintering in the southeast and east. Cod fatness became higher when consuming these species. Blue whiting did not play a significant part in cod feeding, since blue whiting were, mainly, consumed by cod having completed the return from feeding migration, in the west (November-December). Euphausiids were stabilizing as a food supply for the plankton eaters in 1999-2004.

At present, the stock of capelin is close to the new collapse. With a high accessibility of capelin for cod in the warm years 1999-2004, capelin was under a great predation pressure. The impact of predation on the capelin stock was intensified by a fishing pressure that resembled the one in 1993-1995. It was absolutely different from the situation in the 1970s, when the predation pressure was practically absent. Presently, the influence of cod is greater than the fishery effect on capelin.

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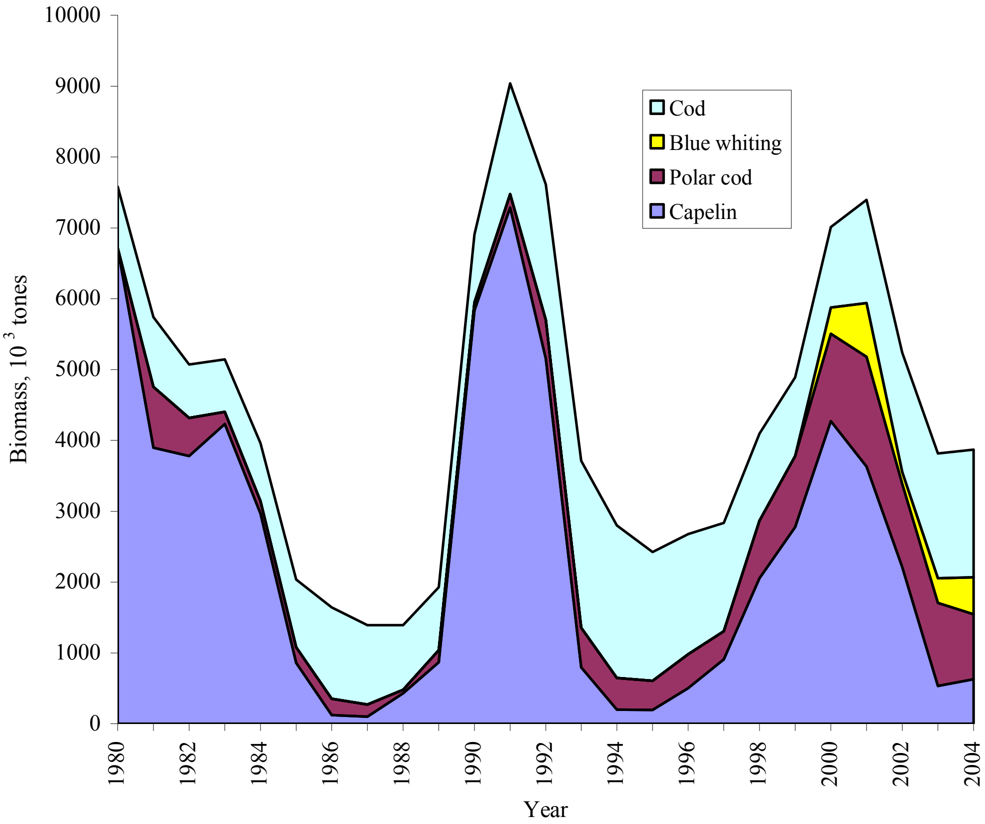

Fig. 1. Stocks dynamics of cod, capelin, polar cod and blue whiting in 1980-2004

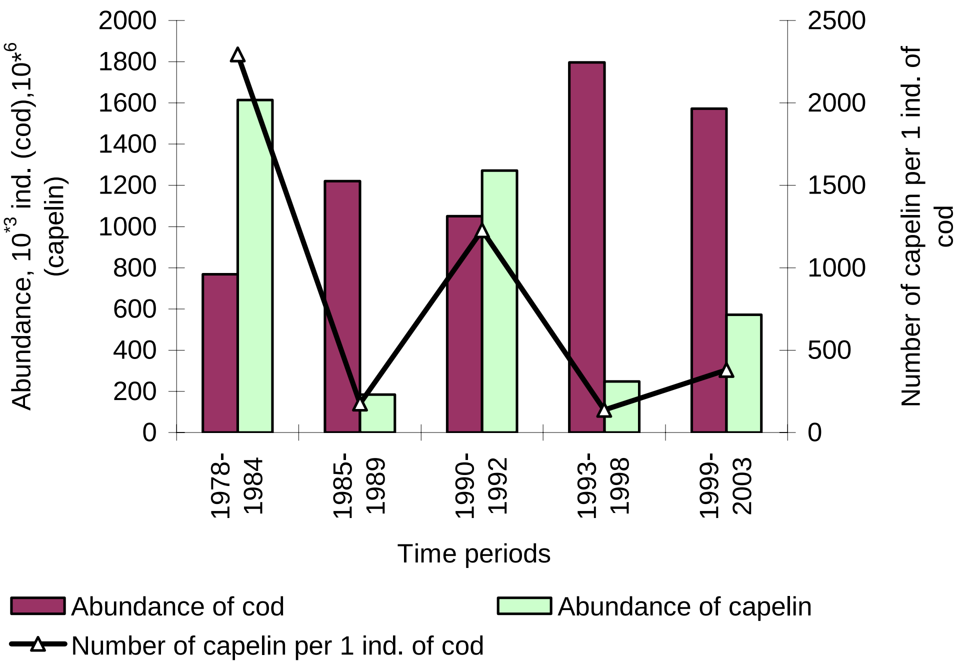

Fig.2. Stock dynamics and cod supply by capelin in the different time periods in 1978-2003

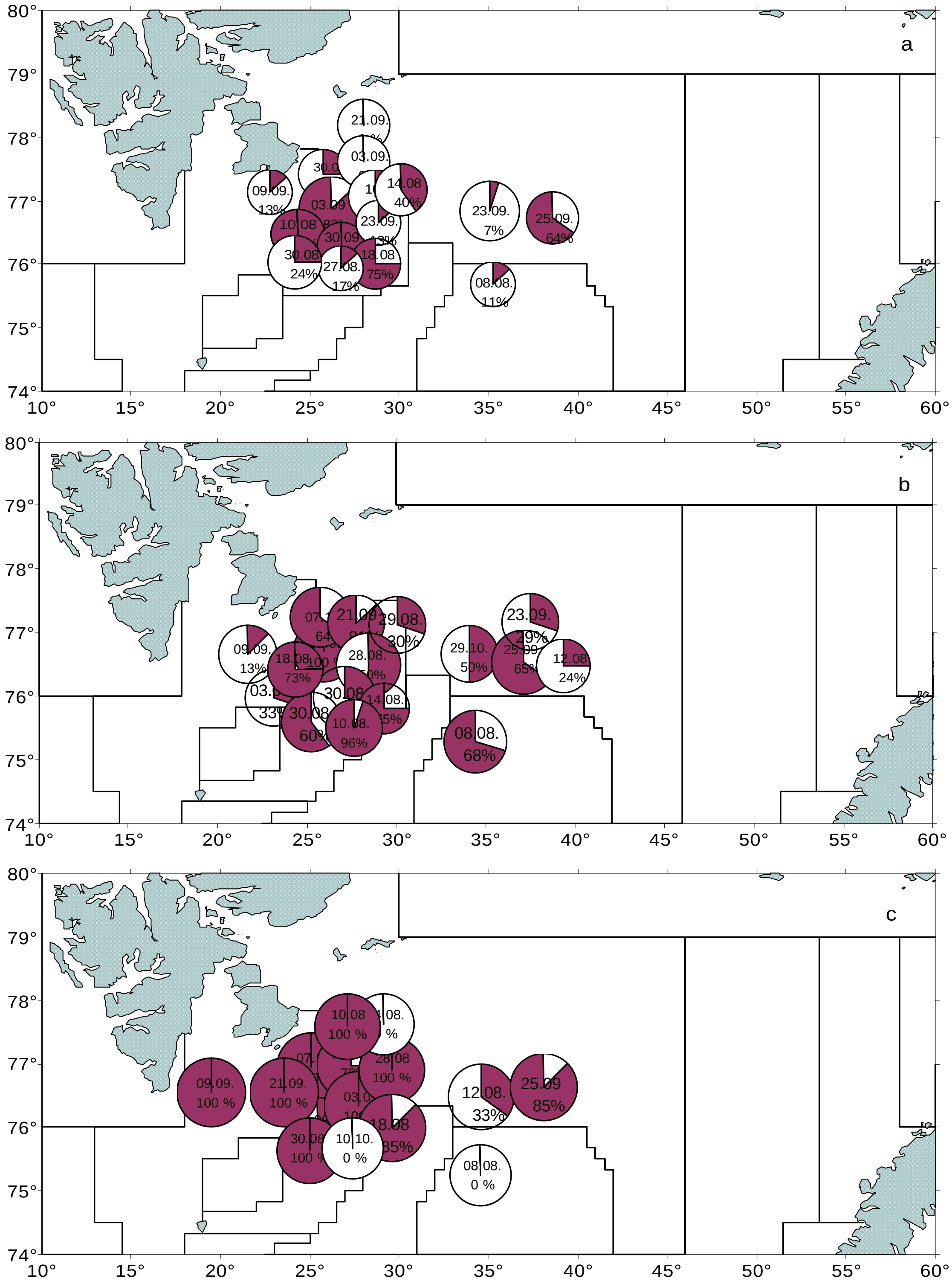

Fig. 3. Frequency of occurrence (%) euphausiids in stomachs of capelin by age 2 (a), 3 (b) и 4 (c) in August-Oktober 1979

Fig. 4. Frequency of occurrence (%) euphausiids in stomachs of capelin by age 2 (a), 3 (b) и 4 (c) in August-November 1980

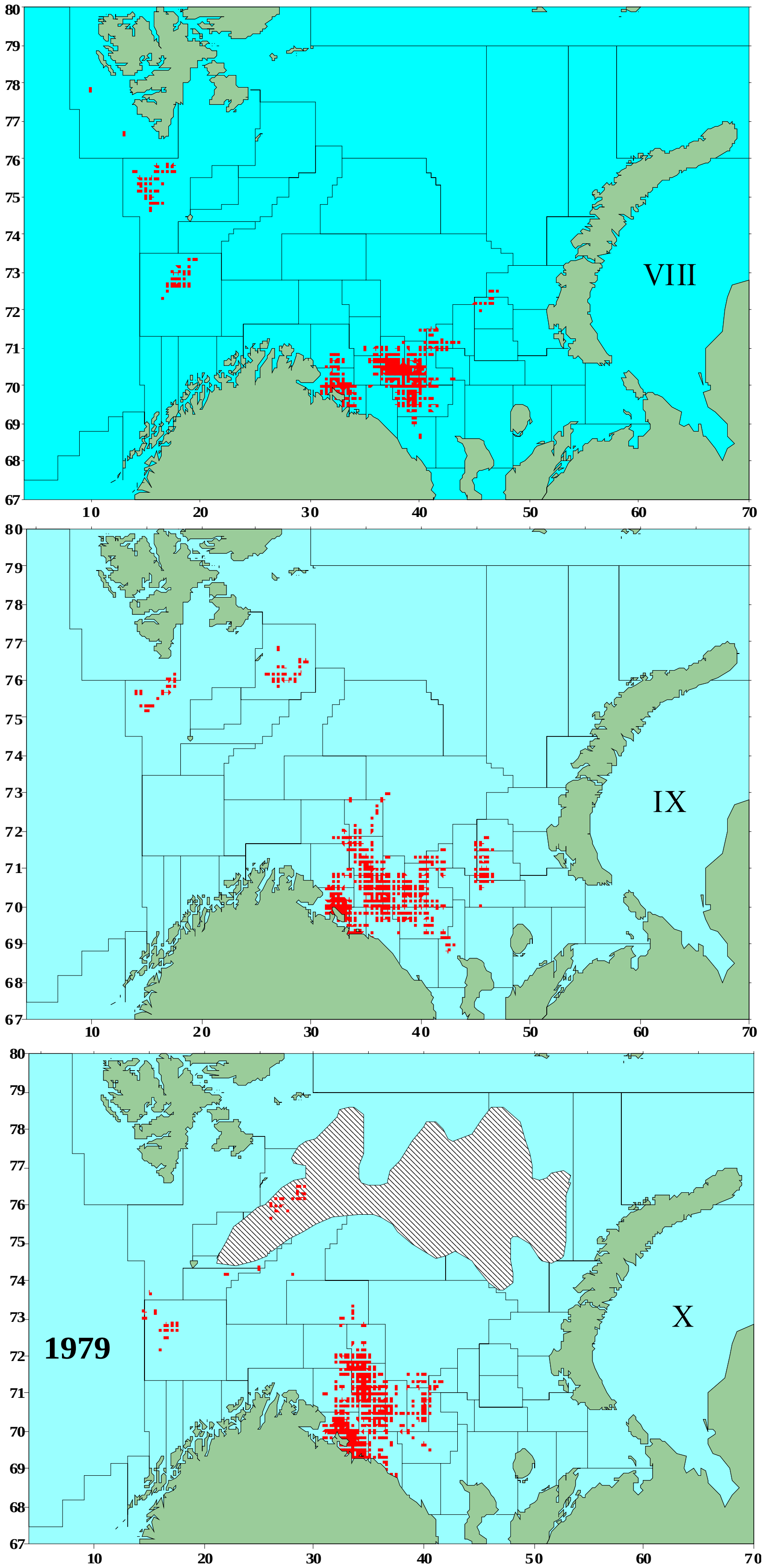

Fig.5. Distribution of cod (red color) and capelin (shading) aggregations in the Barents Sea in 1979

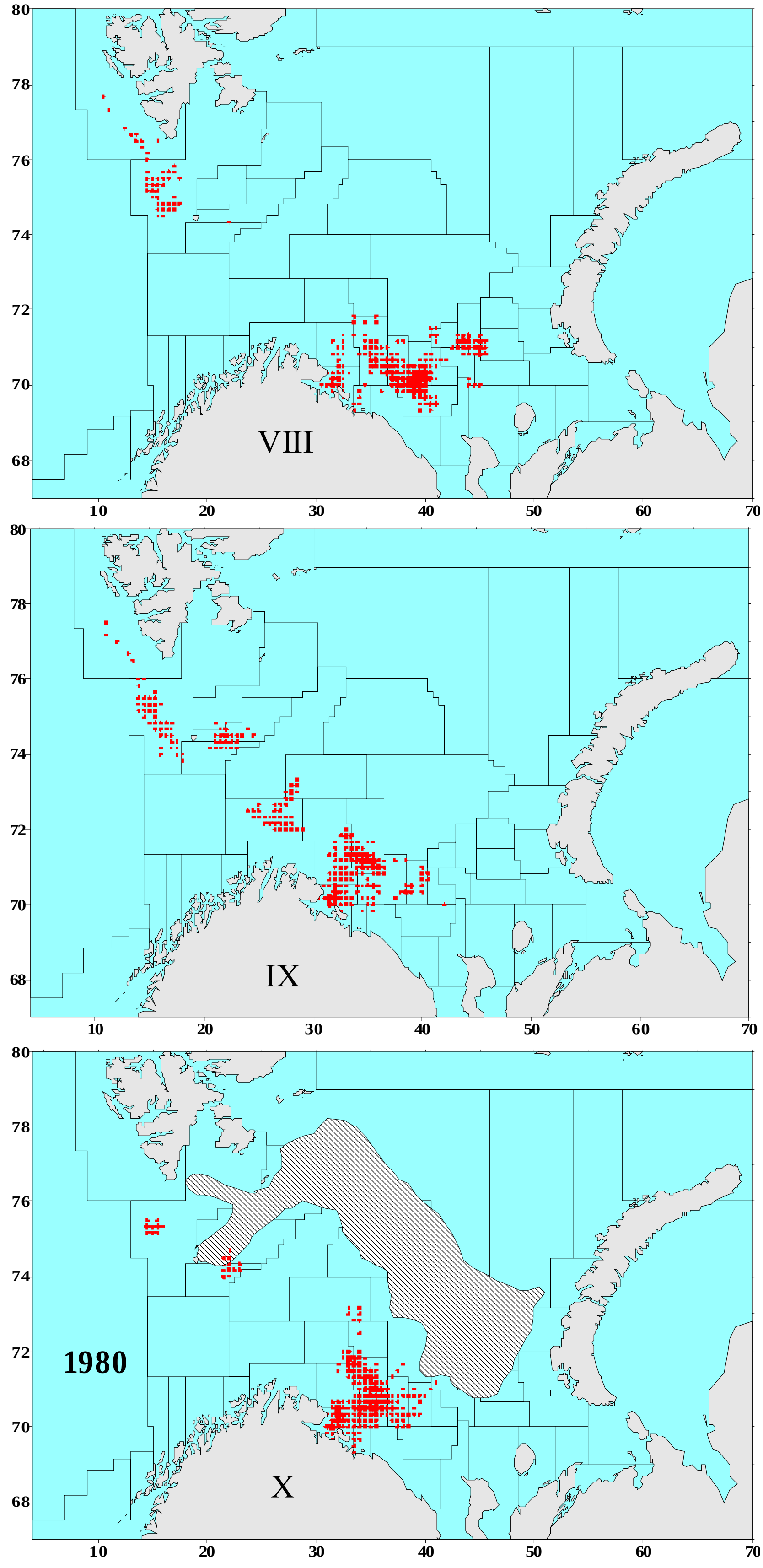

Fig.6. Distribution of cod (red color) and capelin (shading) in the Barents Sea in 1980

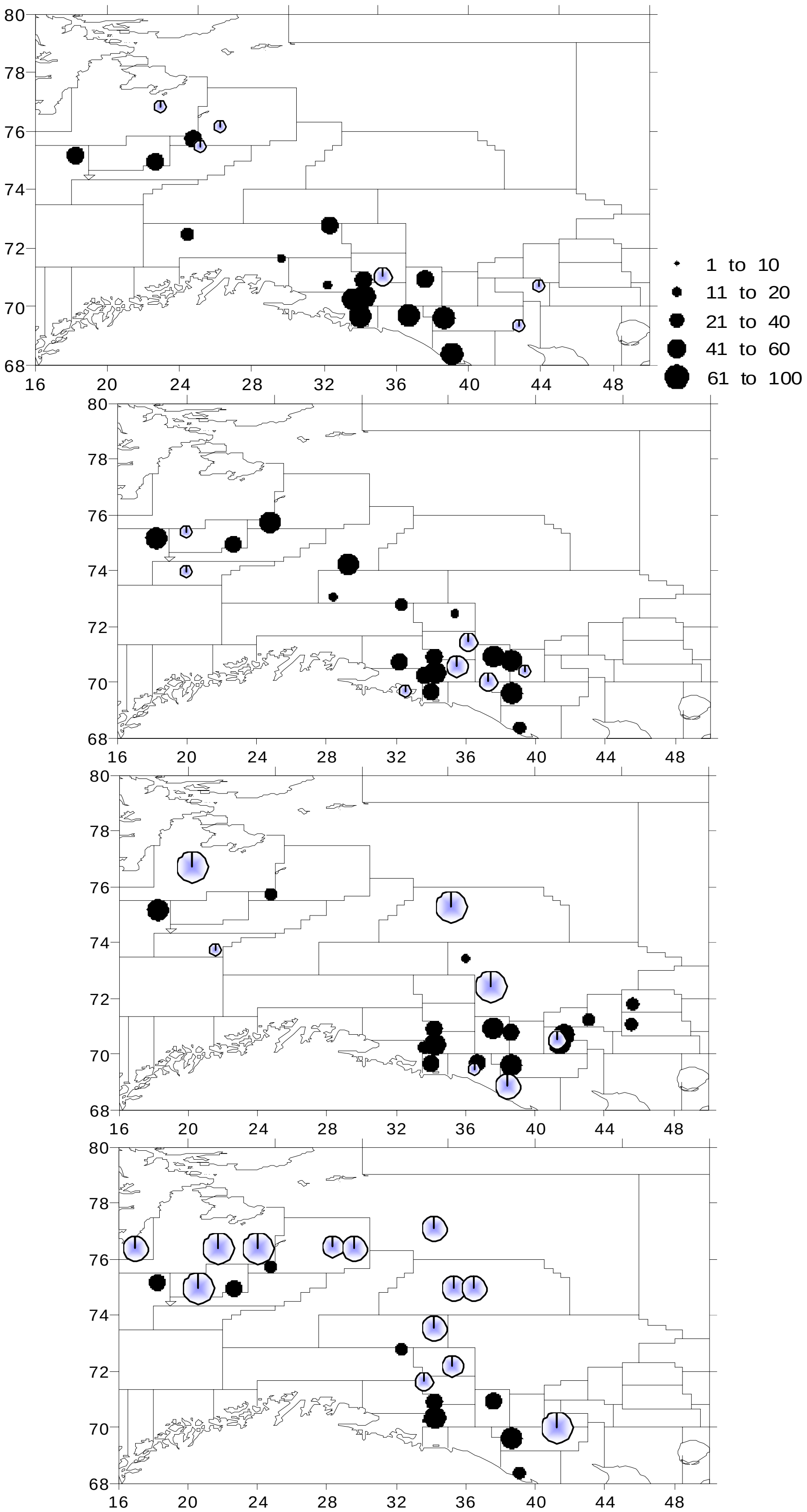

Fig. 7. Frequency of occurrence (%) euphausiids (black colour) and hyperiids (blue colour) in cod stomachs in June (a), July (b), August (c) and September (d) 1998

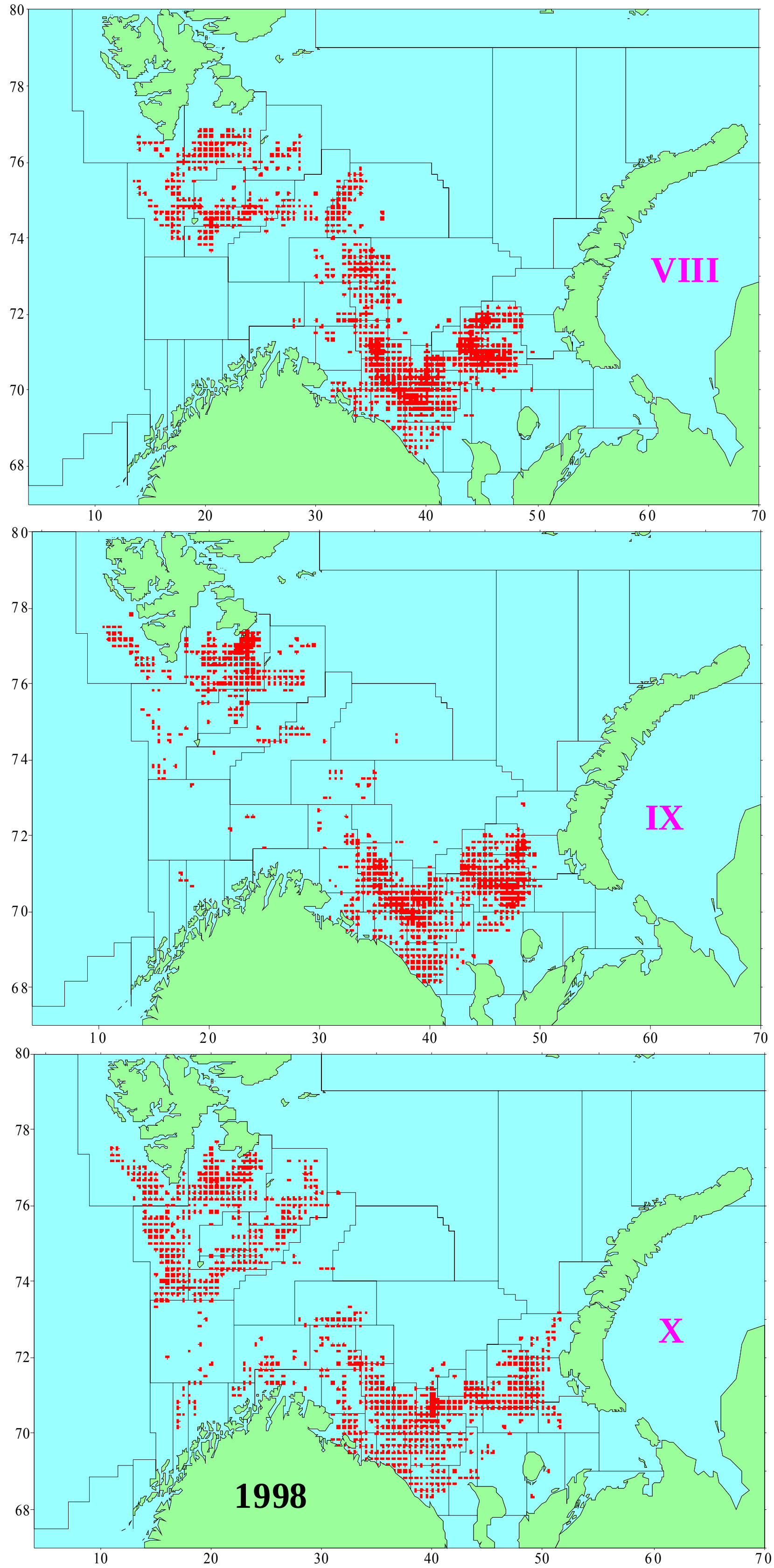

Fig. 8. Distribution of cod aggregations (red color) in the Barents Sea in August-October 1998

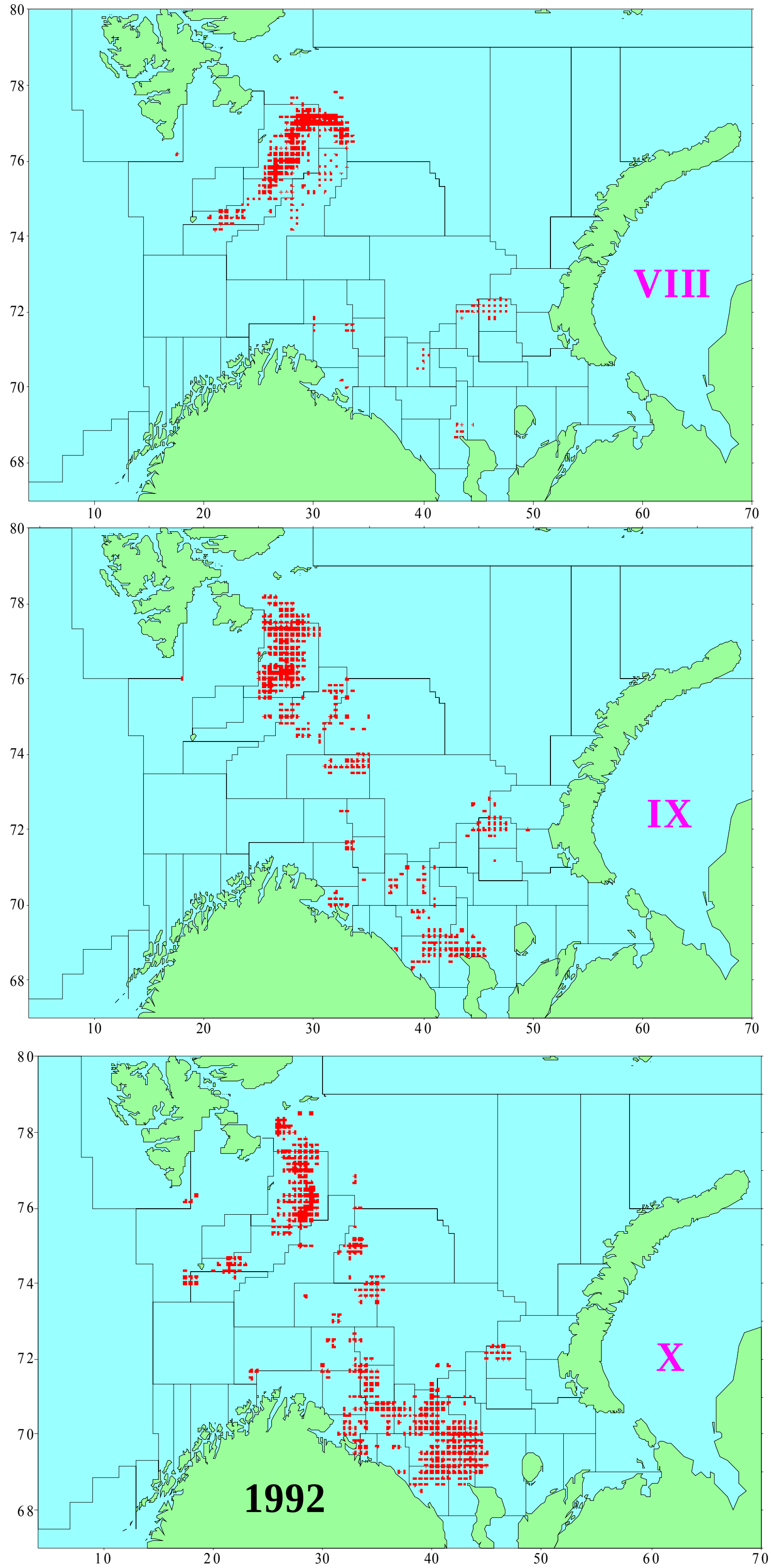

Fig.9. Distribution of cod aggregations (red color) in the Barents Sea in August-October 1992

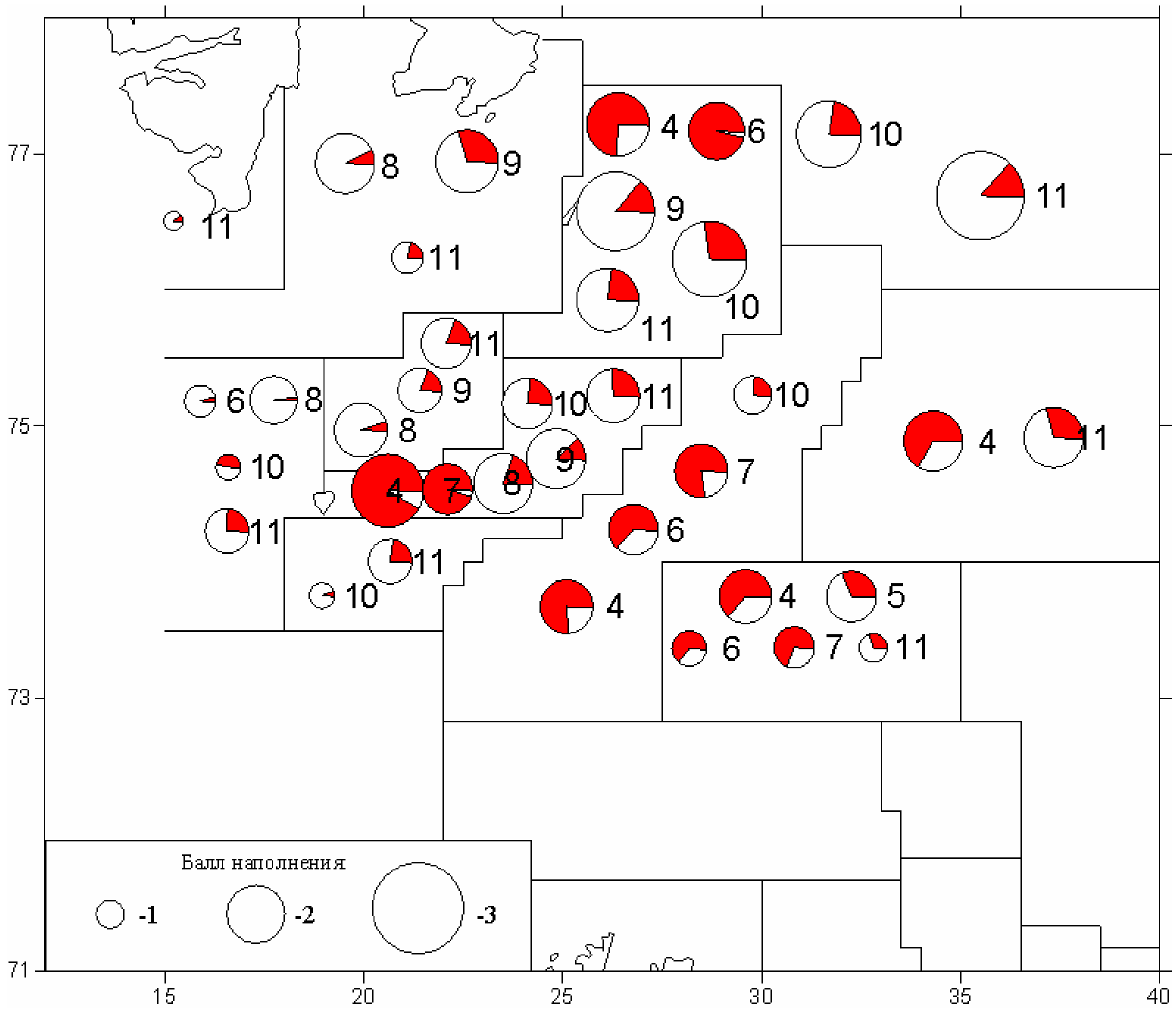

Fig. 10. Frequency of occurrence (%, red colour) shrimp in cod stomachs
in Barents Sea by months 1995 (ciphers show months)

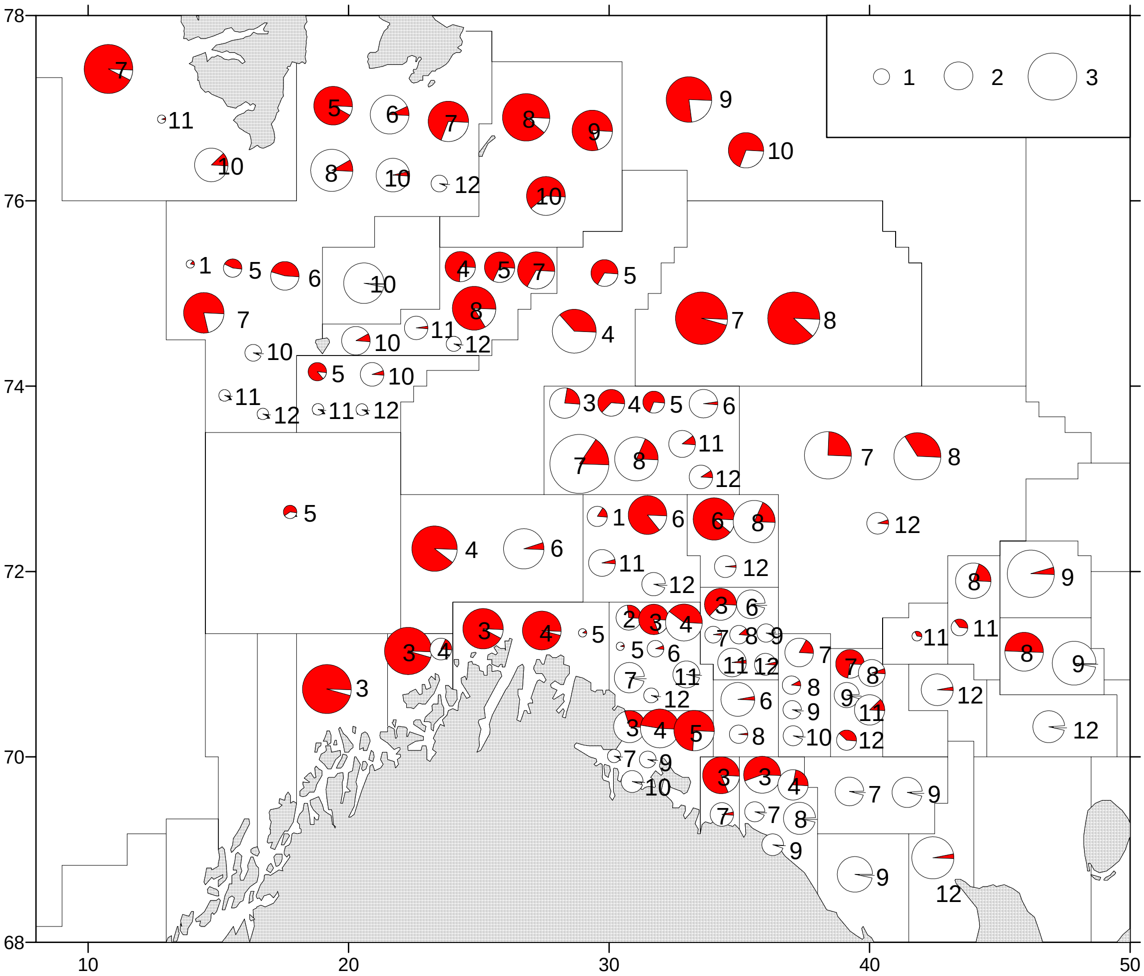

Fig. 11. Frequency of occurrence (%, red colour) capelin in cod stomachs
in Barents Sea by months 1999 (ciphers show months)

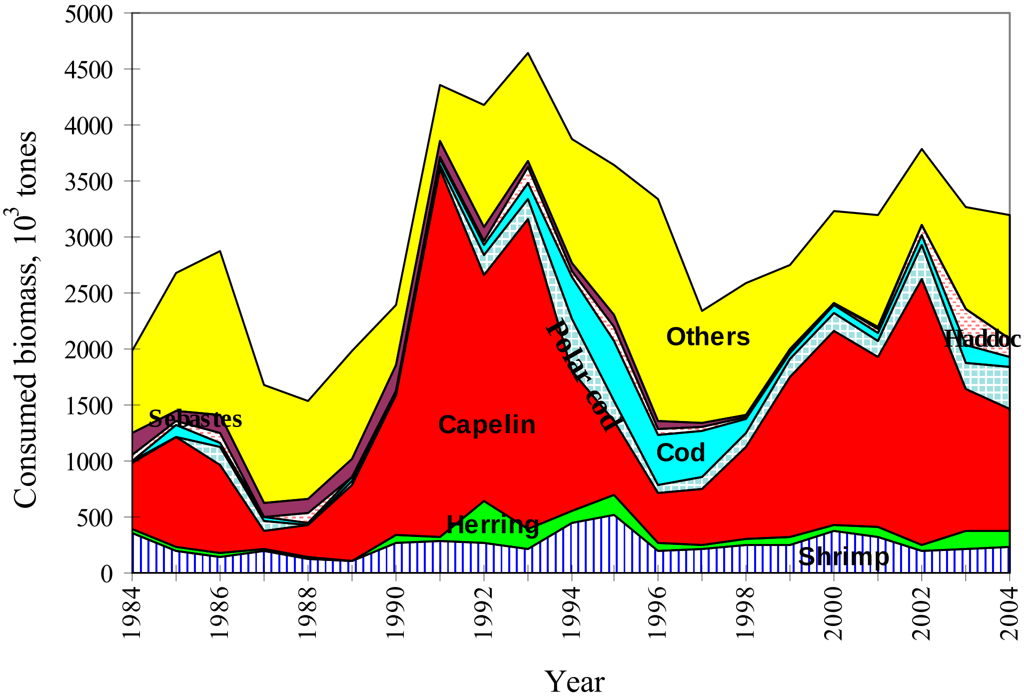

Fig. 12. Food consumed by cod in the Barents Sea in 1984-2004

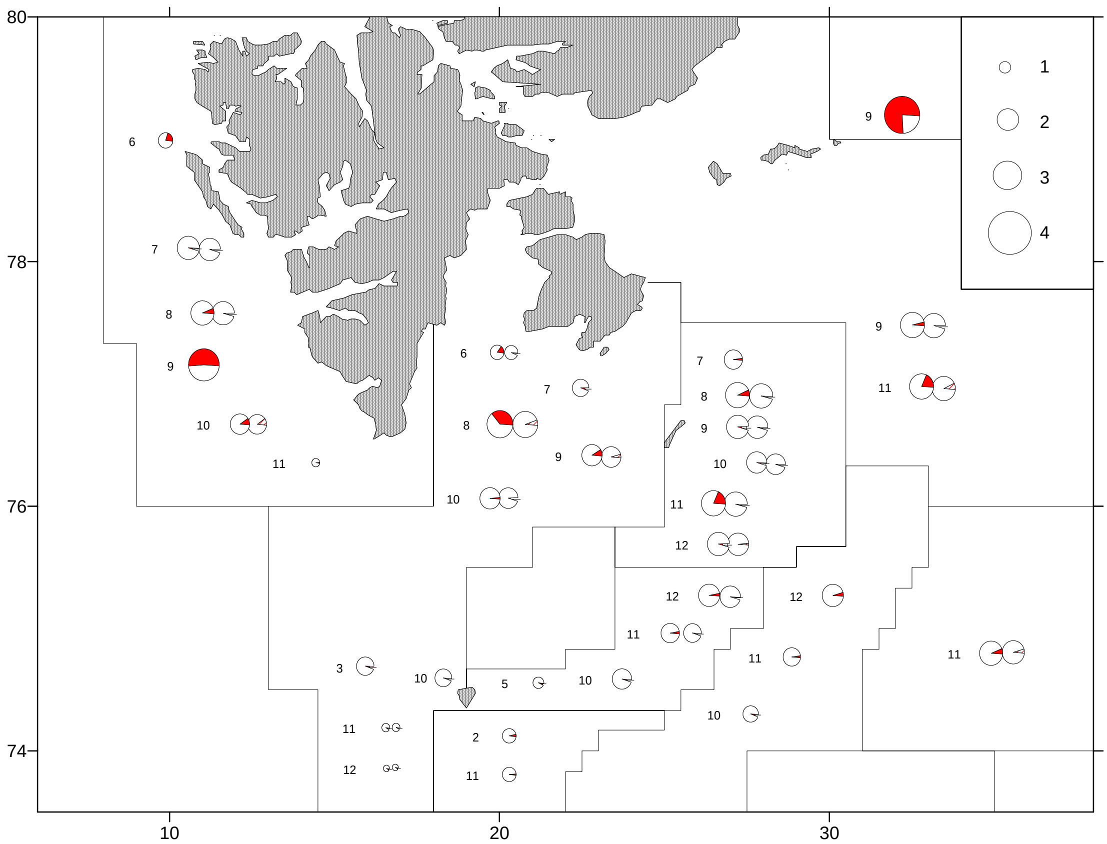

Fig. 13. Frequency of occurrence polar cod (red colour) and young polar cod (shading) in cod stomachs in Barents Sea by months 2001 (ciphers show months)

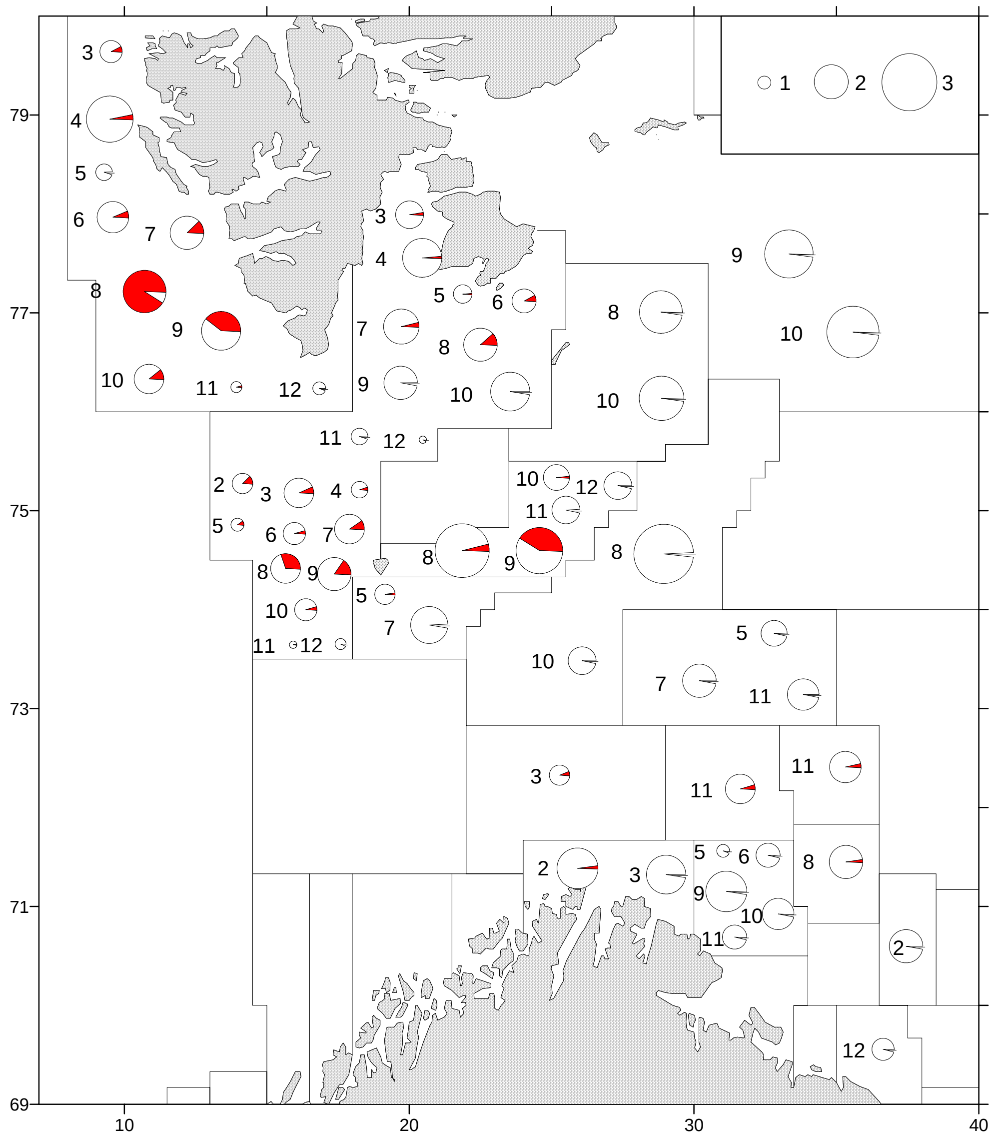

Fig. 14. Frequency of occurrence (red colour) blue whiting in cod stomachs in Barents Sea by months 2002 (ciphers show months)

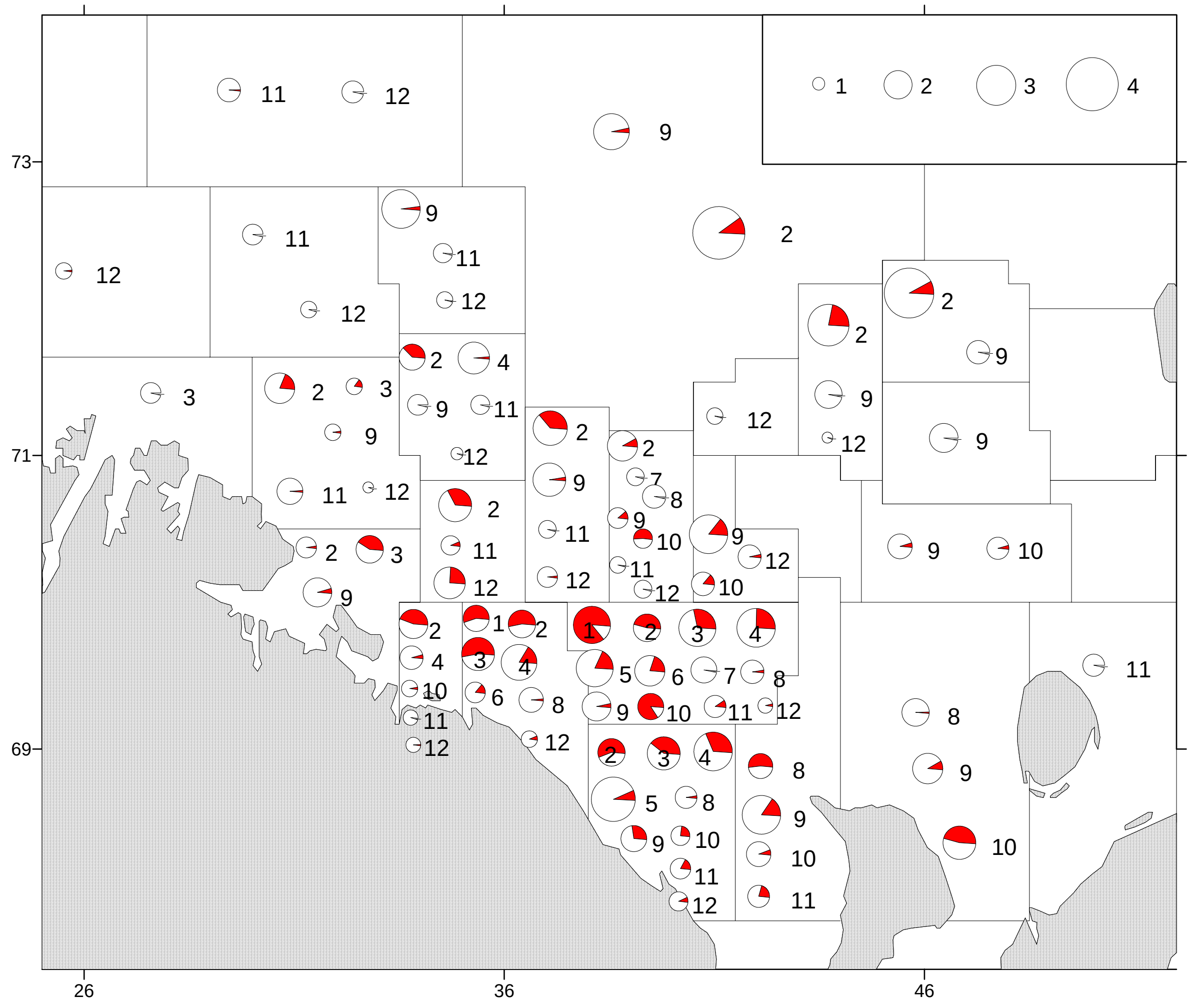

Fig. 15. Frequency of occurrence (red colour) herring in cod stomachs
in Barents Sea by months 2003 (ciphers show months)

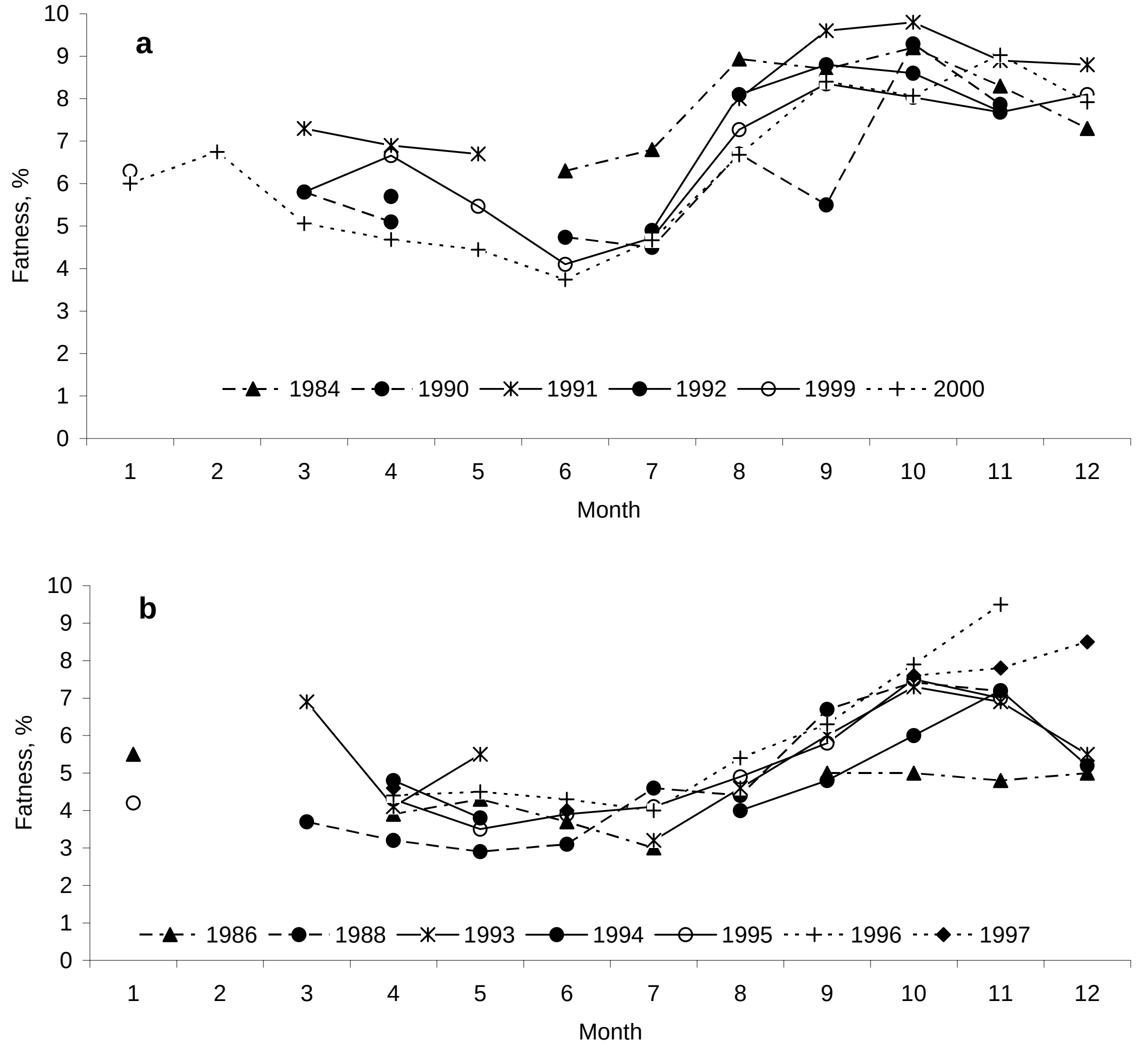

Fig. 16. Seasonal changes in cod fatness with high (a) and low (b) capelin supply

Table 1. Food composition of cod in the Bear Island-Spitsbergen area in 1984-2004, % of bolus weight

Food items	Years																				
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Hyperiids	9,80	28,00	28,47	24,84	3,81	13,90	1,24	0,83	0,29	5,89	9,69	7,38	27,38	3,97	8,88	2,69	9,39	2,82	0,82	5,01	6,25
Euphausiids	1,96	0,07	0,62	0,98	3,89	1,54	0,19	0,64	0,31	0,26	1,37	4,35	8,59	6,09	2,50	3,06	4,26	1,81	2,63	2,21	0,74
Northern shrimp	13,32	6,19	6,47	9,84	1,87	9,43	11,27	4,60	14,64	17,02	8,00	11,30	11,78	5,45	18,46	6,76	7,08	6,08	4,42	14,30	12,17
Herring	1,12	0,00	0,00	0,00	2,69	0,00	0,00	0,00	0,87	0,18	0,09	0,03	0,00	0,00	0,01	0,17	3,07	1,00	1,63	0,06	1,27
Capelin	6,68	20,37	8,24	5,09	12,92	24,08	40,77	64,21	36,19	6,41	4,32	1,57	8,15	4,26	14,62	58,82	18,61	19,22	31,15	22,71	11,16
Polar cod	0,00	0,00	14,75	6,97	0,00	0,28	0,35	0,55	6,37	14,57	6,23	5,68	0,82	0,10	8,04	1,91	6,86	8,51	17,69	6,25	20,64
Cod	0,04	2,11	2,45	1,61	0,00	0,00	0,28	1,17	1,18	1,76	6,54	17,12	17,53	38,70	17,26	6,76	9,37	13,24	4,63	5,46	4,13
Haddock	0,00	1,49	0,06	0,00	1,40	0,00	0,05	0,90	0,20	0,01	0,92	0,14	0,18	0,61	1,90	0,27	1,45	1,81	2,25	3,18	0,83
Norway pout	0,00	0,01	0,11	0,00	9,08	0,15	0,06	0,00	1,91	0,03	0,03	0,00	0,06	0,00	0,00	0,01	0,00	0,77	0,00	0,03	0,14
Blue whiting	0,14	2,28	0,00	0,00	0,00	0,00	0,32	0,38	0,00	0,00	0,00	0,03	0,05	0,77	1,50	0,57	2,42	14,23	9,95	6,02	4,26
Redfish	1,53	9,89	10,90	21,61	1,11	7,70	13,19	11,46	6,53	2,89	5,43	7,55	7,62	7,67	1,08	0,52	0,70	1,00	0,89	0,62	0,00
Wolffish	0,01	0,06	0,02	0,00	0,00	0,57	0,38	0,00	2,29	0,50	0,55	0,06	0,09	0,00	0,19	0,08	0,00	0,54	0,00	0,00	0,01
American plaice	1,85	3,14	1,79	0,76	0,62	1,11	2,31	0,96	1,54	14,56	3,42	1,51	1,83	4,22	1,05	0,31	2,64	4,40	1,08	2,60	3,16
Greenland halibut	0,00	0,00	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,12	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,42	0,04	0,00	2,81
Other fish	24,42	19,04	22,34	15,79	29,52	17,31	21,25	8,66	13,31	14,13	10,83	8,18	6,48	13,45	10,07	6,70	14,27	15,84	12,18	22,81	18,38
Other food	39,13	7,35	3,70	12,51	33,09	23,93	8,34	5,64	14,37	21,67	42,57	35,10	9,44	14,71	14,44	11,37	19,87	8,31	10,64	8,74	14,05

Total amount of stomachs	1002	1282	1858	2558	987	855	1804	1302	1510	1235	1625	2185	2422	1613	3528	4343	3152	5338	5757	1560	1471
Food items	Years																				
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Empty stomachs, %	16,1	18,4	13,2	13,4	10,8	3,9	7,6	10,2	15,6	18,9	12,5	12,7	12,0	26,8	29,3	23,0	17,3	27,8	25,9	31,3	30,2
Mean fullness.	2,8	2,8	3,0	2,2	2,8	3,1	2,9	3,2	3,1	3,2	3,1	3,1	2,9	2,2	2,2	2,4	2,5	2,6	2,6	2,0	2,2
Mean index of fullness.	186,9	180,9	222,9	169,3	184,3	226,9	314,6	181,8	211,6	171,6	154,4	176,5	169,8	134,9	168,8	252,9	217,1	205,0	235,9	197,9	156,2

DISTRIBUTION AND NUMBER OF MARINE MAMMALS IN THE OPEN BARENTS SEA AND THEIR CONNECTION WITH CAPELIN AND POLAR COD DISTRIBUTION

by

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Abstract

This paper presents the data on the character of distribution and the assessment of the number of marine mammals in the open part of the Barents Sea in autumn 2001-2004 by the results from PINRO's aerial surveys using the airborne laboratory AN-26 "Arktika" and the annual joint Russian-Norwegian vessel ecosystem survey for pelagic fish including capelin and polar cod. The aerial surveys were carried out being combined with the vessel surveys and their tacks coincided or crossed in several points.

Introduction

The aerial surveys for marine mammals were conducted by the transects oriented, primarily in the latitudinal direction (Fig.1). If it was possible, the distance of not more than 30 nautical miles between the transects was kept, the flying altitude was from 100 m to 500 m depending on the height of the lower border of cloudiness. The visual observations were made by not less than two observers through the board bubble windows from the right and left boards that allowed us to have enough wide observation strip. The observers registered marine mammals within the observation strip of their board, the information was sent through the internal communication means to the operator of the board computer station who input it to the protocol of the flight in the mode of real time with time, altitude, positions and others associated automatically.

The data on the distribution of marine mammals were collected in parallel with the observers from the research vessels participating in the survey. The observations aboard vessels were made using the standard methods. Only the vessel observation data which had been processed were presented here. Owing to that, the data on distribution of marine mammals are of generalized character. In processing the data from the aerial observations of marine mammals the areas of their largest concentration for each species were separated out, the areas for each group were mapped out. The position of such groups on the map shows the main parts of this species in the Barents Sea area in the given time period.

Among 20 species of the marine mammals dwelling in the Barents Sea about half of them are seasonal spending a certain time period there. As a rule, it is a warm season, spring-autumn, when migrations of the marine mammals in the Barents Sea are mainly caused by the movement of the large concentrations of the feeding objects, which are both plankton and fish (Geptner et al., 1976).

Now, based on the data from the surveys it is safe to say that the relative number of marine mammals spending the summer-autumn period in the Barents Sea area significantly increased. It may be explained by both the increase in population abundance of the cetaceans after the ban of their fishery and some reduction in harvesting press on pinnipeds. At the same time, the distribution of marine mammals in the area may differ much by years depending on change of status and distribution of the organisms constituting the food supply (Zabavnikov, 2005).

Among the large cetaceans a minke whale (*Balaenoptera acutorostrata*) was observed the most often. This species is easy identified and one of the most frequently occurring cetaceans in the Barents Sea. A humpback whale (*Megaptera novaeangliae*) is comparable with it in occurrence. It was not possible to identify species of some cetaceans.

A white-beaked dolphin (*Lagenorhynchus albirostris*), a representative of small cetaceans, is the most frequently occurring species in the Barents Sea. At present, this species being common and abundant is distributed, practically, all over the Barents Sea. The other dolphins (such as harbour porpoise *Phocoena phocoena* and common dolphin *Delphinus delphis*) were recorded more seldom.

Results

2001. In the area of the Hopen Island and the southeastern extremity of the Spitsbergen Archipelago, the dolphins which were not identified (groups of 5-12 individuals) and single specimens of minke and humpback whales were observed. Judging on the TAS (trawl-acoustic survey) data, all the cetaceans occurred in the areas where the capelin density was moderate (Fig.2).

According to the poor data obtained this year, the large stocks of the harp seals were registered in the area of maximal capelin concentration density. In the area of the southern extremity of the Spitsbergen Archipelago, the dolphins (from single to ten specimens), the stocks of harp seals and single killer whales were recorded. All the animals were distributed in the periphery of the polar cod poor concentration (Anon., 2002).

2002. In the area of the Hopen Island, the southern extremity of the Spitsbergen Archipelago, whales and dolphins had different direction of the migration and the conclusion may be drawn that all the animals were in that area looking for the available food. Whales, primarily, were distributed in the areas of capelin moderate concentration and dolphins – in those ones of small dense coastal concentration of polar cod (Anon., 2002a).

In the northern central Barents Sea, the white whales (single individuals), dolphins (single individuals), harp seals (groups consisting of to hundred animals), as well as whales including humpback and minke whales (Fig.3) were observed.

In the southwestern Barents Sea, both dolphins (mainly, white-beaked dolphins (groups to ten and a half tens individuals), killer whales (groups of to 10 animals) and whales including the minke and humpback whales (single individuals) were registered. The western and northern groups, most likely, fed on polar cod which occurred in quite dense concentrations and the eastern one – on capelin (Anon., 2002b).

In the central Barents Sea, predominating were humback whales (single individuals) consuming capelin which were distributed in dense concentrations.

In the central eastern Barents Sea, according to the observations from vessels, dolphins including the white-sided ones (from single individuals to several tens in groups) and whales (humpback whales, sei whales, killer whales) (from single individuals, that was the most often, to two tens in a stock (killer whales)) were recorded. In that area, the animals concentrated on dense aggregations of polar cod (Anon., 2002a).

That year, cetaceans primarily fed in the northwestern area of the Hopen Island. The feeding migrations were mainly connected with capelin.

2003. The most abundant marine mammal groups fed in the Hopen Island – the southeastern extremity of the Spitsbergen Archipelago area, the animals consumed capelin occurring in dense concentrations and polar cod, to a lesser degree. In that area, everywhere, dolphins including the white-beaked dolphins and northern bottlenose whales (single individuals), whales (the humpback whales and minke ones) and killer whales (groups consisting of 15-20 animals) were recorded (Fig.4).

An interesting regularity is observed marine mammals (with available data on migration direction) along the line from the Rybachy Peninsula to the southern extremity of the Frantz Josef Land moving in the eastern (southeastern and northeastern) directions towards the large concentrations of capelin and polar cod in the central Barents Sea (primarily white-beaked dolphins in groups being composed of from several individuals to ten) (Anon., 2003).

In the southern part, near the Spitsbergen Archipelago, the dolphins (inclusive of the white-beaked, dolphins white-sided dolphins and harbour porpoises), whales (the humpback whales and killer whales) and the harp seals (single individuals) were observed. Certain food items couldn't be identified based on the data from TAS.

In the central Barents Sea, whales (the humpback whales and sperm whales), dolphins (primarily, the white-beaked dolphins) as well as white whales (single individuals) were recorded. That group most likely fed on the both food items (capelin and polar cod) and had constant migrations to find dense concentrations.

2004. In the central Barents Sea, where, by the data from TAS, the densest concentrations of capelin and polar cod (more eastward) (Fig.5) occurred, the large stocks of dolphins (mainly, of the white-beaked dolphins (to thousand individuals in a stock), as well as common and non-identified ones), humpback whales and minke whales (to one and a half tens in a group), fin whales and killer whales (single specimens) were found. In accord with the data from both aerial and vessel observations, southern and southeastern migrations of animals (humpback whales and killer whales, harp seals and white-beaked dolphins) feeding in the areas of polar cod and capelin dense concentrations were prevailing (Anon., 2004).

To the west of the Bear Island, the group of animals (mainly white-beaked dolphins, northern bottlenose whales, humpback whales, minke whales and others) was found. The northern part of the group migrated mostly east and northeastwards, to the dense concentration of polar cod (white-beaked dolphins and humpback whales). The southern part had the migrations, chiefly, to the southeast (possibly to feed on herring).

In the northeastern Barents Sea, near the southwestern extremity of the Frantz Josef Land, the dolphins (primarily the white-beaked dolphins (groups consisting of to two hundreds of individuals), the white whales (to a thousand of animals (about two minute flight crossed the way of migration to the north-east)), the harp seals (to a hundred individuals in a group), whales (more seldom), the species of which could not be identified were registered. The direction of animal migrations coincided with the areas of concentrations of capelin (it was for the white whale) and polar cod (Anon., 2004).

In the area of the northwestern extremity of the Novaya Zemlya Land, large concentrations of the harp seals migrating in the eastern and northeastern direction to the coast and feeding on mainly polar cod having poor concentrations there were registered.

As the results of observations showed, in 2004, cetaceans and pinnipeds were widely distributed all over the area surveyed. The concentration of marine mammals on those ones of the food items was denser and more prolonged (humpback whales and dolphins) than in 2003. Against low strength of capelin (the lack of dense concentrations) the large groups of marine mammals primarily concentrated on polar cod and herring aggregations. In the Barents Sea area, the migrations of cetaceans have become more prolonged in respect of the period of stay in the sea area and distance. The character of revealed distribution of the marine mammals in the Barents Sea area in autumn is, possibly, a consequence of the effect of warming (pronounced earlier spring migration) as well as of the change of the food supply towards the reduction (capelin).

In the Barents Sea, a relative increase in occurrence of such species as sei whales, pilot, fin whales and sperm whales was noted. For the first time, in April, in the central Barents Sea, over the areas of capelin wintering concentrations, the groups of white-beaked dolphins were recorded. The number of minke whale in the coastal groups, near the Murman coast of the Barents Sea, grew (Zabavnikov, 2005).

Conclusions

Based on the data obtained mainly as a result of PINRO's aerial surveys it may be stated that:

- a relative increase in the number and the areal size in the Barents Sea of such species as humpback whales and minke whales and white-beaked dolphins was found;
- the distribution of cetaceans in the Barents Sea area is more connected with capelin, than with polar cod distribution; it was noticed that the distribution may be caused by the concentrations of the other food items;
- the trophic role of marine mammals in the ecosystem of the sea at present may be very significant;
- further research on marine mammals of the Barents Sea including special-purpose aerial surveys and study of feeding of marine mammals is necessary.

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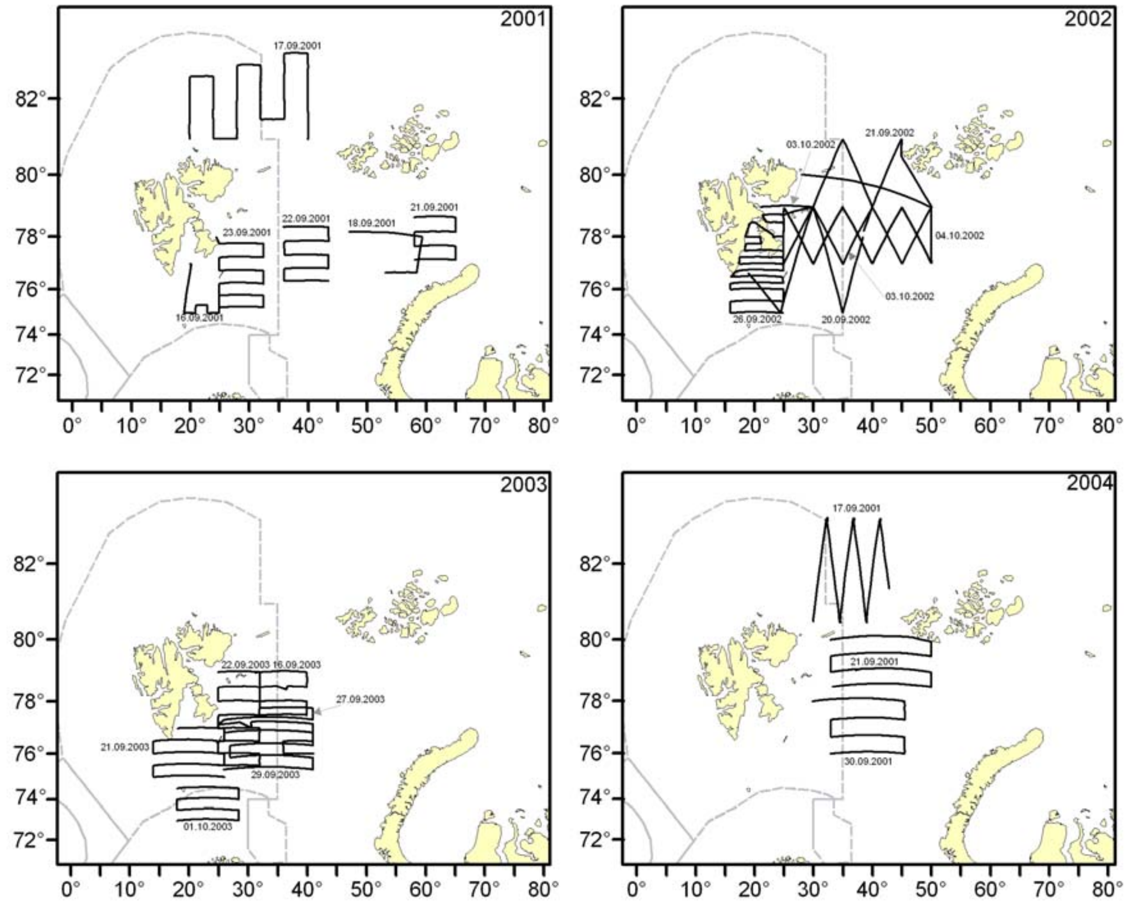

Fig.1. Situation of transects of air surveys 2001-2004

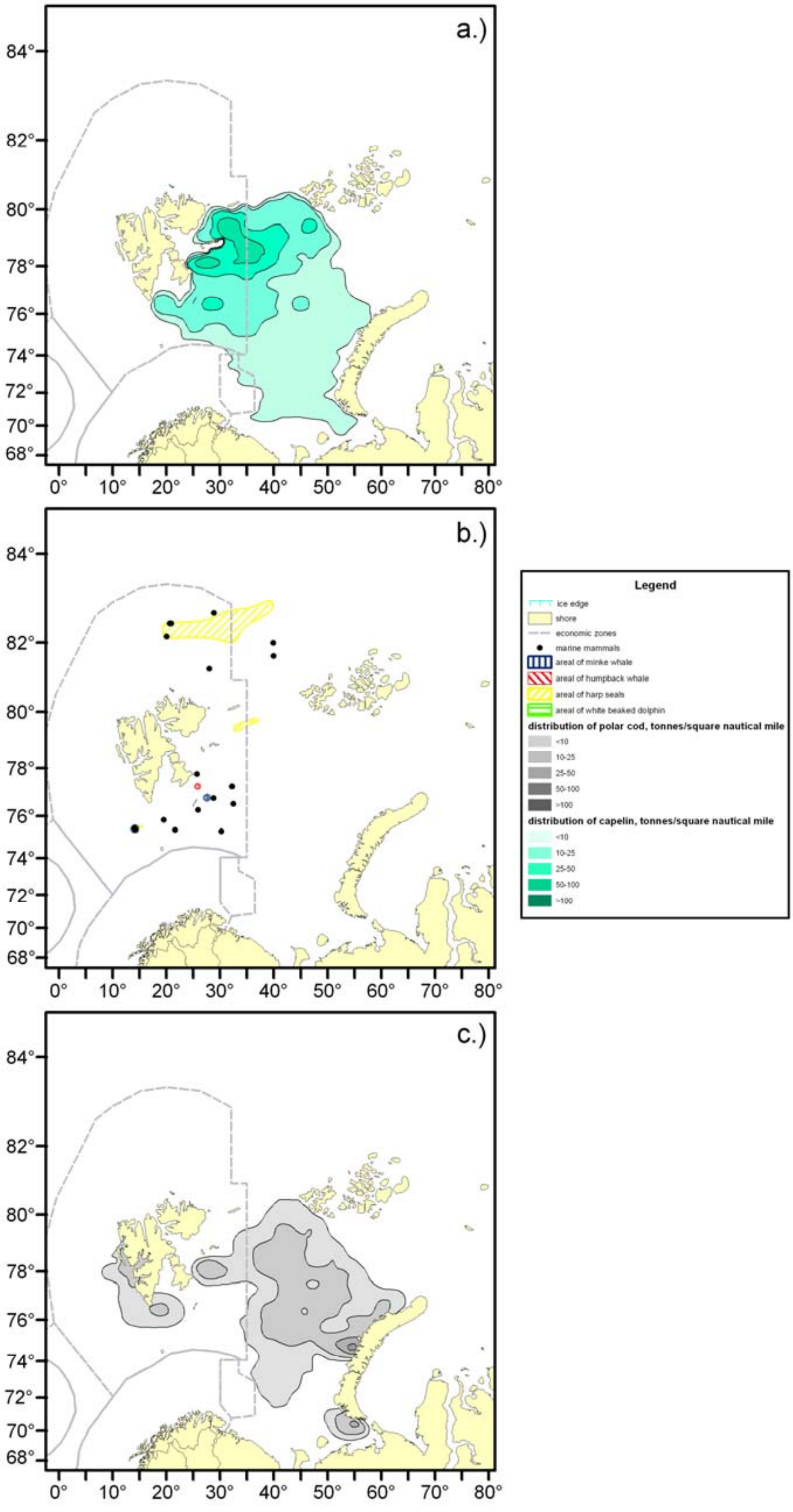

Fig.2. Distribution of capelin (a), marine mammals (b) and polar cod (c) in the open part of the Barents Sea during autumn 2001

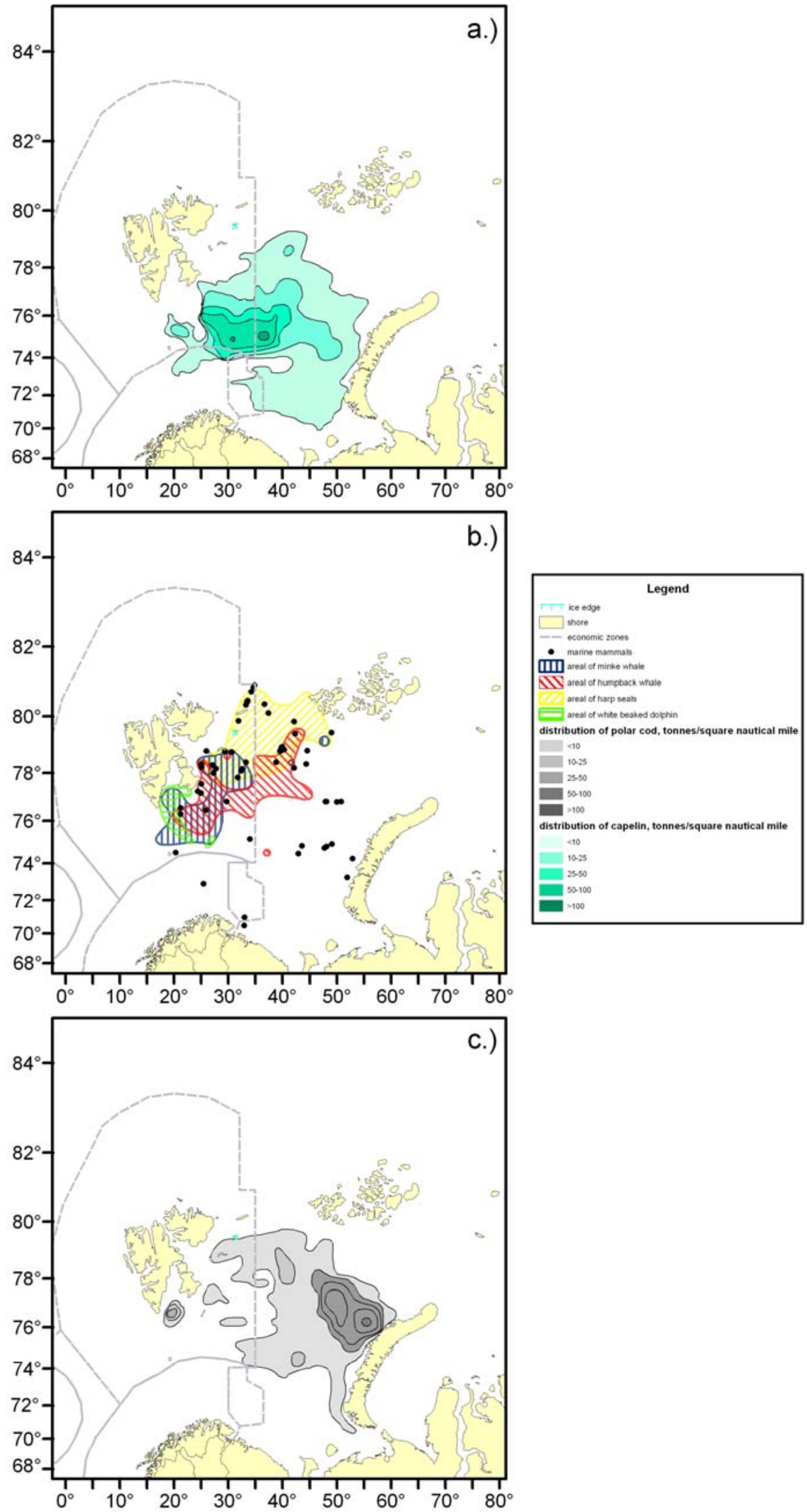

Fig.3. Distribution of capelin (a), marine mammals (b) and polar cod (c) in the open part of the Barents Sea during autumn 2002

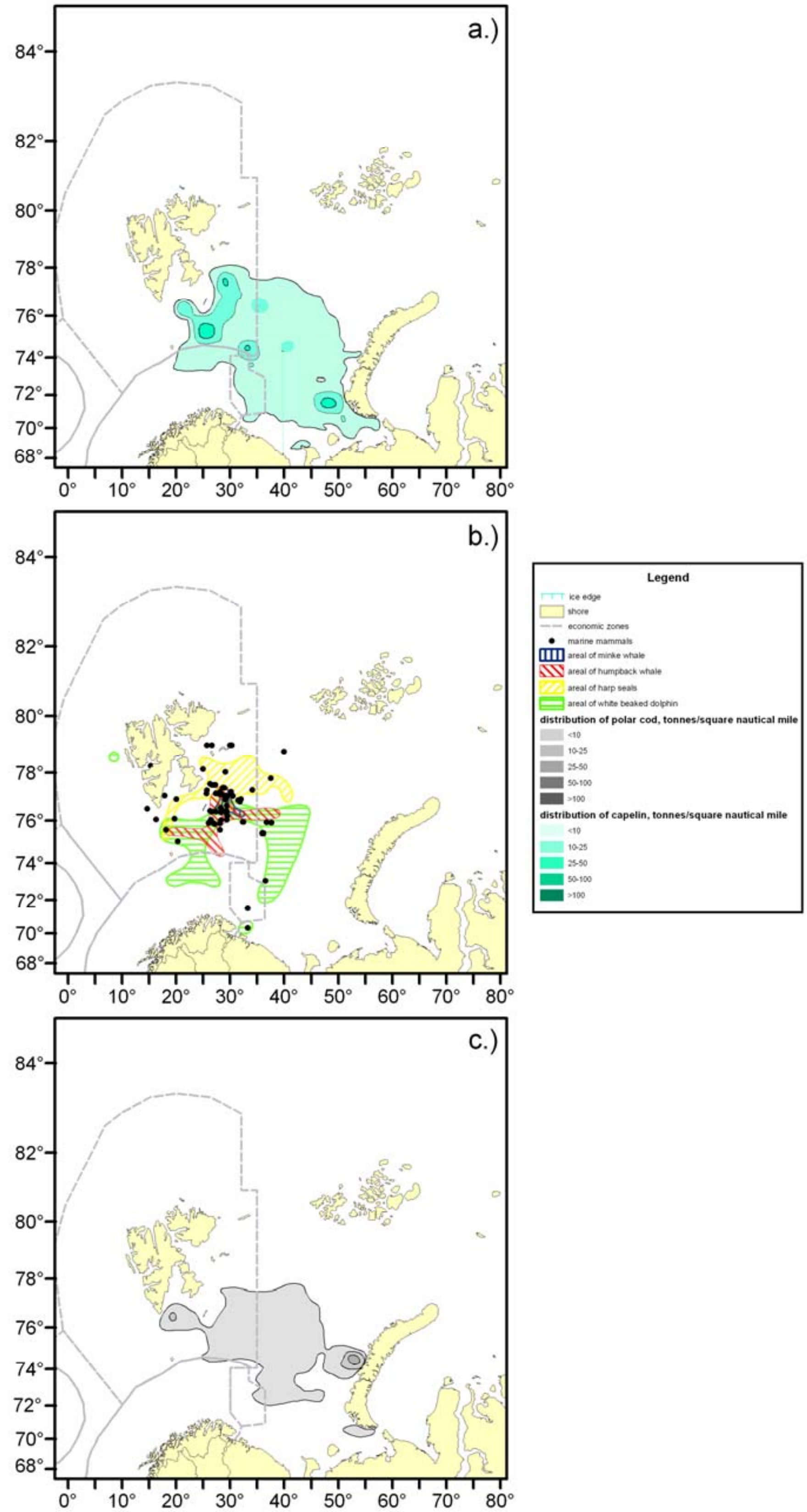

Fig.4. Distribution of capelin (a), marine mammals (b) and polar cod (c) in the open part of the Barents Sea during autumn 2003

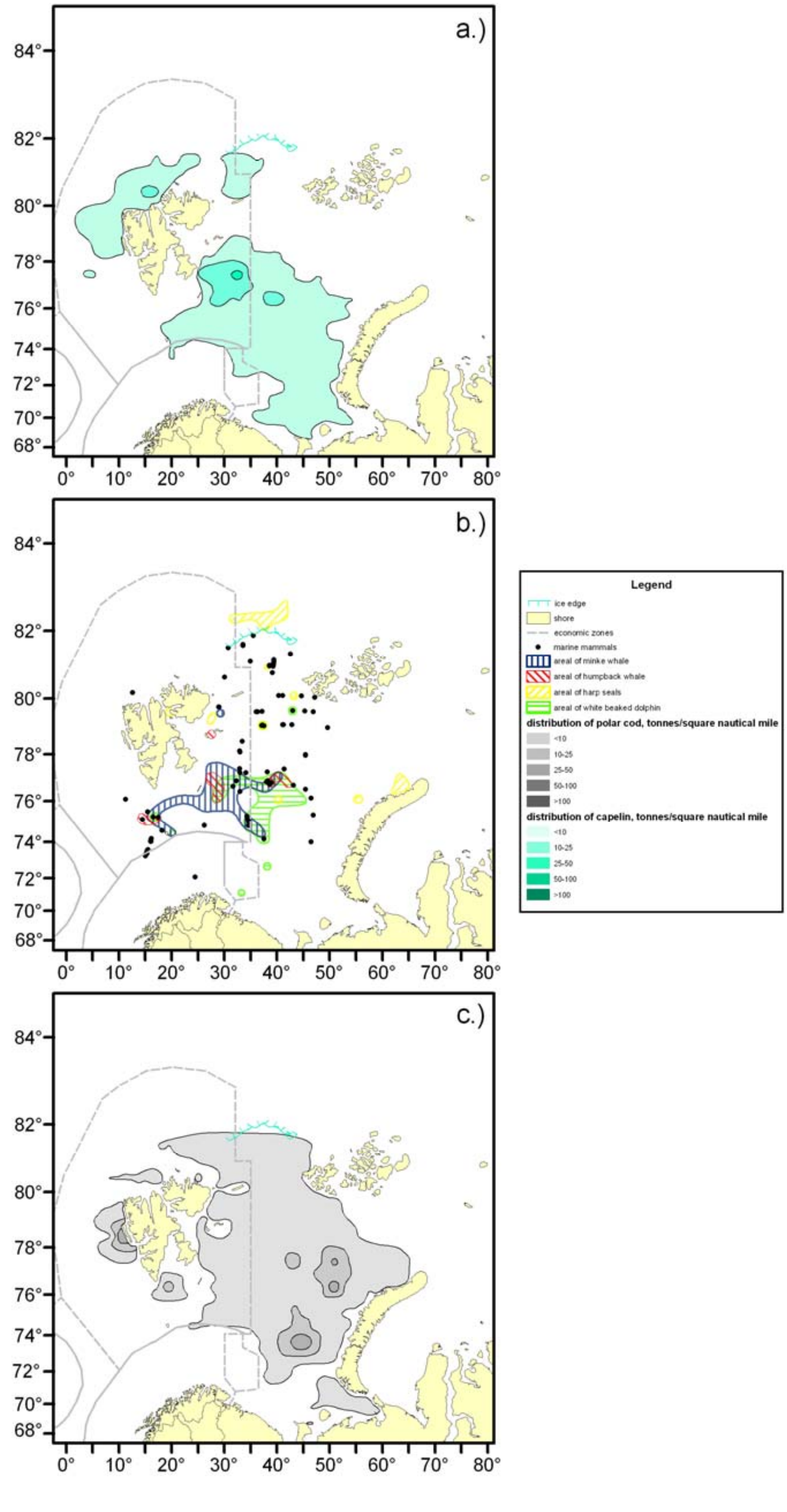

Fig.5. Distribution of capelin (a), marine mammals (b) and polar cod (c) in the open part of the Barents Sea during autumn 2004

SYSTEM OF DATA COLLECTION IN THE BARENTS SEA BY THE OBSERVERS FROM PINRO

by

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Introduction

Rational management of marine living resources is an activity directed to the avoidance of the collapse of marine organism stocks and the provision with their optimal utilization. The developed measures to regulate stocks must supply with deciding the three main tasks: to provide reproduction, to get stable catches during a long period and to have high economic efficiency in the fishery with a minimal damage for the exploited species population.

The measures on conservation and management of the stocks of aquatic biological resources should be based on the most accurate available scientific data assigned to provide a long-term stability of fishery resources at the level which would favour their optimal utilization and allow them to be kept for the present and future generations.

This information may be only obtained if fishery, biological and hydrographic data used to estimate fishery and spawning stocks of the commercial fishes and invertebrates and to work out regulation measures (age composition of catches, percentage of mature individuals, catches per effort, discards, underestimated catch size and others) are regularly collected. One of the two most important sources of these data is (besides the surveys for stocks of commercial marine organisms aboard the research vessels) the work of observers aboard fishing or institute's vessels operating in the fishery regime in the course of the monitoring and test fishing.

Basis of observer work and data collection

The legal basis of work and data collection by PINRO's observers aboard fishing or institute's research vessels is a Federal Law "On fishery and protection of aquatic biological resources" No.166 of 20 December 2004, the Act of the Government of the Russian Federation No.704 and the decisions of the annual meetings of the Joint Russian-Norwegian Fisheries Commission.

In accordance with the Act of the Government of the Russian Federation No.704 "On the quotas for harvesting the aquatic biological resources" of 20 November 2003, the body of executive power which provides legal regulation in the field of fishery and the conservation of aquatic resources has the right to cancel the agreement on shares of quotas for harvesting the aquatic biological resources with an applicant in accordance with a legal procedure in the case of the non-execution of obligation to receive aboard and pay the costs of the stay aboard of "not more than two specialists from the research institutions of the Federal Agency of Fisheries executing the monitoring of the state of the aquatic biological resources within not more than 10% of the total period of fishing operations in the area where the user executes fishing in accordance with the given licenses”.

In other words, during the calendar year, each shipowner is obliged to create the conditions for work of observers at their own vessels, during 10% of fishing time spent in the period of works to realize the commercial quotas allocated. At that, the realization of Act No.704 and the provision with the mentioned time by the shipowners may be different and depends on the agreement between the institute and the shipowner.

Taking into consideration that the standard duration of the commercial cruise is three and a half months or 105 days, the most preferable is the variant when the observers don’t work at each vessel during the 10 days, but carry out the research at the same vessel during the whole cruise and 10% of time are not calculated individually by vessels, but for company, on the whole. This practice allows the Polar institute to provide the collection of the minimal fishery and biological data volume which is necessary to estimate stocks and solve the other problems facing.

Unfortunately, carrying out research works and data collection on the basis of the Act No.704 is considerably complicated. In the first place, it is connected with the imperfection of the Act in which the legal and financial obligations of the parties were defined indistinctly. So, the different interpretation of the concept “stay aboard the vessel” and the uncertainty of the labour payment source for the observers in the period of their stay aboard the vessel result in the situation, when, in the most of cases, practically all the expenses for the observer stay (payment, feeding, special clothes and et cetera) are paid by the Polar institute with the lack of the special-purpose funding of this kind of work from the state budget. It is also necessary to regard the expenses connected with the delivery of the observers to sea in the cases when fishing vessels are in the fishery.

The technical equipment of most fishing vessels which is insufficient to carry out scientific research and, in the number of cases, to accommodate the observers creates insuperable obstacles to conduct works even in the case of a positive solution about sending the observers to a commercial vessel. In these cases, data collection is often limited by mass measurements and age sampling, as the other works cannot be done, practically, at the vessels which are only equipped to fish and produce the fish products.

A considerable shortcoming of realizing the Act No.704 in practice is the impossibility to collect data in all the areas of marine organism distribution and fishing fleet activity, since in the process of vessel operation by their own commercial quotas, the observers from PINRO cannot change the route or dislocation.

The other source of fishery, biological and hydrographic data is a work of observers in fishing for research and control purposes. The legal basis of such kind of fishing is a Federal Law “On fishery and protection of the aquatic biological recourses” No.166 of 20 December 2004 and the annual decisions of the Joint Russian-Norwegian Fisheries Commission on the allocation of a certain part of TAC for scientific and management purposes.

In compliance with Article 21 of the Law No.166:

1. Fishery for research and control purposes is undertaken to study the aquatic biological resources and their environment, to conduct state monitoring of the aquatic biological resources, to search the new fishing areas and the stocks of the aquatic biological resources, to determine total allowable catches, to develop measures for conservation of the aquatic biological resources.

2. Fishery for research and control purposes is undertaken on the basis of the annual plan of the resource investigations and state monitoring of the aquatic biological resources, as well as of the scientific programmes.

3. The order of fishery for research and control purposes is established by the federal body of the executive power exercising the legal regulation in the field of fishery and conservation of the aquatic biological resources.

The quotas for harvesting the aquatic biological resources to undertake fishing for research and control purposes (scientific quotas) including those ones allocated to the Russian Federation in accordance with the international agreements, are annually allocated by the federal body of executive power in the field of fishery and approved by the federal body of the executive power exercising the legal regulation in the field of fishery and protection of the aquatic biological resources.

The size of catch of the fish species and invertebrates which are the objects of the joint regulation by Russia and Norway, as well as the programmes of the joint Russian-Norwegian researches on the marine living resources implementing which this catch is taken, for research, control and management purposes is annually approved at the sessions of the Joint Russian-Norwegian Fisheries Commission (JRNFC).

Fishery for the scientific, control and management purposes is realized in accordance with the procedure established by the acts of the government of Russian Federation and the orders of the Federal Agency of Fisheries. At the first stage, the regional research institutes including the Polar institute submit their proposals concerning the kinds and periods of the investigations to the main branch institute (VNIRO). Based on the received proposals VNIRO develops a summary plan of marine resource investigations and state monitoring which is further considered by the Federal Agency of Fisheries and approved by the Ministry of Agriculture. After having established the quota size for the scientific and control purposes the branch research institutes prepare the projects of schedules specifying vessels, periods and areas of research, purposes and tasks of works which are agreed with the other organizations and approved by the Federal Agency of Fisheries. After the schedules have been approved and the research and control fishing licenses have been given by *Rosselkhoznadzor* (before – *Murmanrybvod*) the branch research institutes start carrying out investigations.

The abovementioned procedure has its merits and demerits. Among the positive sides of the data collection system, in the course of implementation of the Programme of joint Russian-Norwegian research on marine living resources, there is, in the first place, a possibility of data collection in all the areas of fishing fleet operation and distribution of mass concentrations of marine organisms. The necessary condition in the contract between the Polar institute and a fishing company providing a vessel to carry out researches for scientific and control purposes is the possibility to change the vessel operation areas and make search and check hauls outside the commercial fleet operation area.

The other merit consists in equipping the vessels which are used when realizing the scientific quotas to conduct comprehensive investigations according to the tasks from the Polar institute. In compliance with the established procedure, the vessels to carry out research and control works are selected by competitive specially set up commission. As a result of its work, the schedule of PINRO's researches includes the vessels equipped with necessary research and scouting instruments, as well as having the rooms for accommodation and work of the research group.

At the same time, in some cases, strictly regulated procedure of approving the plan of marine resource investigations and state monitoring led to the unjustified delay in the terms of the research start. In particular, in 2003 and 2004, the schedules of marine resource investigations were only approved in the Federal Agency of Fisheries in September that resulted in the frustration of the data collection programme.

Problems solved by observers and planning of works

All-the-year-round observations made aboard the commercial vessels are used to solve the main problems facing the institute:

- the collection of biological data (species, size, age and sex composition of catches) for monitoring of marine organism population state, preparation of the scientific data for international scientific organizations, using fishery and biological information in the forecasts with different lead time;

- study of regularities of forming, distribution and behaviour of marine organisms depending on the environmental conditions, fish biological state and fishery intensity;
- study of the trophic interactions of marine organisms in "predator-prey" system;
- estimation of juvenile by-catch in respect of quantity and working out recommendations together with the fishery inspection to protect fish of the noncommercial size by the way of establishing constant or temporary fishery limitations in the areas of distribution of the noncommercial size fish densest concentrations;
- control of sea pollution as a result of anthropogenous factor influence;
- collection of the hydrographic data (water temperature and salinity, hydrochemical parameters) to estimate sea temperature conditions;
- the assistance to fishing fleet by recommendations and advice on the distribution and behaviour of marine organisms, fishery conditions for the purpose of efficient realization of the national quotas and PAC for the fishery objects which are not allocated by quota at most.

The kinds of work and the volume of information for each certain cruise are determined by the cruise programmes depending on the number of scientists in the scientific group (as a rule, from 1 to 3 persons), vessel technical equipment to carry out the scientific works (availability of the room to process data, electron scales, hydrological winch, probe), seasons and areas of work et cetera. At that, each individual cruise programme is determined by the general plan of fishery and biological data collection which is annually made up with the participation of the leaders in all the departments of the institute and considers the kinds work and species of marine organisms, terms and areas of data collection.

Volumes and kinds of data collected in 2003-2004

Hydrographic data

The effect of environmental factors on distribution of bottom and pelagic fish species in the Barents Sea is corroborated by the long-term investigations of PINRO. To develop the scientific basis for rational utilization of fish resources, provide and optimize fishery full unbiased and timely information about the current and expected variations in the marine fishing ecosystems is required. This need determines the urgency of the directed fisheries ecological monitoring combining the control and forecast of marine environment conditions with the estimation of current and future biological and fishery consequences of the biotope variability.

The initial data to analyze hydrographic situation and the conditions of the distribution of marine organisms in the Barents Sea are taken from the deep-water observations at the standard sections and trawl stations made in the cruises of the research (RV) and fishing vessels according to the programme of PINRO during the year.

Most part (about 60%) of the total number of hydrographic observations at sea are the data collected during the surveys for the fish stocks in the cruises of the research vessels.

The increase in the number of vessels equipped with the CTD-probes allowed us to raise the economic effectiveness of using commercial vessels due to more even planning the volumes of observations. Since 2002 the cruise programmes of practically all the vessels have been containing the observations at standard hydrographic sections that permits us to estimate seasonal and year-to-year trends of variations of the conditions in the fishing areas.

These measures enable us to optimize data collection allowing for the possible peculiarities of seasonal fish distribution, to widen the area of the hydrographic data collection recently (Fig.1).

The analysis of fishery, biological and hydrographical data collected in the Bear Island-Spitsbergen area showed the actual possibility to use operative information for study of the environment factor effect on fish distribution and fishing (Pedchenko, Guzenko, Karsakov, 2005). Keeping the order of the scientific information collection aboard the fishing vessels in the wide area of the sea will permit us to apply this approach in the other fishing areas and consider the influence of hydrographic processes on the conditions of fishery.

It should be noticed that a significant delay in signing the schedules of the resource investigations in 2003 and 2004 resulted in the unjustified losses of necessary hydrographic information.

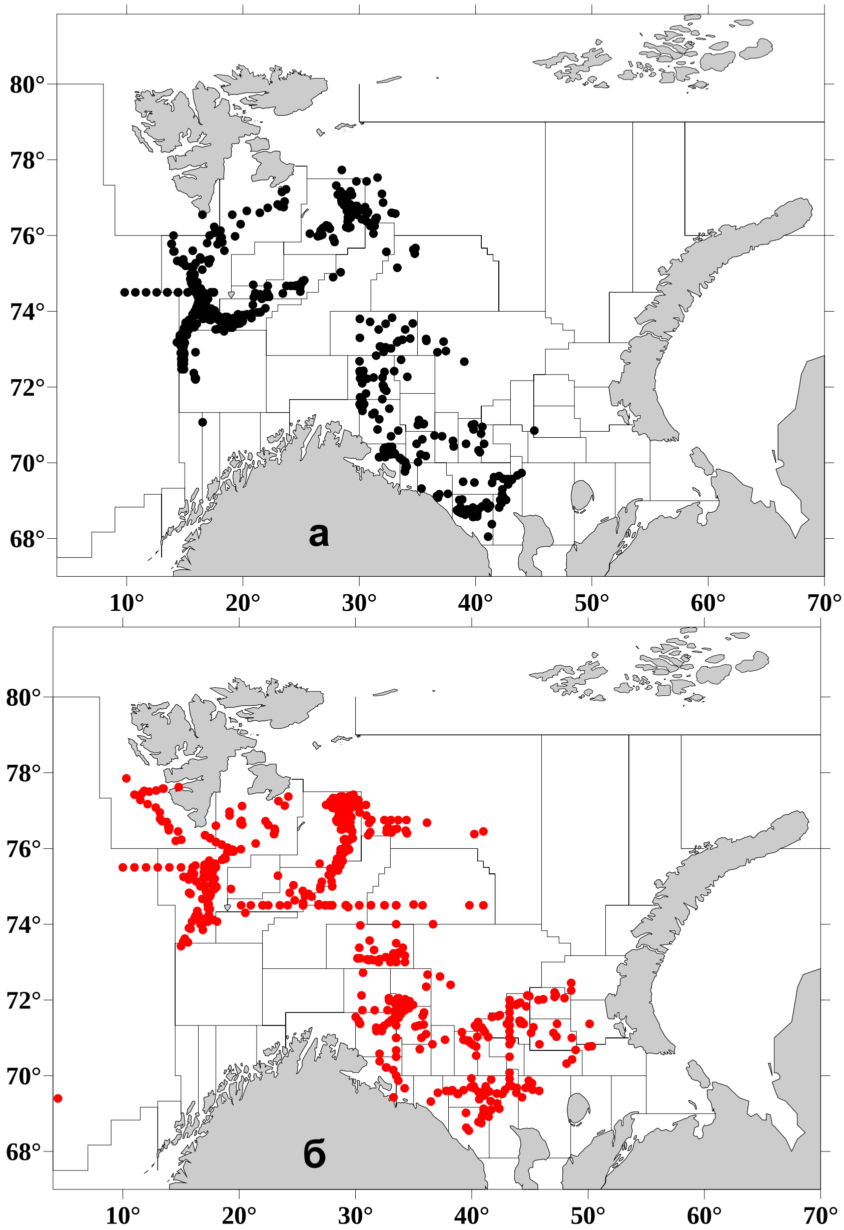

Fig. 1. Hydrographic stations made by the exploratory vessels in the Barents Sea in 2003 (a) and 2004 (b)

It is necessary to mention that in 2003-2004, the total number of the trawl stations made by the observers from the institute aboard fishing vessels during the realization of Act No.704 amounted to about 10% of the total volume of the obtained hydrographic information (Table 1) with the fact that the period of the data collection was longer in three times (January-August).

Fishery and biological information

To show the merits and demerits of data collection by the observers from PINRO we consider the certain examples. In 2004, till August inclusive, the information was collected exceptionally in the course of realization of Act No.704 aboard fishing vessels operating by their commercial quotas, in September-December, – during the realizing of the scientific quotas allocated to PINRO. The data collected in 2004 are presented in Table 2, the information about the two abovementioned types of cruises – in Fig.2, investigations of the areas of fishing fleet operation and the areas of cod distribution – in Fig.3.

Table 1. Hydrographic stations made in 2003-2004 by the observers from PINRO aboard commercial vessels

	2003		2004	
	Number	%	Number	%
According to Act No.704	40	7	78	12
According to the fishery programme of JRHFC	516	93	550	88
Total	**556**	**100**	**628**	**100**

Table 2. Kinds and volume of data collected by the observers from PINRO in 2004

ICES Areas	Data collected						
	Measurement	Feeding	Age	Tagging	Stomachs	SKAP	Genetics
In the course of realization of Act No.704 (January-August)							
I	113214	14081	1776	-	-	1320	-
II-a	70371	6776	1814	-	-	1665	100
II-b	38282	2950	550	-	-	575	-
Total	**221867**	**23807**	**4140**	**-**	**-**	**3560**	**100**
In accordance with the Protocol of the 33d Session of JRNFC (September-December)							
I	298688	29671	7164	-	-	5056	300
II-a	19212	1844	233	-	150	235	-
II-b	402085	40554	7924	915	-	7579	75
Total	**719985**	**72069**	**15321**	**915**	**-**	**12870**	**375**
Total							
I	411902	43752	8940	-	-	8630	300
II-a	89583	8620	2047	-	150	1900	100
II-b	440367	43504	8474	915	-	8154	75
Total	**941852**	**95876**	**19461**	**915**	**150**	**18684**	**475**

As most data (mass measurements, data on feeding collected in the field conditions including the quantitative estimates of these or those marine organism consumption, age samples, the samples of muscles to determine cod groups in the population) show, the percentage of the material obtained in the cruises by scientific quotas in accordance with the programme of the Russian-Norwegian investigations amounts to over 75% taking into consideration that those works were only executed during four months.

Tagging, the collection of data on species composition and determination of the conversion factor necessary to estimate discards were only executed in such cruises. It is connected with considerable time periods and special equipment needed to provide the same work (tagging) that is practically excluded in the fishing vessels as well as with the impossibility to have the information about fish products which is a commercial secret of the shipowners.

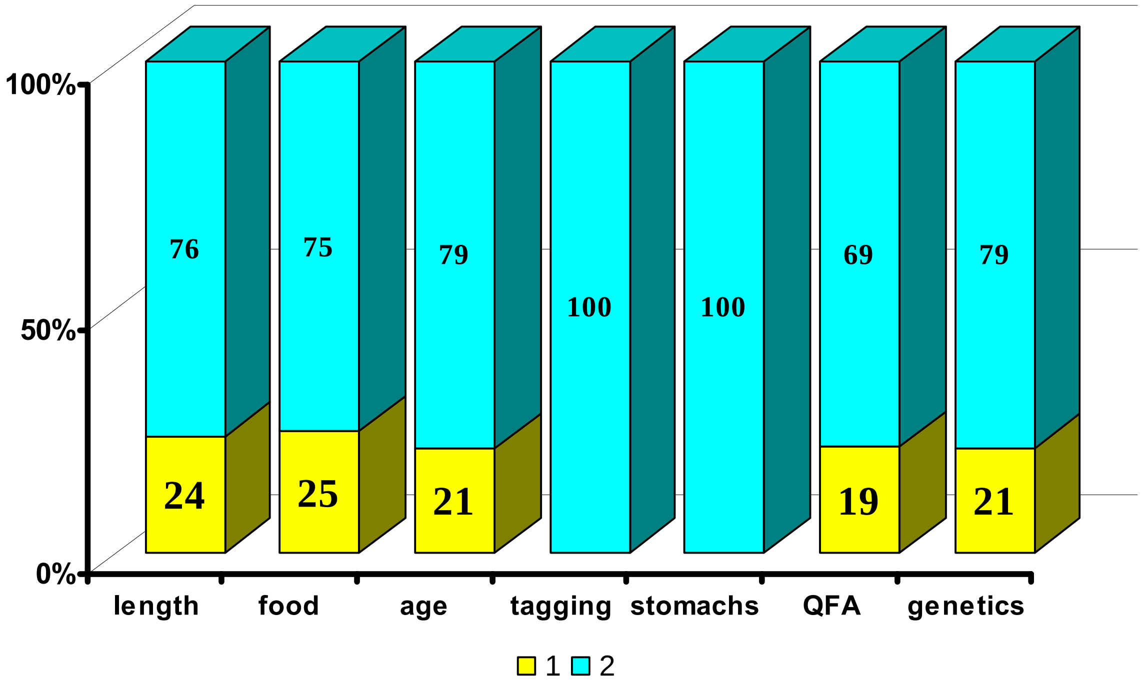

Fig.2. Percentage of fishery and biological data from cruises carried out in accordance with the Act No.704 (1) and when the realizing of the scientific quotas (2) in the whole volume of the information obtained in 2004

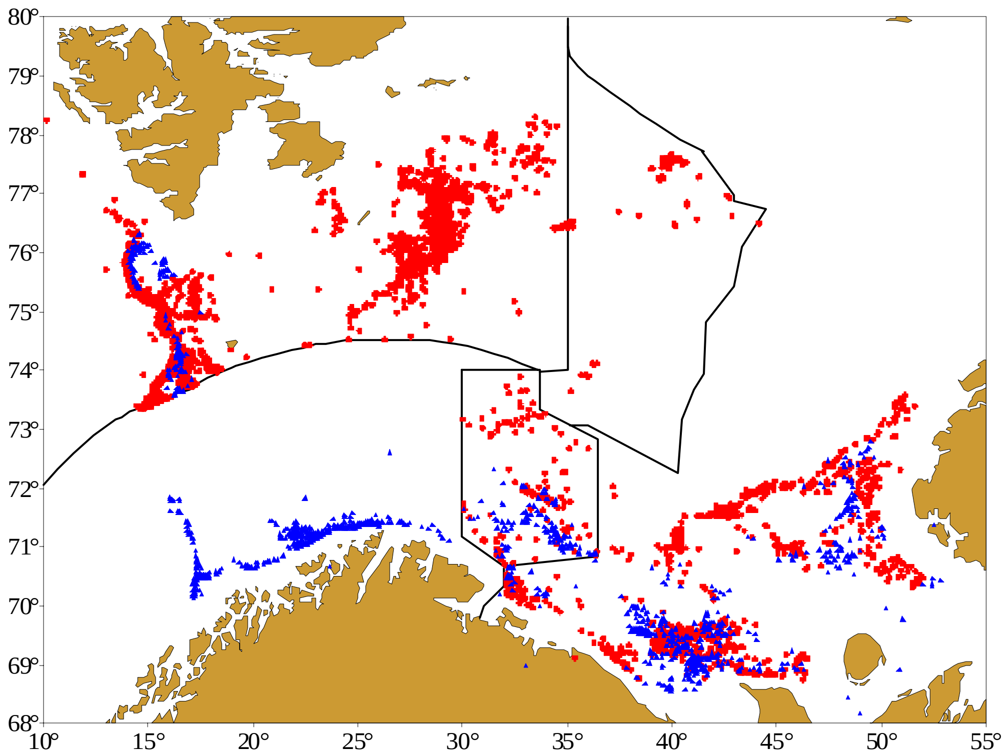

Fig.3. Areas of operation of vessels with observers when realizing the Act No.704 (dark-blue colour) and JRNFC programme (red colour) in 2004

It is also should be noticed that the tests of new fishing methods and gears, development and improvement of measures to protect biological resources (selectivity, long-lining et cetera) with the allowance for the special character and great time expenditures of these works are only possible when realizing scientific quotas.

The same situation with the data collected by the observers from PINRO is noticed for 2003. They only differ in greater percentage of data collected by the observers when realizing the scientific quotas (Table 3, Fig.4).

Table 3. Kinds and volume of data collected by the observers from PINRO in 2003

ICES areas	Kinds of data collected						
	Measurement	Feeding	Age	Tagging	Stomachs	QFA*	Genetics
	In the course of realization of the Act No.704 (January-August)						
I	176117	27873	3328	42	-	2043	8
II-a	24380	2135	100	-	-	-	-
II-b	2685	410	250	-	-	250	-
Total	**203182**	**30418**	**3678**	**42**	-	**2293**	**8**
	In accordance with the Protocol of the 33d Session of JRNFC (September-December)						
I	538879	55188	7822	31	216	6026	85
II-a	94481	7551	775	179	-	413	-
II-b	583320	56780	9799	407	-	9272	265
Total	**1261680**	**119519**	**18396**	**617**	**216**	**15711**	**350**
	Total						
I	714996	83061	11150	73	216	8069	93
II-a	118861	9686	875	179	-	413	-
II-b	586005	57190	10049	407	-	9522	265
Total	1464862	149937	22074	659	216	18004	358

**QFA – quantity feeding analysis.*

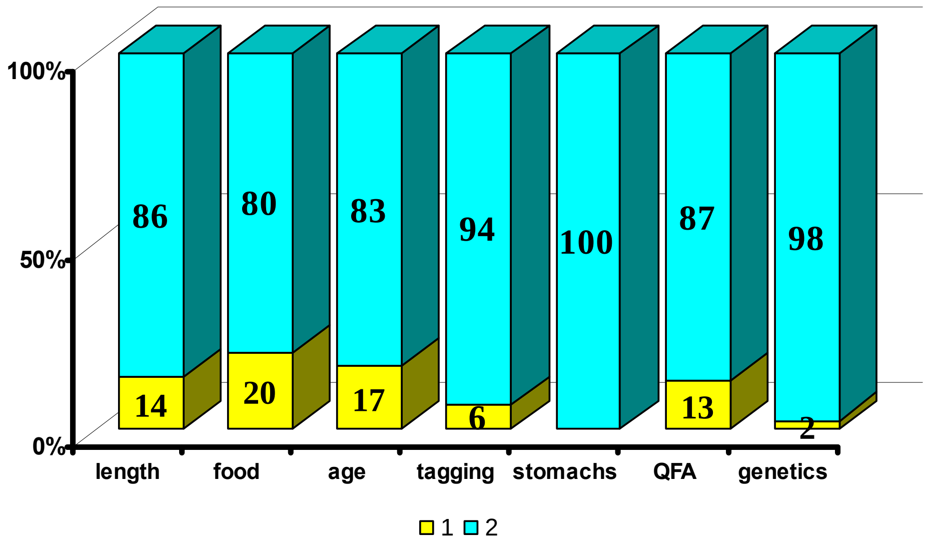

Fig. 4. Percentage of fishery and biological data from cruises conducted in accordance with the Act No.704 (1) and when realizing scientific quotas (2) in the whole volume of the information obtained in 2003

The coverage of the area of cod distribution and fishing fleet operation was much greater during the work of the fishing vessels carrying out the research according to the scientific programmes and the cruise tasks of the institute (Fig.5).

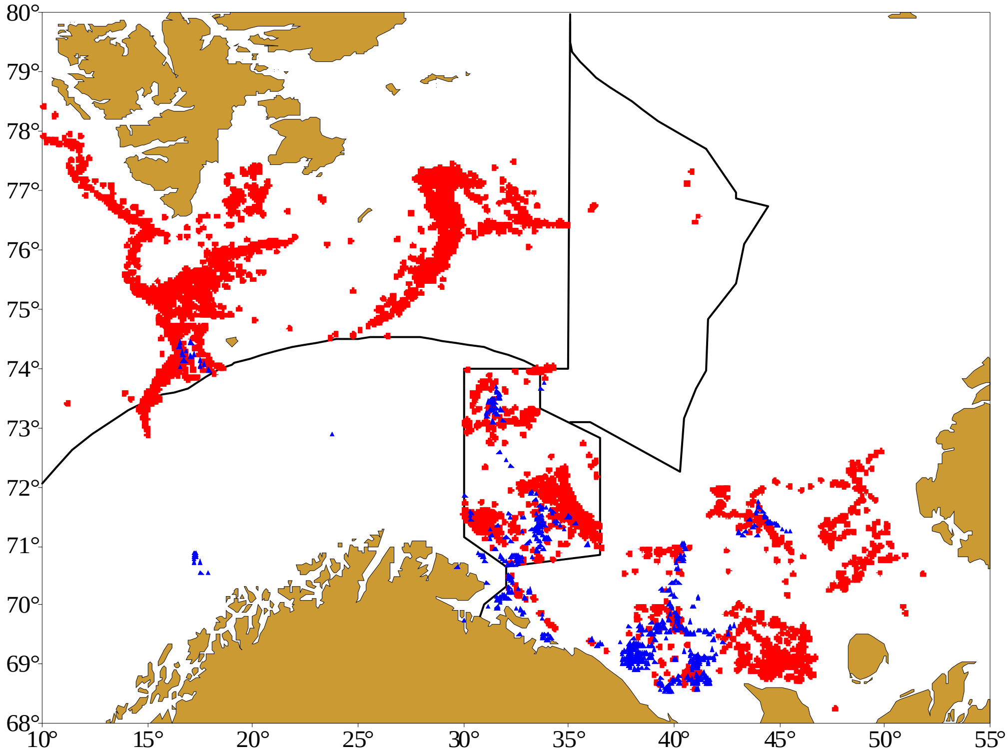

Fig.5. Areas of operation of vessels with observers in realizing the Act No.704 (dark-blue colour) and the programme of JRNFC (red colour) in 2003

Size of scientific quotas

The problem of the size of quotas annually allocated by JRNFC for the scientific and control purposes should be discussed separately. The size of the scientific quotas for the Arctic cod, the main commercial object of the Barents Sea, have been reduced in succession recently: from $20x10^3$t in 2002-2003 to $18x10^3$t in 2004 and, at last, to $7x10^3$t in 2005.

Because of great migration stretching of the main Barents Sea fishing objects along all the branches of the warm currents, spatial and seasonal variability in distribution of their concentrations in the sea area, the valuable collection of hydrographic, fishing and biological data is only possible providing all-the-year-round monitoring and trial fishing. At that, operation of, as a minimum, one vessel carrying out the monitoring and test fishing in the fishing regime both in the area of the abundant concentration distribution (the areas of fleet operation) and outside, in each ICES area, is needed. In this case, the whole period during which the data are collected will be equal to 900 days (all the year round in ICES Subarea I and Div.IIb and half a year in ICES Div.IIa). With the average daily efficiency of 13 tonnes per a fishing day of those types of vessels the contribution of which in Russian cod fishery is maximal (SRTM, PST, STM, non-serial vessels with 1000-2000 kWt engine power) and the mean long-term portion of cod and haddock in catches amounting to 85% and 10%, respectively, the size of scientific quotas for these fish species must equal to, as a minimum, $10x10^3$t and $2x10^3$t, accordingly. Thus, the size of scientific cod quota allocated to Russia for scientific and control purposes for 2005 is insufficient and does not give the opportunity to conduct the complete research aimed at collecting fishery, biological and hydrographical data which are necessary to estimate stocks, correct fishing statistics, determine the size of discards et cetera. Already at the coming meeting of JRNFC it is necessary to increase the size of scientific quota for cod to $10x10^3$t, as a minimum. Smaller size of quota for cod and, moreover, remaining the trend towards its further reduction will inevitably lead to the decrease in volume and representativness of the data collected that will have a negative impact on the quality of stock estimates and, as a result, on joint regulation of harvesting the most valuable object in the Barents Sea area.

Conclusions

The current system of the collection of hydrographic, fishery and biological data used to estimate stocks and develop fishery regulation measures, mainly, allows the Polar institute to provide the necessary volume and quality of the material at present.

The most efficient is the work of observers at specially selected fishing and institute's vessels in the course of realization of the scientific quotas annually allocated at JRNFC meetings. At the same time, the possibility to collect data using fishing vessels is considerably limited.

The remained trend towards the reduction in cod and haddock scientific quota size undoubtedly is leading to the decrease in the data volume and representativeness and, as a consequence, to the stock management deterioration. The volumes of scientific quotas annually allocated to Russia for the scientific and control purposes by the sessions of JRNFC should be equal to, as a minimum, $10x10^3$t of cod and $2x10^3$t of haddock. It will not only provide obtaining necessary volume of data on the sea areas and fishing seasons, but also ensure the collection of data which cannot be obtained during the fishing cruises.

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Theme Session 2: OPTIMAL LONG-TERM MANAGEMENT STRATEGIES OF COMMERCIAL STOCKS IN THE BARENTS SEA

THE USE OF BIOECONOMIC CRITERIA FOR OPTIMAL LONG-TERM EXPLOTATION OF THE BARENTS SEA COD

by

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Abstract

The aim of investigations is development of optimal management decisions for reaching of long-term stable equilibrium under interaction of economical and biological factors in the process of exploitation of the Barents Sea cod.

Daily vessel's data, on-line information of PINRO's observers collected during the check haul and the state monitoring of cod, and results of analysis of conditions of fish seasonal distribution are used in the paper. Bioeconomic efficiency of realization of the national quota for cod by Russian trawlers having operated in the Barents Sea and the adjacent waters in 2003-2004 is discussed.

It was found that in 2003-2004 the economic efficiency of realization of the national quota for cod by the Russian fishing fleet in the economic zone of Norway (NEZ) and the Bear-Spitsbergen area (BSA) was sufficiently higher than in the Grey Zone (Russia-Norway). However, the quantity of fishing efforts in the NEZ and BSA, where the highest fishing efficiency was registered and predominantly large fish were distributed with big by-catches of other species valuable as food and trade objects, turned out to be 2 times lower than the advised one.

As a result, fishing enterprises received much less profit than they are due, and the cod population suffered from the unjustified biological damage.

The main reason of under-exploitation of the cod stock in the NEZ and BSA and surplus fishing efforts in the Exclusive Economic Zone of RF, including the Grey Zone, is the weakening of the state management of the water bioresources and, first of all, the failure by ship owners to execute advice of PINRO.

Terms, definitions and abbreviations

In the present paper the following terms, definitions and abbreviations are used:

Directed fishery – fishery at which proportion of the target species in the catch constitutes more than 50 % by weight.

Effectiveness – the intended result, social effectiveness and the desired social effect reached per time unit or unit of natural resource.

Economic efficiency – output per cost unit or unit of natural resource, labour productivity, a satisfactory result, productivity.
Price of fish of the first demand – value in terms of money at the first sale or first exchange of product by its direct manufacturer.

Gross domestic product (G.D.P.) – cost of all goods and services produced on the territory of the country by its residents or temporal residents regardless whether citizens of this country or foreigners demand them.

ABR – Aquatic biological resources;
EEZ RF – Exclusive Economic Zone of RF (EEZ RF);
NEZ – Exclusive Economic Zone of Norway (NEZ);
LBS – Loophole (enclave) of the Barents Sea;
BSA – Bear-Spitsbergen Area;
VDR – Vessel daily reports;
R/V – Research vessels.

Introduction

The main principle of the rational fishery is a tendency to the maximum possible gain within the biologically safe limits

The most important fishing resource of the Barents Sea at present is cod.

At the big diversity of fishery species in the Barents Sea, a portion of cod in the total cost of all caught marine organisms exceeds all the other fish species (Komlichenko and Shevchenko, 2004).

Therefore, development of ways and methods directed to the sustainable use of the cod stocks in the process of fishing and processing is the primary importance goal of the fishery science.

Exactly "the sustainable use of resources in the process of fishing and processing is the priority direction for the maximum contribution of the fishing industry into the ensuring of food supply security of the country" (S. Podolyan, 2005).

In connection with that and considering the necessity of the realization of a strategy on the optimal long-term sustainable use of marine organisms of the Barents Sea adopted at the 33d session of the Russian/Norwegian Joint Fisheries Commission it seems very topical to analyze reasons and a mechanism of biological and economic losses under specific conditions of the use by the national fishing fleet of such an important fishing object as cod of the Barents Sea.

Material and Method

The official data of the vessel daily reports (VDR) transmitted to the regional information center of the Northern Basin are used in the paper as the information base (fishing efficiency by different fishing gear, location of fishing vessels, quantity of fishing efforts, catch and etc.). Fishing efforts (a number of vessel/days of fishing operation) and efficiency of the directed fishery for cod were determined considering the predomination of cod (50% and more) in catches, and the daily duration of trawling constituted not less than 10 hours for each vessel.

Analysis of bioeconomic efficiency of realization of the national quota for cod is carried out on the basis of the operation data of the middle fishing refrigerator stern trawler (SRTM) of the "Valisy Yakovenko" type, since vessels of this type are the most numerous and take 20 % of the national catch of cod (Fig. 1). Besides, at present this type of vessels is less modernized technically than others that permit to compare fishing efficiency without probable influence of modernization on it.

The borders of economic zones of the Barents and Norwegian Seas are in Figure 2.

Biological material was collected by PINRO scientists onboard of the Russian research/fishing and fishing vessels in the process of all-the-year-round fishing monitoring and check haul (Table 1). The raw material resources in the areas of commercial schools concentrating were investigated day and night by the method of check hauls during fishing. Not less than 300 individuals of cod were measured in each catch. Catches less than 500 kg were measured completely. During a year, all economic zones and areas of the traditional fishing for cod were monitored (Fig. 3).

Spatial distribution of cod and their main biological characteristics were analyzed by the main stages of the annual life cycle of fish, which was conditionally divided into four periods:

a) January-February: a period of pre-spawning and wintering migrations;
b) March-May: a period of spawning in mature cod, wintering of immature fish and beginning of feeding migrations;
c) June-September: a period of mass feeding migrations and dispersal over a wide feeding area;
d) October-December: a period of wintering and pre-spawning migrations into the areas of wintering and spawning.

Technical equipping of trawlers and its influence on the fishing capacity of vessels were analyzed on the basis of data of the vessel's roll and "Certificates of Conformity" of 250 vessels applied for the participation in the resource investigations.

Prices for the fish production of the first demand were determined predominantly by data of the "Norges Råfisklag", as well as with the account of the analytical information of the Research Institute of the Economics and Fisheries (VNIERKH) ("The world market prices for fish and other fish products" and "On-line information of fish products").

A quantity of small fish discards was determined as a disparity between the length-weight composition of catches and length-weight composition of the finished commodity. For that data were used collected onboard of 45 research/fishing vessels operated in 2003-2004 in all areas of fishing for cod.

The cost of catches was estimated with the account of a portion of fish of different weight in the total volume of the finished commodity. On the basis of the mass measurement of cod, the virtual processing of fish catches was carried out with the use of special electronic worksheets in EXCEL.

Daily profit was calculated as a disparity between the cost of the finished commodity of the first demand and capital inputs for fishing and producing of a half-finished product (including the cost of package).

Results and discussion

Analysis of results of the national trawl fleet operation in 2003-2004 shows that contradictions arising at the interaction of biological and economic factors in the process of exploitation of the cod stock of the Barents Sea registered earlier by scientists (Vasiljev and Kuranov, 2002; Anon., 2002; Makoedov and Dyagilev, 2002; Ogorodnikova, 2003) still exist at present.

In the first place these contradictions become apparent in the evident disproportion between volumes of catches on different fishing grounds. Apparently, the predominating quantity of fish should be caught in the sea areas, where the maximum efficiency of fishing vessels and the best length-weight composition of cod catches are registered. A combination of these the most important factors determines to a great extent the achievement of the main goal of the fishing industry, the obtaining of the maximum gain at the use of ABR within the biologically safe limits.

Distribution of the commercial fleet efforts when fishing for cod concentrations in 2003-2004 is presented in Fig. 4, and the length composition of fish in catches by the fishing trawl with the mesh of 125 mm and 135 mm is in Figures 5 and 6.

It is known that in January-May a sufficient quantity of large mature and immature cod is distributed over a comparatively limited area of the North Norway coast. The reason is the pattern of the yearly life cycle of fish, the spawning and spring capelin feeding of which take place annually in the NEZ predominantly.

Concentrations of large fish migrating to the spawning grounds, as well as a “school” type of cod concentrations during the capelin feeding, promote the unique possibilities for fishing, much better there than in the other areas of fishing.

It should be underlined that, fortunately for the national fish processing plants, the present governmental fisheries policy of Norway promotes to a large extent a maximally free access of law-abiding national trawlers to the NEZ to permit them to fish for larger cod than in the other areas.

The mean length of cod in catches in the NEZ in January-February 2004 constituted 69.6 cm, mean weight was 2.7 kg, and a mean daily catch of SRTM was 10.2 t (Table 2). In the result of combination of high indices of the fishing efficiency and a cost of a semi-finished product of large cod (Table 3) the daily profit of a SRTM in that period constituted about $11.7 thou.

Compared to NEZ, the corresponding official indices of the fishing efficiency of a SRTM (4.9 t per a fishing vessel/day) and mean length-weight characteristics of fish in catches in the EEZ RF and in the Grey Zone in January-February were much worse (56.2 cm and 1.4 kg, correspondingly). As a result, mean daily profit of a SRTM in the EEZ RF and in the Grey Zone in January-February was almost 5 (!) times lower than in the NEZ and did not exceed $ 2.5 thou. (Tables 2 and 4).

In spite of such a big disparity in the daily profit ($ 9.2 thou.), the mean daily number of SRTM fishing in the NEZ in January-February constituted 3 pieces, whereas in the EEZ RF and in the Grey Zone there were 7 vessels.

Thus, each of 7 vessels of the SRTM type fished in January-February 2004 the scattered concentrations of predominantly small and middle-sized cod in the Grey Zone and in the EEZ RF received daily $ 9.2 thou. less than due. As a result, total under-received profit of a group of SRTM (with the account of 273 days of fishing by a SRTM in the EEZ RF and in the Grey Zone in January-February) constituted in the mentioned period about $ 2.5 mill. ($9.2 thou. per day multiplied by 273 days).

In March-May 2004, daily fishing efficiency of SRTM (9.2 t), as well as mean length and mean weight of fish in catches in the NEZ (67.7 cm and 2.6 kg, correspondingly) decreased, but they continue to be quite high. This led to a sufficient daily profit of SRTM operated in the NEZ, which constituted in the mentioned period $ 9.9 thou.

In the Spitsbergen Area, a daily fishing efficiency of SRTM in March constituted 7.7 t, mean length and weight of fish in catches were 62.7 cm and 2 kg, correspondingly. Mean daily profit of SRTM reached $ 7 thou.

In March-May 2004 mean length and weight of cod in catches in the EEZ RF and in the Grey Zone kept at the level registered in January-February (56.6 cm and 1.4 kg, correspondingly), and mean daily catch of SRTM (7.6 t) increased. Nevertheless, mean daily profit of SRTM did not exceed $ 6.3 thou., i.e. it was 1.5 times lower than in the NEZ.

Thus, fishing enterprises, SRTM of which operated in the EEZ RF and in the Grey Zone in March-May, under-received every day by each vessel not less than $ 3.6 thou. of gain ($ 9.9 thou. – $ 6.3 thou.). Total economic losses of SRTM with the account of 1 873 vessel/days of fishing in March-May for scattered concentrations of middle- and small-sized cod in the EEZ RF and in the Grey Zone constituted more than $ 6.7 mill. ($ 3.6 thou. per day multiplied by 1 873 days of fishing).

In total, underused gain of fishing enterprises, SRTM of which in January-May of 2004 operated in the EEZ RF (including the Grey Zone) constituted about $ 9.3 mill. Considering the mean cost of one tonne of cod half-finished product of the first demand (2 400 $), the economic losses are adequate to under-catch of 5.8 thou. t of cod ($ 9.3 mill.: 2 400 $ = 3.9 thou. t headed x 1.5 = 5.8 thou. t of raw material).

Negative consequences of the irrational distribution of fishing efforts in January-May 2004 during fishing for cod lie not only in the economic losses.

It is known that in order to get maximum gain, when fishing for cod, the ship owners prefer to realize the own limited quotas with the use of large expensive fish. However, onboard of many trawlers this is achieved by means of discards of all small (to 45 cm long) and, the recent time, a big number of middle-sized cod (to 55 cm long). By data of observers of PINRO worked onboard of fishing vessels, a portion of cod with a weight of a half-product of less than 500 g (the "reestablished" length of fish 45 cm and less) was absent in the total volume of the finished commodity of fishing vessels in 2004, whereas individuals of such length constituted about 14 % by abundance in catches in the Grey Zone and in the EEZ RF in January-May 2004 by data of mass measurements. Therefore, about 14 % of cod as minimum were discarded when fishing in the EEZ RF and in the Grey Zone in January-May 2004. In the NEZ, small cod practically were absent in catches (about 0.3 %), and in the BSA they did not exceed 3 %.

Besides, a portion of mature cod in catches in the EEZ RF and in the Grey Zone (11 %) in January-February 2004 was much less than in the NEZ (72 %).

In spite of the absence of data on the influence of fishing for various length-age groups of fish on the dynamics of the status of existing commercial cod stock, one can contend that from the biological point of view the withdrawing of immature cod from the population is less justifiable than catching of individuals having posterity. Besides, it is scientifically proved that a portion of consumed food used for increment of fish weight decreases with age. Therefore, the biological effectiveness of cod quotas realization is very much determined by a portion of large mature cod in catches.

Thus, much less daily profit, large discards of cod and sufficient predomination in catches of small, immature fish, led to the fact that fishery for cod in January-May 2004 in the EEZ RF and in the Grey Zone, compared to that in the NEZ, was unjustified from the economical point of view and less expedient from the biological point of view.

In June-September 2004, the predominating number of fishing efforts for catching of cod was concentrated mainly on two fishing grounds: in the EEZ RF including the Grey Zone (44 thou. t were caught, i. e. 72 % of total catch) and in the Spitsbergen Area (14 thou. t were caught, i. e. 23 %). Differences in the fishing-biological characteristics of cod from catches in those areas were less sufficient than those in January-May in the NEZ and EEZ RF including the Grey Zone. Nevertheless, the economical indices of profit, as well as portions of small and mature fish in catches, were different (Table 5). Mean daily profit of SRTM operated in the Spitsbergen Area constituted $ 7.2 thou., and that in the EEZ RF including the Grey Zone – $ 6.8 thou. Considering that in July-September, SRTM vessels in the EEZ RF operated for 2 222 vessel/days, the total under-received profit constituted $ 0.9 mill. ($ 0.4 thou. per day x 2 222 days).

Due to data of mass measurements, abundance of cod less than 45 cm constituted more than 8 % in catches in the Grey Zone and in the EEZ RF in June-September 2004. Consequently, minimum as 8 % of cod were discarded during fishing of national vessels in the NEZ RF and in the Grey Zone in June-September 2004. In the Spitsbergen Area, a portion of small cod in catches did not exceed 2 %, i. e. discards of small cod were 4 times less.

Besides, a portion of mature cod in catches in the EEZ RF and in the Grey Zone (35 %) in June-September 2004 was less than that in the BSA (40 %). It is indicative that a ratio between small and large (more than 70 cm) cod in catches in the Grey Zone and in the EEZ RF (2.6) was 5 times less than that in catches in the BSA (12.5).

Thus, it is evident that in June-September 2004, the bioeconomic efficiency of the cod quota realization in the BSA was higher than in the Grey Zone and in the EEZ RF.

In the final period of the annual migration cycle (October-December) the national vessels carried out a trawl directed fishery for cod also only in two main areas: in the EEZ RF including the Grey Zone (the catch was 31 thou. t, 55 %), and in the BSA (25 thou. t, 43 %). Fishery, especially in November-December, based mainly on cod schools migrating to the areas of spawning and wintering. Usually, the formation of migration flows of large and, mainly, mature fish takes place actively in the northwestern areas of the sea, where summer feeding conditions of cod are much better than in the southern and southeastern sea. Distribution of a migration flow of cod along the oceanic shelf edge increased much the fishing density of concentrations and, correspondingly, the fishing efficiency. As a result, due to the official statistics, in October-December 2004 the mean daily efficiency of SRTM in the BSA (10.7 t) during the fishing for cod was 1.6 times higher than in the EEZ RF including the Grey Zone (6.6 t). Higher mean daily catch promoted higher daily profit of SRTM during fishing for cod in the Spitsbergen Area ($ 11.1 thou.) that was 2.3 times higher than in the EEZ RF and in the Grey Zone ($ 4.8 thou.). In spite of such a big disparity in the daily profit, SRTM vessels carried out fishing for 2 067 vessel/days in the EEZ RF (including the Grey Zone) in October-December 2004. Therefore, total under-received profit of all SRTMK operated in the EEZ RF and in the Grey Zone with less than possible fishing efficiency constituted not less than $ 13 mill. ($ 6.3 thou. per day x 2 067).

Totally, in the result of non-compliance with the advice of PINRO on the optimal distribution of fishing efforts, the underused profit of fishing enterprises constituted in June-December 2004 about $ 14 mill. With the account of the mean cost of one tonne of the cod half-product of the first demand (2 400 $) the economic losses are adequate to almost 8.8 thou t of cod ($14 mill.: 2 400 $ = 5.8 thou. t headed x 1.5 = 8.8 thou. t).

It should be mentioned that the raw material base of the trawl fishing in the Spitsbergen Area permitted to enlarge greatly the fishing efforts in this area without any damage to the fishing efficiency. Due to data of TAS carried out in October-December 2004, the commercial cod stock in the BSA available for fishing constituted more than 250 thou. t, and in connection with the heightened heat content of the sea the commercial concentrations stayed there till December. Irrational usage of fishing possibilities in the Spitsbergen Area caused not only the economic losses.

Due to data of mass measurements, the abundance of small cod in catches in the Grey Zoneand in the EEZ RF in October-December 2004 (10%) was much more than in the BSA (2.7 %). Therefore, a number of discards of small fish in the EEZ RF including the Grey Zonewas, as a minimum, 3 times higher than in the Spitsbergen Area.

Figures 7-8 present the recommended and actual distribution of fishing efforts when fishing for cod in the economic zones of the Barents Sea and in the area of the Spitsbergen archipelago in 2003-2004. Evidently that in spite of the concentration of the predominating number of cod fishing efforts in the NEZ in the first half of the year, many fishing enterprises preferred to carry out fishery in the EEZ RF and in the “Grey Zone”. We should also mention the fact of irrational distribution of efforts by fishing seasons.

Thus, on the basis of analysis of the fisheries-biological characteristics of cod and distribution of fishing efforts, catch volumes and daily profit of fishing efforts it was stated that the irrational exploitation of cod stocks caused the under-receiving by one type of trawlers (SRTM) of about $ 23 mill. of profit and sufficient decrease of the biological efficiency of realization of the national cod quota.

It should be mentioned that the biological peculiarities of cod fishing in 2004 are not the exclusion from the long-term frequency of observations.

In January-February 2003 the mean daily catch of SRTM in the NEZ constituted 10.1 t and in the Grey Zone– 7.9 t (Table 6). Taking into account the disparity in the fishing efficiency (data on the length composition of cod catches are absent), each of SRTM under-received every day about $ 3.5 thou. Thus, only in that period the total under-received profit of a group of SRTM (with the account of 552 days of fishing in the EEZ RF and in the “Grey Zone”) constituted about $1.9 mill. ($3.5 thou. per day x 552 days of fishing).

In March-May 2003, high daily fishing efficiency of SRTM (13.3 t), as well as mean length and weight of fish in catches in the NEZ (63.9 cm and 1.9 kg, correspondingly) stipulated a sufficient daily profit of SRTM operated in the economic zone of Norway ($ 15.7 thou.).

In the EEZ RF and in the Grey Zonein March-May 2003, mean catch of SRTM (7.8 t), as well as mean length and weight of cod in catches were noticeably less (59.2 cm and 1.6 kg, correspondingly). Mean daily profit of SRTM did not exceed $ 7 thou., i.e. it was lower more than 2 times than in the NEZ.

Thus, each trawler operated in March-May in the EEZ RF and in the Grey Zoneunder-received every day about $ 8.7 thou. of profit. With the account of 1 776 vessel/days of fishing for scattered concentrations of middle- and small-sized cod in the EEZ RF, including the “Grey Zone”, in March-May, the under-received profit constituted about $ 15.5 mill. ($ 8.7 thou. per day x 1 776 days).

In total, underused profit of fishing enterprises in January-May 2003 constituted about $ 17.5 mill. Taking into account the cost of one tonne of the cod half-product of the first demand (2 400 $) the economic losses are adequate to under-catch of almost of 11 thou. t of cod ($ 17.5 mill.: 2 400 $ = 7.3 thou. t headed x 1.5 = 11 thou. t of raw material).

In June-September 2003, mean daily profit of SRTM in the BSA constituted about $10.3 thou. (mean daily catch was 9.7 t, mean length – 63.7 cm, mean weight – 2.1 kg). The corresponding indices in the Grey Zoneand EEZ RF were much less – $ 7.2 thou. (Table7).

Taking into account the fact that in July-September the SRTM vessels operated for 1 977 vessel/days in the Grey Zoneand EEZ RF, total under-received profit constituted in that period about $ 6 mill. ($ 3.1 thou. per day x 1 977 days).

In October-December 2003, mean daily efficiency of SRTM fishing for cod in the BSA (9.7 t) was a little bit higher than in the EEZ RF including the Grey Zone (8.4 t). Mean length and weight of fish in the southern part and in the northwestern sea did not differ. Daily profit of SRTM fishing for cod in the BSA ($ 10 thou.) was higher than in the EEZ RF and in the Grey Zone ($ 8.3 thou.). Total under-received profit of all SRTMK operated in the EEZ RF and in the Grey Zoneconstituted about $ 5.5 mill. ($ 1.7 thou. x 1 891 vessel/days).

In total, underused profit of SRTM in the results of non-compliance with the advice of PINRO on the optimal distribution of fishing efforts constituted in June-December of 2003 about $ 11.5 mill. Taking into account mean cost of one tonne of the cod half-product of the first demand (2 400$) the economic losses are adequate to under-catch of 7 thou. t of cod ($11.5 mill.: 2 400 $ = 4.8 thou. t headed x 1.5 = 7 thou. t).

In the Spitsbergen Area, by-catches of fish of un-fishing sizes and a portion of small individuals less than 45 cm in June-December of both 2003 and 2004 were much lower.

Total under-received profit of the SRTM vessels in 2003 and 2004 was adequate to the economic losses in the result of under-catch approximately to 32.5 thou. t of cod and constituted more than $ 52 mill. (about 1.5 milliards of roubles).

In the result of under-received profit, budgets of all levels have lost the direct tax proceeds of 220 mill. roubles.

It should be mentioned that annually when preparing to the current session of the Russian-Norwegian Joint Fisheries Commission the PINRO scientists suffer from the strong psychological press from the side of the fishing enterprises, which insist on the increase of TAC of cod. They motivate that by the necessity of the “physical survival” of unwarranted big number of trawlers, the total fishing efficiency of which exceeds at present 3 times as a minimum the resource potential of all demersal fish species (cod and haddock, first of all) of the Barents Sea. Keeping of quotas at the same level or their slight (5-10 thou. t) increase is considered as a victory of fisheries businessmen over conservatism of scientists. However, a big number of enterprises realize the received quotas spontaneously, without taking into account predictions and advice of the fisheries science.

Thus, it is evident that at the organization of the optimal long-term exploitation of cod stocks of the Barents Sea the national fishing fleet should change sufficiently the strategy of fishing in order to decrease a portion of small immature fish in catches, withdrawing of which leads to sufficient economic and biological losses.

Fishing enterprise should use cod stocks in such a way as to obtain maximum economic profit without overstepping the biological safe limits.

Conclusion

1. In 2003-2004 the most favourable, compared to the other areas, conditions for the effective use of cod stocks were registered in the economic zone of Norway and in the Spitsbergen Area. The highest fishing efficiency, as well as maximum portion of the large and the most expensive cod and the highest weight of the most valuable marine organisms fished as by-catch and minimal catches and, consequently, discards of small fish, were registered there.
2. A big number of fishing vessels did not use as due the resource advantages of the western and northwestern areas of the sea. A number of efforts for fishing for cod in the NEZ and Spitsbergen Area in 2003-2004 turned out to be actually 1.5-2 times lower than recommended. At the same time the predominating part of the fishing time was realized in the Grey Zoneand in the EEZ RF, where small and middle-sized immature fish constitute a sufficient part of cod catches.
3. Insufficient use of raw material base in the NEZ and Spitsbergen Area caused the under-receiving by fishing enterprises of a big profit, which (only for a group of SRTM vessels) constituted in 2003-2004 not less than $ 52 mill.
4. Redundancy of fishing efforts in the nursery grounds of the EEZ RF and in the “Grey Zone”, where small immature fish concentrate mainly, caused not only the economic losses, but the negative biological consequences for the cod population as well.
5. In connection with ineffective use of the cod stock potential of the Barents Sea as a natural capital of Russia it is necessary to improve the existing system of the all-the-year-round state fisheries monitoring, including the introduction of a system of registration of the length-weight and species structure of catches promoting the increase of the bioeconomic efficiency of cod stock exploitation.
6. To realize the mentioned aims and in accordance with the Article 21 “The Law of the Russian Federation on Fisheries…”, it is necessary that the Government of Russia would share the strongly sustainable quantity of raw material in order to carry out fisheries monitoring.

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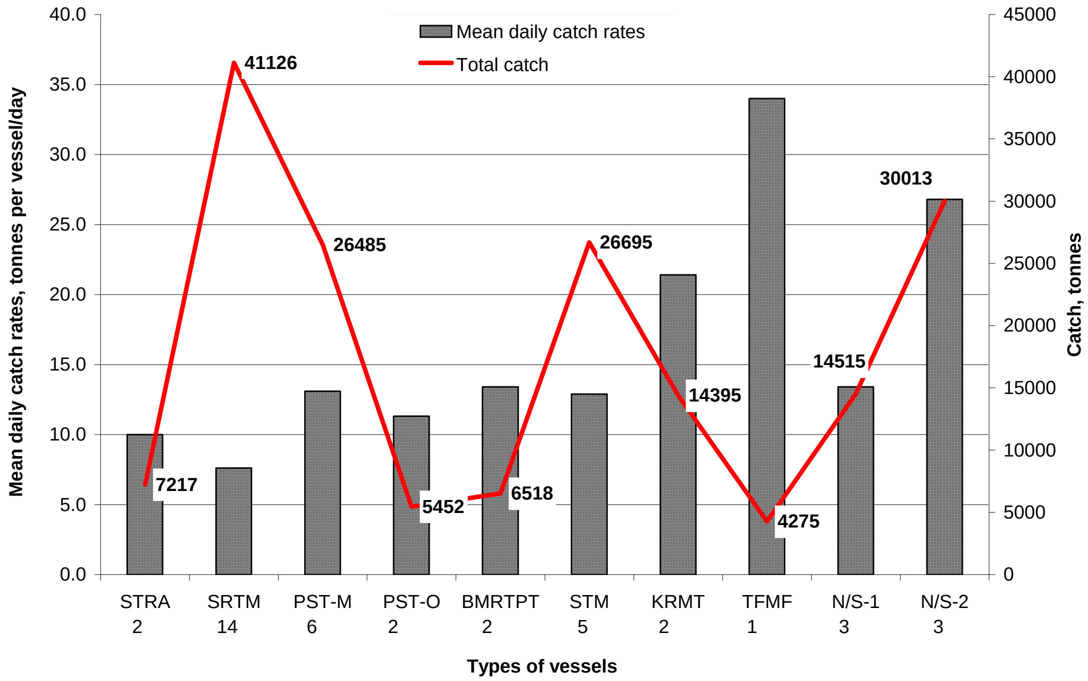

Fig. 1. Mean daily catch rates in the cod fishery (tonnes) and total catch by trawlers of different type in 2004

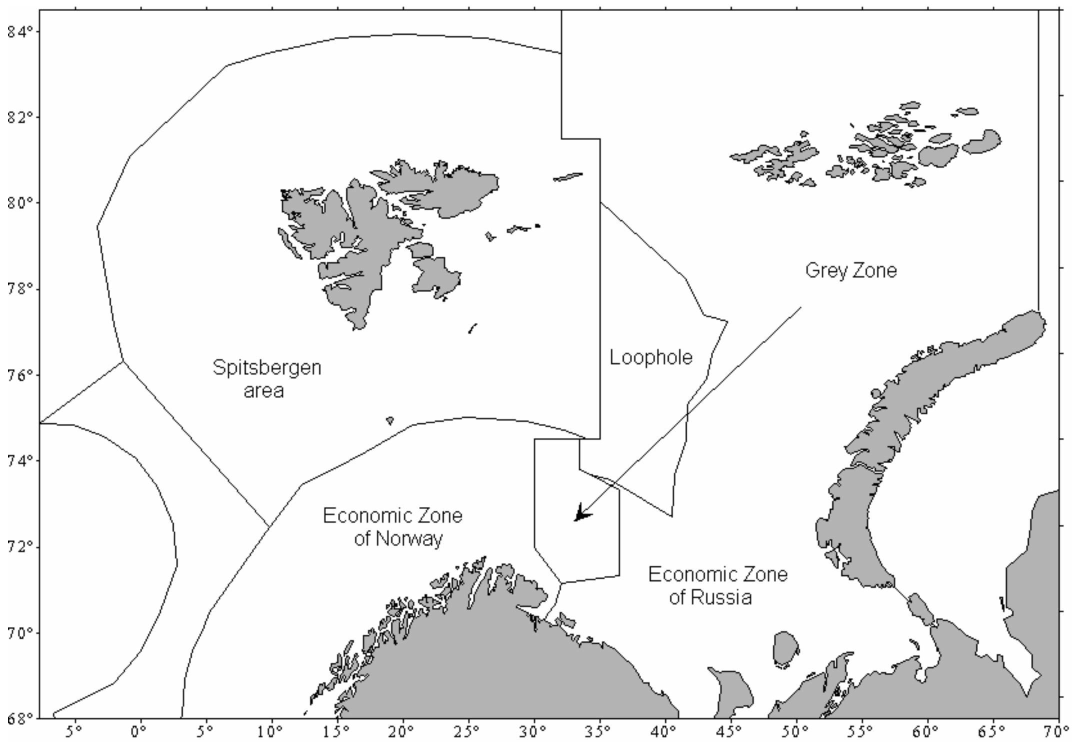

Fig.2. Scheme of areas of the Barents Sea and adjacent waters

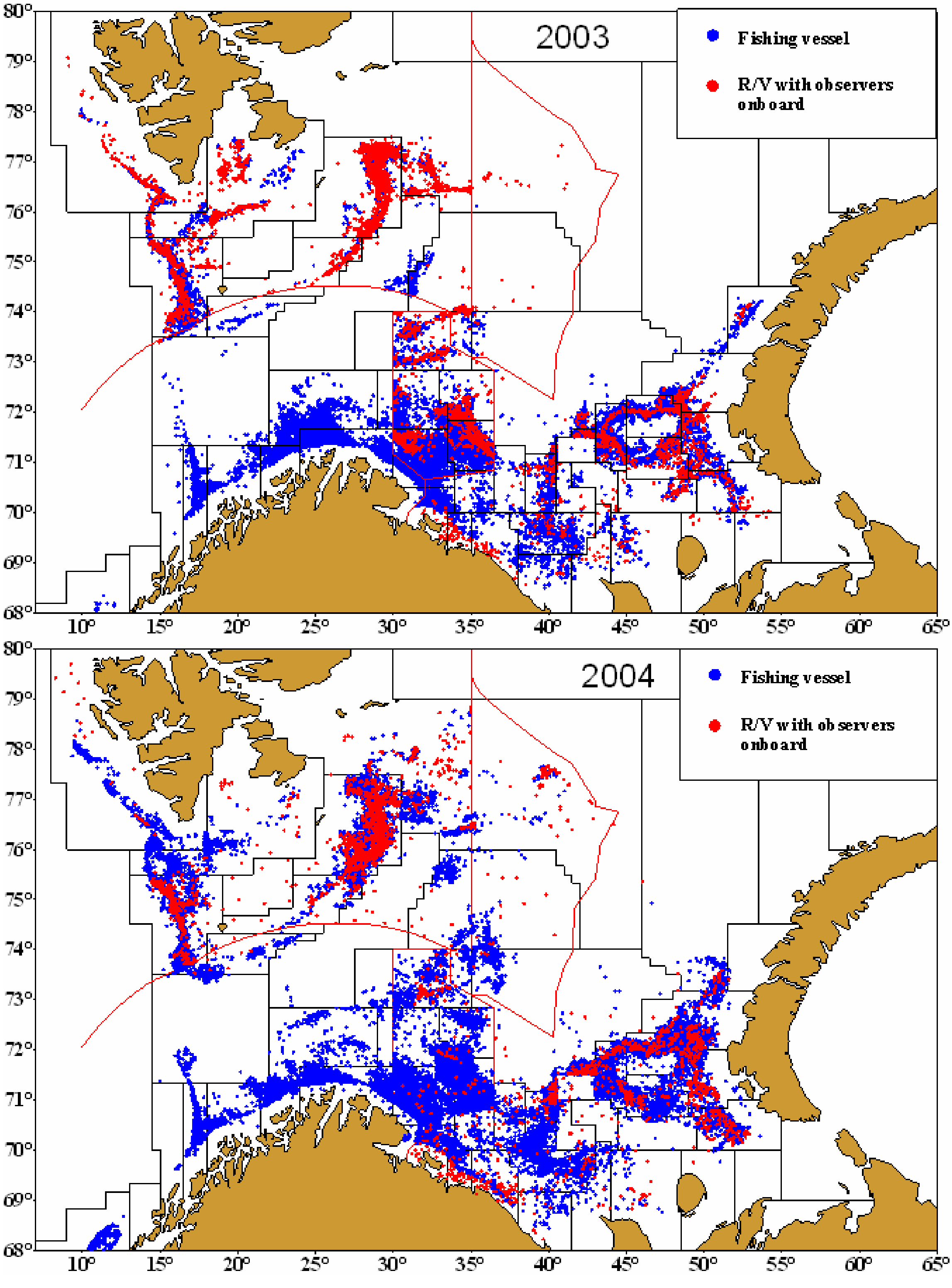

Fig.3. Location of fishing and research vessels during the fishery for cod concentrations in 2003 and 2004

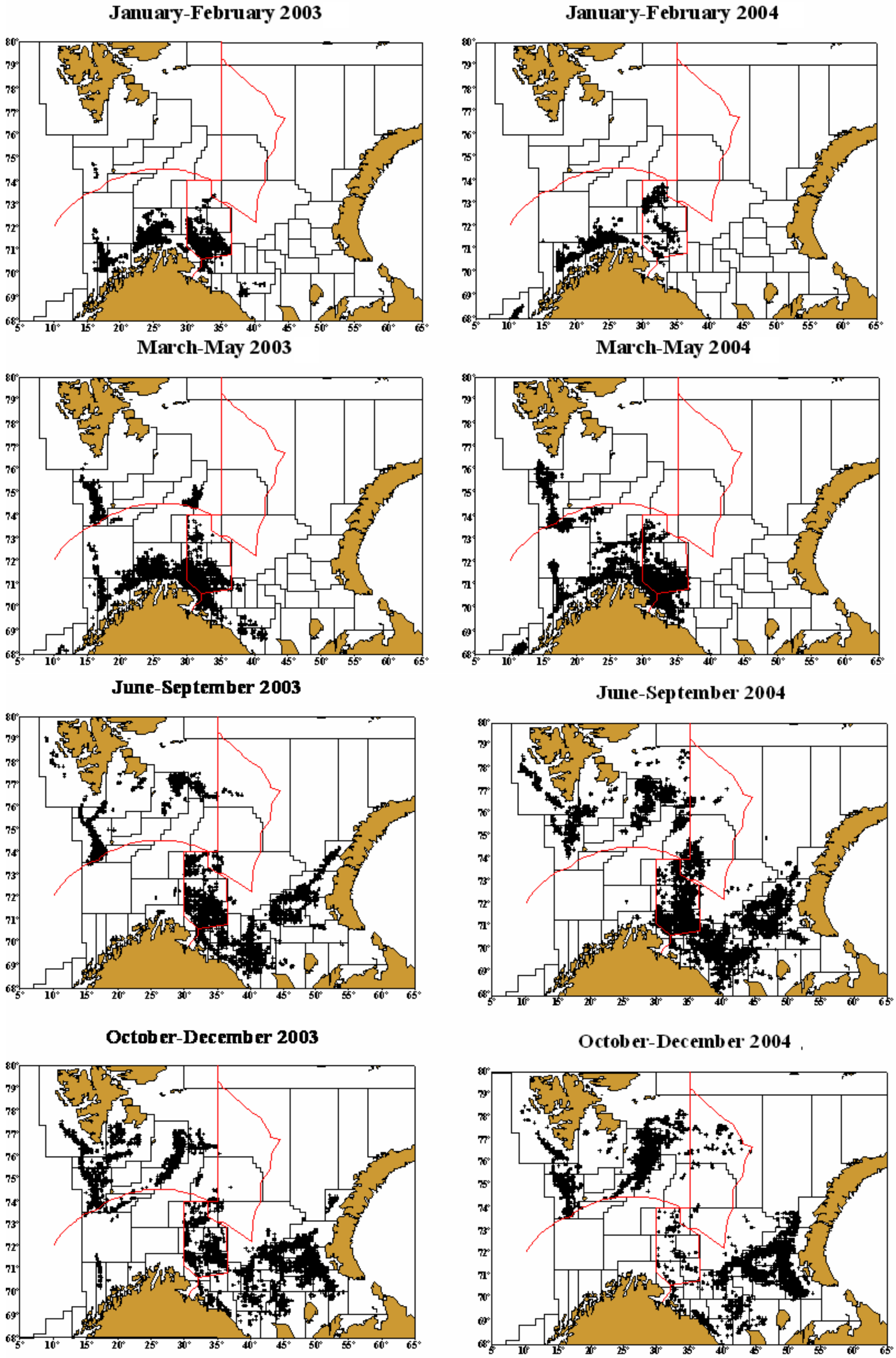

Fig.4. Distribution of trawlers during cod fishery in 2003-2004

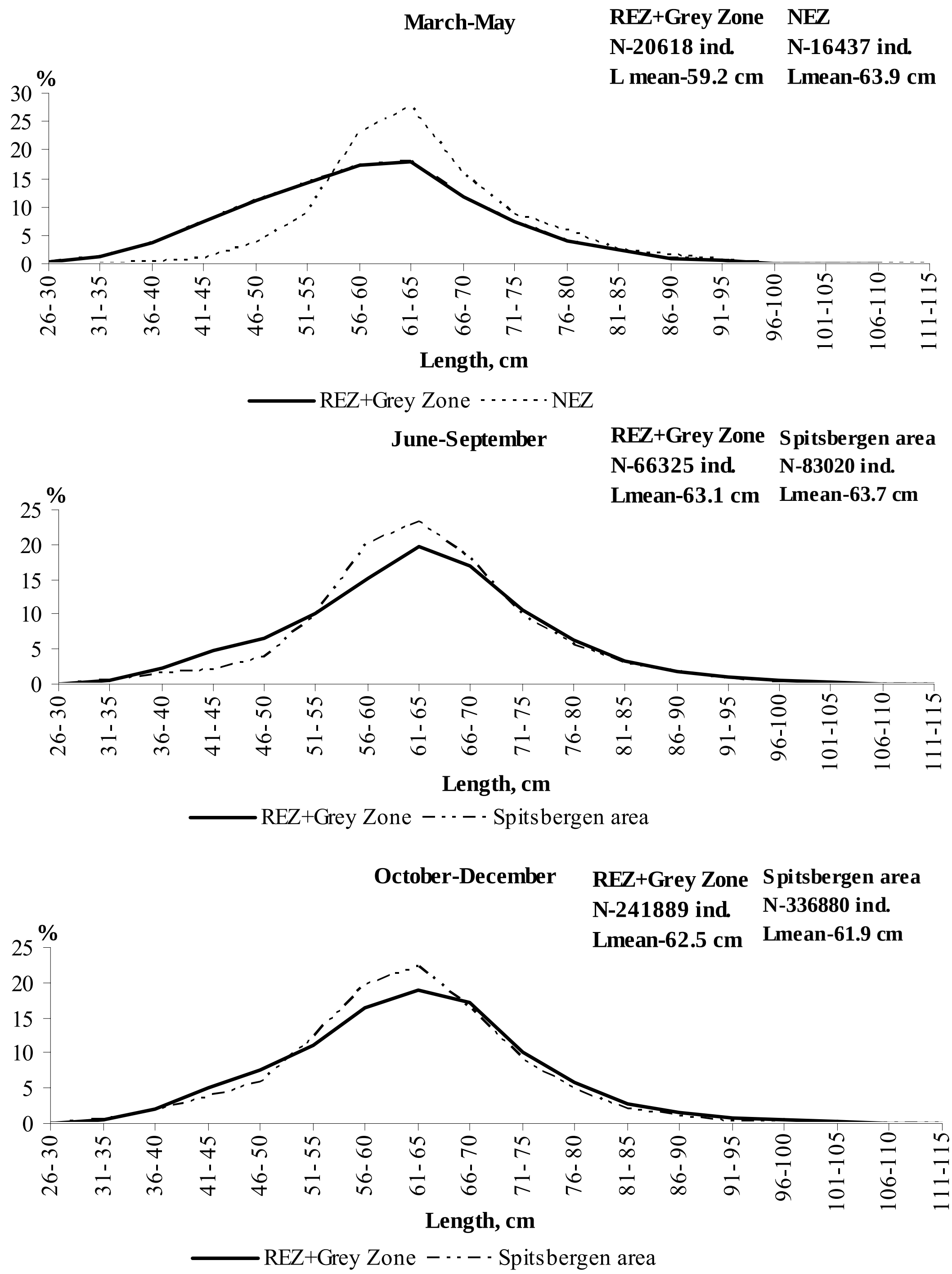

Fig.5. Size composition of cod in trawl catches (mesh size 125 mm and more) within economic zones by fishing seasons in 2003

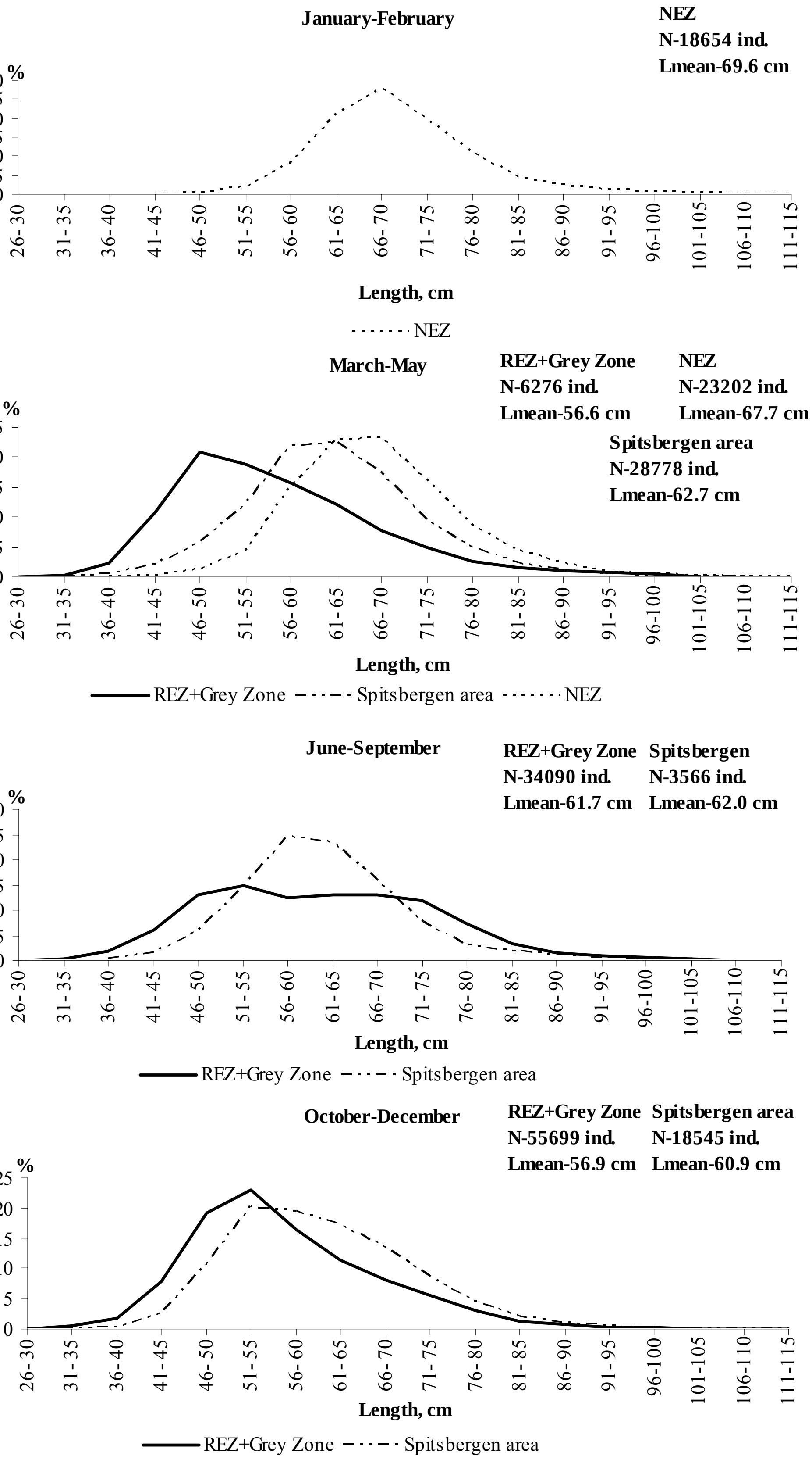

Fig.6. Size composition of cod in trawl catches (mesh size 125 mm and more) within economic zones by fishing seasons in 2004

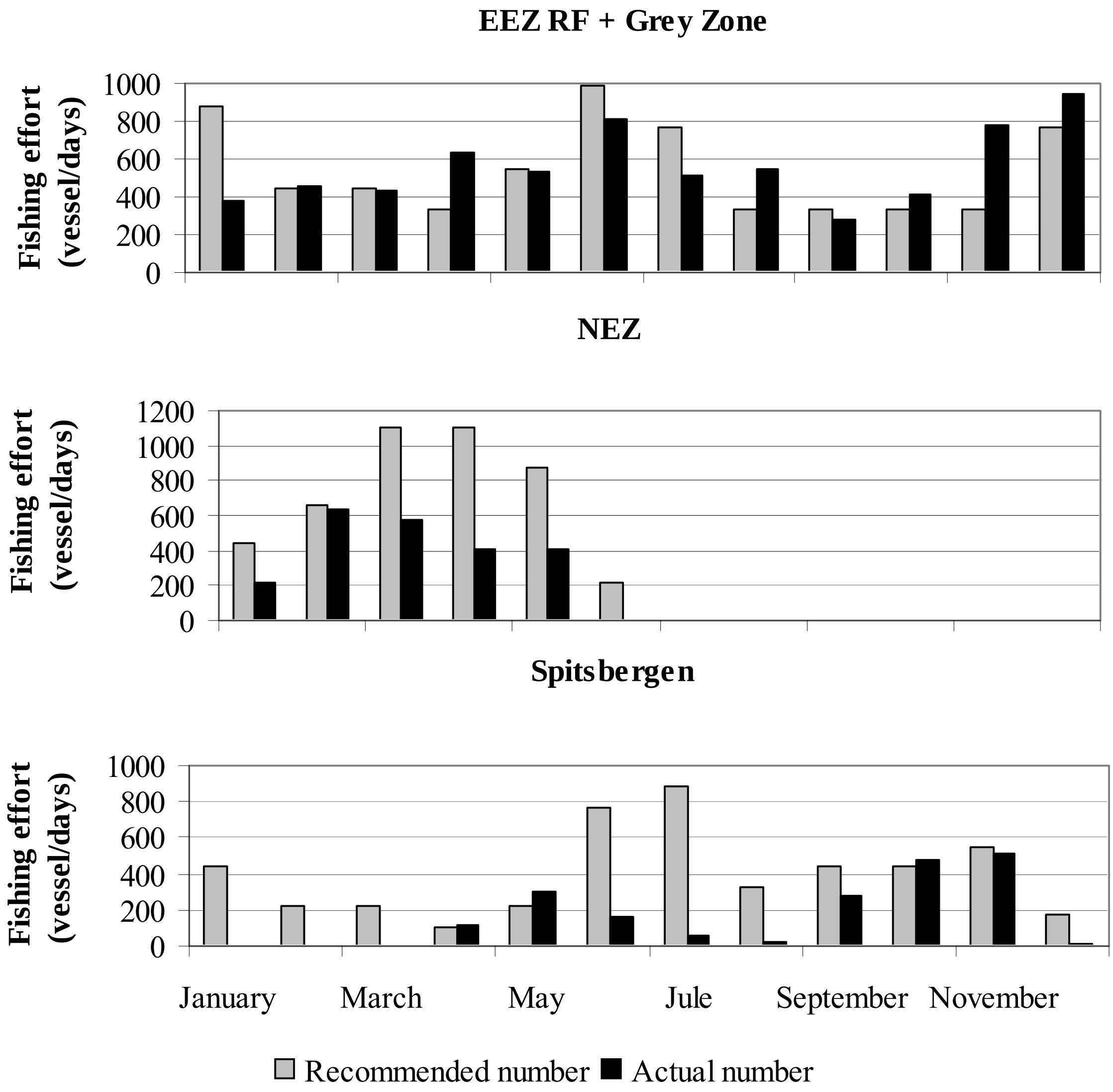

Fig.7. Recommended and actual number of vessel/days in the directed fishery for cod in the economic zones and fishing areas in 2003

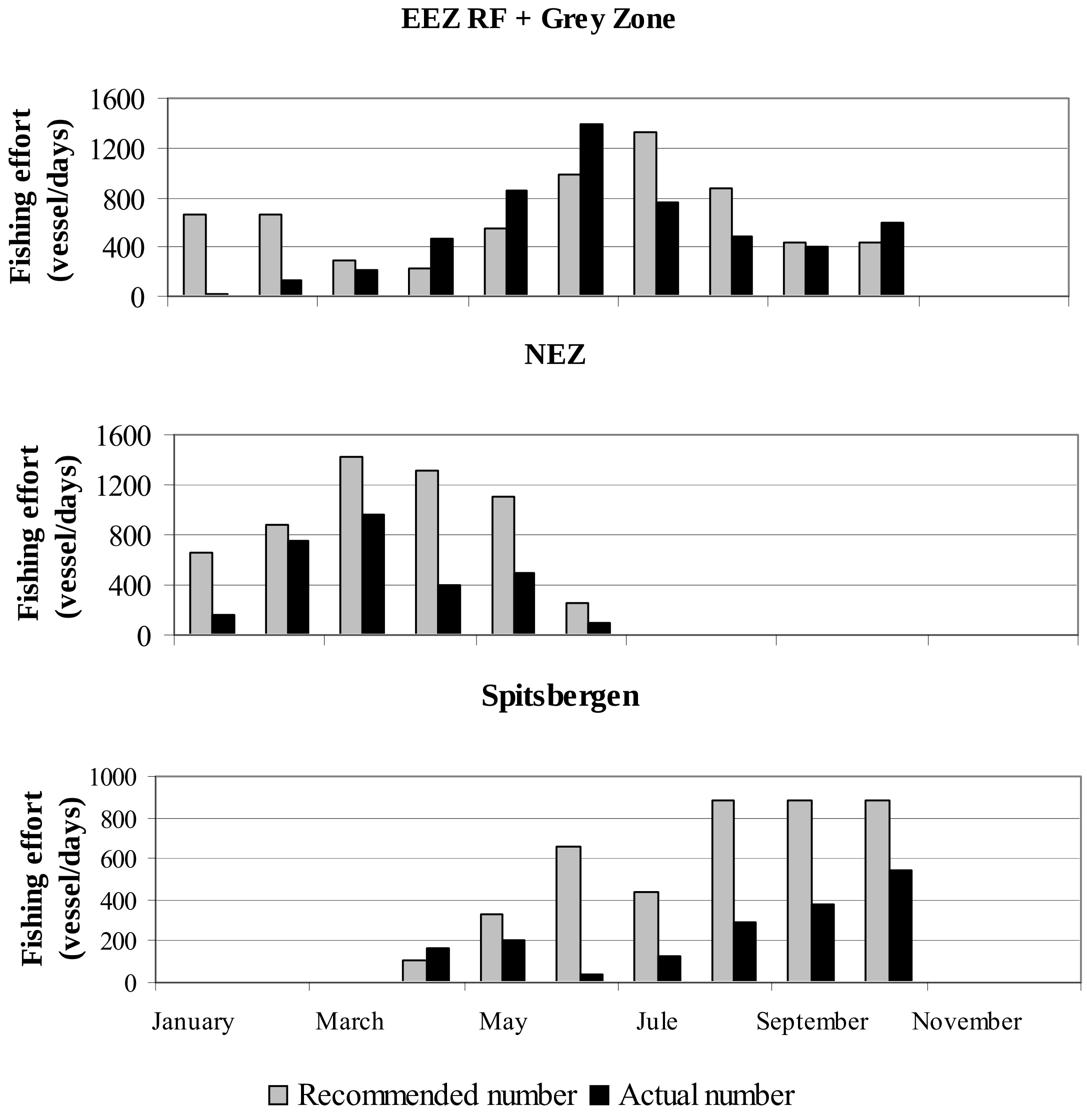

Fig.8. Recommended and actual number of vessel/days in the directed fishery for cod in the economic zones and fishing areas in 2004

Table 1. Biological data on cod collected by PINRO observers on trawlers of fisheries enterprises in 2003-2004

Fishing areas	Measured	Field analysis of feeding	Short version of quantitative analysis of feeding
EEZ RF (including Grey Zone)	487 817	50 693	5 393
NEZ	59 526	4 788	858
Spitsbergen area	711 825	52 086	7 511
Total over the study areas	**1 259 168**	**107 567**	**13 762**

Table 2. Characteristics of cod catches and efficiency of the use of national cod quota by domestic vessels of SRTM-type in January-May 2004

Fishing areas	January-February									March-May								
	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes
NEZ	69.6	2.7	10.2	72	0.1	3	90	11.7	17,3	67.7	2.6	9.2	61	0.8	4	250	9.9	34,4
EEZ RF and Grey Zone	56.2	1.4	4,9	11	14	7	273	2,5	0,9	56.6	1.4	7.6	21	14	11	1873	6.3	15,8

Table 3. Size-weight composition of catches and cost of product of cod caught by SRTM-type vessels in NEZ in January-February 2004

Mean length 69.6 cm	**Size composition of cod, cm**														
	<35	**36-40**	**41-45**	**46-50**	**51-55**	**56-60**	**61-65**	**66-70**	**71-75**	**76-80**	**81-85**	**86-90**	**91-95**	**96-100**	**>100**
Size composition, fish	0	0	19	93	410	1548	3955	5186	3656	2033	858	429	224	131	131
Size composition, %	0.0	0.0	0.1	0.5	2.2	8.3	21.2	27.8	19.6	10.9	4.6	2.3	1.2	0.7	0.7
Number of fish in the given commercial grade, %	**2.8**					**76.8**				**20.4**					
Discards, % by number	**0.1**														
Weight of 1 cod, g	0	0	820	930	1280	1631	2011	2524	3029	3928	4686	5483	6783	9007	15000
Weight of 1 product, g	0	0	547	620	853	1087	1341	1683	2019	2619	3124	3655	4522	6005	10000
Weight of product in size group, kg	0.0	0.0	10	58	350	1683	5302	8726	7383	5324	2680	1568	1013	787	1310
Commercial grade, kg	0 - 1 kg					1 - 2,5 kg				2.5 kg and more					
Weight of product by grade, kg	418					23095				12682					
Grades is catch weight, %	**1.2**					**63.8**				**35.0**					
Cost of 1 tonne of product, $	1627					2222				2698					
Cost of grade in 1 tonne of product, $	19					1418				945					

Catch rate per vessel/day, tonne	**Weight of product per vessel/day,**	**Cost of 1 tonne of product, $**	**Totsl cost of product per vessel/day $**
10.2	**6.8**	**2382**	**16197**

Table 4. Size-weight composition of catches and cost of product of cod caught by SRTM-type vessels in EEZ RF and Grey Zone in January-February 2004

Mean length 56.2 см	**Size composition of cod, cm**														
	<35	**36-40**	**41-45**	**46-50**	**51-55**	**56-60**	**61-65**	**66-70**	**71-75**	**76-80**	**81-85**	**86-90**	**91-95**	**96-100**	**>100**
Size composition, fish	19	144	684	1318	1174	985	753	490	314	163	94	63	44	25	6
Size composition, %	0.3	2.3	10.9	21.0	18.7	15.7	12.0	7.8	5.0	2.6	1.5	1.0	0.7	0.4	0.1
Number of fish in the given commercial grade, %	**53.2**					**40.5**				**6.3**					
Discards, % by number	**13.5**														
Weight of 1 cod, g	307	470	659	890	1190	1573	1904	2264	2765	3500	4340	5718	8100	8190	10000
Weight of 1 product, g	205	313	439	593	793	1049	1269	1509	1843	2333	2893	3812	5400	5460	6667
Weight of product in size group, kg	3.9	45.1	301	782	931	1033	956	740	579	380	272	240	238	137	40
Commercial grade, kg	0 - 1 kg					1 - 2,5 kg				2.5 kg and more					
Weight of product by grade, kg	2063					3307				1307					
Grades is catch weight, %	**30.9**					**49.5**				**19.6**					
Cost of 1 tonne of product, $	1627					2222				2698					
Cost of grade in 1 tonne of product, $	503					1101				528					

Catch rate per vessel/day, tonne	**Weight of product per**	**Cost of 1 tonne of product, $**	**Totsl cost of product per vessel/day $**
4.9	**3.3**	**2131**	**6962**

Table 5. Characteristics of cod catches and efficiency of the use of national cod quota by domestic vessels of SRTM-type in June-December 2004

Fishing areas	June-September									October-December									
	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes	Fishable stock from TAC data, '000 tonnes
NEZ	**62.0**	**2.0**	**7,9**	**40**	**1.4**	**4**	**429**	**7.2**	**14,2**	**60.9**	**2.1**	**10.7**	**41**	**2.7**	**8**	**697**	**11**	**25.2**	**250**
EEZ RF and Grey Zone	**61.7**	**1.9**	**7,5**	**35**	**8.2**	**19**	**2222**	**6.8**	**43,8**	**56.9**	**1.6**	**6.6**	**32**	**10.2**	**23**	**2067**	**6.1**	**31.3**	**500**

Table 6. Characteristics of cod catches and efficiency of the use of national cod quota by domestic vessels of SRTM-type in January-May 2003

Fishing areas	January-February									March-May								
	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes
NEZ	-	-	10.1	-	-	1	22	11.7	18.7	63.9	1.9	13.3	22.1	1.2	3	288	15.7	34.5
EEZ RF and Grey Zone	-	-	7.9	-	-	11	552	8.2	8.7	59.2	1.6	7.8	23.2	12.3	20	1776	7	17.5

Table 7. Characteristics of cod catches and efficiency of the use of national cod quota by domestic vessels of SRTM-type in June-December 2003

Fishing areas	June-September									October-December								
	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes	Mean length, cm	Mean weight of cod, kg	Mean catch rate, tonnes	Percentage of mature cod in catches	Percentage of cod less than 45 cm long	Mean daily number of SRTM-type vessels (fishing)	Number of vessel/days (SRTM)	Mean dayli profit USD'000	Catch by trawlers of all types, '000 tonnes
NEZ	**63.7**	**2.1**	**9.7**	**37**	**3.7**	**4**	**298**	**10.3**	**9.9**	**61.9**	**1.9**	**9.7**	**43**	**6.1**	**7**	**436**	**10**	**12.7**
EEZ RF and Grey Zone	**63.1**	**2.0**	**7.7**	**21**	**7.7**	**16**	**1977**	**7.2**	**34.2**	**62.5**	**1.9**	**8.4**	**47**	**7.4**	**21**	**1891**	**8.3**	**26.9**

EVALUATION OF LONG-TERM OPTIMAL EXPLOITATION OF COD AND CAPELIN IN THE BARENTS SEA USING THE BIFROST MODEL

by

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Introduction

The multispecies model for the Barents Sea Bifrost (Boreal integrated fish resource optimisation and simulation tool) has evolved over a long time. The main problem for management of the Barents Sea capelin stock is that since the capelin dies after spawning the logical management variable is the spawning stock, for which there are no measurements. One has to rely on modelling the spawning stock's evolvement from the yearly measurement in September to spawning in April. The starting point was a single species model for capelin that was used in what probably was the first evaluation of a target reference point in the ICES area (Hamre and Tjelmeland, 1982). In this model – CAPELIN – the dynamic entity was number of capelin by age. Later, in recognition of the different dynamics of male and female capelin, the number by age was distributed on sex (Tjelmeland and Bogstad, 1993). This model (CAPSEX) was then the foundation of Multspec in which the capelin model framework was parameterised for different species which were connected through a predation module (Tjelmeland and Bogstad, 1998). The emphasis was on the dynamics of the predation of pre-spawning capelin by cod. Even if Multspec as a multispecies model was more complex than CAPSEX, limiting the management-related study to this subsystem was tractable because during the modelled period there also was conducted a cod-directed survey. Thus, the cod dynamics could to a large extent be disregarded. Multspec had area structure and a migration module and was used for estimating the predation mortality prior to spawning during the yearly assessment of the capelin stock. Bifrost is in many respects a step back from Multspec, in that the area structure is removed in order to make the model a more robust and versatile instrument for management-close multispecies analyses in the Barents Sea.

The management of Barents Sea capelin is in practice conducted using the spreadsheet based model CapTool (Gjøsæter et al., 2002), which gets its dynamics from Bifrost. There is thus an unbroken line of model development since 1982 that always has been close to the assessment and management of Barents Sea capelin.

The present-day management of Barents Sea capelin has a multispecies basis in that the consumption by cod in the pre-spawning period of capelin is accounted for. In the present paper, the cod-capelin dynamics is extended throughout the year. Also, a recruitment module for cod is added. When there is a large year class of Norwegian spring spawning herring in the Barents Sea, the recruitment of capelin is severely hampered (Gjøsæter, 1998). The herring stock is assessed with the model SeaStar (Tjelmeland and Lindstrøm, 2005) and during prognostic simulations Bifrost and SeaStar are connected, so that the herring model used in Bifrost is essentially the same as the SeaStar prognostic simulation. Bifrost is thus now a multispecies simulator with which harvesting control rules in the cod-capelin-herring system can be studied.

Figure 1 shows the development of cod 1+ biomass from 1946, from the Arctic Fisheries WG assessment. Good recruitment conditions in 1962-1964 and 1969-1970 led to a temporary increase 1966-1977. However, the general trend is a decline since 1946 that lasted until 1982, after which the stock has stablized. The present yield form the stock is much smaller than it was in the period 1946-1982. This may naively be interpreted as the catch regulations in the recent period preventing good catches. There may be two alternative interpretations of recent history. One interpretation is that the present regime is different in that decreased harvesting of harp seals and minke whales – both preying on cod – and increased harvesting of capelin – which is the most important food item for cod – gives smaller prospects of yield from the cod stock than in the pre-1982 period. The other interpretation is that the yield before 1982 was not sustainable. The spawning stock was kept so small by fishing that the recruitment on the average failed to replenish the stock.

The value of the spawning stock for future recruitment is crucial to the management of the stock, as the size and structure of the spawning stock is the way humans affect future stock development. In order to properly understand the spawning stock – recruitment dynamics one must understand the cannibalism on the pre-recruiting part of the stock. This is a multispecies problem, in that large abundance of alternative food (e.g. capelin) partly may shield cod recruits from cannibalism. It is an important part of the present paper to clarify the spawning stock – recruitment relation in cod by estimating recruitment parameters taking cannibalism on pre-recruiting cod into account.

Input data

The capelin stock is surveyed in a joint Russian-Norwegian survey with 4 vessels each September (Gjøsæter, 1998). The vessels follow a pre-agreed sailing plan. Using a model for the uncertainty connected to this survey (Tjelmeland, 2002) survey replicates by year, age, length and sex are constructed prior to any Bifrost estimation of parameters.

The joint IMR-PINRO stomach content data base (Bogstad and Mehl, 1997) comprises nearly 200 000 stomachs, most of them from cod. For each predator the stomach content has been grouped on capelin, cod and other food. Since the evacuation rate depends on the temperature, the temperature from the closest station is added to each stomach content data point. If there is no temperature station near by, the closest temperature station in an adjacent year is used, scaled with the difference of temperature between the two years as observed in the Kola section data.

The stomach evacuation rate of cod has been measured in laboratory experiments at the university of Tromsø (Santos and Jobling, 1992). These data are used in yearly calculations of consumption of various prey species by cod (Bogstad and Mehl 1997) using the expression:

$$consumptionModelCod = \ln 2 \frac{S_i^{\xi} W^{\delta} e^{\gamma T}}{S_0^{\beta} \alpha_i}$$

where S_i is the stomach content of species *i*, W the weight of the predator, S_0 the total stomach content immediately after the last meal and α_i a species-specific constant. ξ, δ, γ, $\beta$and α are parameters that are estimated from laboratory data.

This expression, however, involves the initial meal size, which is not known in the field. Following the argument of Temming and Andersen (1994) a consumption model without the initial meal size is fitted to the data by forcing β to zero during the estimations. Repeated estimations are performed and the replicates stored for later use by Bifrost. It should noted that when ξ is zero, the stomach size dependency is represented by the parameter ξ, which is estimated. When ξ is different from 1 (exponential model), the stomach content data cannot be summed before the estimation of consumption is carried out, but must be treated individually.

Calculation of consumption

The parameters in the predation function are estimated by comparing modelled consumption to consumption calculated from stomach content data. In addition, comparison between modelled and estimated stock abundance at October 1 has some bearing on the predation parameters. Exogeneously to the model, replicates of consumption per cod by age and degree of maturation is calculated quarterly using the following information:

Stomach content data
Replicates of evacuation rate parameters
Temperature from stations, with uncertainty
Swept area estimates of cod

The area dimension is necessary because it cannot be assumed that the stomach sampling is in proportion to cod abundance. The calculations are done several times, each time drawing temperature data from the assumed distribution and each time using a different replicate of evacuation rate parameters. The replicates of consumption per cod are stored on file for later use by Bifrost.

When the empirical consumption is calculated for the likelihood terms, the consumption per cod is multiplied to the number of cod of the appropriate maturation degree using number at age from the Arctic Fisheries WG assessment.

Estimation of parameters

There are two different classes of parameters, those that are determined iteratively on historic data and those that are estimated using a likelihood function. This distinction is purely practical. In each simulation run during likelihood estimation the historic period is run 10 times, during which the number of cod recruits as 0 year old, the number of 1-group capelin and the residual mortality of capelin are found iteratively. The number of modelled 0-group is scaled so that the modelled number of 3 year old cod matches the number of 3 year old cod from the assessment. The number of 1-group capelin is scaled so that the simulated number of 2-group capelin matches the measured number of 2-group capelin the following year. The residual mortality of 1-4 year old capelin is determined to that value which yields the number of 2-5 year old capelin the next year. Thus, the number of recruits of both cod and capelin are consistent with consumption of cod and capelin by cod.

Parameters other than residual mortality of capelin, capelin 1-group and cod recruits are simultaneously estimated using maximum likelihood estimation. The probability of observing the data, given the model is correct, can be partitioned by data sources:

$$L(obs|par) = L_{cap}(obs_{cap}|par)\ L_{cons}(obs_{cons}|par)$$

L is the likelihood of the observations, i.e. the probability of having observed the actual data, given that the model formulation is correct and that the parameters *par* have correct values. obs_{cap} is the number of 4 year old capelin, females and males taken separately. Only the period 1973-1980 has been used for the capelin observation data in the likelihood. In this period the population dynamics of capelin was relatively stable, and problems caused by a possible sex-dependent mortality are probably less severe. obs_{obs} is the exogeneously estimated consumption of capelin, cod and other food in the period 1984 and later. L_{cap} is the probability of observing the capelin data and L_{cons} is the probability of observing the exogeneously estimated consumption. The parameters *par* are described in the sections below.

The assumption of a normal distribution of data on log-basis is used throughout. The standard deviations of the capelin data and the consumption are parameters that are estimated along with the biological parameters. In the present version of the Bifrost model the information about uncertainty in the exogeneously estimated consumption that is inherent in the number of stomachs used in each quarter and in each year is not used, so that outliers stemming from too few stomach content data can have unduly large weight in the estimation.

Maturation

For cod and herring, the proportion mature at age is taken from the VPA data during simulations over the historic period. For capelin, for which the mature and immature part of the stock are considered different dynamic entities, the following length-based model is used:

$$m(l) = \frac{1}{1 + e^{capelinP_1(capelinP_2 - 1)}}$$

where *capelinP1* and *capelinP2*, which are both sex-dependent, are parameters that can be estimated from data. *capelinP1* is fixed to 0.6 for both males and females, a value that is commonly obtained when the above function is estimated on empirical maturation data. *capelinP2* is estimated. Here, as elsewhere in the paper, the name of parameters and variables is the same as used in the model software, although sometimes abbreviated.

For the prognostic period, the proportion mature by age for capelin is taken from the pool of estimated proportion mature by age during the historic period. For herring the proportion mature by age is kept constant. For cod, a model for maturation as function of biomass, temperature and individual weight is used. Figure 2 shows the proportion mature at age during the historic period, from which the tendency to earlier maturation in later years (Nakken, 1994) is evident. Figure 3 shows the proportion mature as function of stock biomass and weight for each age group. The proportion mature is modelled as a linear function of total biomass, temperature and weight at age:

codOgiveAtAge = codOgiveConstant + codOgiveTemperaturePar codOgiveTemperature + codOgiveBiomassPar codOgiveBiomass + codOgiveWeight weightAtAge

codOgiveConstant, *codOgiveTemperaturePar*, and *codOgiveBiomassPar* are parameters that are estimated from historic data for each cod age group in each prognostic iteration. *codOgiveTemperature* is the mean yearly temperature at the Kola section.

Growth models

The weight at age for capelin during prognostic simulations is taken from historic data, selected at random for each year prognostic year. Alternative runs where the historic period is used cyclically have been performed, and show no significant deviation in mean long-term yield from the runs where the weight at age has been drawn at random. Thus, neglecting possible autocorrelations does not seem to be a serious deficit.

Strong year classes of cod tend to be distributed further east, thereby experiencing slower growth (Michaelsen et al 1998). This form of abundance dependence should not be confused with abundance effects related to consumption. Figure 4 shows the weight as function of SSB the year before for different age groups. Each point has been coloured from blue to red according to the mean temperature along the Kola section the year before.

It is difficult to see a definite temperature effect, so the model for weight at age for cod is given by:

codWeightAtAge = codWeightAgeConstant + codWeightAgeBiomass (0.6 – codSSB) + codWeightAgeCapelin capelinConsumption, codSSB > 0.6
codWeightAtAge = codWeightAgeConstant + codWeightAgeCapelin capelinConsumption, codSSB < 0.6

capelinConsumption is the total consumption of capelin in the preceding year, *codSSB* is the spawning biomass of cod, *codWeightAgeConstant* and *codWeightAgeCapelin* are constants that are estimated from historic data for each cod age group in stochastic iteration run.

The weight at age for herring during prognostic runs is assumed constant.

Recruitment models

The capelin recruitment model has a Beverton-Holt formulation with effects from herring, cannibalism, and 0-group cod in the denominator. Thus, predation on the capelin recruits determines good or bad recruitment conditions, but does not affect the asymptotic value. The temperature effect is made a proportional effect, affecting the asymptotic value as well as recruitment for medium and low values of the spawning stock. The mathematical formulation of the number of capelin recruits is:

$$capMax * e^{capTemp*tempdiff} \frac{SSB}{capHalf + capPred + SSB}$$

where:

$$cap\Pr ed = capHer\Pr op(herring + capHerOffset)^{capHerExp} + capCod\Pr op * zeroCod + capcap\Pr op * capelin$$

SSB is the capelin spawning stock biomass, *capelin* is the biomass of capelin that may be considered predators on 0-group capelin, *tempdiff* is the difference between the mean temperature during August-December and the mean temperature during January-April in the Kola section. Herring is the biomass of young herring in the Barents Sea, taken as herring of age 1 and age 2 in the VPA, *zeroCod* is the 0-group cod from the model, *capHerProp*, *capHerOffset*, *capHerExp*, *capCodProp* and *capCapProp* are parameters that are estimated prior to a prognostic run.

Figure 5 shows modelled and measured recruitment as 2 year old capelin. The mean value of R^2 for the prognostic runs is 0.83. Figure 6 shows modelled and measured recuitment when cannibalism on cod is not modelled. The mean value of R^2 is 0.78. It is clear from comparing the two figures that the cod's predation on juvenile cod affects the predation on capelin and hence the capelin recruitment model.

There is no built-in predation term in the recruitment model for cod, because the historic simulated 0-group is consistent with subsequent consumption by cod until the recruits are 3 years. As for capelin, the recruitment model for cod is built on the Beverton-Holt formulation. However, the spawning stock effect is made a power function of the spawning stock, thus accommodating a somewhat more flexible formulation. As for capelin, a temperature effect is built into the proportional term. Also, effects of mean age and mean weight are built into the proportional term. The rationale for building in mean age is the possibility that older females have a higher value as parents because of their large eggs and longer spawning time (Solemdal, 1997). The rationale for building in mean weight is the possibility of a higher degree of skipped spawning when the condition is poor (Filina, 2002). In Icelandic cod the spawning stock-recruitment relationship is improved by including age information of the spawners (Marsteinsdottir and Thorarinsson, 1998) and a simulation study shows that the recruitment deteriorates when the percentage of repeat spawners falls (Scott et al., 1999). Using mean weight as a (inverse) proxy for skipped spawning has also an age effect. However, skipped spawning occur at a larger frequency for younger fish. These amendments of the recruitment function are key activities in the joint IMR-PINRO programme "Evaluation of long-term yield of cod" (Filin and Tjelmeland, this symposium). The recruitment model is:

$$codMax\operatorname{Re}c * e^{codTemp*temp + meanWeightPar*meanWeight + meanAgePar*meanAge} \frac{SSB^{codExp\operatorname{Re}c}}{codHalf^{\,codExp\operatorname{Re}c} + SSB^{codExp\operatorname{Re}c}}$$

codTemp, *meanWeightPar*, *meanAgePar*, *codHalf* and *codExpRec* are parameters that are estimated from data during each prognostic run. *temp* is the mean temperature in the Kola section during August-October, *meanAge* is the mean age and *meanWeight* is the mean weight.

Figure 7 shows the modelled recruitment and the VPA age 3 as function of SSB. Figure 8 shows the modelled recruitment and the VPA age 3 as function of SSB without modelling effects from temperature, mean age or mean weight. Figure 9 shows the modelled recruitment vs. VPA age at 3 years without modelling cannibalism. Figure 10 shows the modelled recruitment vs. VPA age at 3 years without modelling effects from temperature, mean age, mean weight or cannibalism.

The mean value of R^2 without modelling cannibalism or including temperature, mean weight or mean age is 0.17, see Figure 10. When temperature, mean weight and mean age is included it is 0.59, see Figure 9, when cannibalism is included it is 0.50, see Figure 8, and when all of the factors temperature, mean age, mean weight and cannibalism are included, R^2 is 0.78, see Figure 7. Attempts of estimating the spawning stock -recruitment relation for cod have earlier resulted in values of R^2 well below 0.30 (Godø, 2003). An R^2 of 0.43 was obtained using total lipid content, wind stress and temperature as explanatory variables (Matrshall et al., 2000). Those regressions were performed for a considerably longer time series of data, however. Sparholt (1996) demonstrated that the number of recruits of Baltic cod must be evaluated by a multispecies model (MSVPA) in order to achieve good recruitmet models, as the present result demonstrates this also seems to be the case for North-east arctic cod.

Predation

In the model, cod is a predator on cod and capelin. Other predation interactions are capelin and herring preying on capelin larvae, but those interactions are built into the recruitment function for capelin.

Predation is determined on the one hand by the spatial overlap between predator and prey and on the other hand by the density of the predator and prey stocks in the overlap area. Bifrost has no explicit spatial structure. However, the geographical extent of both capelin and cod are dependent on stock size, and it may be necessary to take into account the dynamics of the size of the overlap area. Both the part of capelin that overlaps with cod and the part of cod that overlaps capelin, as well as the feeding level, are modelled with functions of the form $\frac{abundance^k}{constant^k + abundance^k}$, where *constant* and *k* are to be determined from the data. Figure 11 shows an example of how the overlap model may be interpreted. As the capelin abundance increases, the capelin area (yellow) expands and the overlap (magenta) between cod and capelin increases. As the cod abundance increases, the cod area (blue) expands northwards, aslo increasing the overlap. The total area (red), which determines the area density of other food is assumed constant with size 1.

The predation by cod on capelin is modelled by:

$$consumptionCapelinByCod = P\,F\,\frac{capelinFood}{totalFoodCapelinArea}$$

where P is the predation pressure exerted by cod on capelin and F is the feeding level of cod in the overlap area. Here:

$$P = maxConsCod * predationAbilityCodOnCapelin * overlapping$$

F = $$F = \frac{totalFoodCapelinArea^{consExponent}}{halfCodExtension^{consExponent} + totalFoodCapelinArea^{consExponent}}$$

$$predAbilityCodCapelin = \sum_{age} suitCap * codN * (1 - codOgive) * (1 - svalbComp) * codW^{0.801 + codWExp}$$

$$overlapping = partOfCapelinOverlappedByCod * partOfCodOverlappingCapelin$$

$$partOfcapelinOverlappedByCod = \frac{capelinFood^{capExtensionExp}}{halfCapelinExtension^{capExtensionExp} + capelinFood^{capExtensionExp}}$$

$$partOfCodOverlappingCapelin = \frac{codBiomass^{codExtensionExp}}{halfCodExtension^{codExtensionExp} + codBiomass^{codExtensionExp}}$$

suitCap represents the size-specific suitability for cod consuming capelin and is a vector where the first two element (ages 0 and 1) are zero, the third element (age 2) is 0.5 and the elements for older ages are 1.0. The cod starts eating capelin at age 2 (Dalpadado and Bogstad, 2004). However, further studies are needed in order to establish the suitability for age 2 on data, and the value of 0.5 remains at the moment somewhat speculative. *codN* is the number by age of cod, *codW* is the weight at age of cod, *svalbComp* is the proportion by age of cod that during the first quarter reside in the Svalbard area (B. Bogstad, pers comm). *consExponent*, *halfCodExtension*, *codWExp*, *capExtensionExp*, *halfCapelinExtension*, *codExtensionExp*, *halfCodExtension* are parameters that can be estimated from data.

Cannibalism is one of the potential most important processes for cod dynamics. For relatively long-living species having highly dynamic recruitment cannibalism can be an important source of food (Longhurst, 1999). Usually, cannibalism is incorporated into the recruitment function using a Ricker model. In Bifrost, cannibalism is modelled directly as cod is one of the food items of cod, and the recruitment as 3 year old cod is thus dependent not only of the consumption of juvenils by adult cod, but also of the relative abundance of juvenile cod with respect to capelin and other food.

Simulation

The investigation of harvesting control rules is based on 150 years of prognostic simulation, where the first 50 years are discarded to avoid initial effects. Maturation and weight at age of cod are explicitly modelled, as is recruitment for all stocks. For processes that are not modelled (e.g. temperature, maturation and residual mortality of capelin), the values used during prognostic runs are drawn at random from the historic values. If, alternatively, these entities are used cyclically, the results do not differ much. Hence, neglecting a possible autocorrelation in these variables does not seem to be a serious problem.

Harvesting control rules

The simulations have been performed with a target spawning stock of capelin of 0 (removing capelin from the system), 0.25, 0.50, and 1.5 million tonnes and F-value for cod of 0.125, 0.4, 0.75, 0.875, 1.0, 1.125 and 1.25 relative to current exploitation. Figure 12 shows the mean longterm catch of cod and capelin for F-values for herring of 0.125, 0.20 and 0.30. The maximum long-term yield of cod corresponds to a fishing mortality of about half the current fishing mortality, and the optimal fishing mortality is about constant, irrespective of the fishing mortality applied for herring. However, as the fishing mortality for herring increases, the long-term yield of cod increases substantially for all levels of fishing mortality of cod, due to increased availability of capelin.

Naturally, the long-term yield of capelin increases substantially with increased fishing pressure on herring. In order to maintain an average capelin yield above 0.5 million tonnes, the fishing pressure on cod should not be reduced from the present level.

The long-term yield of herring is 0.81, 0.73 and 0.46 million tonnes for F-values of 0.125, 0.20 and 0.30, respectively. The present-day F-value on herring of 0.125 is nearly optimal, and increasing the fishing pressure above this reduces yield of herring considerably.

It should be noted that the strong dependence of long-term yield of cod on the fishing pressure on herring (and thereby on the availability of capelin) mainly is an effect of the capelin partly shielding cod recruites from cannibalism. Only to a little extent does the effect of capelin abundance on cod growth contribute to the long-term yield, in the present model. The amount of other food is kept constant during all model runs, and it may be dubious whether this assumption holds true when the cod stock gets very large.

It should be noted that the present work is preliminary. Sub-models and estimation procedures can be significantly improved. Therefore the presentation in this paper has deliberately been made somewhat sketchy. I believe the main result that the fishing pressure on cod must be lowered in order to obtain maximum long-term yield will stand the test of time, however. Whether the low maximum long-term yield calculated here of about 0.4 million tonnes will change when the model is improved, for instance by including cannibalism for cod of age 3 and older, remains to be seen.

Bifrost and Russian-Norwegian efforts to estimate long-term yield of cod

Bifrost is a simulator for cod, capelin and herring in the Barents Sea, where the interaction between these species has been taken into account, and in the present paper it has been demonstrated that it can be used to evaluate 3-species harvesting control rules. The Russian-Norwegian Fishery Commission has mandated IMR and PINRO to evaluate the long-term yield of cod taking into account the interaction between species and the influence from the environment. Formally, Bifrost could be used for that purpose as it stands. However, other multispecies models may be as useful. Bifrost relies solely on estimating historic consumption by cod from stomach samples, while the Russian model STOCOBAR (A Filin, this symposium) uses stomach content data only for partitioning consumption on species, while the total consumption is estimated from the observed weight increase. Both approaches should be tried and compared before the final choice of multispecies model is made.

A part of the future work with Bifrost should be to include the effect of consumption on growth in the likelihood function, thereby bringing it closer to STOCOBAR. Also, effects from harp seals and minke whales on capelin and cod should be included, using results from the corresponding sub-projects (see below).

The formally comprehensive results regarding longtime yield from a multispecies model should not distract the attention from the fact that a chain is not stronger than its weakest link. A multispecies model is comprised of a number of sub-models, some of which deal with interactions between species, some of which deal with processes pertaining to a single species. The IMR-PINRO response to the request from the Commission is to define subprojects in which sub-models can be built from studies of historic data. The results from these sub-projects (e.g. skipped spawning in starving cod, eggs from older cod more viable than eggs from younger cod) will be used in several multispecies models. As the work goes on, the results from the sub-projects are also combined into a model that evolves with the project – EcoCod. This model can also serve as a candidate for the final multispecies model.

Implementation in management

Once the general guideline for management is found by long-time simulation the question arises of implementation in the year to year management. As pointed out by Walters and Punt (1994) the best way of conveying the uncertainty to managers is by using a graph that shows the risk of not meeting the objective next year as function of catch. In the present context of a 3-species harvesting control rule, in order to arrive at a single-valued objective value must be attributed to the catch of each of the species. This is complicated by the fact that the stocks are shared between countries which may want to value the species differently, depending on the use of catches in each country. This complication might partly be avoided by the two countries delivering fish and fish products on the world market, but still large regional differences may prevail (e.g. the use of capelin). Thus, aiming at a comprehensive management where the species interactions are taken into account may lead to complications in the economic domain, where the countries must co-operate. Also, the biological science must connect to the economic science in order to provide adequate background for managers.

In recent years, the question whether large fishing pressure leads to evolutionary changes has arisen. Heino (1998) discusses management implications of evolutionary evolving fish stocks using a simple simulation model as example. The technical problems of extending this type of simulations to a more complicated management-oriented model like Bifrost should be modest.

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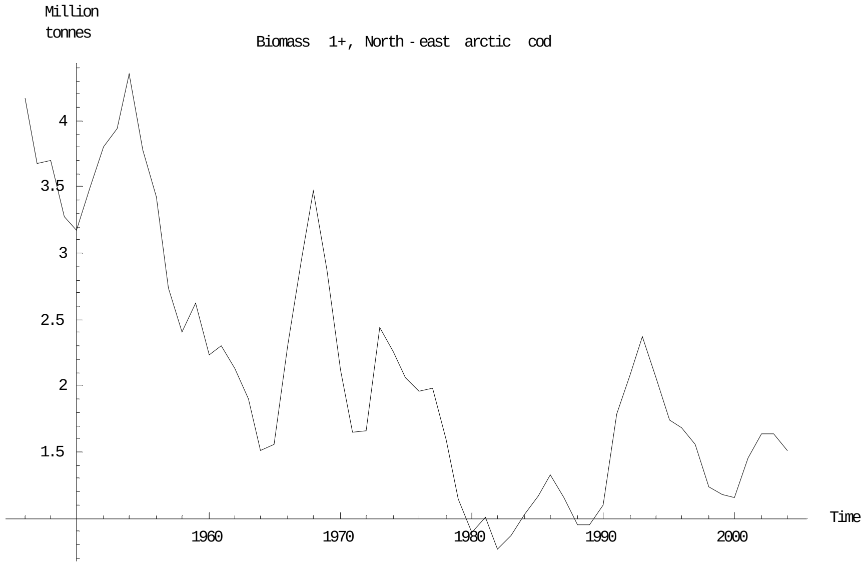

Figure 1. Biomass of 1+ cod, VPA data

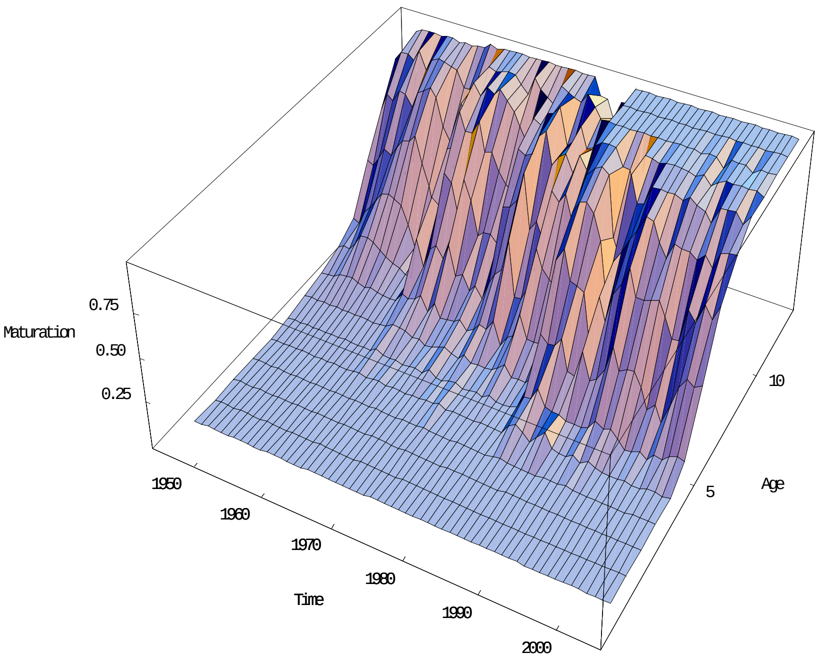

Figure 2. Proportion mature for cod, VPA data.

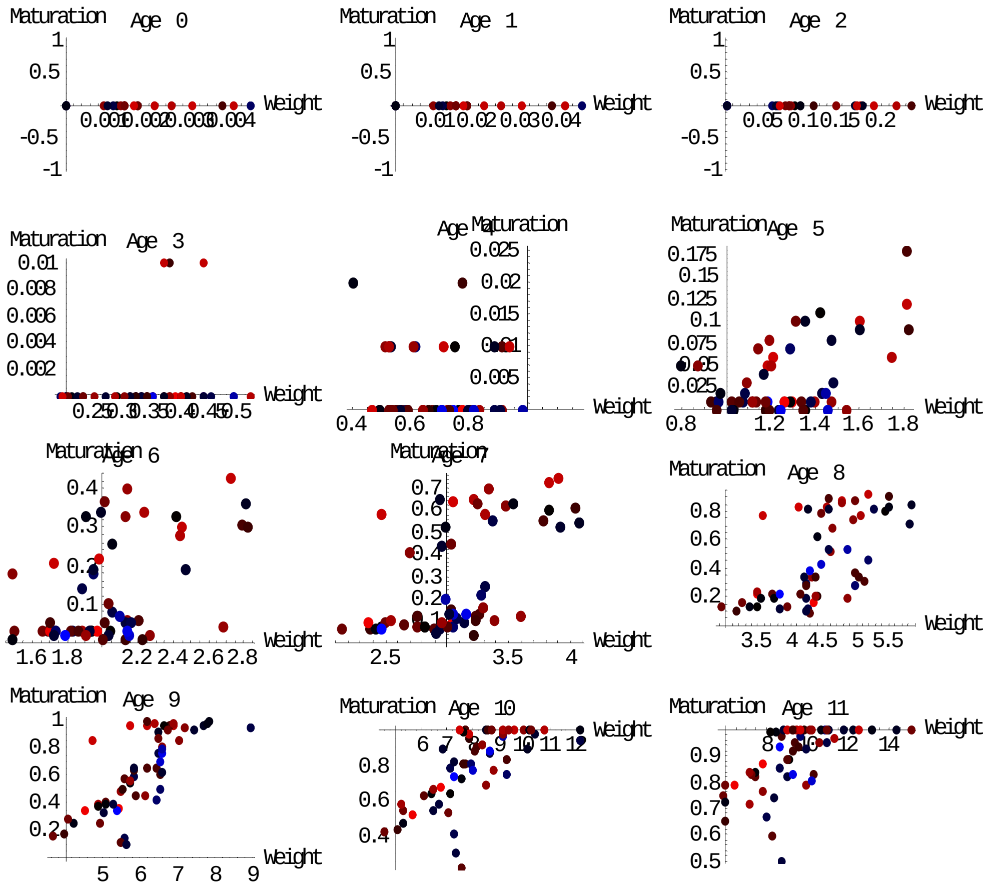

Figure 3. Proportion mature for cod as function of individual weight for different age groups, VPA data. Points are coloured according to temperature, red is warm, blue is cold.

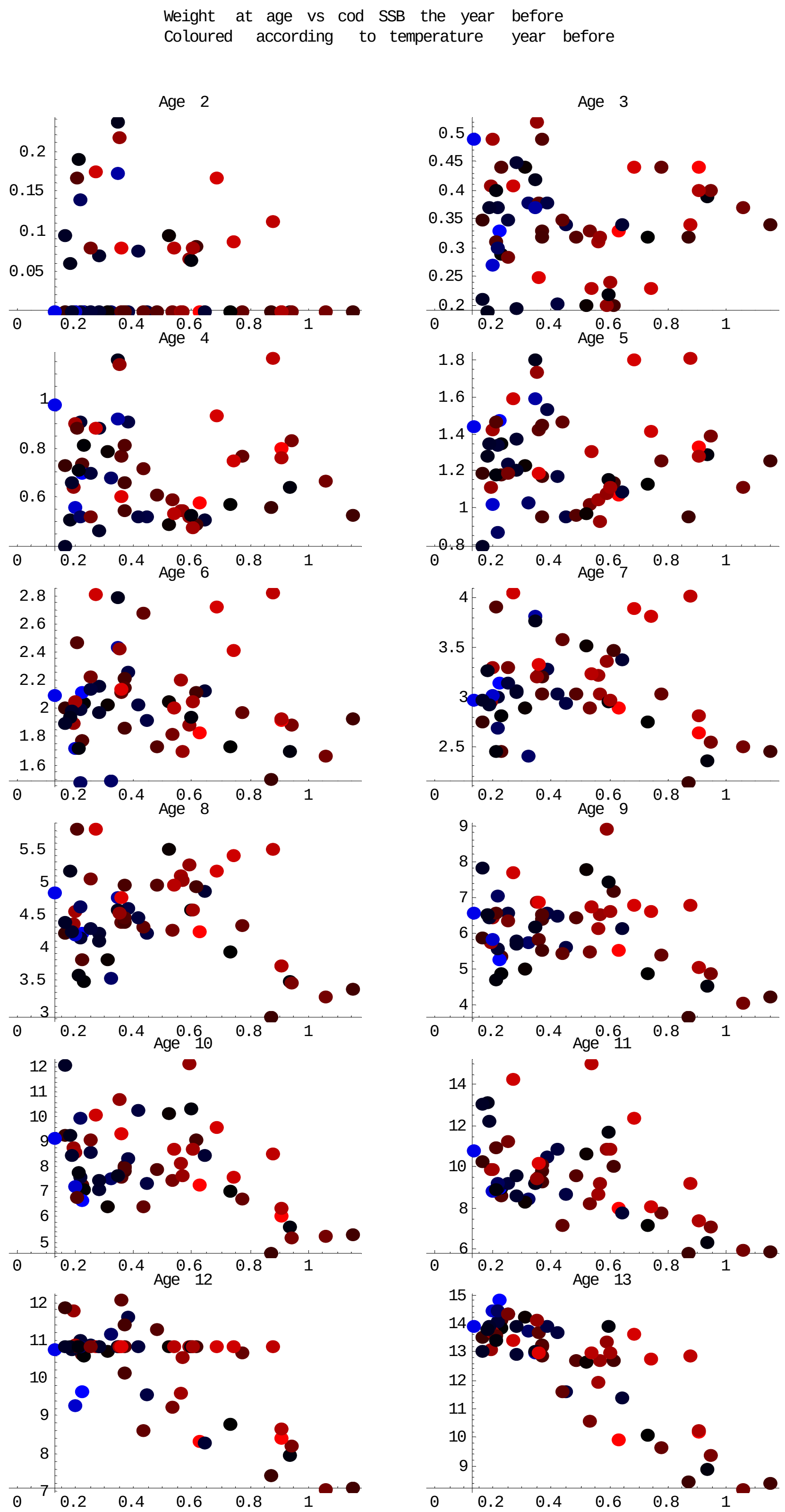

Figure 4. Individual weight of cod vs SSB for different age groups. Points are coloured according to temperature, red is warm, blue is cold

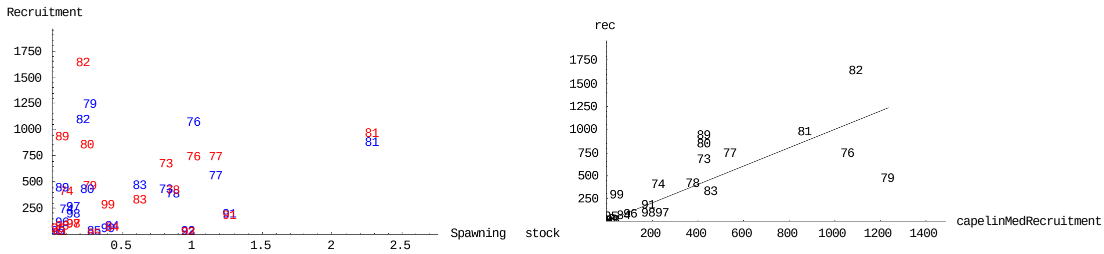

Figure 5. Capelin recruitment. Left panel: Measured (red) and modelled (blue) recruitment as 2 year old capelin vs spawning biomass. Right panel: Measured (vertical axes) vs modelled (horizontal axis) recruitment as 2 year old capelin

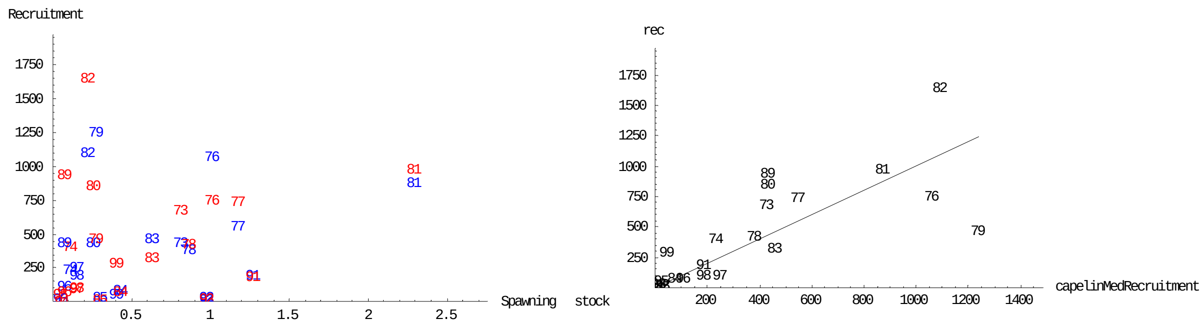

Figure 6. Recruitment of capelin. Same data and explanations as for figure 5, but without cannibalism of cod in the model

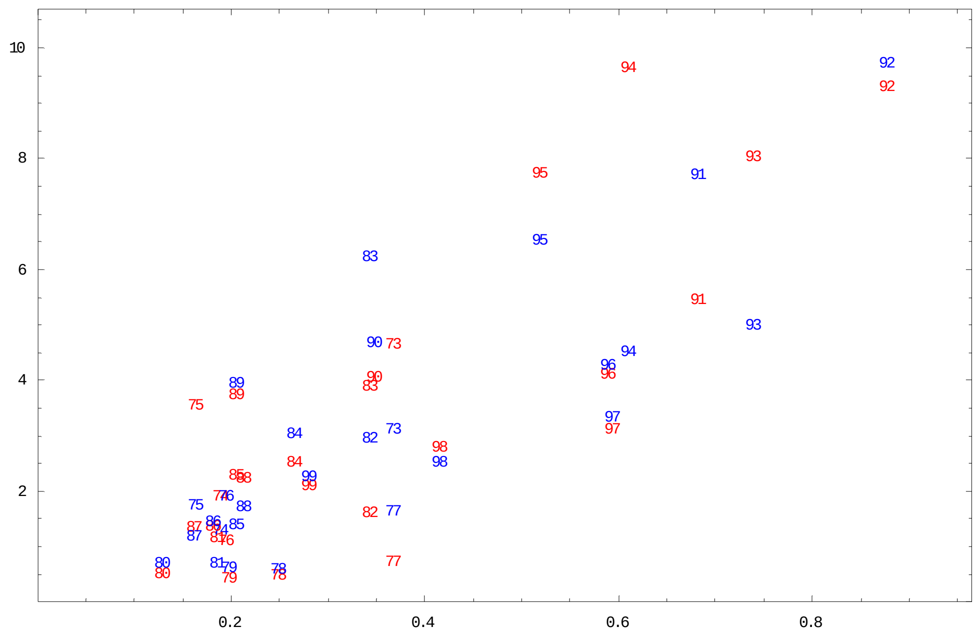

Figure 7. Recruitment of cod with cannibalism, temperature, mean age and mean weight vs spawning stock biomass. Red is number of 0 year old cod as fitted to 3 year old cod in the VPA, blue is modelled recruitment

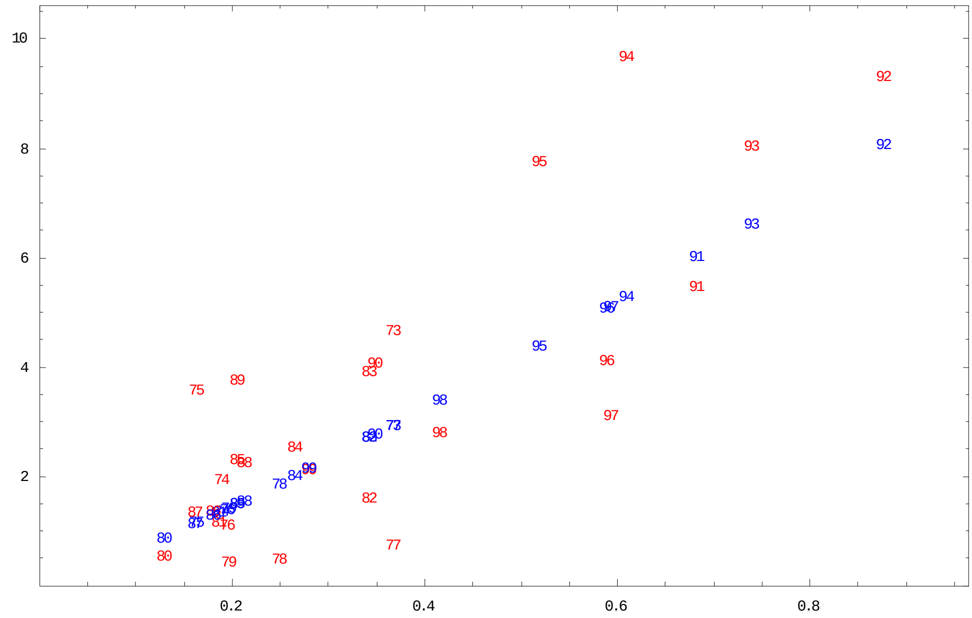

Figure 8. Cod recruitment (billion) with cannibalism, but without temperature, mean age and mean weight in the model. Red is number of 0 year old cod as fitted to 3 year old cod in the VPA, blue is modelled recruitment. Horizontal axis is spawning stock biomass

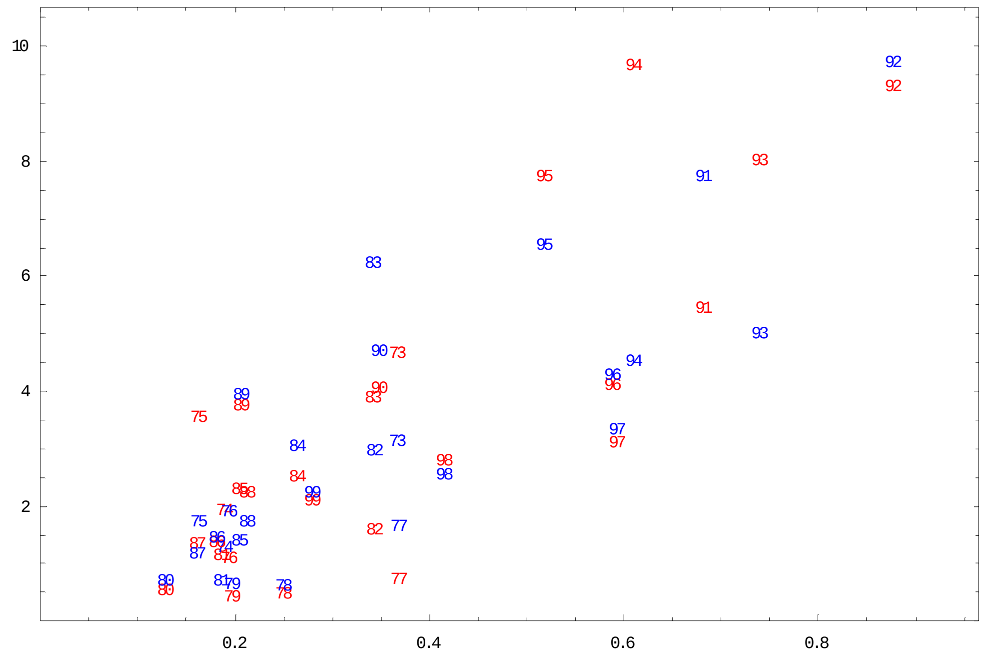

Figure 9. Cod recruitment (billion) with temperature, mean age and mean weight in the model, but cannibalism is excluded. Red is number of 0 year old cod as fitted to 3 year old cod in the VPA, blue is modelled recruitment. Horizontal axis is spawning stock biomass

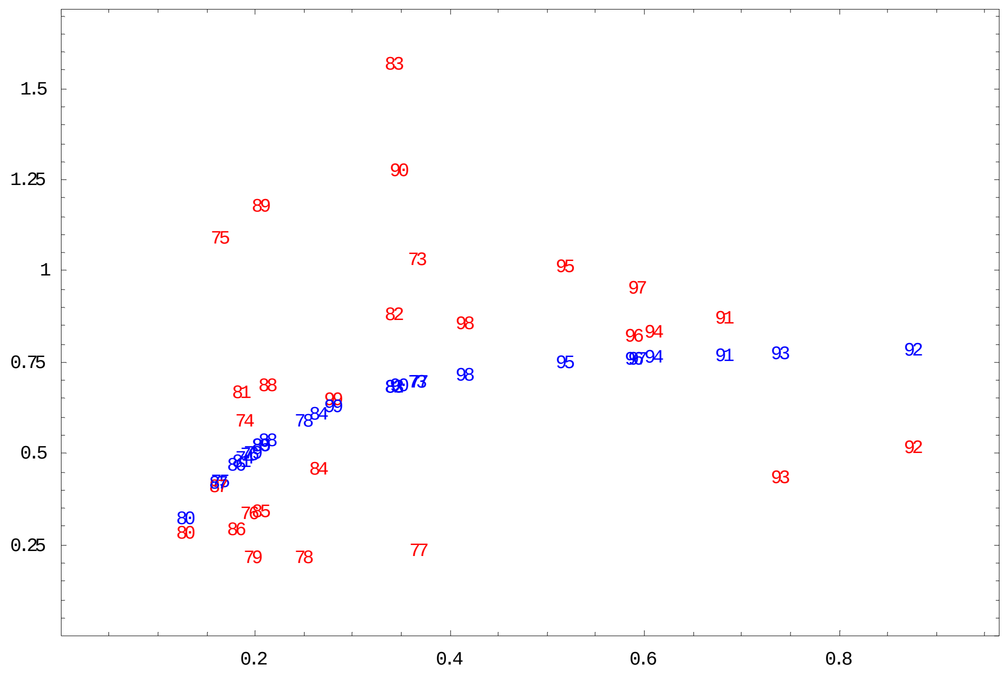

Figure 10. Cod recruitment (billion) when neither cannibalism, temperature, mean age or mean weight affect recruitment in the model. Red is number of 0 year old cod as fitted to 3 year old cod in the VPA, blue is modelled recruitment. Horizontal axis is spawning stock biomass

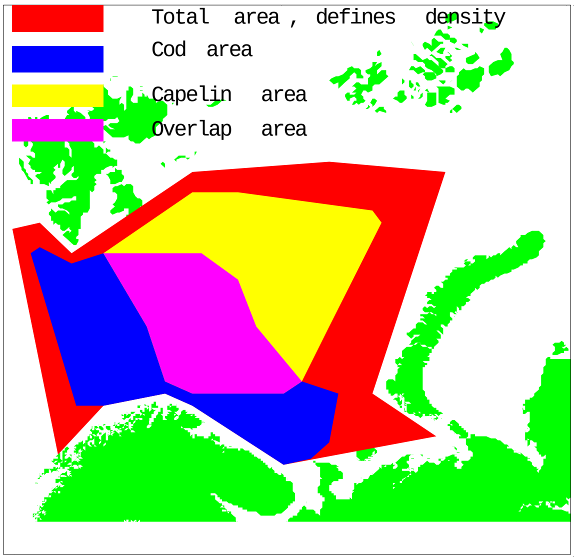

Figure 11. Example of overlap. Yeallow: capelin area, blue: cod area, magenta: overlap area, red: total area.

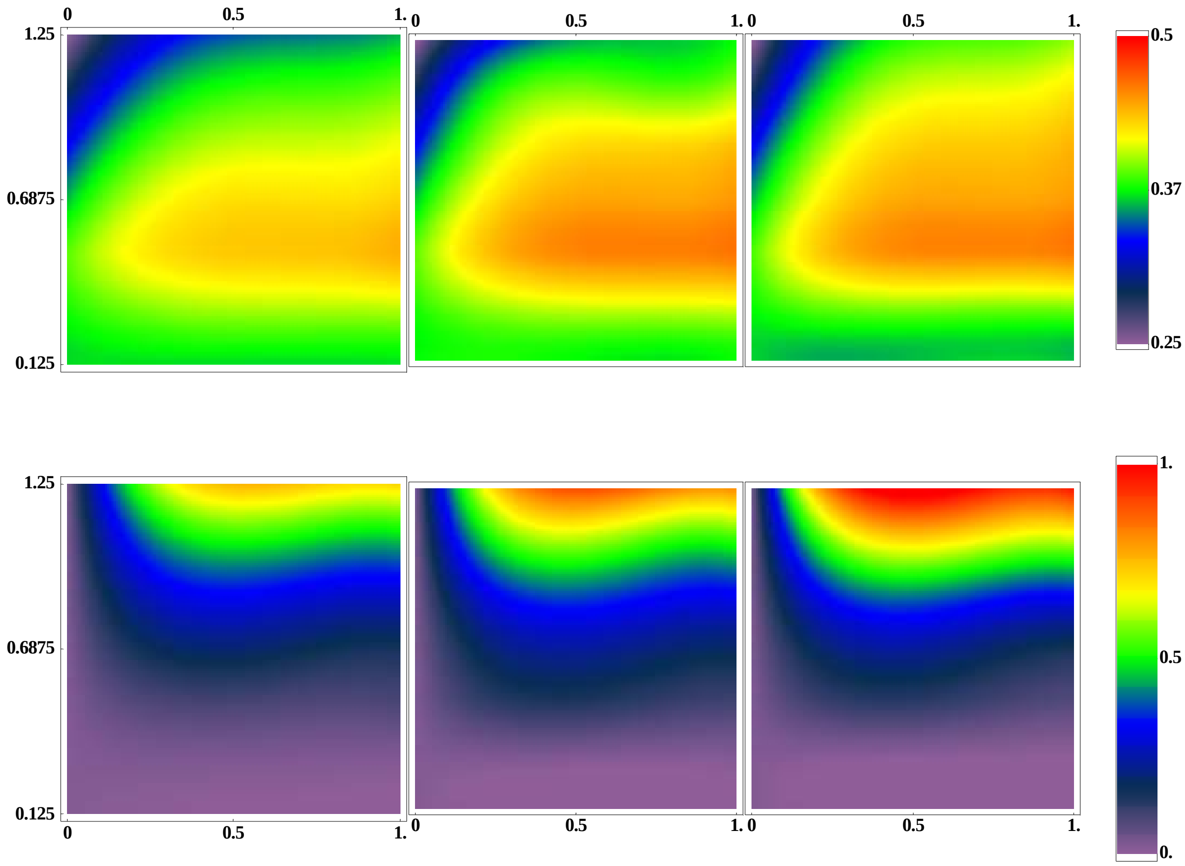

Figure 12. Long-term yield of cod (upper panel) and capelin (lower panel) for a two-dimensional cod-capelin harvesting control rule, given fixed harvesting control rule for herring. Horizontal axis: target spawning biomass of capelin. Vertical axis: F-value of cod, relative to present. Left figures: $F_{herring}$ = 0.125, middle figures: $F_{herring}$ = 0.20, right figures: $F_{herring}$ = 0.30. Colouring according to mean long-term yield, values correspond to panel on the far right

ECOSYSTEM APPROACH TO ESTIMATION OF LONG-TERM YIELD OF COD IN THE BARENTS SEA

by

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Introduction

Existing management strategy for cod stock in the Barents Sea is based on the precautionary approach concept employed in ICES. According to this concept, the fishing mortality is set depending on spawning stock biomass and such biological reference points as B_{lim}, B_{pa}, F_{lim} and F_{pa}, which are expressed in values of fishing mortality and biomass of spawning stock. The major advantage of these rules is that they are simple and the main drawback of this approach is that it ignores effect of interannual variations of ecosystem factors on stock dynamics. The values of reference points remain constant despite the current or expected situation in the ecosystem. At the same time, productivity of the stock and its reproductive capacity will significantly differ depending on feeding resources, thermal conditions and abundance of predators or feeding competitors (Blindheim, Skjoldal, 1993; Filin, 2004a). Our knowledge proves that in many cases ecosystem factors have a decisive effect on recruitment, growth and mortality of commercial marine organisms (Skjoldal, 1990; Filin et al., 2003). Underestimation of these factors in justification of harvest strategy can lead to both critical overfishing and groundless reduction of a possible catch.

The stock management strategy is based on expected estimate of long-term yield. Such estimates are used to set optimal harvest intensity according to the accepted management targets. Management strategy for cod stock based on existing concept of precautionary approach is probably able to ensure conditions when the risk of critical stock depletion will not exceed allowable limits. However, the following questions arise. Is this harvest strategy good enough to ensure maximum sustainable yield of cod considering interannual variations in the ecosystem of the Barents Sea? Do the existing precautionary rules for deciding on TAC of cod correspond to the principals of rational harvest of this stock, taking into account natural fluctuations of the population under the influence of ecosystem factors? Is it possible to increase harvest efficiency of cod stock in the Barents Sea by improving the management strategy implementing ecosystem approach in harvest management without breaking the accepted precautionary principle?

Nowadays, these questions still lack clear answer and non of the existing opinions can be accepted as well-grounded since no methodical basis of ecosystem approach for estimation of long-term sustainable yield of cod in the Barents Sea is developed.

Considering the urgency and practical importance of this issue, a 10-year research programme in the framework of joint Russian-Norwegian project on development of optimal harvest strategy for marine organisms in the Barents Sea taking into account their interactions and the effect of ecosystem factors was adopted at the 33rd session in 2004. At the first stage of this work, we should focus on cod.

The purpose of this paper is to ground methodical approaches to development of harvest strategy for cod in the Barents Sea that is based on estimates of long-term yield taking into account the effect of ecosystem factors on stock dynamics.

Long-term yield and ecosystem strategy for harvest of cod in the Barents Sea

The only method for estimation of expected long-term yield is mathematic modelling. In the mostly simple form, it can be implemented under conditions of equilibrium state of the population, which means that mortality corresponds to recruitment of fishing stock that has constant biological parameter. Based on these assumptions, a maximum sustainable yield (MSY) can be calculated and its value is often considered as one of the reference points used in harvest management. It is obvious that using this approach the effect of ecosystem factors on stock dynamics is completely neglected.

A more realistic calculation of long-term yield can be obtained by using variables from year to year population parameters that are randomly chosen from a set of historic data. This approach allows us to take into account natural variability of population parameters when modelling the stock dynamics and can give stochastic estimates of long-term yield after repetitive runs of the model. However, it cannot ensure an adequate estimate of population parameters variation under the influence of environmental changes since it does not expose such dependences, but only indirectly allows for it. Such an estimate can be obtained only by using multispecies and ecosystem based models that take explicitly into account the effect of species interaction and oceanographic factors on population parameters of the stock, which define the productive capacity of the species (Tjelmeland, Bogstad, 1998; Filin, 2004b).

The development of cod harvest strategy based on the estimation of long-term yield taking into account the effect of ecosystem factors shall consist of the following stages:

1) define the management targets;

2) specify ecosystem factors for simulation;

3) develop models for stock management that take into account the effect of species interaction and ecosystem factors on stock dynamics;

4) develop stochastic ecosystem scenarios for testing the harvest strategy;

5) perform simulations of stock dynamics and statistic analysis of the obtained data;

6) develop rules for stock harvest that take into account adjustable fishing effort depending not only on the state of the stock but also on the situation in the ecosystem;

7) assess economic efficiency of the stock harvest using the developed strategies.

Management targets

For Northeast Arctic cod, the existing harvest strategy is aimed at maximum and stable long-term yield. From the ecosystem perspective, these aims should be considered as hardly compatible. No measures for harvest management are able to eliminate interannual natural abundance fluctuations of commercial species since they are caused by large-scale oceanic processes that cannot be controlled by human. Therefore, the most effective harvest strategy in terms of maximum long-term yield is a strategy that takes explicitly into account ecosystem mechanisms of the stock dynamics when estimating fishing mortality. In order to obtain the highest long-term yield we should follow natural stock dynamics instead of trying to smoothen it applying certain management measures.

However, such harvest strategy is not optimal in the economic perspective since industry is interested in interannual stability of cod catches. In order to eliminate these contradictions we should define allowable limits of interannual variations of cod catches for calculation of maximum long-term yield. The consequences for stock dynamics and fishing efficiency under different variants of these conditions should be analysed while simulating the stock harvest strategies.

Identifying ecosystem factors for simulation

When identifying the ecosystem factors for simulation of harvest strategy we should consider both the effect on the dynamics of cod stock and availability of data that is necessary for simulation. The results of many researches show that it is thermal conditions and the situation in capelin stock that have the greatest effect on growth, maturation and recruitment of cod (The Barents Sea cod…, 2003). Quantitative estimates of effect of these factors on cod population parameter are well documented and this effect is better studied then effects of other factors. The dynamics of capelin stock abundance in the Barents Sea has been monitored since 1972, while temperature observations have been carried out since the beginning of the last century. Therefore, water temperature and capelin stock biomass were chosen as main ecosystem parameters that effect natural dynamics of cod stock in the Barents Sea.

Cod feed not only on capelin but also on other species. Cod is a polyphage species and it can feed on more than 200 species of the Barents Sea (The Barents Sea cod…, 2003). When it lacks capelin cod can switch to own juveniles, shrimps, herring, polar cod and euphausiids. The abundance of Norwegian spring-spawning herring to large extend is opposite to that of capelin. These two species are close to each other in nutritional value and we can expect that when abundance of capelin is low, juveniles of herring can substitute capelin in cod diet. According to the publications herring was of great importance for cod in 1930s-1960s (The Barents Sea cod…, 2003). However, in the next period the importance of herring was relatively low, even in the years when its abundance was high. Nevertheless, juveniles of herring should be considered as an important ecosystem component for cod stock in the Barents Sea taking also into account negative impact of herring on capelin stock.The most catastrophic consequences for feeding recourses of cod in the Barents Sea will occur when periods of low abundance of capelin will overlap with the absence of spring-spawning herring.

According to the existing estimates, cannibalism is the main contributor to cod mortality caused by predation (Dolgov, 1999). However, predation by marine mammals should also be considered as an ecosystem factor that can affect stock dynamics of cod (Bogstad et al., 2000). The predation of marine mammals on capelin, polar cod and herring can also have important consequences for cod stock. Unfortunately, the possibility to incorporate the effect of marine mammals into simulations is limited due to incomplete data. Therefore, the activities to increase the collection of necessary data on feeding and migrations of marine mammals are planned in the framework of joint research programme on estimation of optimal harvest strategy of marine organisms in the Barents Sea. Nowadays, among over 20 species of marine mammals that occur in the Barents Sea, only minke whale and harp seal can be considered as potential species for simulations.

Development of multispecies and ecosystem models for cod stock management

Development of models to improve harvest management of bioresources in the Barents Sea based on species interactions started in IMR in mid-80s and in PINRO in the early 1990s of the last century. At the first stage, the work was focused on complex models that included maximum number of species interacted according to their trophic relations. The time intervals used in modelling were minimal (one or three months) and in some cases, the dividing the Barents Sea in areas was also used. On the one hand, the model became more realistic but on the other hand, the result was the opposite since it required employing a number assumptions cause by insufficient knowledge and incomplete data.

This approach was used in IMR to develop such models as MULTSPEC, AGGMULT and Systmod. In PINRO this approach was employed for development of MSVPA model (Tjelmeland, Bogstad, 1998, 2000; Hamre, Hatlebakk, 1998; Korzhev, Dolgov, 1999). All these models can give quantitative characteristics of species interaction of cod in the Barents Sea and can be useful to solve theoretical problems of multispecies harvest management. However, the use of these models for practical tasks of estimating long-term yield and biological reference points for cod fishery is limited by high level of uncertainty in calculations due to assumptions employed in the models and incomplete data.

Therefore, since the second part of the 1990s some more simple, in structural sense, models have been prioritised. They only reflect separate elements of species relations (not interactions) between main species targeted by fisheries in the Barents Sea, which is cod and capelin. IMR has developed and uses in practical work Bifrost model, which is oriented to capelin (Gjøsæter et al., 2002). PINRO has developed STOCOBAR model that describes dynamics of cod stock in the Barents Sea and is based on multispecies approach (Filin, 2004b). Both models can be adapted for estimation of long-term yield of cod in the Barents Sea taking into account species interactions.

Bifrost and STOCOBAR models simulate mechanisms of the processes that define dynamics of modelled biological parameter. In this sense, they are different from the models that based on regression equations. Incorporation of regression equations that describe elements of species interactions, into a single species model of the stock dynamics is probably the simplest way to employ multispecies approach in development of harvest management model. Therefore, at the first stage in the framework of joint programme employing the principal of succession in the transition from single species model to multispecies model it is planed to develop EcoCod model, which will incorporate correlation dependences of cod population parameters on ecosystem factors. This model shall be a successor of the joint single species model CodSim used for estimation of long-term yield of cod. The CodSim model will be modified by incorporating regression equations in the calculation algorithms. These equations describe correlation dependences of cod growth, maturation, recruitment and natural mortality on ecosystem parameter.

Development of stochastic ecosystem scenario

The identification of the scenario should be based on targets of model analysis. Proceeding from this, a number of ecosystem parameters for the scenario and the range of their variations are set. Ecosystem scenarios based on historic data should be employed for estimation of biological reference points in harvest management. Prognostic scenarios cannot be applied for this purpose. The main indicator that characterises ecosystem scenario is its capacity to give a realistic picture exposing a match between variations of the ecosystem parameter based on a scenario and historic data.

The scenario of thermal condition development does not depend on scenarios of development of biological processes and it should be based on short-term cycles and long-term warm-cold periods obtained from historic data taking into account occasional deviations from general pattern. The thermal scenario is based on historic data set. For stochastic scenario, the data can be selected by several means:

- random selection;
- random selection in the given interval;
- in successive order combining warm, cold and moderate periods, based on data randomly selected in the given interval.

The scenario of development of thermal conditions should determine scenarios of feeding resources dynamics for cod that are also based on historic data on capelin stock biomass and other prey species for cod in the Barents Sea.

Simulations of stock dynamics and statistic analysis of the results

Simulations should be used to study the necessity to apply different approaches to the harvest management depending state of the ecosystem. For this purpose, it is necessary to have comparative data obtained from modelling of productivity of cod stock under different scenarios of development of thermal conditions, abundance of prey species and predators. In particular, it is necessary to conduct a comparative analysis of cod stock dynamics in warm, moderate and cold periods with different levels of capelin stock. Fishing mortality that ensures maximum long-term yield should be estimated for each of these scenarios. Besides, we should take into account uncertainties connected to the prediction of dynamics of ecosystem parameters.

The most convenient way to present the results of statistic analysis of model calculations is in form of probability estimates of possible variations of the modelled parameters. Applying this method to take into account uncertainty, the probability can be presented in from of a risk estimate of undesirable consequences for the stock and harvest implementing a testing strategy. Especially it concerns the probability of declining of stock level bellow the established threshold level. In order to perform risk analysis, the results of multiple runs of stochastic model will be analysed.

Improvement of harvest control rules for cod based on ecosystem approach

Estimation of biological reference points (B_{lim}, F_{lim}, B_{pa} and F_{pa}) based on multispecies and ecosystem models will probably become the first step forward in implementing ecosystem approach for existing scheme of TAC calculation. From the ecosystem point of view the stock harvest level should vary depending not only on the state of the stock but also on the ecosystem parameters that determine recruitment, growth and natural mortality of the species. This will require changing over to a differentiated estimation of biological reference points for cod under different states of ecosystem in the Barents Sea. Besides, a further development of ecosystem approach is likely to be related to the incorporating of additional ecosystem reference points into the harvest control rules.

Therefore, it is possible to identify three successive stages to improve harvest control rules for cod in the Barents Sea applying ecosystem approach:

- the harvest control rules remain unchanged, but new values of biological reference points obtained with ecosystem based simulations are used;

- the existing scheme for calculation of TAC remains unchanged, but the values of biological reference points become variable depending on the situation in the ecosystem;

- new additional reference points and new scheme for stock management are applied.

The specification of optimal rules for cod stock harvest should be based on model calculations, which requires development of adequate management models. The use of differentiated values of biological reference points while deciding on TAC of cod presupposes prediction of ecosystem parameters dynamics, especially thermal conditions and feeding resources. The values of biological reference points calculated with the predicted parameters will have a higher uncertainty. This will lead to a larger gap between the values of limit reference point and corresponding precautionary reference point.

Estimation of economic efficiency of the stock harvest based on ecosystem strategy

The major purpose of stock harvest is a maximum income. Several long-term economic parameters that characterise the efficiency of stock harvest should be considered for estimation of the harvest strategy. These parameters can be obtained only with bioeconomic models. The development of such models is planned for the second stage of the joint PINRO and IMR programme for development of optimal ecosystem strategy for harvest of marine organisms in the Barents Sea.

Conclusion

The improvement of harvest control rules for cod is a prioritised task for fisheries research conducted in the Barents Sea. Ecosystem approach to harvest management as well as precautionary approach should ensure long-term sustainable and plausible harvest of marine biological resources. The developed 10-year programme for joint Russian-Norwegian research in this filed provides a good background for first practical advice on optimising harvest strategy for cod in the Barents Sea based on ecosystem approach already in the next three years.

One of the main tasks is to solve concept and methodology problems linked to implementation of ecosystem approach in the management of harvest in the Barents Sea. The lack of developed theory is an obvious obstacle to practical work. There is no common understanding of main principles for ecosystem approach to the management of marine biological resources. Besides, there is no clearly harmonised usage of terms and the proposed approaches to solve the practical problems are inadequate. Due to this, we need to unify definitions and methodical advice related to the ecosystem approach to the management of bioresources in the Barents Sea. It is also important that developed theoretical principles were discussed and agreed by ICES, which is the most competent international organisation responsible for advice on stocks management in the Barents Sea.

The main analytical tool for justification of ecosystem strategy for harvest should be multispecies and ecosystem based models intended for estimation of biological reference points and testing of different harvest control rules. The work on development of such models should be prioritised to improve management of marine biological resources based on ecosystem approach. There is a need to involve specialists in different fields in this work, for instance, mathematicians, biologists, oceanographers and economists, who work on stock assessment, species interactions, environment and harvest management.

Nowadays, there are different approaches to development of multispecies models in PINRO and IMR. The developed models differ both in concept and in structure. It is obvious that we should join efforts and unified approaches that will lead to a joint multispecies model for the Barents Sea. However, the ambition to create a joint model should not limit the range of possible optimal solutions. Such joint model can be based on more then one of the existing or developing models. To fuse several independent models developed by different groups of specialists could be a perspective approach to the creation of such model. In this case, a joint database should be used for all calculations and output data for one model should act as input date for other model.

A necessary requirement for development and effective use of multispecies models is a corresponding database. The Barents Sea is considered as a well-studied region. Extensive data on abundance, biology and trophic interactions between important for fisheries species as well as their feeding resources, hydrological conditions and fishing statistics were collected. Unfortunately, available historic data can be only partly used for multispecies modelling. A considerable part of biological data collected by PINRO before 1970s exists only on paper and is not available for computerizing. These data in electronic format could considerable expand possibilities for parameterization of multispecies models designed for the Barents Sea. Besides, the use of raw data is also an issue that lacks solution. The most perspective approach for it is to create joint Russian-Norwegian databases.

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EVALUATION OF MAXIMUM LONG-TERM YIELD FOR NORTHEAST ARCTIC COD

by

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1. Introduction

Evaluation of the long-term yield of Northeast Arctic cod (*Gadus morhua*) in a single-species context is the first sub-project in the research program: "Optimal long-term harvest in the Barents Sea ecosystem", suggested by the Joint Norwegian-Russian Fisheries Commission in 2003. An overview of the sub-projects within this research program is given on the web page http://www.assessment.imr.no/Request/index.html .

2. Background

2.1. Evaluation of the proposed harvesting strategy by ICES' Arctic Fisheries Working Group in 2005

In 2005, the ICES Arctic Fisheries Working Group (ICES, 2005) evaluated the harvesting strategy for Northeast Arctic cod proposed by the Joint Norwegian-Russian Fisheries Commission in 2004. The strategy (see Section 6) was found to be in accordance with the precautionary approach. A biologically detailed population model for cod, CodSim (Bogstad et al., 2004a) was used in that evaluation. CodSim was amended later (Kovalev, 2005) and further improved in the present paper.

However, it is important to search for optimal harvesting strategies, and not only be concerned about whether a harvesting strategy is precautionary. The present paper is a first step in that directions for Northeast Arctic cod.

2.2. Previous analyses of MSY for Northeast Arctic cod

Most studies of MSY (e.g. Nakken et al., 1996; Tretyak, 1987; Kovalev and Korzhev, 2002) have used rather simplistic population biology, with no modelling of density-dependent effects and recruitment only being dependent on SSB. However, we found it appropriate to try to include as much biological knowledge as possible in our population model, as advocated e.g. by Ulltang (1996).

The work by Kovalev (2005) is the only study of MSY for NEA cod after the time series of weight at age and maturity at age was revised in 2001.

3. Methodology for evaluation of MSY

3.1. Simulation approach

Stochastic long-term simulations were carried out in order to evaluate long-term yield, for different harvest strategies and population models. The same population age range (3-13+) and reference F age range (5-10, arithmetic mean) as in the current assessment was used.

3.2. Software

The computer program PROST (Åsnes, 2005) was used for making stochastic long-term simulations for the NEA cod stock based on the population model (CodSim) described in this paper.

3.3. Data used for developing the population model

The time series for weight (in catch and in stock), maturity, fishing mortality and natural mortality at age used in this document were taken from the 2005 report of the ICES Arctic Fisheries Working Group (ICES, 2005). The time series covers the period 1946-2004.

3.4. Model units

The following units are used in this paper:
Individual weight: kg
Recruitment: million individuals
Stock biomass: thousand tonnes

4. Population model for Northeast Arctic cod

4.1. Recruitment

4.1.1. Choice of stock-recruitment relationship

Possible choices for the stock-recruitment relationship include the segmented regression approach, Beverton/Holt and Ricker. ICES (2003) modelled the stock/recruitment relationship for NEA cod using the segmented regression approach. We will extend that in essentially the same way as done by Bogstad et al. (2004a), by including a cyclic term as well as a stochastic term.We thus look for a stock-recruitment relationship of the form shown in Eq. (1):

$$R_3(year+3) = f(SSB(year))e^{A*Sin(\frac{2\pi(year-1946+\varphi)}{T})+\varepsilon} \qquad (1)$$

where $f(SSB) = \min(\frac{\alpha}{\beta}SSB, \alpha)$ (2)

The segmented regression function (i.e. only the first term on the right-hand side of equation (1) is included) fit to the data for the year classes 1946-2001 is shown in Fig. 1.

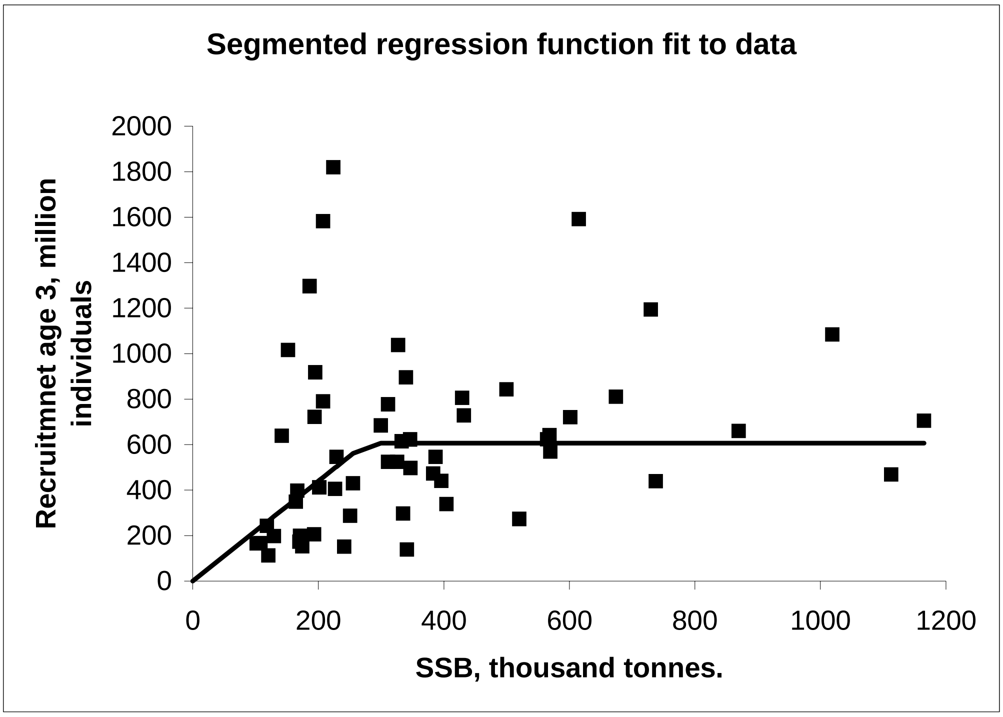

Fig. 1. Segmented regression recruitment function fit to data for spawning stock biomass and recruitment at age 3 (no cannibalism)

4.1.2. Extending the segmented recruitment function by including a cyclic term

Fig. 2 shows the residuals obtained when fitting the segmented regression stock-recruitment relationship. These residuals vary in a cyclic way with time.

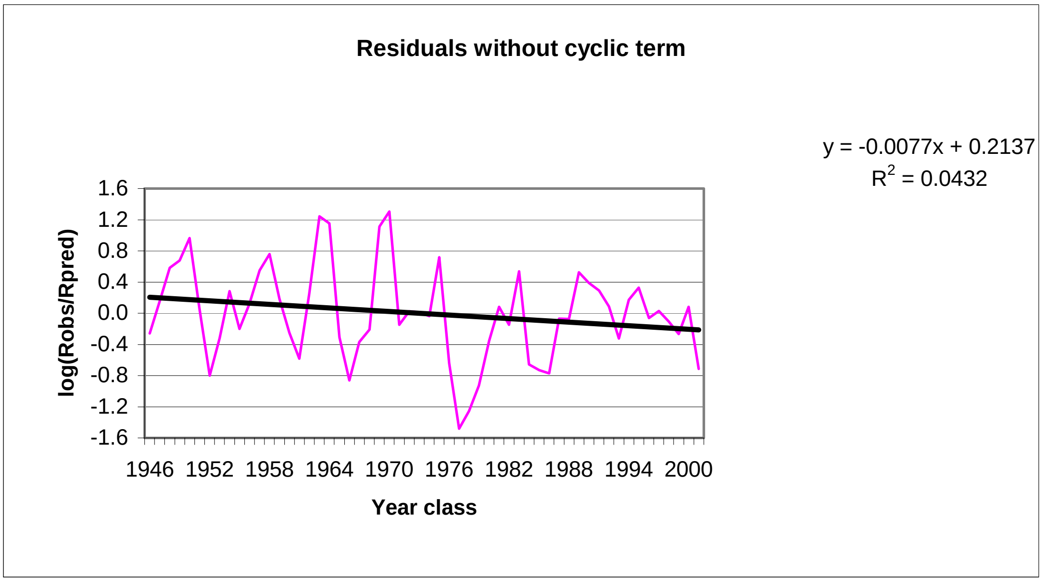

Fig. 2. Time variation of residuals of segmented regression recruitment function

We then tried to include the cyclic term in the exponent in equation (1). The results of the model fit (minimising log SSQ), which was carried out using Solver in Excel, are given in Table 1. The residuals when the cyclic term is included are shown in Fig. 3, and the predicted vs. observed values of recruitment using equation (1) with $\varepsilon = 0$ are shown in Fig. 4.The model does not pick up the outstanding year classes, but still performs fairly well. The time trend is no longer significant ($p>0.05$).

Table 1. Results of fit of recruitment model

Model	a	b	A	φ	T	ε	Log (SSQ)	proportion of variability explained compared to constant recruitment
Constant recruitment							27.55	0.00
Segmented regression	606	276					19.79	0.28
Segmented regression+ cyclic term	606	276	0.40	-1.97	6.56		15.32	0.44
Segmented regression + cyclic term + stochastic term	599	275	0.40	-1.97	6.56	0.528	15.33	0.44

Several authors (e.g. Ottersen and Stenseth, 2001) have found a good correlation between temperature and recruitment, and there are cyclic variations in temperature. However, reliable long-term (or even medium-term) predictions of temperature variation are not available (Ottersen et al., 2000), and thus we do not include temperature in our recruitment model.

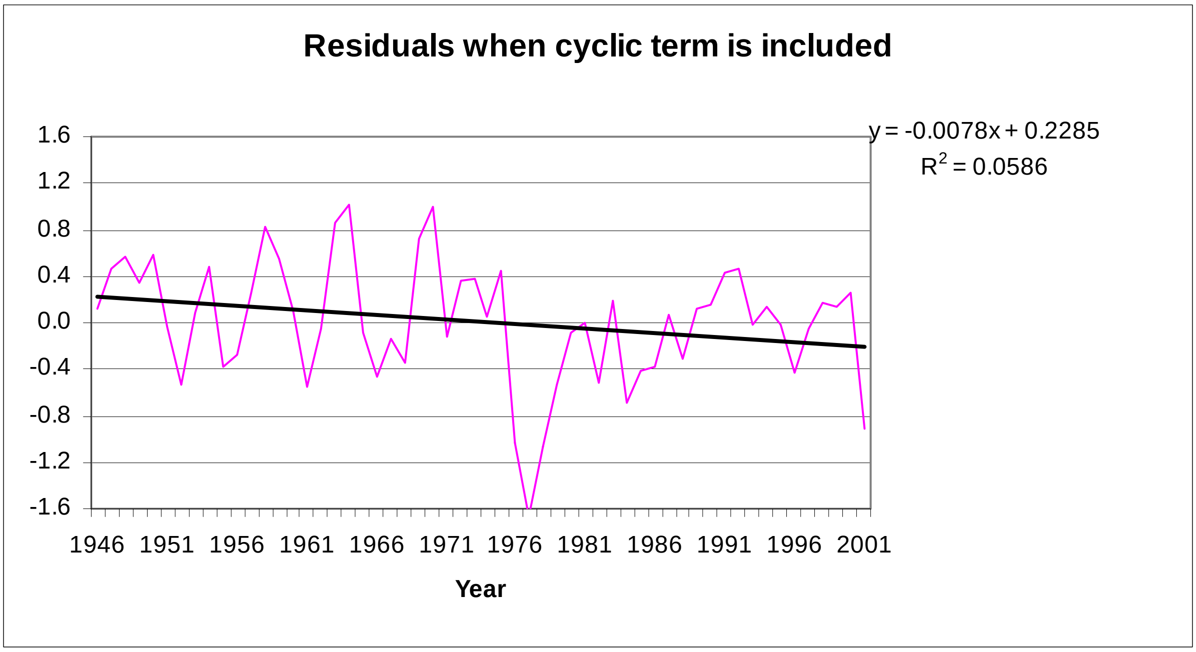

Fig. 3. Residuals when cyclic term is included in the recruitment function

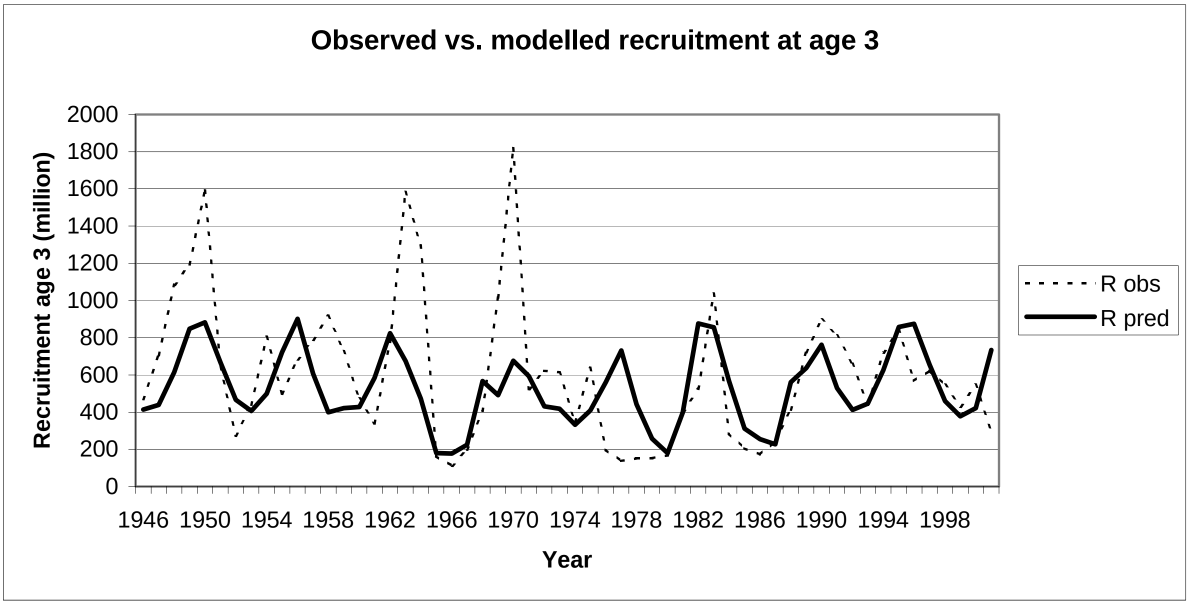

Fig. 4. Observed vs. modelled recruitment when cyclic term is included in the recruitment function

Fig.5 shows the residuals vs. SSB. The residuals are not significantly correlated ($p>0.05$) with SSB

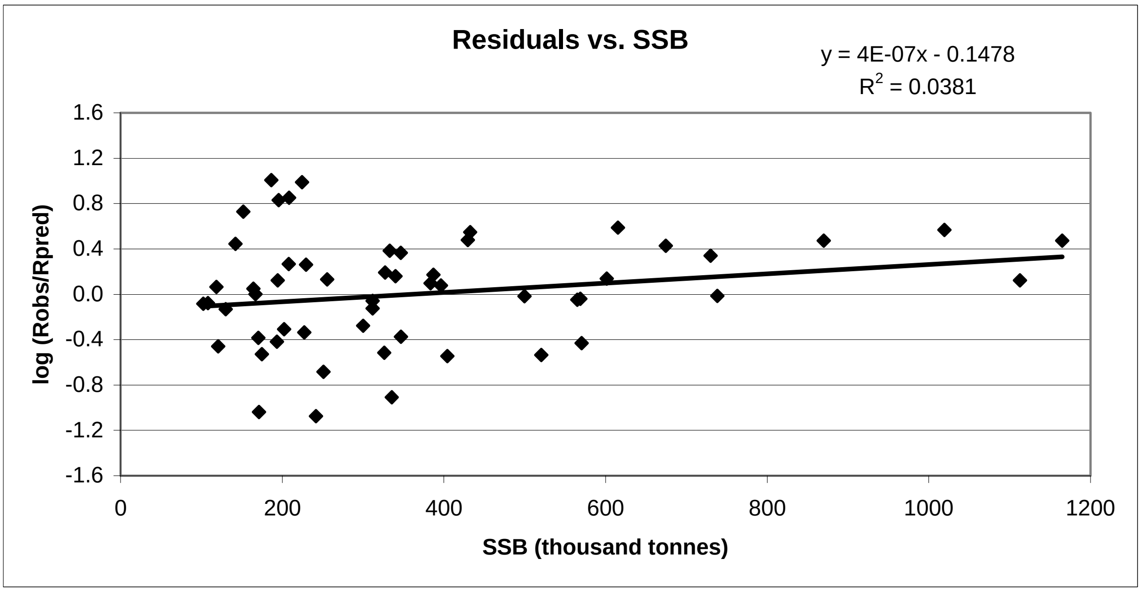

Fig. 5. Dependence of residuals on SSB

4.1.3. Determining the variance in the stock-recruitment function

We then need to determine the stochastic term ε in equation (1). We will follow the approach outlined by Skagen and Aglen (2002). They suggested 3 quality criteria for stochastic stock-recruitment functions:

1. Independence between residuals and SSB
2. Probability coverage
3. The recruitment estimates should be unbiased.

Criterion 1) has been tested for by looking at the deterministic stock-recruitment function (Fig. 5). The residuals are not correlated with SSB, but the variability in recruitment seems to be higher at low SSBs, and this could be modelled by making the variance a function of SSB.

2) is a control that the distribution assumed for the residuals is adequate, while 3) may be used as an additional constraint when finding the parameters of the stock-recruitment function.

Assuming that each of the historic residuals is equally likely, the rank of each of them, divided by the number of observed residuals, gives the empirical cumulated probability of the historical residuals. On the other hand, according to the model that is assumed for the residuals in the prediction, there corresponds a cumulated probability for the value of each observed residual. Each of these model probabilities should be close to the empirical cumulated probability of the same historic residual. The Kolmogorov goodness of fit test is based on this reasoning, and the Kolmogorov test statistic can be derived directly from the pairs of modelled and observed values.

The fit was done using Solver in Excel spreadsheets described by Skagen and Aglen (2002).A constraint on the sum of the difference between modelled and observed recruitments being zero was applied. In the fitting procedure, all the parameters in the stock-recruitment function were re-estimated (Table 1).The parameters a and b in the segmented regression equation (Eq. 1) changed somewhat, but the other parameters were very close to the values estimated using the corresponding deterministic model. Assuming a log-normal distribution, i.e. $\varepsilon = N(0,\sigma)$, σ =0.528 gave the best fit to the data. Fig. 6 and 7 show the probability coverage and observed vs. modelled recruitment for this distribution. The fit seems to be rather satisfactory.

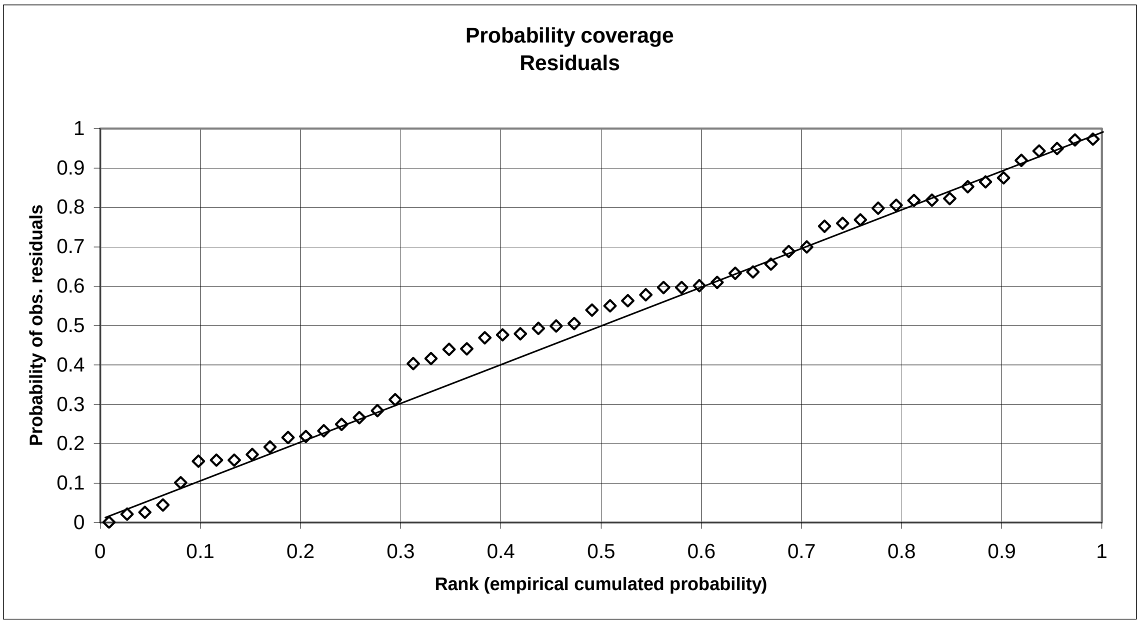

Fig. 6. Probability coverage for stochastic stock-recruitment function

The final test in any case is to take the distribution (or at least the standard percentiles) of recruitments from a long-term prediction and compare with the historic recruitments generated by similar levels of SSB.

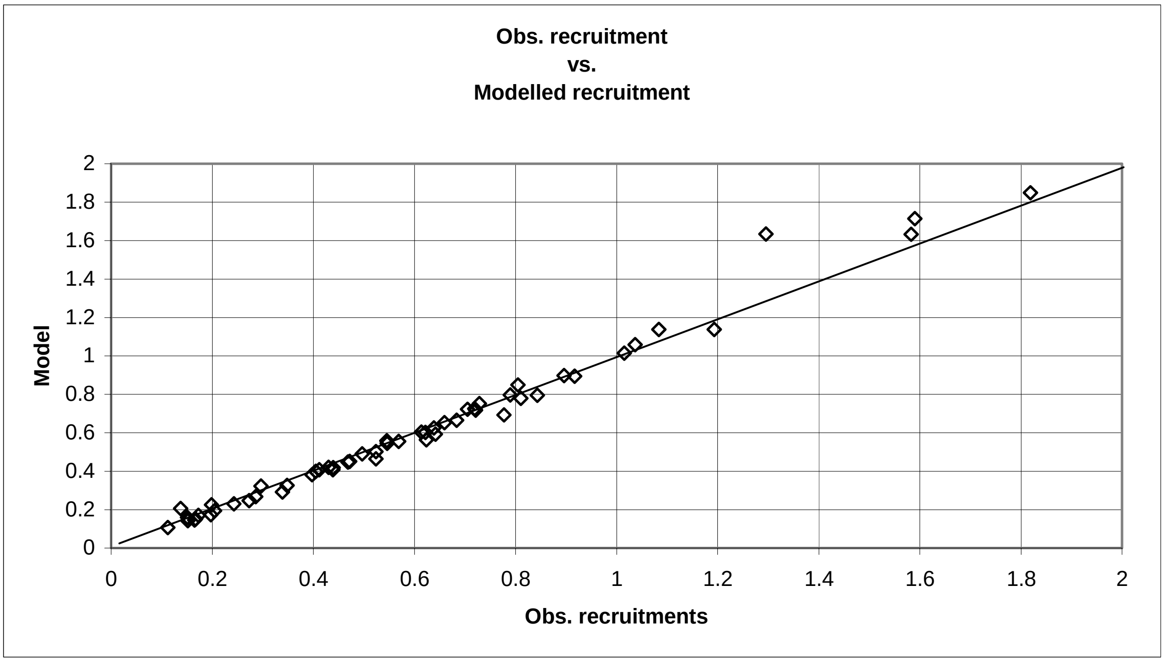

Fig. 7. Observed vs. modelled recruitment for stochastic stock-recruitment function.

4.2. Weight and maturity at age

There are several possibilities for modelling this:

1) Using a time series average
2) To draw randomly weight at age in stock and catch and maturity at age from the entire time series (i.e. draw a year)
3) To fit a model for stock size dependence of growth and maturity to the entire time series and to simulate the uncertainty using a statistical model (e.g. normal distributed residuals with estimated σ) or draw randomly observed residuals around fitted trends. For weight at age, the model could e.g. be linearly dependent of total stock biomass (TSB), while for the maturity at age; it could e.g. be assumed to be a sigmoid function of TSB.

Approach 1 does not take the uncertainty in those parameters in account. Approach 2 will overestimate the uncertainty related to changes in those parameters. We have not observed such a wide range of annual changes in values for weight and maturity at age this approach will give. This approach will also give a bias in the results. When F is low, we will overestimate TSB, SSB and yield, when F is high we will underestimate those quantities. In order to avoid that, we will try approach 3). For all approaches, it could be discussed whether the entire time series should be used.

Heino et al. (2002) found that both increase in growth rate and change in age-and sex-specific tendency to mature have contributed to the observed trend towards earlier maturation. Thus, part of the change may represent a fisheries-induced adaptive genetic change. We will not take this into account in our analysis.

4.2.1. Weight at age in the stock

We have used the entire time series (stock weights in 1947-2005 vs. total stock biomass in 1946-2004) to fit a density-dependent model for weight at age (kg) in the stock $ws_{a,y}$ for ages 3-9. The model is of the form

$$ws_{a,y} = \alpha_a TSB_{y-1} + \beta_a \qquad (3)$$

where TSB_y is the total stock biomass in year y,a is age and$\alpha_a$and β_a are constants. The parameters in the regressions are given in Table 2.

It may also be necessary to truncate the range of possible values of cod weight, in order to avoid unrealistic values due to extrapolations.We chose to use the highest/lowest observed values of cod weight at each age as upper/lower bounds in the model.

Table 2. Parameters in regression for density-dependent weight at age in the stock and minimum, maximum and average values

age	α_a	β_a	R^2	p	min observed weight	max observed weight	mean weight
3	0.000011	0.318	0.02	> 0.05	0.19	0.52	0.341
4	-0.000029	0.753	0.02	> 0.05	0.40	1.17	0.692
5	-0.000058	1.373	0.05	> 0.05	0.79	1.82	1.253
6	-0.000118	2.285	0.12	< 0.01	1.48	2.82	2.041
7	-0.000213	3.521	0.21	< 0.01	2.14	4.06	3.079
8	-0.000371	5.190	0.28	< 0.01	2.92	5.83	4.418
9	-0.000703	7.472	0.43	< 0.01	3.65	8.93	6.017
10	-0.001113	10.290	0.42	< 0.01	4.56	12.15	7.990
11	-0.001441	12.404	0.47	< 0.01	5.84	15.03	9.431
12	-0.000888	12.065	0.45	< 0.01	7.08	12.09	10.217
13	-0.001429	15.528	0.59	< 0.01	8.15	14.85	12.563

We see that the relationship for ages 3-5 is insignificant. For those ages TSB will not be used as predictor. The biology and food composition of those age groups is different from that of older ages. We use average values for these age groups, as well as for age 10+, where the data set is less reliable.
For simplicity, we do not include uncertainty from the regression in our simulations.

4.2.2. Weight at age in the catch

Weight at age in catch is modelled as a function of weight at age in stock, using equation (4):

$$wc_{a,y} = \alpha_a ws_{a,y} + \beta_a \qquad (4)$$

The values of α_a and β_a for ages 3-8 are given in Table 3. The regressions are based on data from 1983-2004, when observations of stock weights at age from surveys are available.

Weight at age in the catch is calculated directly from weight at age in the stock using equation (4). Uncertainties associated with the regression will not be taken into account. For ages 9 and older weight at age in the catch is set equal to weight at age in the stock.

Table 3. Parameters in regression for weight at age in the catch vs. weight at age in the stock

age	α_a	β_a	R^2	p
3	1.671	0.295	0.59	< 0.01
4	0.927	0.565	0.81	< 0.01
5	0.975	0.495	0.89	< 0.01
6	0.891	0.605	0.89	< 0.01
7	0.794	0.972	0.64	< 0.01
8	0.653	1.933	0.56	< 0.01

4.2.3. Maturity at age

Maturity at age is modeled as a function of weight at age in the stock in the same year:

$$P_{a,y} = P(ws_{a,y}) = \frac{1}{1+e^{-\lambda_a (ws_{a,y} - w_{50,a})}} \qquad (5)$$

Fitting this model for ages 5-10 gave the following results:

Table 4. Parameters in regression for maturity at age vs. weight at age in the stock

age	λ_a	$W_{50,a}$	R^2	Historical mean value
5	2.7551	2.5571	0.338	0.032
6	1.6567	3.2453	0.242	0.121
7	1.7360	3.6743	0.324	0.272
8	1.3006	4.5418	0.380	0.451
9	1.1647	5.4599	0.588	0.626
10	0.6278	5.4517	0.496	0.790

For ages 3-4 we use P=0 and for ages 11+ P=1.
The fit (admittedly not very good) is shown in Fig. 8

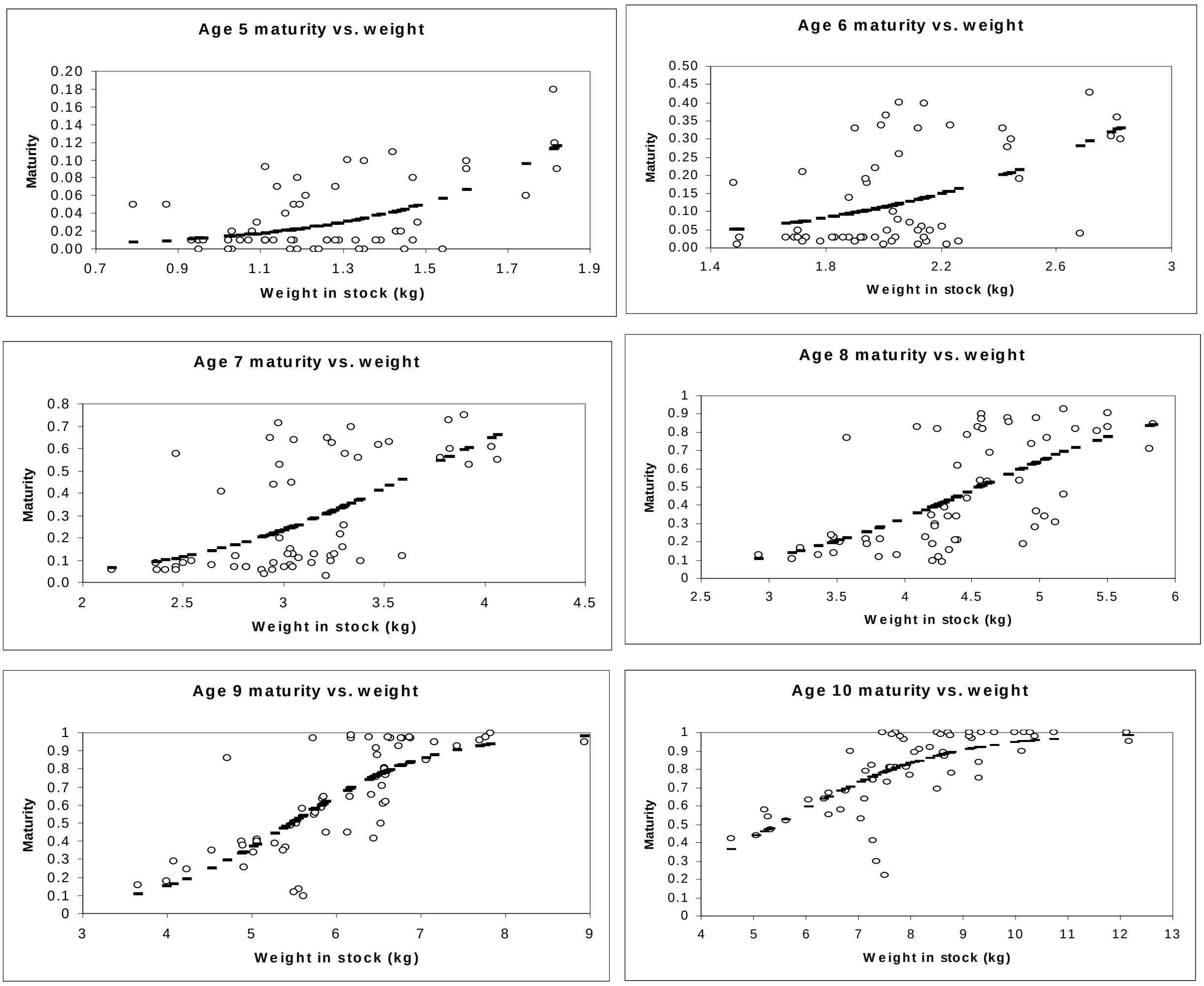

Fig. 8. Maturity at age 5-10 as a function of weight at age in the stock in the same year (open circles). The model described in eq. (5) is also shown (black line)

4.3. Mortality

The (residual) natural mortality (M) was set to 0.2 for all age groups. In addition, cannibalism mortality (M2) was included in some simulations (see below).

4.3.1. Cannibalism mortality

As mentioned in Section 4.1.1, cannibalism will not be included in our main analysis because the data used to fit our stock-recruitment function does not include cannibalism. However, it is important to have models for cannibalism mortality available so that the effect of cannibalism on the population dynamics can be explored. Natural mortality due to cannibalism (M2) has been calculated for the period 1984-present, when annual cod stomach content data are available. This mortality can be significant for age 3 and 4 cod (ICES, 2005), and should thus be modelled. Using data for the period 1984-2002, Kovalev (2004) found that cannibalism mortality for age 3 and 4 in year *y* showed good correlation both with SSB_{y-3} and with the biomass of age 6 and 7 cod in the beginning of year *y*. The two models can be described by the following formulas:

$$M2_{y,a} = \alpha_a SSB_{y-3} + \beta_a \quad (6)$$

or

$$M2_{y,a} = \alpha_a (N_{y,6}W_{y,6} + N_{y,7}W_{y,7}) + \beta_a \quad (7)$$

where the parameter values based on data for the period 1984-2004 are given in Table 5 for equation (6) and in Table 6 for equation (7).

Table 5. Parameters in regression for cannibalism mortality as a function of spawning stock biomass 3 years earlier

Age	α_a	β_a	R^2	p
3	0.000636	-0.123	0.74	<0.01
4	0.000271	-0.064	0.74	<0.01

Table 6. Parameters in regression for cannibalism mortality as a function of the biomass of age 6 and 7 cod in the beginning of the year

Age	α_a	β_a	R^2	p
3	0.000391	- 0.068	0.28	<0.05
4	0.000195	- 0.055	0.38	<0.01

The positive relationship between biomass of age 6 and 7 cod and cannibalism mortality on age 3 and 4 cod can be explained as increasing cannibalism when predator abundance increases. Adding biomass of older ages gave a worse fit. It should be noted, however, that cod predators are usually at least twice as long as cod prey (Bogstad et al. 1994). Since cod growth in length is approximately linear until age 7 (Ozhigin et al. 1995, 1996; Jørgensen 1992), biomass of age 6 and 7 cod does not seem to be the most appropriate measure, particularly as the proportion of cod in the diet of cod increases with increasing cod (predator) length (Bogstad et al., 1994).

The cause and effect between high cannibalism M in one year and high SSB three years before, which gives the strongest correlation, is less clear. A possible interpretation is that cannibalism is higher when SSB and thus recruitment is good. It is also seen from the data that high level of cannibalism coincides not only with high SSB 3 years before but also to some extent with low abundance of capelin (Figure 9).

Thus, in order to properly study the effect of cod cannibalism, a cod-capelin model is needed. In such a model, the following multispecies effects should be included: Effect of capelin abundance on individual growth of cod (Mehl and Sunnanå, 1991), effect of capelin abundance on cod cannibalism, and predation by cod on capelin (Bogstad and Gjøsæter 2001). Such an extension of CodSim is planned within the research program: “Optimal long-term harvest in the Barents Sea ecosystem”.

At a later stage, CodSim should also be extended down to age 1 and cannibalism on age 1 and 2 cod could then be modelled explicitly instead of including it in the stock-recruitment relationship. Such work is in progress (Bogstad et al., 2004b).

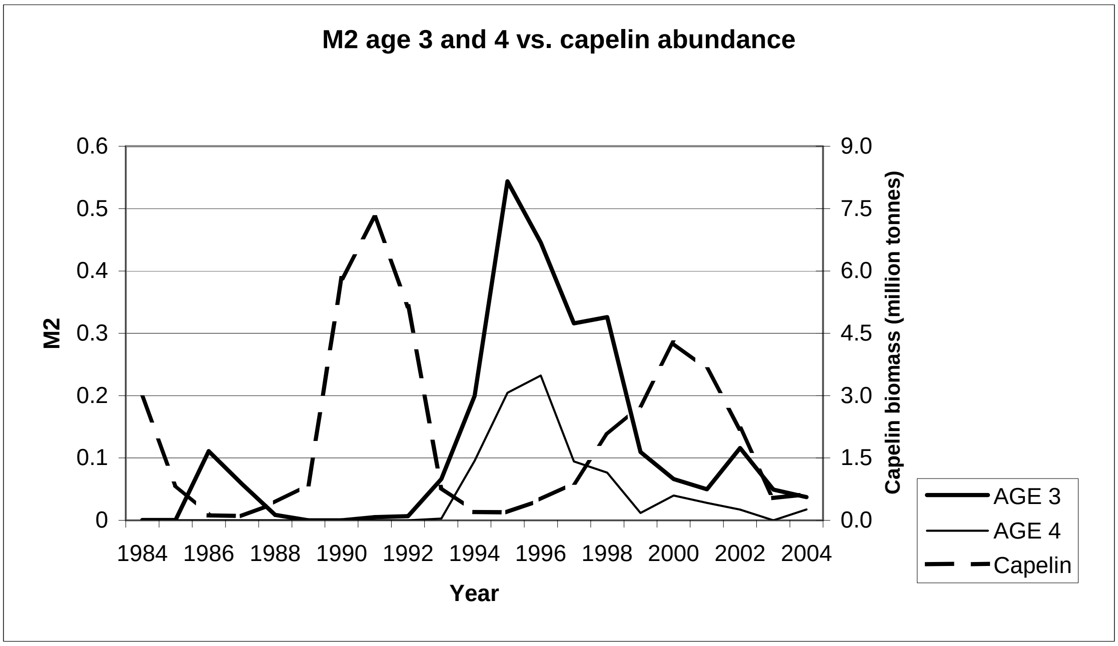

Fig. 9. Cannibalism mortality of age 3 and 4 cod versus capelin abundance (acoustic survey in September) in the same year

It would also be useful to utilise the long time series of qualitative Russian stomach content data for cod (Ponomarenko et al., 1978; Ponomarenko and Yaragina, 1979) in order to investigate how abundance of capelin in cod stomachs affects the level of cod cannibalism.

We decided to make model runs with both cannibalism models, and to apply an upper limit for the level of cannibalism in order to avoid unrealistic values. As an upper limit we chose the highest observed values (rounded): age 3 – 0.6, age 4 – 0.25. The lower limit of M2 was of course set to 0.0.

4.4. Exploitation pattern

The selection pattern used by AFWG 2005 in their prognosis (i.e. the 2002-2004 average) was chosen as the default exploitation pattern S(a) (Table 7). In order to study the effect of changing the exploitation pattern, this pattern was then shifted by 1 age group upwards and downwards.

Table 7. Default exploitation pattern

Age	3	4	5	6	7	8	9	10	11	12	13+
Selection	0.0179	0.1543	0.4643	0.8316	1.1905	1.2805	1.1840	1.0490	0.9404	1.5830	1.5830

Ulltang (1987) and Kvamme and Bogstad (2005) both studied the effect of changing the exploitation pattern on the yield per recruit for NEA cod. Both studies showed that shifting the exploitation pattern towards older fish would increase the yield per recruit.

Since we allow for variable weight-at-age in our model, it would be appropriate to make a weight-dependent selection curve. This could be done e.g. by modifying the commonly used length-dependent selection curve

$$S(a) = \left(1 + \exp\left(-4\alpha\left(l - l_{50}\right)\right)\right)^{-1} \tag{8}$$

by assuming a constant length-weight relationship and substituting weight for length in equation (8). Such a modification should be introduced in future studies.

5. Modelling of assessment error

Assessment error/bias was not included in these simulations.

6. Choice of harvest control rules to be explored

The harvest control rule suggested by the Joint Norwegian-Russian Fisheries Commission in 2004 is:

- estimate the average TAC level for the coming 3 years based on F_{pa}. TAC for the next year will be set to this level as a starting value for the 3-year period.
- the year after, the TAC calculation for the next 3 years is repeated based on the updated information about the stock development, however the TAC should not be changed by more than +/- 10% compared with the previous year's TAC.
- if the spawning stock falls below B_{pa}, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at B_{pa}, to F= 0 at SSB equal to zero.At SSB-levels below B_{pa} in any of the operational years (current year, the year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC.

F_{pa} =0.40 and B_{pa} =460 thousand tonnes.
This rule was evaluated by the AFWG in 2005, and found to be precautionary. (ICES, 2005). In this paper, we will explore a rule of this kind, but will concentrate on studying fixed F strategies (same F applied irrespective of stock size, no stabilizing elements).

The rule for determining the reference F level ($F_{5\text{-}10}$) is then:

$$\begin{cases} F(y) = \dfrac{SSB(y)}{B_{pa}} F_1 & \text{if SSB(y)} < \text{B}_{pa} \\ F(y) = F_1 & \text{if SSB(y)} > \text{B}_{pa} \end{cases} \tag{9}$$

and the fishing mortality at age is given by

$$F(y,a) = S(a)F_1 \tag{10}$$

7. Choice of model runs

7.1. Default settings (Run 1)

Initial data were taken from the 2005 AFWG assessment (ICES, 2005) and the population model described in Section 4 was used from 2006 onwards. Simulations were carried out for a 100-year period (2006-2105). The mean yield over the last 80 years of the period was used for evaluation of MSY. 2000 simulations were carried out in each case, and a 100% limit on annual TAC change was applied.

For all runs, the reference F was varied from 0 to 1.2 in steps of 0.05.
Density-dependent weight at age was assumed, and weight at age in catch and maturity at age was assumed to depend on weight at age in the stock. No cannibalism was assumed. The default exploitation pattern (2002-2004 average) was used.

7.2. Exploring rules of the type evaluated by ICES in 2005

In Run 2, we explored strategies with a reduction of F below B_{pa} (i.e. of the type outlined in Section 6).

7.3. Changing population dynamics model and exploitation pattern

Runs were made both with (Run 1) and without (Run 3) density-dependence in weight at age (and thus in weight at age in catch and maturity at age). Also, 3 different exploitation patterns (the default pattern and this pattern shifted 1 age group upwards and downwards) were explored (Run 1, 4 and 5). Runs were also made with both cannibalism functions (Run 6 and 7). For technical reasons, such runs could at present only be made without uncertainty in recruitment. Cyclic recruitment is included, however.

Table 8. Overview of runs

Run no.	Harvest strategy	Fishing pattern	Density-dependence	Cannibalism
1	Fixed F	AFWG2005	Yes	No
2	JRNC rule	AFWG2005	Yes	No
3	Fixed F	AFWG2005	No	No
4	Fixed F	AFWG 2005 shifted 1 age upwards	Yes	No
5	Fixed F	AFWG 2005 shifted 1 age downwards	Yes	No
6	Fixed F	AFWG 2005	Yes	Function 1
7	Fixed F	AFWG 2005	Yes	Function 2

8. Results and discussion

The results of Run 2, using the JRNC rule for various F levels above B_{pa} (F1 in eq. 9) are shown in Figure 10.It is seen that for F1 values above 0.5, the realized mean F will be much lower than F1 because SSB will be below B_{pa} in many cases.

Figures 12-13 only show the SSB/TSB for F values from 0.2 upwards. The reason for this choice is that for lower Fs, SSB and TSB are well outside the observed range (e.g. about 10 million tonnes SSB and 15 million tonnes TSB at F=0), and showing SSB/TSB for the F range 0.0-0.2 would make the plots less informative for moderate and high F values because all the curves will then be close to the Y-axis for such values.

Figure 11 shows that the MSY is around 900 000 tonnes in all cases. The yield curve is relatively flat on top in all cases. All curves except the curve where the exploitation pattern is shifted one age group upward show a sharp decrease at high F values, when recruitment starts decreasing (Figure 14). The reason why this is not seen when the exploitation pattern is shifted towards older fish, is that such a pattern gives a much lower exploitation of the youngest fish so that some fish will always mature before being caught.

Figure 11 also shows that the yield starts to decrease sharply for F values above about 0.7, when density-dependence is not included. This is in good accordance with ICES (2003) who found a F_{lim} value of 0.74 in an analysis where density-dependence was ignored.

Figure 15 shows the yield as a function of F for cannibalism functions 1 and 2. Cannibalism function 1 shows a peak in yield at about F=0.7, while cannibalism function 2 gives a yield curve with about the same shape as the curves without cannibalism. Both curves show a much lower maximum yield (about 600 thousand tonnes) than the curves without cannibalism (about 900 thousand tonnes). It should be noted that stochastic recruitment would shift the peak somewhat towards lower Fs, because SSBs below the breakpoint in the segmented regression would occur more often than in simulations without stochasticity.
F values around 0.3-0.4 seem to be optimal. This is in accordance with earlier work (e.g. Nakken et al., 1996; Kovalev and Korzhev, 2002).

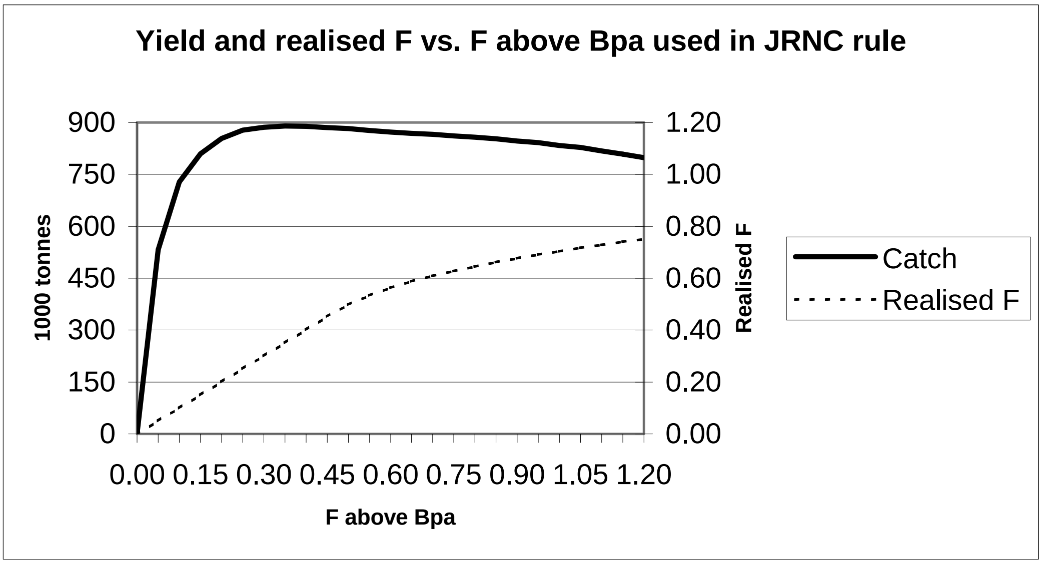

Fig. 10. Average catch and realized F for the period 2026-2105 using the JRNC rule

It should also be noted that the MSY measured in economic value will be found at lower F values than the MSY measured in biomass, because catch costs are higher at low stock sizes and because larger cod is better paid than smaller cod.

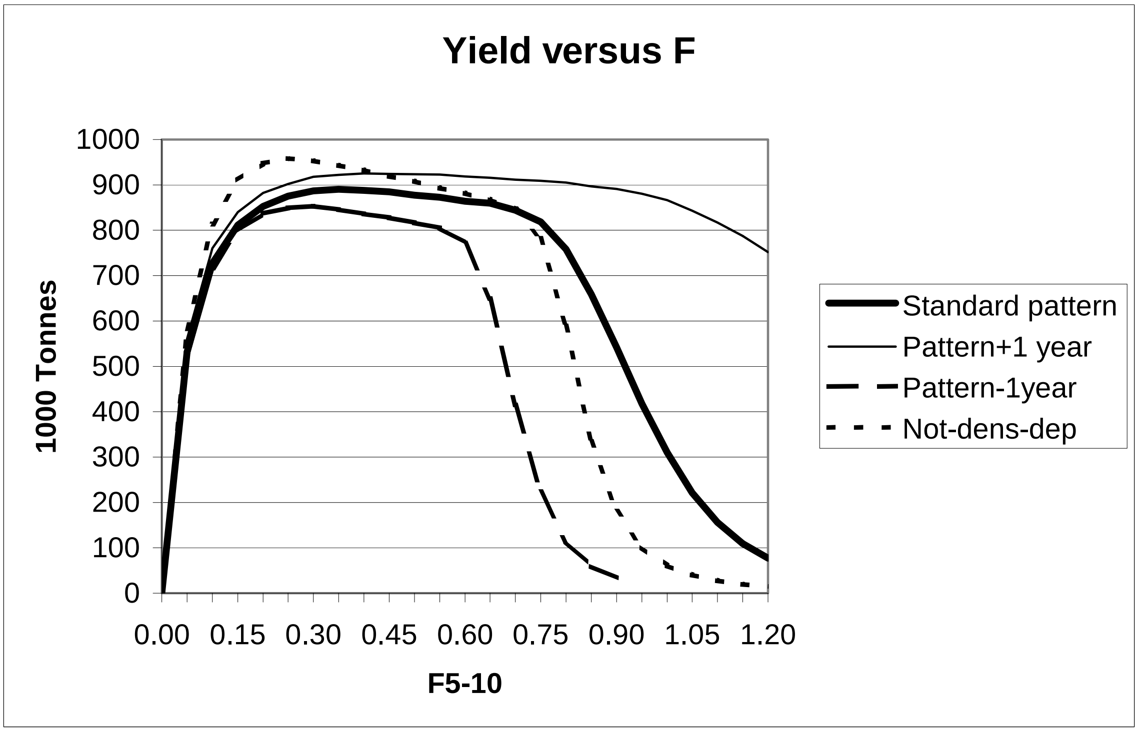

Fig. 11. Average catch for 2026-2105 as a function of fishing mortality for different exploitation patterns and population models

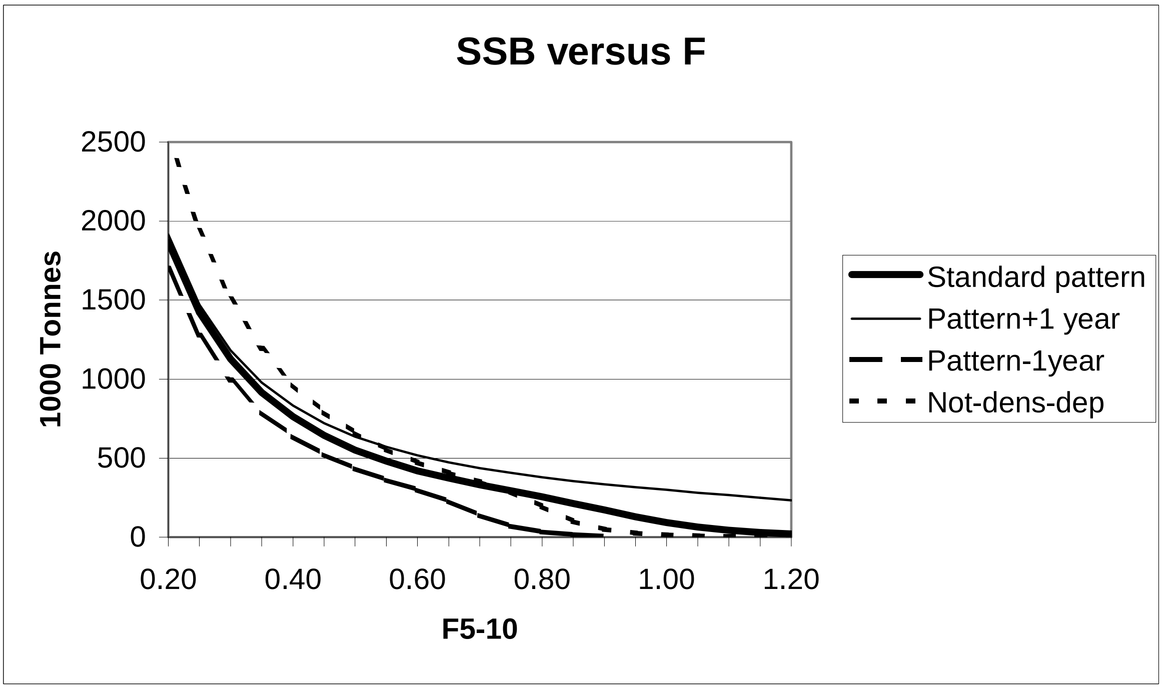

Fig. 12. Average spawning stock biomass for 2026-2105 as a function of fishing mortality for different exploitation patterns and population models

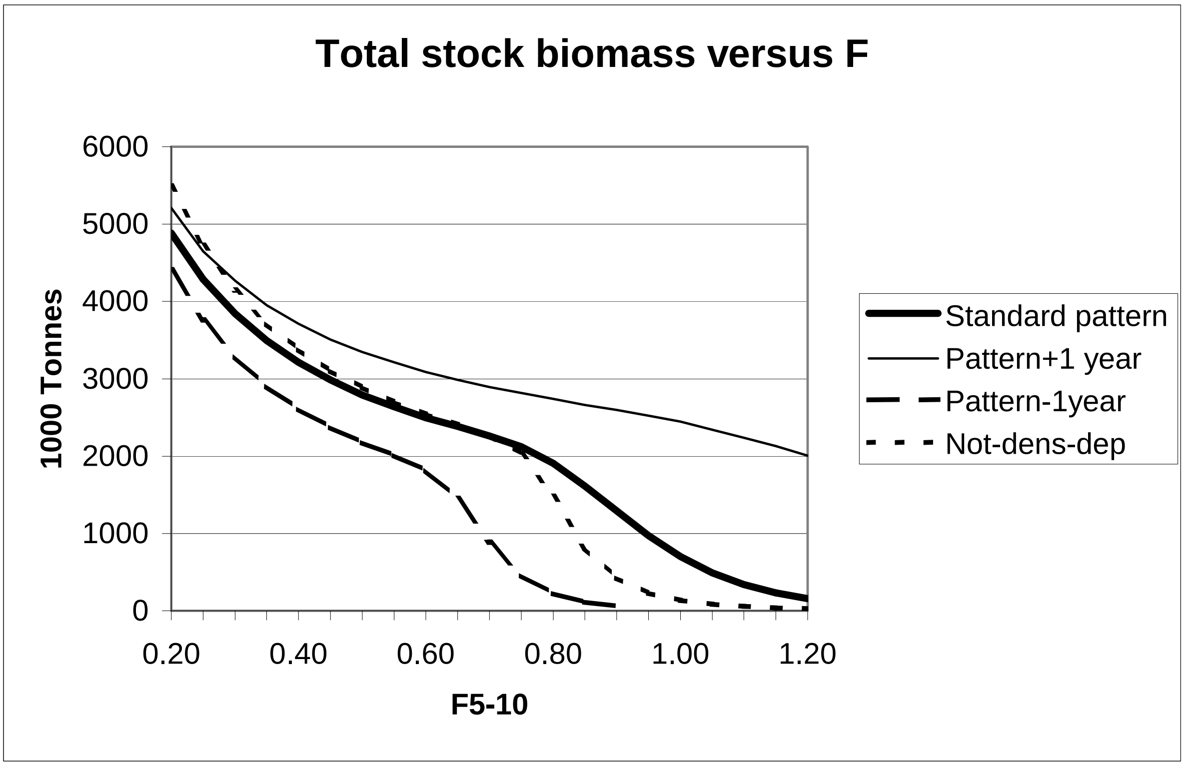

Fig.13. Average total stock biomass for 2026-2105 as a function of fishing mortality for different exploitation patterns and population models

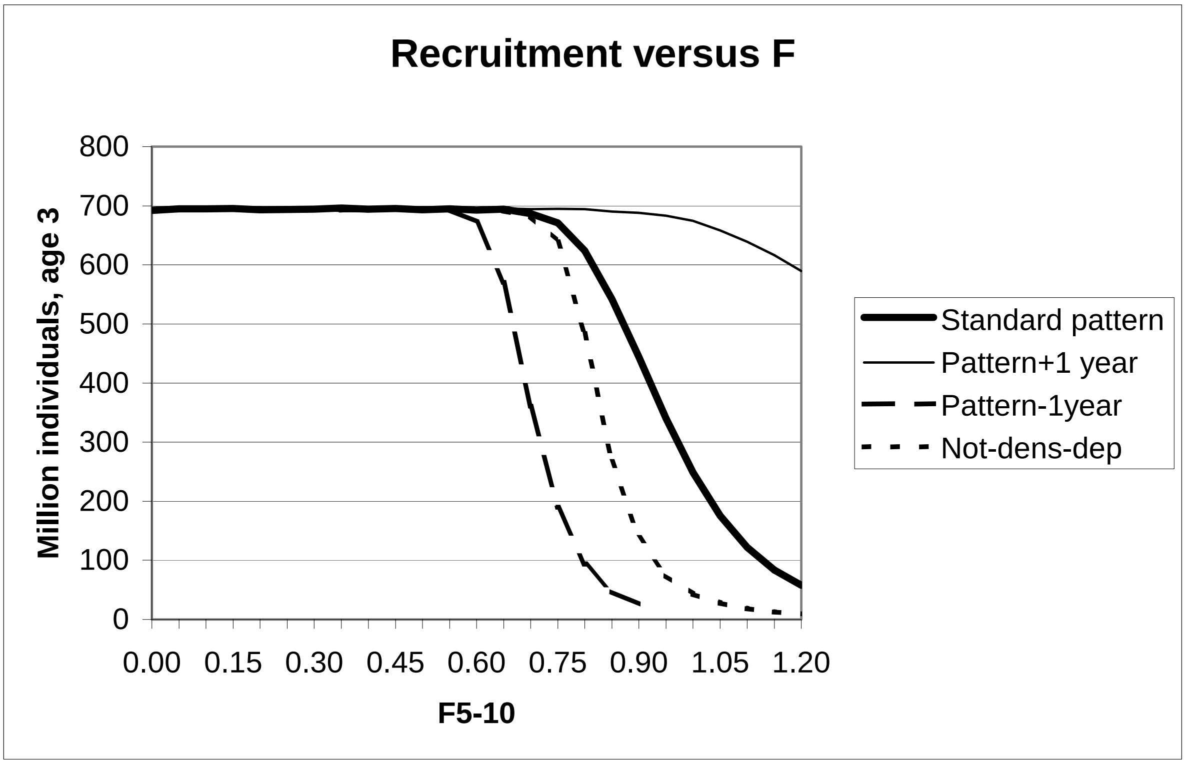

Fig. 14.Average recruitment for 2026-2105 as a function of fishing mortality for different exploitation patterns and population models

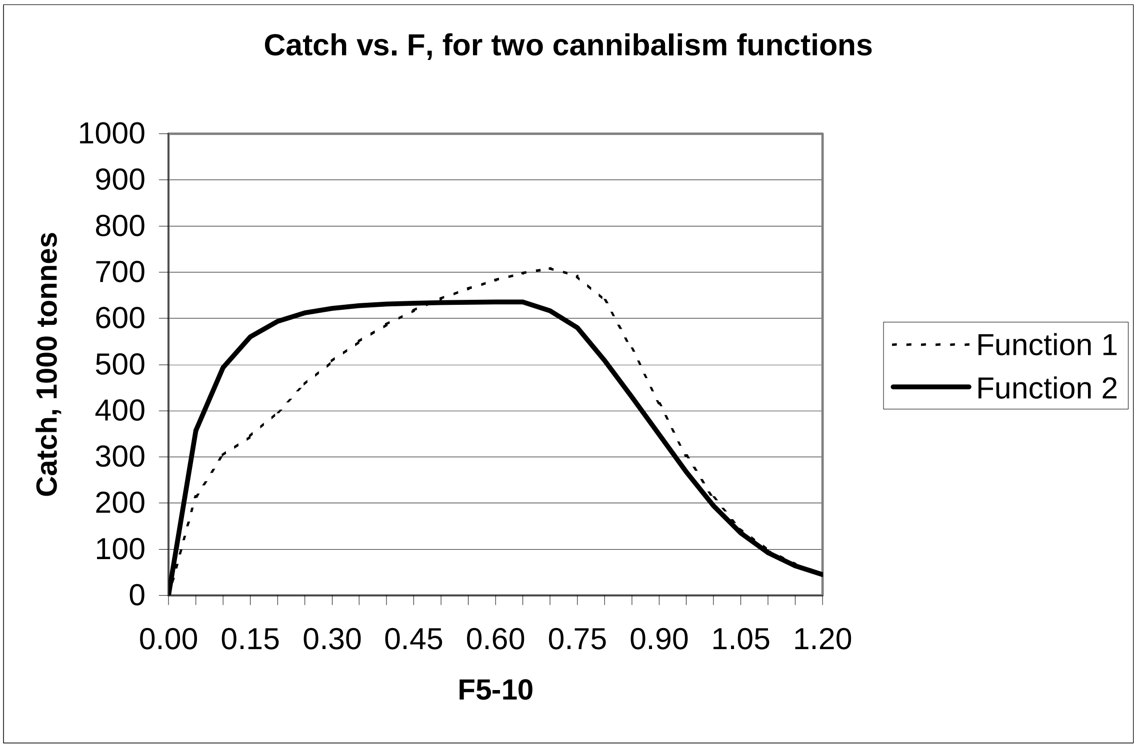

Fig. 15. Average catch for 2026-2105 as a function of fishing mortality for different cannibalism functions

Kvamme and Bogstad (2005) showed that the loss of yield when F is increased above F_{max} is slightly higher when an age-length structured model is used, and that the effect of fishery on mean weight-at-age and maturity-at-age is significant.

9. Further work

The single-species population model for cod presented in this paper may be extended e.g. by extending the age range down to age 1(0) or by adding length structure (see Bogstad et al. (2004b) for a description of a cod model extended down to age 1(0) and including age and length structure). Also, more biological knowledge may be used, e.g. by using the total egg production (TEP) instead of SSB to describe the recruitment potential of the cod stock. The main reason for doing so is that the correlation between TEP, and recruitment at age 3 for Northeast Arctic cod is stronger than the correlation between spawning stock biomass and recruitment (Marshall et al. 2003). Maturity at age (size) as well and mortality at age after maturation differ significantly by sex (Jakobsen and Ajiad 1999, Ajiad et al. 1999) and this should also be taken into account.

We have also recognized that changes in the natural mortality of cod in the plus group could substantially shift F_{msy} to the left/right as the proportion of older fish in stock when F is low will increase considerably. Is it realistic that the population will consist mainly of plus group (cod older than 12 years)? We do not think so, but probably we have not enough data to predict this situation correctly. Such uncertainty of cod population behavior should, however, be taken into account when a long-term maximum yield strategy is implemented in practice.

Model changes (e.g. using a Beverton-Holt instead of a segmented regression stock-recruitment relationship) may alter the perception of maximum long-term yield as well as of how the yield and the fishing mortality are related.

Time series of catch at age should be updated by including discards (see e.g. ICES 2005, Tab. 3.31).

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THE USE OF TAC AS MANAGEMENT MEASURE IN THE BARENTS SEA

by

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The Barents Sea has the same ecosystem the whole sea area, while zoning of the Barents Sea due to existing international and political conditions is quite complicated, which results in certain difficulties for fisheries management even at single species level not to mention ecosystem based fisheries management.

In this area, we have 200-mile exclusive economic zones of Russia and Norway, Svalbard area established according to the Treaty of 1920, Svalbard fisheries protection zone, the Loophole area and finally the Gray Zone, which is an issue that has been negotiated for many years to delimitate the continental shelf and 200-mile exclusive economic zones between Russia and Norway (fig. 1). Not a single area of active international fisheries in the World Ocean has such a legally complicated zoning as in the Barents Sea. Despite a successful harmonisation of fisheries management measures for such main commercial species as cod, haddock, capelin, redfish, halibut, herring and others based on close co-operation in the Joint Russian-Norwegian Fisheries Commission, there are some important problems to be solved that have a negative impact on fisheries management.

For instance, the problem of minimum mesh size in the trawl codend that is 125 mm for exclusive economic zone of Russia (REZ) and 135 for exclusive economic zone of Norway (NEZ) is not solved yet. The issue of minimum commercial size of cod that is 42 cm for REZ and 47 for cm for NEZ is still to be solved. There are several closed for fisheries areas in the Barents Sea where cod and haddock juveniles distribute. These large areas are closed for fisheries mostly in the exclusive economic zone of Russia (fig. 2). Besides, some areas in NEZ and Svalbard area are also closed for fisheries in some periods due to by-catch of fish juveniles. We have also to mention the implementation of sorting grids in the trawls to protect undersized fish. Total allowable catch (TAC) was introduced in 1978 as a main fisheries management measure for such species as cod, haddock, capelin, redfish, Greenland halibut, herring and others. As we can see from this overview, there are many different fisheries management measures implemented in the Barents Sea and that do not make fishermen feel especially happy about them. Despite different legal regimes and many restrictive management measures in the Barents Sea, the fisheries in this area are successfully executed comparing with other areas in the World Ocean, for instance in the Northern and Bering Seas.

The total catch of all marine species in the Barents Sea in the last 30-40 years varied from minimum 716 000 tonnes in 1990 and maximum 4 500 000 tonnes in 1977. The average annual catch was 1 700 000 tonnes. For such important for fisheries species as cod the data for last 45 years shows minimum catch of 212 000 tonnes in 1990 and maximum catch of 1 200 000 tonnes in 1969, while average annual catch was 601 000 tonnes.

It is quite interesting to look at the catch data before 1978 when TAC and other management measures were implemented and after 1978 until 2004. The average annual catch of cod in 1960-1977 was 786 000 tonnes and in 1978-2004 it was 485 000 tonnes. It means that catch in the period when regulatory measures were introduced is almost twice as low comparing with that in the previous period. So the question arises, what is better for fishermen, the catch of 786 000 tonnes or 485 000 tonnes? The answer is obvious. On the other hand if scientific advice on TAC is correct and lower catches can ensure sustainable and long-term fisheries in the future, this message should be explicitly conveyed to fishermen and managers from both countries. Nowadays precautionary approach to fisheries in the Barents Sea lacks common understanding among representatives of fishing industry.

It is obvious that TAC that is set on annual bases remains the main management measure among other implemented measures in the Barents Sea.

The following questions arise. How is TAC observed in general and at the national level? Is it possible to control TAC in the whole area of the Barents Sea? In relation to this, I would like to refer to quotas allocation and control system in Russia. For instance, in Russia national quota of cod in the Barents Sea according to the Article 30 of the Federal law “On fisheries and conservation of aquatic biological resources”, the 20th December 2004, Nr. 166 is allocated for 9 main purposes that is commercial fisheries, coastal fisheries, scientific researches and control, farming and acclimatisation, education etc (Table 1).

There are only these nine purposes for allocation of national quota for Russian users of natural resources. In numbers, it looks as follows: 85 % for commercial fisheries; 7-8% for coastal fisheries; 5-7 % for the other activities. Does this dividing of national quota into 9 sections make it easier to control fishing activities? To my mind if the system of control and monitoring is secure and it is correctly executed the violations should me minimal. If the system fails, it can lead to violations and serious problems.

It is important to take into considerations the fact that in Russia the fishing quotas are allocated not to the vessels but to the users of natural resources who own vessels. This is different from Norwegian system, where quotas are allocated to the vessels and not the owners. Another difference between Norway and Russia is that our fisheries are asymmetric. In Russia, 85-90 % of national quota is taken in trawl fisheries and 10-15 % is caught with passive fishing gears. In Norway, it is vice versa, 70 % of quota goes to passive fishing gears and 30 % is taken in trawl fisheries. In third countries, trawl fisheries prevail. I think that these aspects should also be taken into account when considering fishing parameters, stock assessment and development of ecosystem approach to fisheries management. Finally, we should mention another issue. There is doubt that TAC is observed at the international level. We have heard in this forum and read in newspapers some speculative information about annual overfishing of cod TAC by 40 000-107 000 tonnes according to different estimates. This amount includes illegal catches and some researchers include in it discards of undersized fish.

If we refer to official reports from relevant national services in Russia and Norway for the period 1978 – 2000, they read that overfishing of cod TAC was registered several times (Table 2). In some periods this amount was twice as much as national quotas, for instance it occurred in 1981, 1982, 1984 and 1985 (Table 2). In total during last 22 years, Russia in average fished 37000 tonnes less than it was allowed and Norway fished 45 000 tonnes over its quota. It is necessary to emphasize that these data are taken from official reports of national services that did not include illegal catches, discards and cod fishing for sport and recreation purposes in the coastal area. According to different estimates, annual fishing for sport and recreation purposes in the coastal area can make up to 10 000 – 20 000 tonnes annually. The analysis of official reports from national services in Russia and Norway for last 4 years (2001-2004) proves that both countries execute fisheries according to the agreed TAC. However, in this period Russian and Norwegian mass media and some scientific publications gave us different estimates of illegal catches and overfishing of TAC. Despite the scale of estimates of illegal fishing, it is obvious that if it is the case we have to strengthen the control over fisheries and especially with focus on TAC as a main management measure. Taking into account the international nature of fisheries in the Barents Sea and the fact that Russia and Norway are mainly responsible for fair fisheries management and conservation of marine species and the whole ecosystem, our countries have to develop new approaches to control fisheries and optimal management that are based on well-built confidence and experience.

To my mind in order to make this step forward and ensure that fisheries are executed according to the agreed TAC we have to take the following measures:

- establish a joint Russian-Norwegian fisheries monitoring and control centre for the whole Barents Sea and give this centre necessary authorities to carry out joint Russian-Norwegian control over fishing activities at sea and in ports as well as the rights to close and open areas and stop fishing when TAC level is reached;

- harmonise legislation of both countries in the field of fisheries management, control and enforcement in the Barents Sea.

Only harmonised joint Russian-Norwegian mechanisms for control of TAC, fishing activities and fisheries management in general can ensure sustainable long-term harvest of marine species in the Barents Sea. This task is especially urgent in relation to the intensive development of oil and gas production on the continental shelf, which leads to new challenges for fisheries in the Barents Sea.

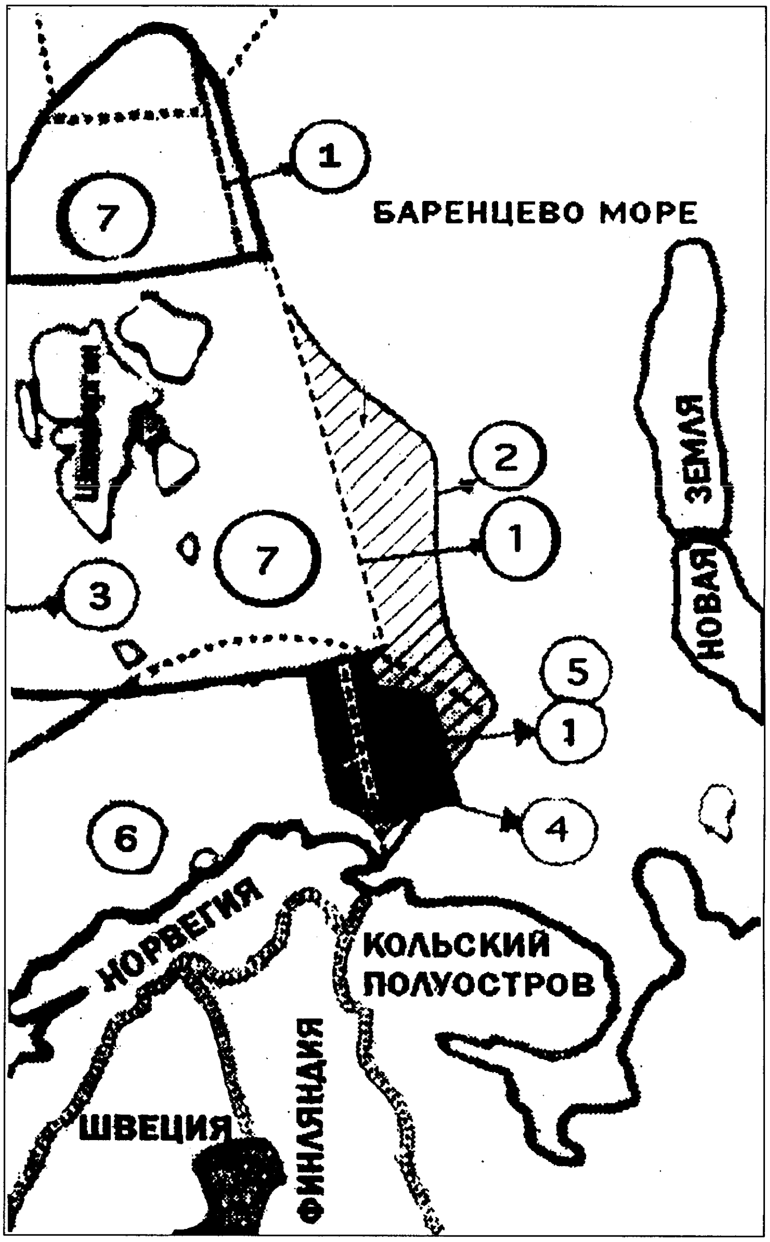

Fig.1. Economic zones in the Barents Sea:
1 – Border of Russian possessions in 1926; 2 – mid-line proposed by Norway; 3 – Svalbard area according to the Svalbard Treaty, 1920; 2 – Gray Zone, 1978; 5 – Exclusive economic zone of Russia; 6 – exclusive economic zone of Norway; 7 – Svalbard fisheries protection zone

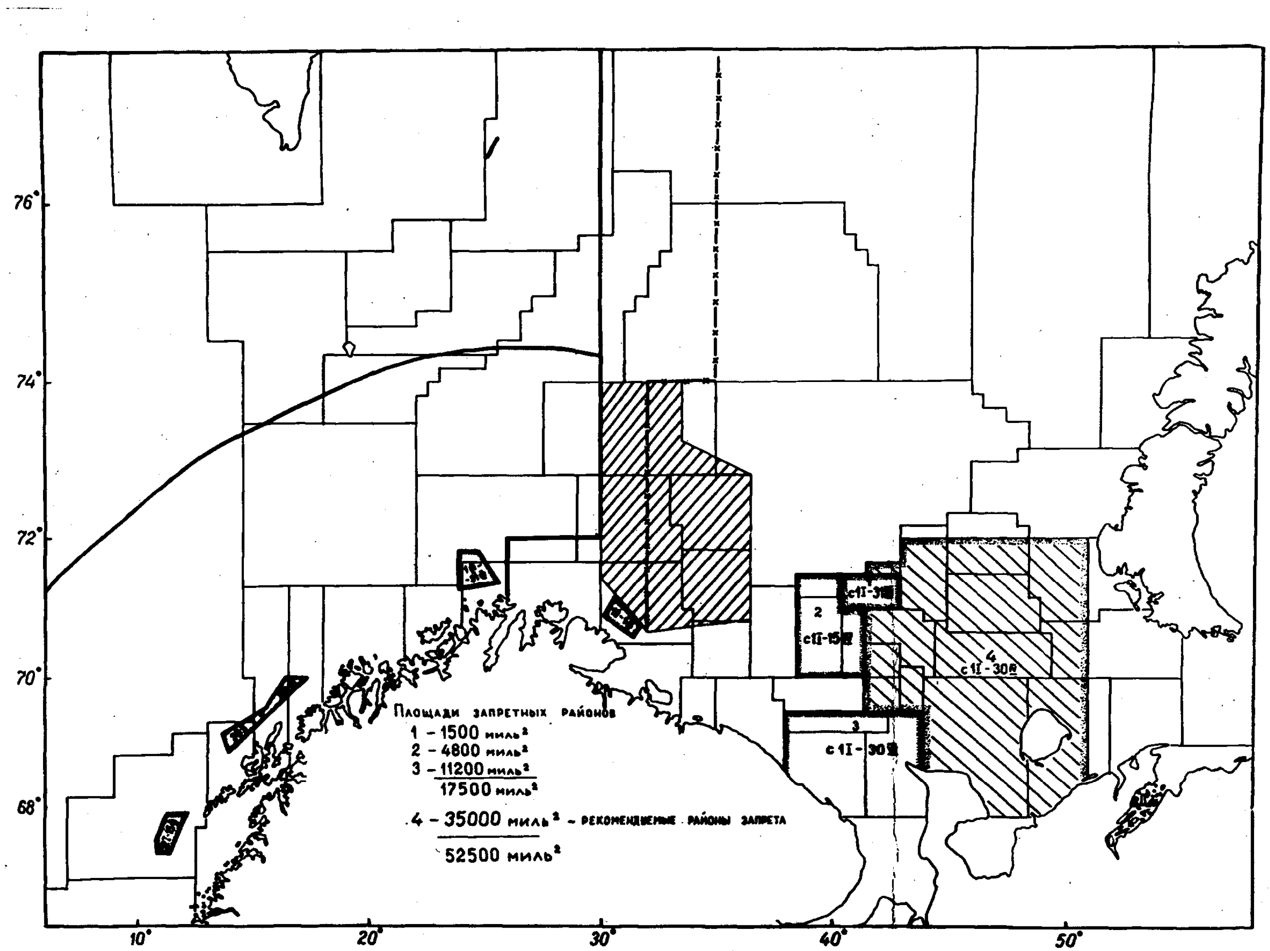

Fig. 2. Areas closed for fisheries in the Barents Sea

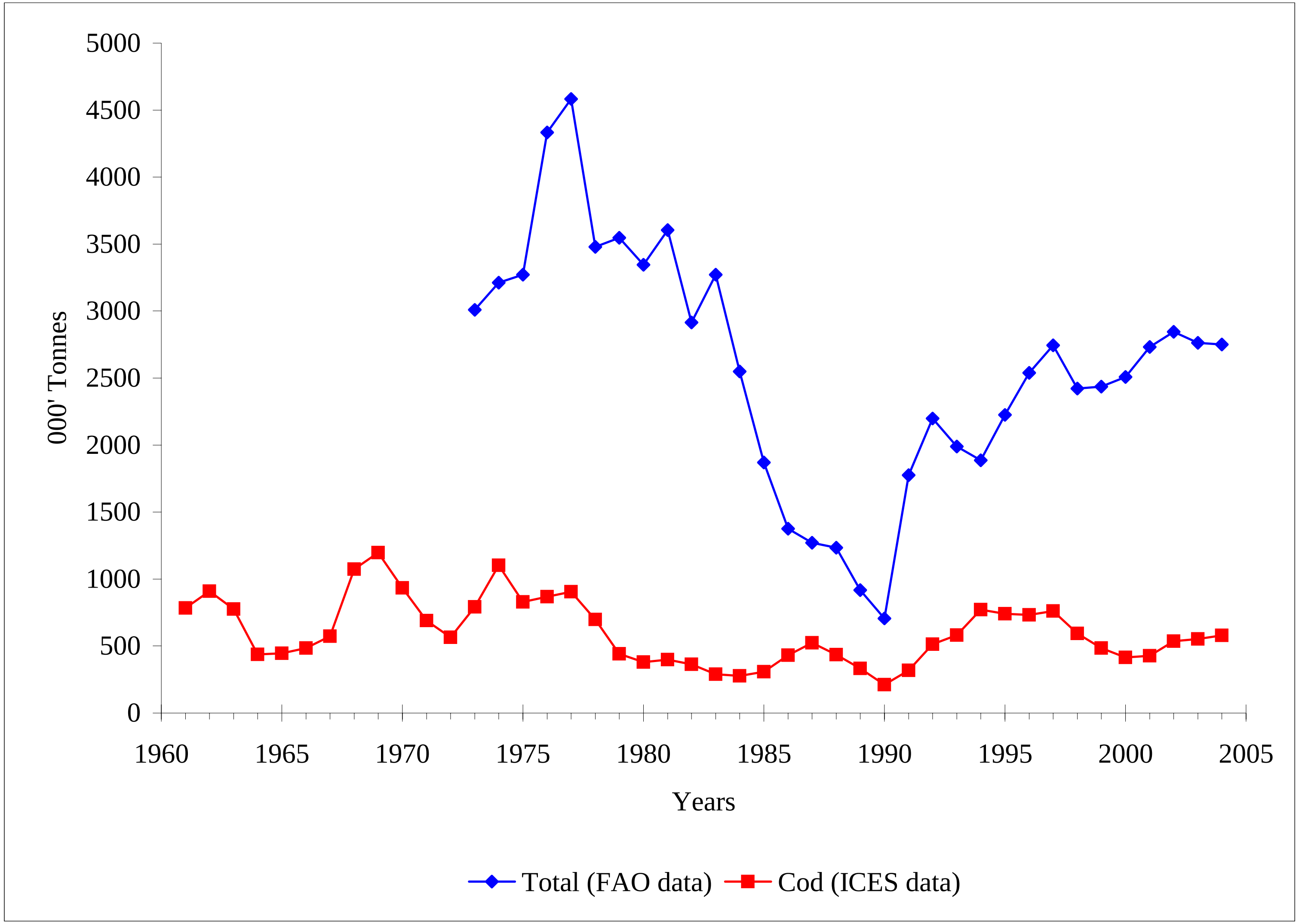

Fig. 3. Total catch of marine species in the Barents Sea

Table 1. Russian federal law "On fisheries and conservation of aquatic biological resources", 20th of December 2004, Nr. 166 (article 30)

1) quotas for harvesting on the continental shelf of the Russian federation and exclusive economic zone of the Russian Federation (commercial quotas);

2) quotas for harvesting in the inlands seas of the Russian Federation, territory waters of the Russian Federation, continental shelf of the Russian Federation and exclusive economic zone of the Russian Federation (coastal quotas);

3) quotas for fishing for scientific and research purposes;

4) quotas for fishing for educational and cultural purposes;

5) quotas for harvesting for the purpose of aquaculture, farming and acclimatisation of aquatic bioresources;

6) quotas for fishing for sport and recreation purposes;

7) quotas for harvesting to ensure traditional life style of indigenous peoples in the North, Siberia and Far East of the Russian Federation;

8) quotas for harvesting in the areas regulated by international agreement of the Russian Federation in the filed of fisheries and conservation of aquatic bioresources;

9) quotas for harvesting in the exclusive economic zone of the Russian Federation for foreign countries set in accordance with international agreements of the Russian Federation in the filed of fisheries and conservation of aquatic bioresources.

Table 2. Quotas, catch and underfishing/overfishing by Russia (USSR) and Norway in 1978-2000 in 1000 tonnes (Data from reports of AFWG and the Joint Russian-Norwegian Fisheries Commission)

Year	**Russia (USSR)**			**Norway**		
	Quota	**Catch**	**Underfishing/ overfishing**	**Quota**	**Catch**	**Underfishing/ overfishing**
1978	380	267	-113	380	363	-17
1979	325	106	-219	325	295	-30
1980	191	115	-76	191	272	+81
1981	152,5	83	-70	152,5	327	+174
1982	107,5	40	-67	197,5	330	+132
1983	80	23	-57	225	272	+47
1984	60	22	-38	180	305	+125
1985	80	62	-18	160	286	+126
1986	150	151	+0,5	250	301	+51
1987	202	202	+0,3	342	329	-13
1988	200	169	-31	250	282	+32
1989	134	135	+,06	178	199	+21
1990	73	75	+2	113	117	+4
1991	108,5	119	+11	128,5	151	+23
1992	170,5	182	+12	190,5	210	+20
1993	228	245	+17	248	274	+26
1994	316	292	-24	339	373	+34
1995	314	296	-18	338	377	+39
1996	318	305	-13	334	381	+47
1997	387	313	-74	399	421	+22
1998	301	245	-56	313	337	+24
1999	224,5	210	-14	236,5	264	+28
2000	181,4	166	-15	193,4	No data available	
1978-2000			**-37,5**	**1978-1999**		**+45,3**

THE EFFECTS OF IUU FISHING (UNREPORTED CATCHES) ON STOCK ASSESSMENTS, PREDICTIONS AND MANAGEMENT ADVICE

by

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Introduction

The term illegal, unregulated, unreported (IUU) fishing reflects activities in direct conflict with the basic playing rules required for a managed fishery. When there is evidence that such activities take place the obvious management advice is to bring the fisheries in order. This might appear rather trivial, however, when discussing technical details on how unreported catch data influence the assessment results, this should be kept in mind; -A precise quantitative advice on regulations is not very helpful in cases when the fisheries do not follow the rules.

From an assessment point of view the main problem with IUU fishing is that catches are unreported. Unreported catch is therefore the main focus for this document. Unreported catch is by its nature very difficult to quantify. Even their magnitude relative to the reported catch is very difficult to judge. It is therefore impossible to properly quantify the associated errors in stock assessment and predictions. The error will depend both of the magnitude of such catches, their time trend relative to the time trend of the official catch, the amount and precision of fishery-independent data, and the assessment method used. Here we will describe some generic cases illustrated by a couple of examples. In all cases it is assumed that no attempt has been made to take account of unreported catches.

The general rule is that in the assessment unreported catches primarily leads to underestimation of the absolute size of the stock, while in the predictions such catches typically increases fishing mortality and reduces stock size. The latter may not always be true in relative terms. A fixed proportion of unreported catch could be hidden both in assessment and predictions, so that the prediction and advice for the legal part of the fishery still might be reasonable although the real catch and stock size is underestimated. In absolute terms, however, it is always true that any additional removal from the stock reduces the future stock size and catches.

<u>How unreported fishing affects the true stock. The cost of rebuilding (repairing)</u>

A typical goal for fishery management is to keep the stock sufficiently large to ensure its productivity. A common strategy for achieving this is to aim for a fairly constant fishing mortality (a target F). This is wise because periods with increased fishing mortality usually lead to increased growth overfishing (the fish is not allowed to survive sufficiently long to utilise its growth potential). If the management strategy is to fish at a constant fishing mortality, then additional unreported catches leads to overfishing of quotas. This will reduce the stock compared to the management goal, and future catches have to be reduced to repair the damage. Typically the time required for repairing is much longer than the duration of the overfishing period. This is illustrated by a simple example in Table 1. This shows the number of years each year-class in the stock has experienced overfishing, when the overfishing took place over a 4-year period (2103-2106). The first year after the overfishing period all fish older than recruitment age plus 4 belong to year-classes that have experienced 4 years overfishing, while the younger age groups have experienced less. For each year passing on the affected part of the stock gets one year older. Recruitment age is 3, which means that the overfishing does not affect age 2 or younger. The 2103 year-class (age 3 in 2106) is thus the latest one affected. This year-class reach age 12 in 2115. Thus in the 10^{th} year after the overfishing took place one might consider the stock fairly well repaired, although some effect will endure in the plus group (13+) for a few more years.

Table 2 is a calculated example similar to Table 1, illustrating the consequences for stock numbers, catch and spawning stock. The recruitment is assumed constant. Before the overfishing period the stock is in equilibrium at a fishing mortality, F=0.4. During the 4 years of overfishing F=0.6. It is seen that after returning to the previous F=0.4 it takes about 10 years to obtain the original stock numbers, catch and spawning stock. If recruitment had dropped due to the decrease in spawning stock (recruitment overfishing), the rebuilding period of the spawning stock, plus the 3 year delay between birth and recruitment had to be added to those 10 years before equilibrium had been obtained.

It is observed in Table 2 that compared to the equilibrium situation the catches were high in the overfishing period and low in the rebuilding period. The average over the whole non-equilibrium period is slightly less than at equilibrium. This reduction is caused by increased growth overfishing in the overfishing period. If recruitment had dropped there would be an additional loss in average catch (caused by recruitment overfishing).

How would overfishing affect Noth-East Arcic cod?

Table 2 is based on cod data and could be a reasonable illustration for that stock if it has been in equilibrium at F=0.4. This has never been the case in the quantified history of the stock. In the 8 year period 1994-2001 F varied between 0.7 and 1.0. The existing management rule aiming at F around 0.4 was first time applied for setting the TAC for 2004. The message from Table 2 is that it requires at least 10 years to obtain the full benefit of the new strategy. The indicated unreported fishing for the years 2002-2004 have reduced the starting point and delayed the process. It has been expected that the new strategy would result in a gradual increase in stock size and TAC, instead stock size and TAC-advice have levelled off due to the unreported catches.

<u>How does unreported catches influence assessment results?</u>

VPA-type assessments (like xsa) is still the most common tool in ICES working groups. This method is basically a bookkeeping of historic catches by year-class. Some years prior to the latest data year the stock consisted of year-classes that has later died out (by fishing and natural mortality). This is technically referred to as the converged part of the vpa. For this part of the time series the stock is fully described by the catches and the (assumed) natural mortality. For the later years in the analysis (the un-converged part) the stock size is fitted both to catches and to the survey data, by using the experienced relationship between the survey and vpa. This fitting is an iterative process referred to as “tuning”.

Other models used in ICES (ICA, Fleksibest (Gadget), Amci) allows for some uncertainty in catch data. Errors in catch data may therefore have different effects on the results of such models, but the main effects of large underreporting are considered to be similar. The following considerations refers to vpa-type assessments.

Unreported catches will in the converged period cause the stock size to be underestimated by roughly the same extent as the catches are underreported. For the un-converged years the effects will depend on the time development of unreported catches.

If unreported catches represent a constant fraction of the total catch over the whole time series, the effect for the un-converged period will be the same as in the converged. If this goes on in the future, the predictions will be confirmed by future assessments. The advices may work ok, even though they are biased to the same extent as the reported catches.

If unreported catch is increasing relative to the official catch, the assessment will (in relative terms) give an overoptimistic stock development in the un-converged part and in the predictions. Future assessments will then show downward revisions of stock size. Advice for reduced fishing may then come too late and rebuilding might become painful.

If unreported catch is decreasing relative to official catch, the assessment will (in relative terms) give a too pessimistic stock development in the un-converged part and in the predictions. Future assessments will then show upward revisions of stock size. Advice for increased fishing may then come later than necessary, but in the meantime the stock has got a chance to increase its production, thereby paying back with high interest.

The above considerations refer to stock size. For the un-converged period and the predictions the conclusions are similar if we consider fishing mortality. For the converged period unreported catches tend to have considerably less impact on F than on stock size. F is a measure of how fast a year-class disappears in the catches, and this is reflected in the annual age sampling, either the total catch is known or not.

Example 1, related to North-East Arctic cod

True catch at age and true stock number at age for each year in the period 1965-2004 are assumed. Then 5 different time series of unreported fishing is assumed. In each of these series this leads to a the reported catch at age that makes up a certain proportion of the true catch at age (same proportion for all ages at the same year).

Case 1: Constant underreporting from 1978
reported catch= true catch in 1965-1977
reported catch= 0.7*true catch in 1978-2004
Case 2: Constant underreporting from 1990
reported catch= true catch in 1965-1989
reported catch= 0.7*true catch in 1990-2004

Case 3: Decreasing underreporting from 1990
reported catch= true catch in 1965-1989
reported catch= 0.7*true catch in 1990, increasing linearly to 1.0*true catch in 2004
Case 4: Increasing underreporting from 1990
reported catch= true catch in 1965-1989
reported catch= 1.0*true catch in 1990, decreasing linearly to 0.7*true catch in 2004
Case 5: Periods of constant and periods of variable underreporting
reported catch= true catch in 1965-1977
reported catch= 0.7*true catch in 1978-2004, except for higher proportions in two periods.

The catch at age matrix corresponding to each of these cases was calculated and a survey series identical to the true stock in the period 1985-2004 was assumed.
Each of these catch at age matrices was then tuned with this "ideal" survey by using a simple vpa-tuning (Laurec-Sheperd, without shrinkage or time weighting). The reason for using an ideal survey and the simple tuning method is that we want to isolate the effects caused by the bias in catch data. Shrinkage, time weighting and noise from survey data could confound some of the effects caused by biased catches.

The results are shown in Figures 1-5. Each Figure has 6 panels; time series of reported catch compared to true catch, the ratio between those, the fishing mortality (F), total stock biomass (TSB) compared to the one corresponding to true catch, spawning stock biomass (SSB) compared to the one corresponding to true catch, and finally the ratios between estimated and true values (relative error) of TSB, SSB and F. Since the survey in these cases equals true stock, the relative error of TSB also show how the survey relate to the assessed stock. The term survey catchability is here inverse to the relative error of TSB.

Case 1: Constant underreporting from 1978
The period with 30% underreporting of catches has 30% underestimation of stock size, with a transition period starting about 5 years before the underreporting starts. Fs are unchanged except for some overestimation in the transition period.

Case 2: Constant underreporting from 1990
Similar to case 1, except for the most recent years, when F is slightly underestimated and stock size is overestimated compared to the first part of the underreporting period (relative error increases), thus giving an overoptimistic view of the most recent relative stock development (but still nearly 30% underestimation in absolute terms). The difference between case 1 and 2 is that in case 2 the underreporting starts within the 20 year survey series. These effects would be stronger if the underreporting shift occurred closer to the most recent year in the analysis.

Case 3: Decreasing underreporting from 1990
Here there is first a sudden shift from zero to 30% underreporting, then a gradual development back to zero. Up to about 2000 (within the fairly converged part of the vpa) the bias in stock size decreases parallel to the decrease in underreporting, while later, when the results is mainly driven by the survey, underestimation of stock and overestimation of F increases again. The result is in relative terms a too pessimistic view of the most recent stock development.

Case 4: Increasing underreporting from 1990
This is opposite to case 3. Up to about 2000 (the fairly converged period) stock size gets gradually more underestimated as underreporting increases, while later turning to less underestimation of stock size. The F in the two latest years is underestimated. In total this gives a too optimistic view of the recent stock situation.

Case 5: Periods of constant and periods of variable underreporting
Since there is a decreased underreporting in the most recent years, the view the most recent stock situation is a bit too pessimistic, similar to case 3. This case involves more variability in underreporting compared to the other cases, and gives larger errors in F.

General remarks on example 1

These analyses are based on manipulated data for the North-East Arctic cod stock. Official catch of cod correspond to case 1. “True catch” and the corresponding “true stock” are constructed so that for the period 1978-2004 the reported catch is 70% of true catch, while there is no underreporting prior to 1978. The catch used in the AFWG assessment (ICES 2005a) corresponds to case 5. It should be noticed that the “true” values of catches and stock used here only serve as an example. The working group values are still considered to be the best estimates.

In view of the large amount of underreporting assumed the errors shown by these simulations may appear small, especially compared to historical revisions experienced in the assessment of this stock. More year to year variability in underreporting, more survey uncertainty, and underreporting focused on certain age groups would all tend to enlarge the errors. Here the main purpose is to illustrate the direction of the error for the last assessment year in the various cases. One general pattern illustrated by these cases is that the largest errors occur when there in the recent period are large changes in the proportion reported.

The analysis was done with a simple vpa without shrinkage or time weighting. An analysis based on the same true catch (cases 1-5) has also been made by using xsa with the exact working-group-settings. This gives similar directions of the errors except for case 4 where the F shrinkage in the xsa compensates for the tendency of underestimating F. This happens because F is falling. If this occurred in a situation when F was increasing such shrinkage would exaggerate the tendency to underestimate F.

The error in the predictions corresponding to cases 1-5 will be in the same direction as the error in the last assessment year. The magnitude of the prediction error tends to be larger than the assessment error, and this tendency increases with increasing true F.

Example 2, North Sea Cod

For this stock discards and unreported landings have been considered to be a problem. In the years when TAC was considerably reduced there are indications that the proportion of the real catch reported has decreased.

In the 2004 assessment (ICES 2005b) the working group made attempts to estimate the catches needed to explain the relative stock changes observed in the surveys (ICES, 2005). Figure 6 shows the estimated catches (with percentiles indicating the uncertainties) compared to reported catch. The estimated “true” catch in 2003 was more than twice the reported. Figure 7 shows the corresponding F-values, and again it is observed that in the converged series the Fs do not change radically, while in the un-converged years the adjusted Fs are higher than those based on reported catch. The adjustments of stock biomass tend to follow the adjustments of catches.

Figures 8 and 9 show a retrospective analysis, indicating the magnitude of annual assessment revisions that would have been the result of using the new assessment approach for the earlier time series. This seems very promising and is in great contrast to Figure 12 showing the real revisions between assessments made historically (based on reported catches). During the last decade there has been a nearly continuous downward revision of stock size and upward revision of F-values.

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ICES 2004. Report of the ICES Advisory Committee on Fishery Management and Advisory Committee on Ecosystems, 2004. ICES ADVICE, Vol 1, no 2.

ICES 2005a. Report of the Arctic Fisheries Working Group. ICES CM 2005/ACFM:20, 19-28 April 2005, Murmansk, Russia.

ICES 2005b. Report on the Assessment of Demersal Stocks in the North Sea and Skagerrak ICES CM 2004/ACFM:07, 7-16 september 2004, Bergen, Norway.

Table 1. Number of years each year-class has experienced overfishing through its life, when the overfishing occured over the years 2103-2106. Year-classes are followed along diagonals from left downward to the right. 13+ is age 13 and older

	Age										
Year	3	4	5	6	7	8	9	10	11	12	13+
2101	0	0	0	0	0	0	0	0	0	0	0
2102	0	0	0	0	0	0	0	0	0	0	0
2103	1	1	1	1	1	1	1	1	1	1	1
2104	1	2	2	2	2	2	2	2	2	2	2
2105	1	2	3	3	3	3	3	3	3	3	3
2106	1	2	3	4	4	4	4	4	4	4	4
2107	0	1	2	3	4	4	4	4	4	4	4
2108	0	0	1	2	3	4	4	4	4	4	4
2109	0	0	0	1	2	3	4	4	4	4	4
2110	0	0	0	0	1	2	3	4	4	4	4
2111	0	0	0	0	0	1	2	3	4	4	4
2112	0	0	0	0	0	0	1	2	3	4	4
2113	0	0	0	0	0	0	0	1	2	3	4
2114	0	0	0	0	0	0	0	0	1	2	4
2115	0	0	0	0	0	0	0	0	0	1	4
2116	0	0	0	0	0	0	0	0	0	0	4
2117	0	0	0	0	0	0	0	0	0	0	4
2118	0	0	0	0	0	0	0	0	0	0	4

Table 2. A calculated example corresponding to table 1. Number at age in millions, Catch and spawning stock biomass (SSB) in thousand tonnes. Recruitment at age 3 is equal for all years. Before overfishing starts the stock is in equilibrium at a stable fishing mortality, F=0.4. In the overfishing period (2103-2106) F=0.6. After this period F returns to 0.4, and the stock approaches equilibrium about 10 years later. The shadowed area is the effected part of the stock, corresponding to non-zero values in Table 1

	Age											Catch	SSB
Year	3	4	5	6	7	8	9	10	11	12	13+	‘000 T	‘000 T
2101	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.3	714	1337
2102	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.3	714	1337
2103	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.3	983	1337
2104	600	431	308	195	110	58	28.1	13.9	6.6	3.0	2.4	842	1098
2105	600	431	307	188	100	50	23.0	10.9	5.2	2.3	1.8	757	944
2106	600	431	307	187	97	45	19.8	8.9	4.1	1.8	1.4	710	853
2107	600	431	307	187	97	44	18.0	7.7	3.3	1.4	1.1	496	805
2108	600	433	317	206	113	53	22.1	8.9	3.7	1.6	1.1	560	937
2109	600	433	319	213	124	62	26.9	11.0	4.3	1.7	1.2	613	1062
2110	600	433	319	214	128	68	31.3	13.4	5.3	2.0	1.3	652	1163
2111	600	433	319	214	129	70	34.4	15.6	6.5	2.5	1.5	678	1236
2112	600	433	319	214	129	71	35.6	17.1	7.6	3.0	1.8	695	1282
2113	600	433	319	214	129	71	35.8	17.7	8.3	3.5	2.2	704	1310
2114	600	433	319	214	129	71	35.8	17.8	8.6	3.9	2.5	709	1324
2115	600	433	319	214	129	71	35.8	17.8	8.6	4.0	2.9	712	1331
2116	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.1	713	1334
2117	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.2	714	1337
2118	600	433	319	214	129	71	35.8	17.8	8.6	4.0	3.2	714	1337
Average 2103-2116												702	1144

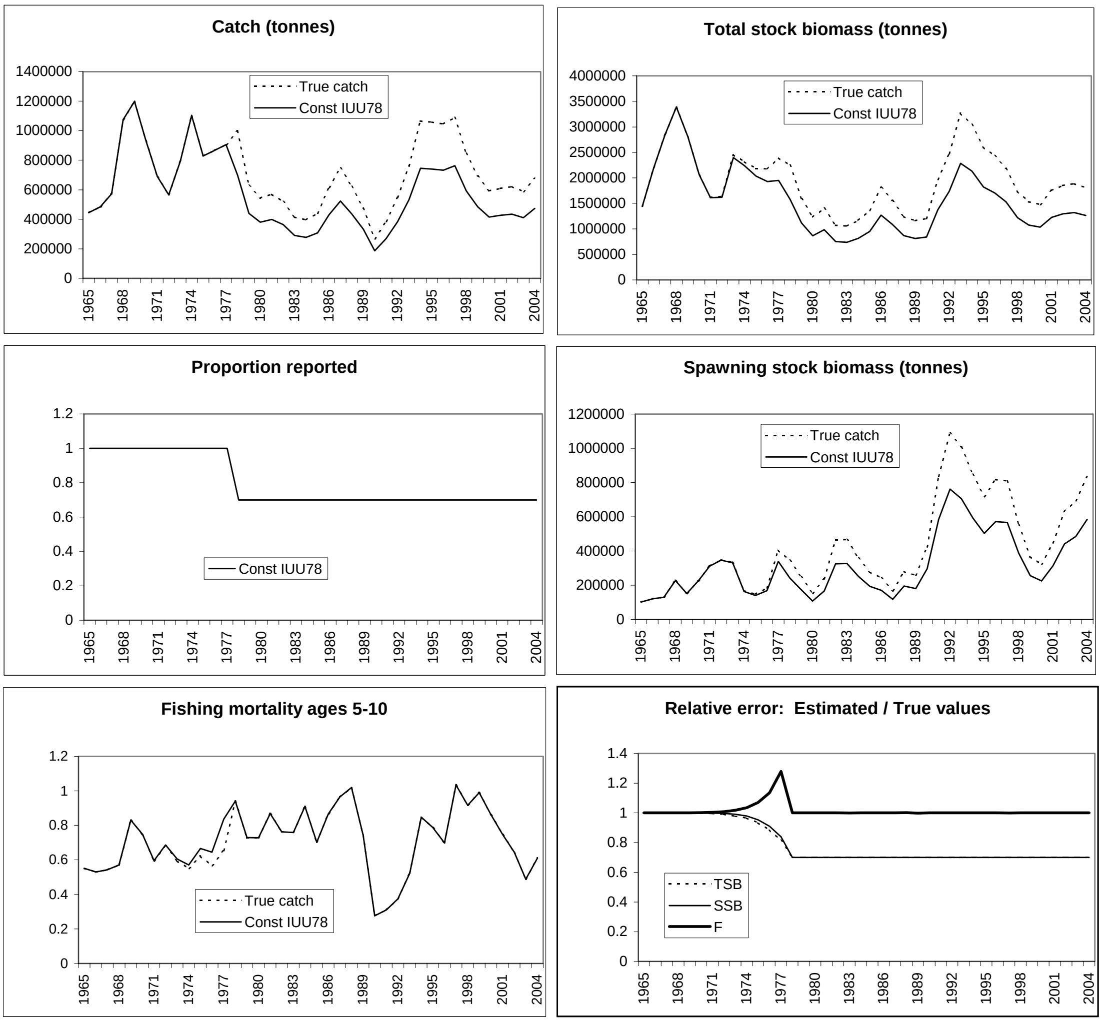

Figure 1. Constant underreporting from 1978. Left panels: Upper; Reported catch (full line) and true catch (broken line). Middle; proportion of the catch reported. Lower; Estimated F (full line) and true F (broken line). Right panels: Upper; Estimated total biomass (full line) and true total biomass (broken line). Middle: Estimated spawning biomass (full line) and true spawning biomass (broken line). Bottom; Relative error of F (thick line), total biomass (broken line) and spawning biomass (thin line)

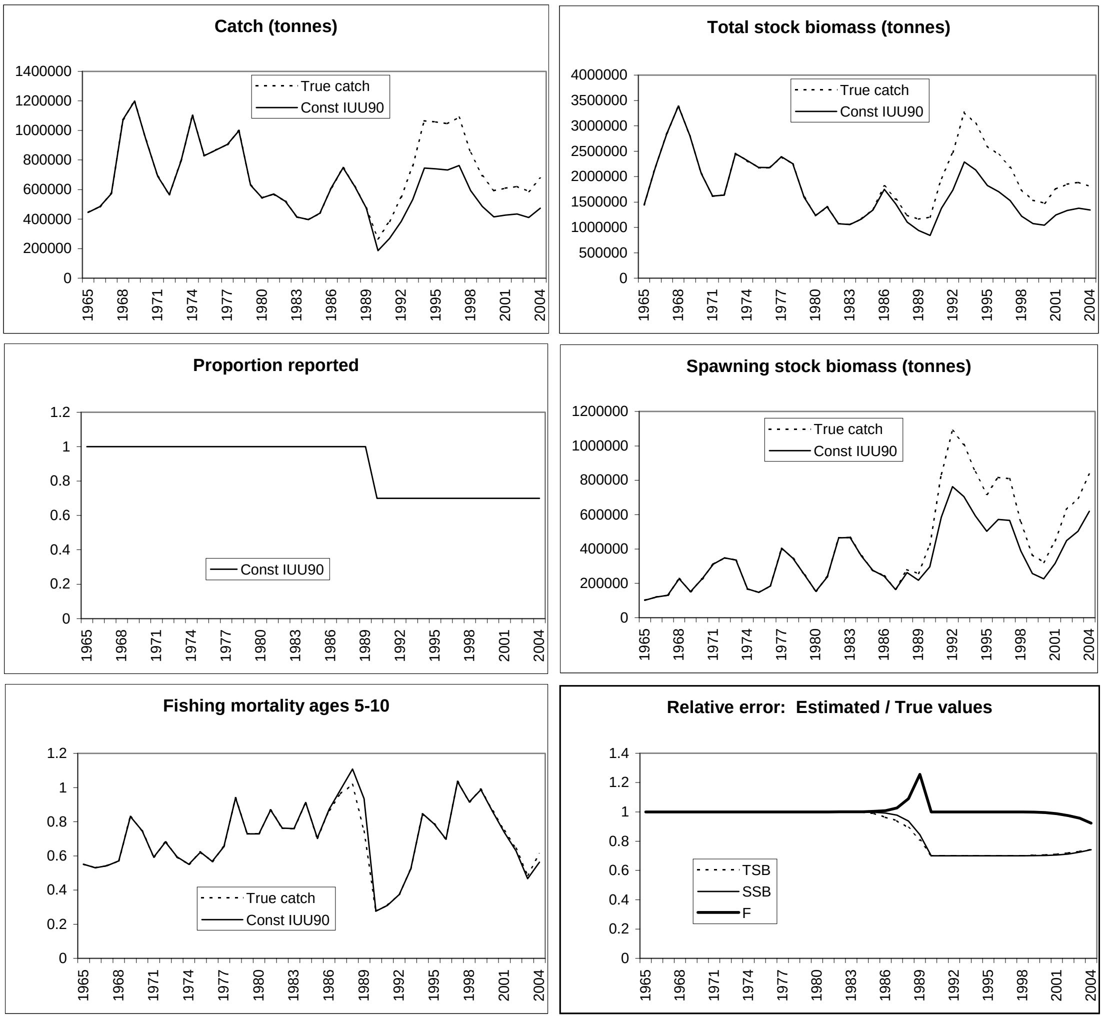

Figure 2. Constant underreporting from 1990. Left panels: Upper; Reported catch (full line) and true catch (broken line). Middle; proportion of the catch reported. Lower; Estimated F (full line) and true F (broken line). Right panels: Upper; Estimated total biomass (full line) and true total biomass (broken line). Middle: Estimated spawning biomass (full line) and true spawning biomass (broken line). Bottom; Relative error of F (thick line), total biomass (broken line) and spawning biomass (thin line)

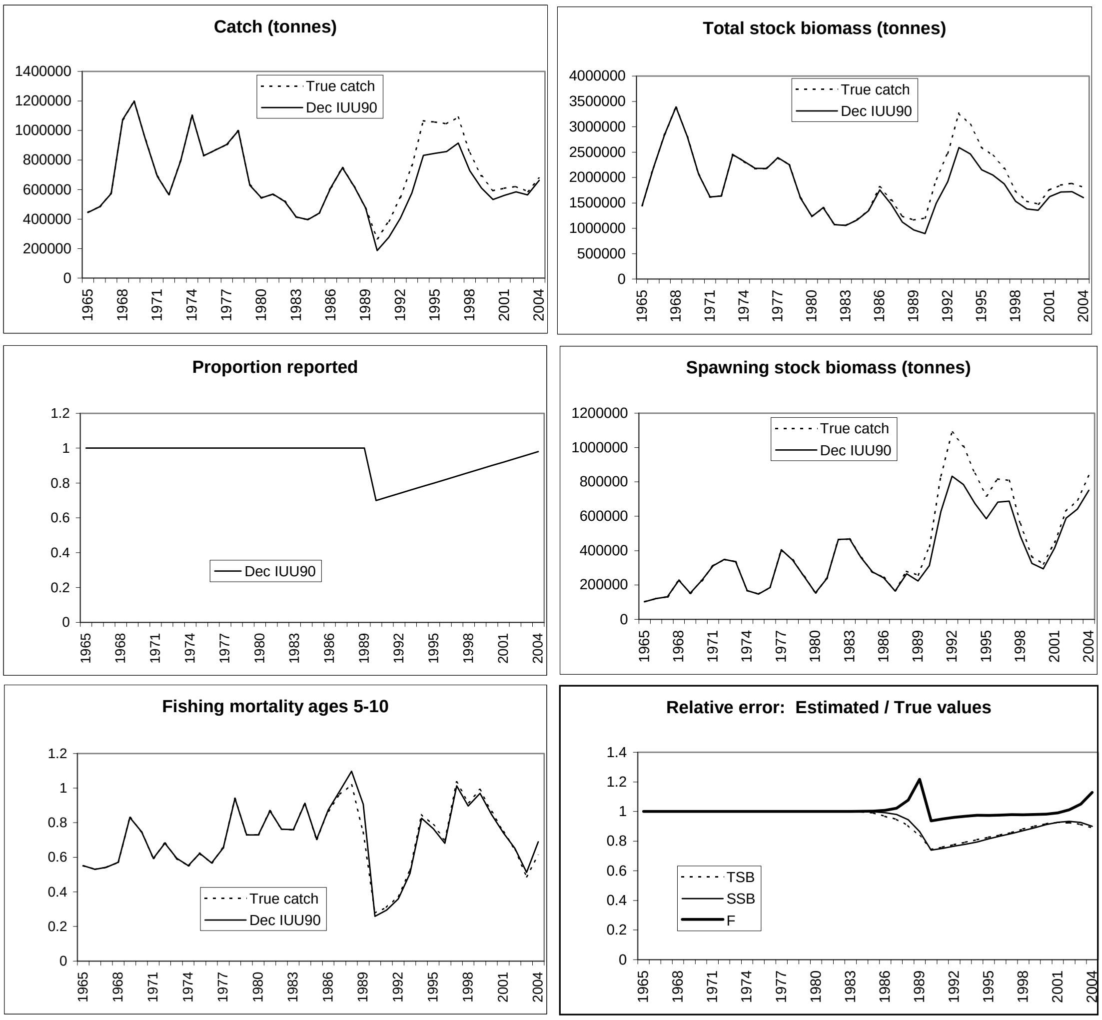

Figure 3. Decreasing underreporting from 1990. Left panels: Upper; Reported catch (full line) and true catch (broken line). Middle; proportion of the catch reported. Lower; Estimated F (full line) and true F (broken line). Right panels: Upper; Estimated total biomass (full line) and true total biomass (broken line). Middle: Estimated spawning biomass (full line) and true spawning biomass (broken line). Bottom; Relative error of F (thick line), total biomass (broken line) and spawning biomass (thin line)

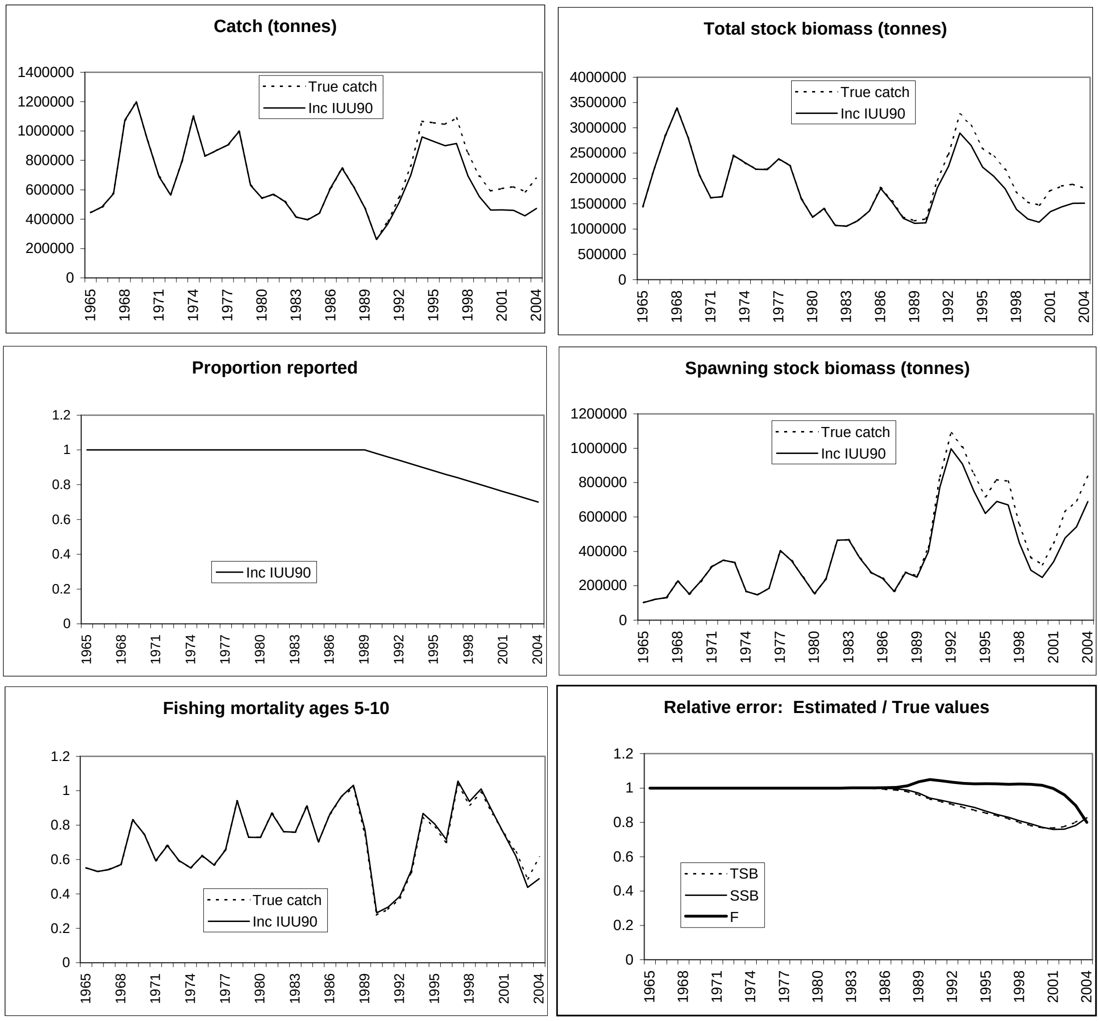

Figure 4. Increasing underreporting from 1990. Left panels: Upper; Reported catch (full line) and true catch (broken line). Middle; proportion of the catch reported. Lower; Estimated F (full line) and true F (broken line). Right panels: Upper; Estimated total biomass (full line) and true total biomass (broken line). Middle: Estimated spawning biomass (full line) and true spawning biomass (broken line). Bottom; Relative error of F (thick line), total biomass (broken line) and spawning biomass (thin line)

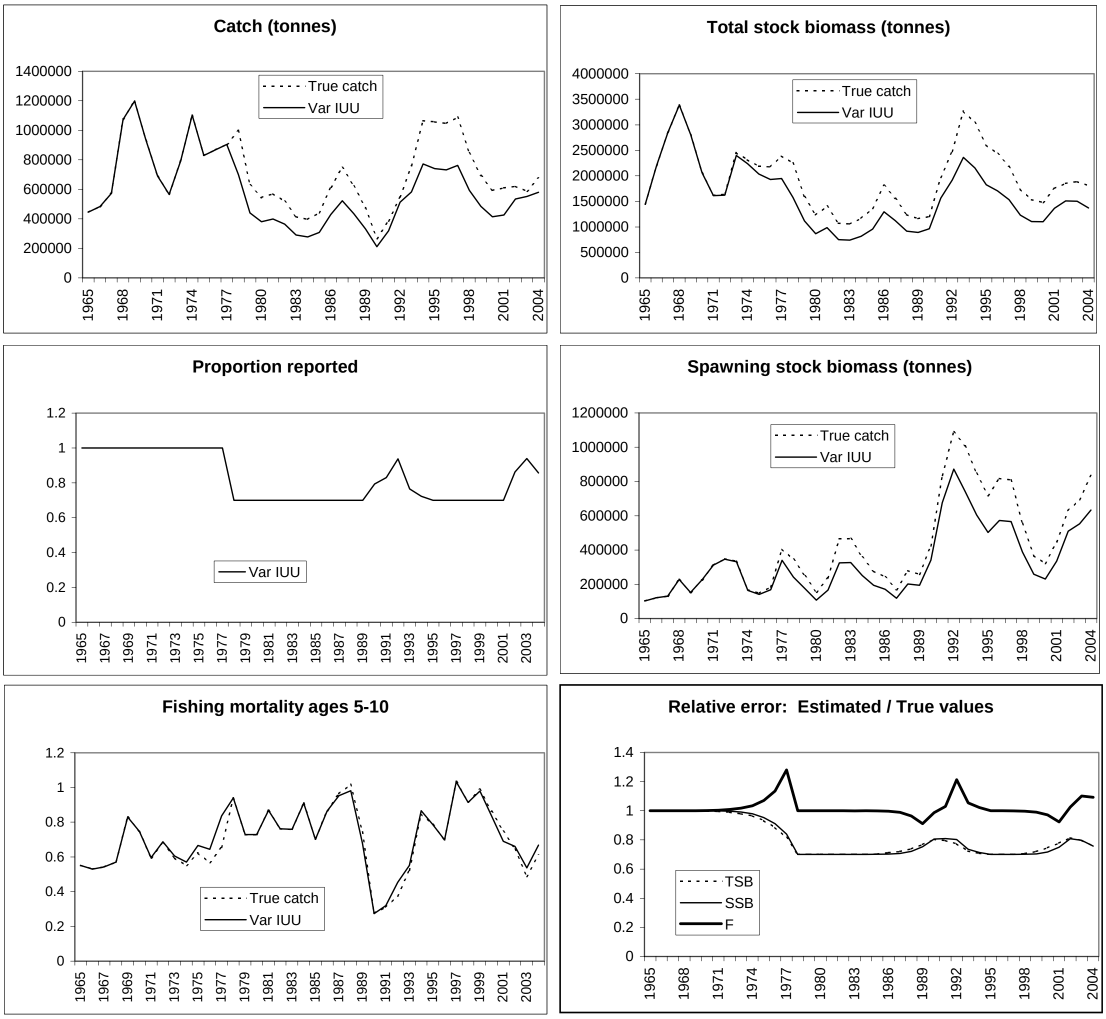

Figure 5. Variable underreporting from 1978. Left panels: Upper; Reported catch (full line) and true catch (broken line). Middle; proportion of the catch reported. Lower; Estimated F (full line) and true F (broken line). Right panels: Upper; Estimated total biomass (full line) and true total biomass (broken line). Middle: Estimated spawning biomass (full line) and true spawning biomass (broken line). Bottom; Relative error of F (thick line), total biomass (broken line) and spawning biomass (thin line)

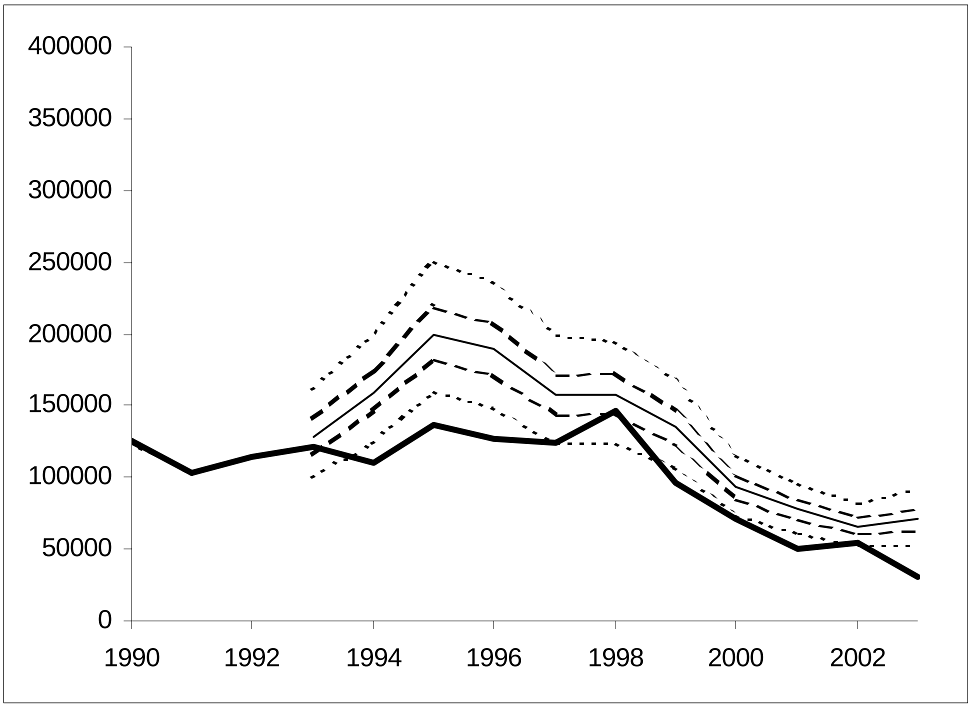

Figure 6. North Sea cod catches (Tonnes). The percentiles (5,25,50,75,95) of estimated “true” catch. The solid line represents the reported catch (Figure 3.4.7.5 in ICES 2005b)

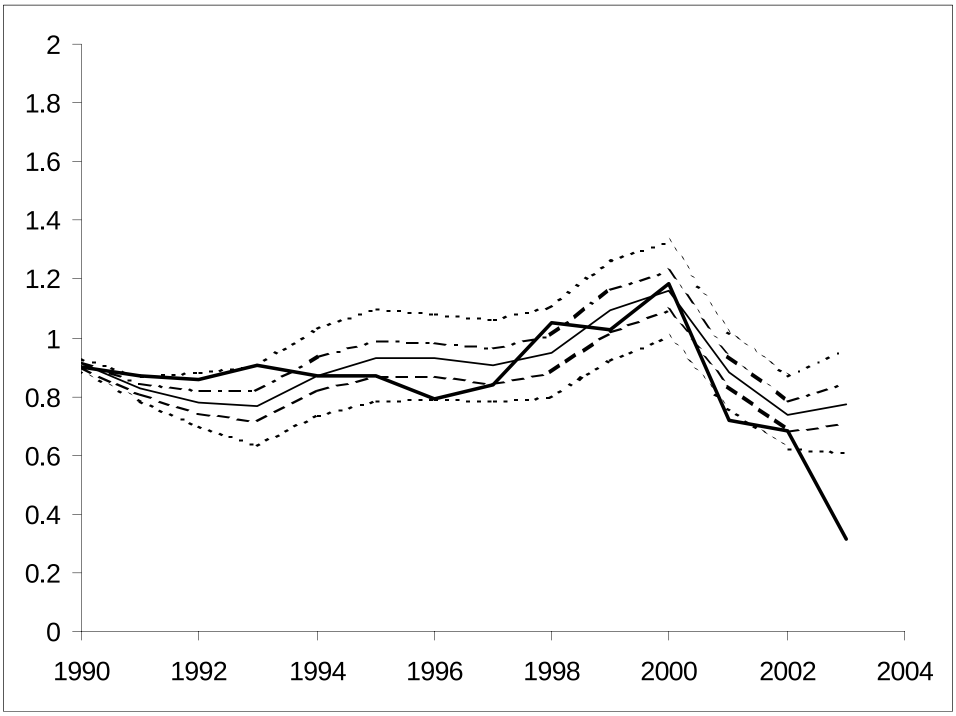

Figure 7. North Sea cod fishing mortality. The percentiles (5,25,50,75,95) of fishing mortality based on estimated catch. The solid line represents fishing mortality based on reported catch (Figure 3.4.7.6 in ICES 2005b)

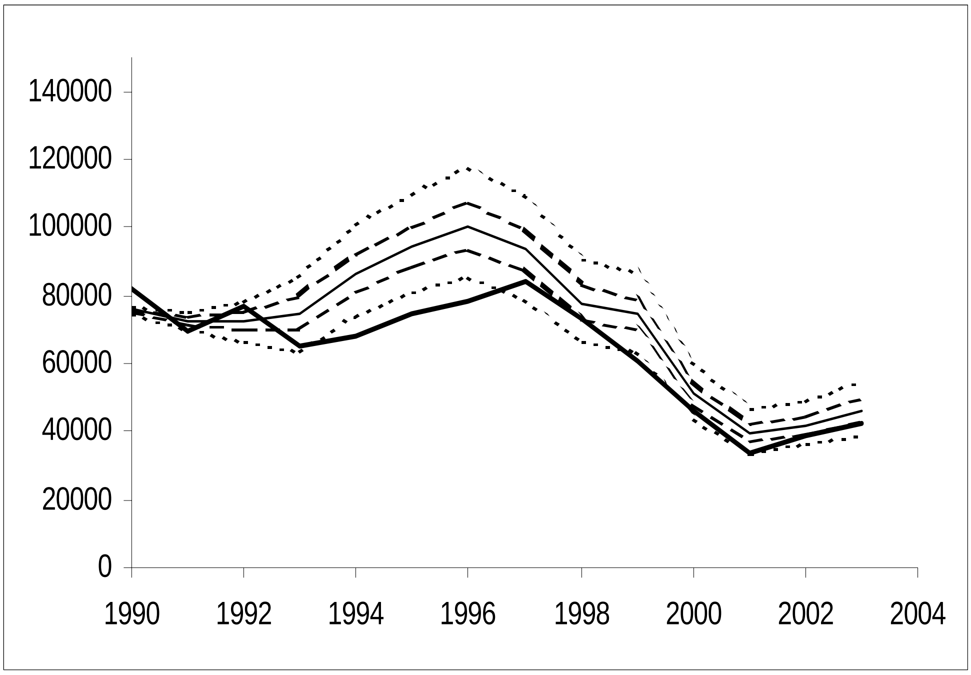

Figure 8. North Sea cod spawning stock biomass (Tonnes): The percentiles (5,25,50,75,95) of the SSB based on estimated catch. The solid line represents the SSB based on reported catch. (Figure 3.4.7.7 in ICES 2005b)

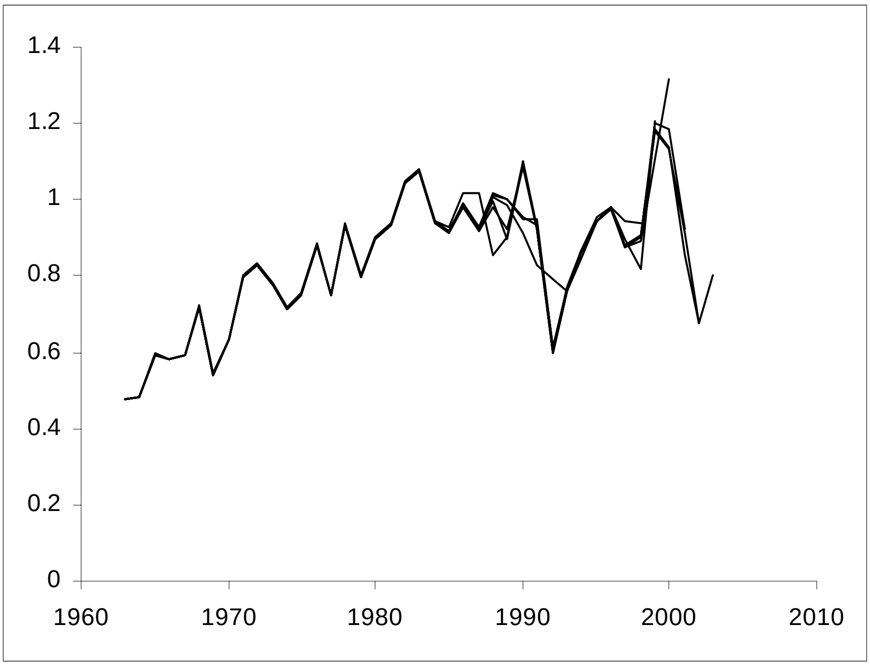

Figure 9. North Sea cod: Retrospective series of average fishing mortality as estimated using the new assessment approach. (Figure 3.4.7.13 in ICES 2005b)

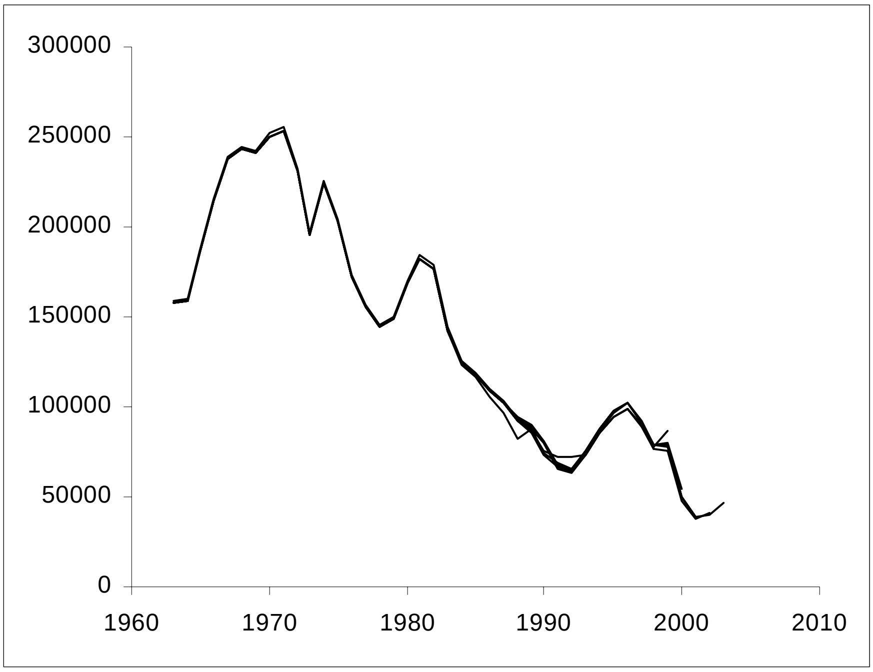

Figure 10. North Sea cod: Retrospective series of spawning stock biomass (Tonnes) as estimated using the new assessment approach. (Figure 3.4.7.14 in ICES 2005b)

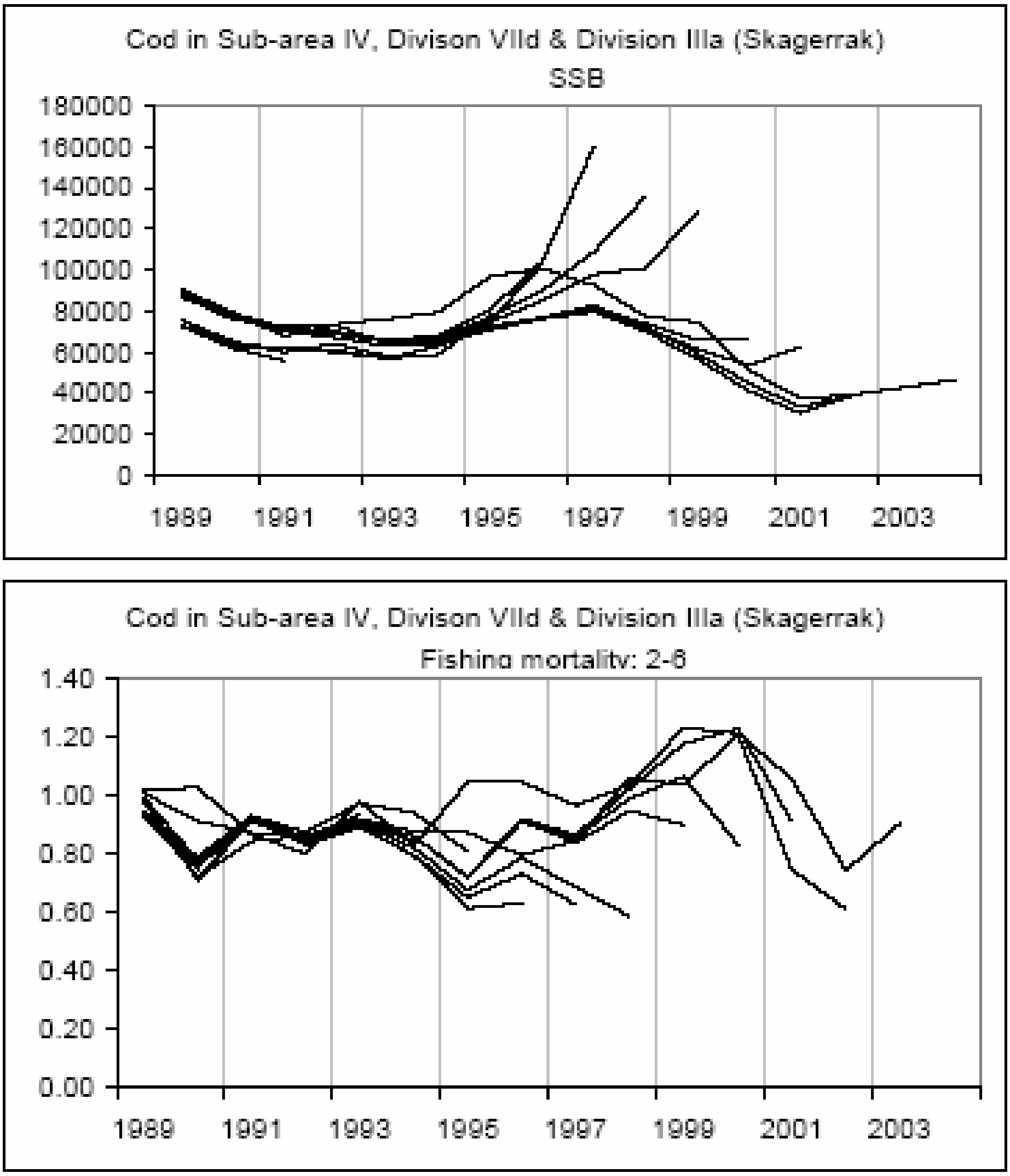

Figure 11. Retrospective plots of the Working Group assessments of North Sea cod, based on reported catches. From ICES 2004

Theme Session 3: RETROSPECTIVE ANALYSES OF ASSESSMENTS AND MANAGEMENT ADVICE FOR BARENTS SEA FISH STOCK

AN EVALUATION OF THE METHODOLOGY FOR PREDICTION OF CAPELIN BIOMASS

by

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Abstract

The one-year prediction of capelin made as part of the assessment after the annual joint acoustic capelin survey during the autumn, is evaluated. Such predictions were made for the period from 1981 till present, and compared to observed stock sizes. The results show that the predictions underestimate the stock size in about half of the years and overestimate the stock size in the others, but in 18 out of the 23 years the observed stock sizes are within the 90% confidence interval of the predictions. It is found that there is a tendency for overestimating stock size in periods when the stock decreases and vice versa. The ratio between predicted and observed stock sizes is variable and some times quite high for stock sizes below one million tonnes (collapsed stock size) but varies between about 0.5 and 1.5 and is unrelated to stock size for larger stock sizes. These results are discussed in light of the various components of the models involved in the predictions.

1. Introduction

The capelin (*Mallotus villosus*) stock in the Barents Sea is surveyed by an annual acoustic survey in September/October (Gjøsæter *et al*., 1998). Almost all capelin die after spawning, and the capelin stock is managed by a target escapement strategy. The quota (TAC) is calculated based on a ½-year prediction of spawning stock size 1 April the year after. The quota is set so that there is a 95% probability for the SSB to be above 200 000 tonnes (ICES, 2005). The Joint Norwegian-Russian Fishery Commission accepted this harvest control rule in 2003.

The capelin stock, as well as the capelin catches, has fluctuated strongly (ICES 2005, Fig. 1). The stock abundance has varied between 0.1 and 7 million tonnes. The maximum annual catch recorded is close to 3 million tonnes, but the fishery has been closed in several periods (1987-1990, 1994-1998, 2004-present).

The current methodology for assessment of the Barents Sea capelin stock, using a combination of the multispecies model Bifrost (Tjelmeland, 2002) and the spreadsheet model CapTool (Gjøsæter et al., 2002) run in the @RISK add-in to MS Excel, has been applied since 1997. Up to 1998 the models served the purpose of giving a ½-year prediction of spawning biomass from the survey in autumn to the spawning next spring, for use in the quota calculations for the winter fishery. The models have been steadily enhanced, and from 1999 a one-year prediction of biomass of 1+ capelin from the autumn survey to the time of the next autumn survey was included. Such predictions include many sources of uncertainty. However, even an uncertain prediction might be of value for some purposes, e.g. for giving a first prediction of the amount of capelin available as food for cod (*Gadus morhua*) and other predators during the coming year (see e.g. Bogstad *et al*. 2000 for a description of predator-prey interactions in the Barents Sea). The amount of capelin available for cod may affect both individual cod growth and cod cannibalism. Another use of the one-year prediction might be to give the management authorities an early indication of the expectances for the capelin fishery one-and-a-half year ahead of time.

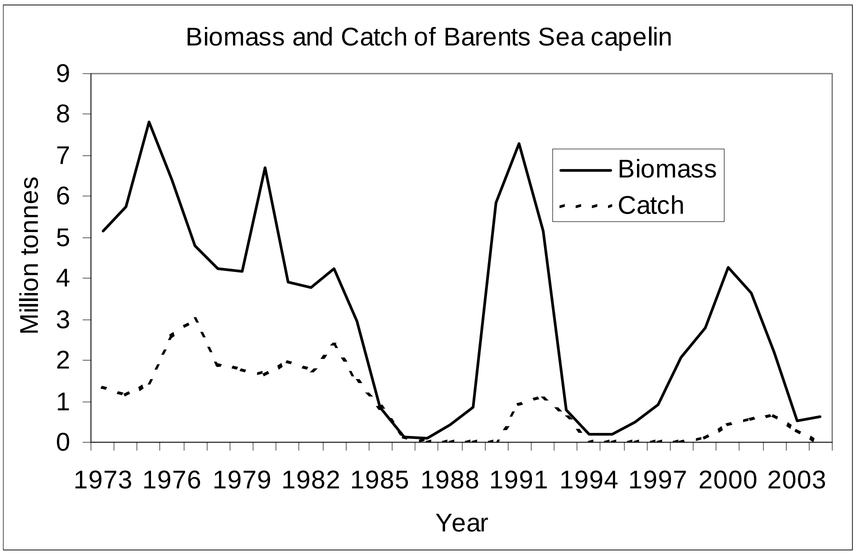

Figure 1. Biomass and catch of the Barents Sea capelin

The aim of this paper is to evaluate the current methodology for one-year-predictions of capelin biomass by comparing them to observed stock sizes, and to discuss the goodness of the predictions in light of the total information about the stock. We will not review the actual one-year predictions made during the period 1998-2004, when varying methodologies were used. We also outline how more biological knowledge could be taken into account in the predictions.

2. Material and methods

The period 1981-2004 was chosen. The reason for this is that before 1981, the coverage of 1-group capelin during the acoustic survey was incomplete (Gjøsæter *et al.*, 1998).

The calculations were performed using Excel spreadsheets with the @RISK add-in. Five thousand simulations were made for each year.

2.1. Input data:

- Capelin abundance and size at age (number by age and length group, mean weight and length at age) measured by an acoustic survey in September (Gjøsæter *et al.*, 1998, updated numbers given in ICES (2005). The uncertainty in the capelin stock estimates is based on resampling the September estimates (both total acoustic abundance and biological samples), as described by Tjelmeland (2002). A CV of 0.2 is used for all years; this is close to the long-term average. The same CV is applied for all age groups, and the CV for the various age groups are assumed to be uncorrelated.

- Capelin 0-group abundance from the annual 0-group survey in August-September (ICES, 2005).

2.2. Models for population dynamics

The following population dynamics processes are modeled: Mortality-Maturation-Recruitment-Growth.

When making the sub-models for these population dynamics processes, we assume that current knowledge (time series from 1981-2004) is available when making the predictions.

2.2.1. Mortality

Two kinds of mortality are modeled: Spawning mortality and residual mortality. Fishing mortality on immature capelin is ignored, and since total spawning mortality on mature capelin is assumed, the fishing mortality on mature capelin is not of interest for the 1-year prediction.

2.2.1.1. Spawning mortality

All mature capelin are assumed to die on April 1, due to spawning mortality. The calculation of the proportion mature is described in Section 2.2.2.

2.2.1.2. Residual mortality

The residual mortality was drawn from the historical time series of natural mortality of immature capelin from the period 1983 till present, calculated as described in Section 2.2.2. Predation by cod on mature capelin in the period January-March is modeled in Bifrost. However, the development of the immature capelin stock from year *y* to year *y+1* is independent of this predation mortality.

2.2.2. Maturation

The proportion mature, *PM(l),* is modeled in the following way:

$$PM(l) = \frac{1}{1+e^{4P_1(P_2-l)}} \quad , \tag{1}$$

where *l* is the fish length.

The maturation function is applied on the acoustic stock estimate in autumn (October 1), in order to separate the modeled stock into a mature and an immature part. The parameters P_1 and P_2 are estimated with uncertainty using the model Bifrost (Gjøsæter et al. 2002, see also www.assessment.imr.no). The estimations are done by simulating one year ahead using the model, assuming total spawning mortality, and comparing the number of modeled fish at ages 3 and 4 with the observations from the survey one year later. The estimations were made using data from 1972-1980, and an M-value for this period was also estimated. The reason for not using the full time series is that during the chosen time range the population dynamics was stable, with relatively constant M-values. Later there were large variations in M as herring (*Clupea harengus*) re-entered the Barents Sea, and possibly also connected to large fluctuations in the harp seal (*Phoca groenlandica*) stock. For years after 1980, annual mortality parameters are estimated using the estimated maturation parameters for the period 1972-1980. P_1 was set to 3.5, which makes the maturation function close to a step-function in compliance with earlier treatment of maturation. The mean value of P_2 is 13.89, which is close to the value estimated by Tjelmeland and Bogstad (1993).

2.2.3. Recruitment

Gundersen and Gjøsæter (1998) established a linear regression between the logarithm of the 0-group area based indices and the logarithm of the 1-group acoustic abundance 1 year later.

This regression has been annually updated with new data, and used in the predictions of capelin stock size. Revised 0-group indices calculated using the method described by Dingsør (2005) and Anon. (2005) are now available (ICES, 2005). Using those indices without correction for length-dependent selectivity in the trawl, we found that a linear regression gave better fit than a log-log regression. The new regression, using data from the 1981-2003 year classes, is shown in Fig. 2.

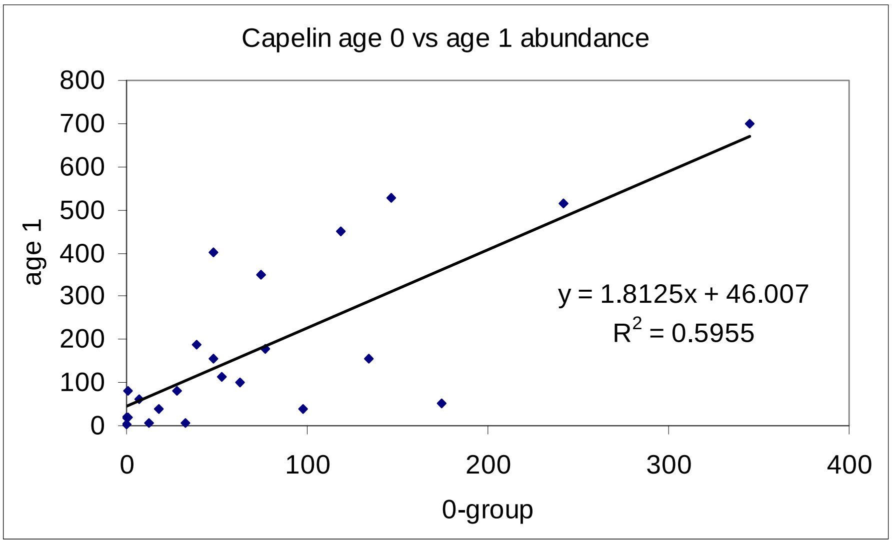

Figure 2. Regression of abundance of capelin at age 0 and age 1

2.2.4. Individual growth

The individual growth in length (cm/year) for each age group can be calculated from values obtained by comparing the mean length at age of immature capelin one year with the mean length at age of the total stock next year, for the period 1981-2004. The individual growth (in cm/year) for age 1 and older fish, i.e. for age groups (1-2, 2-3, 3-4) is drawn randomly from the time series. The length distribution of age 1 fish is drawn from the historical time series.The growth of fish from age 4 to 5 is assumed to be the same as for ages 3-4. The draws from the time series are made separately for each age group, i.e. we do not draw the same year's growth for all ages. However, it might be more logical to change this into drawing one year and use that year's growth for all age groups.

The length growth is implemented by shifting the distribution of immature capelin upwards with the number of 0.5cm length intervals, which corresponds to the growth in length, for each age group and year.

The capelin length-weight relationship for use in the 1-year prediction is drawn randomly from historical data for the period 1981-2004.

3. Results

3.1. Prediction of total stock size

Table 1 shows the results of the simulations for the total stock.

Table 1. Comparison of predicted (with confidence limits) and observed total capelin stock size during the period 1981 to 2003

Year	Stock abundance (1+) in year y (million tonnes)	Predicted stock abundance (1+) in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed stock abundance(1+) in year y+1 (million tonnes)	Ratio predicted/ observed	Residual/ observed
1981	3.90	4.15	1.35	9.64	3.78	1.10	0.10
1982	3.78	4.63	1.76	9.88	4.23	1.09	0.09
1983	4.23	4.59	1.37	10.50	2.96	1.55	0.55
1984	2.96	2.73	0.98	5.35	0.86	3.18	2.18
1985	0.86	1.05	0.39	2.15	0.12	8.73	7.73
1986	0.12	0.35	0.18	0.58	0.10	3.45	2.45
1987	0.10	0.29	0.10	0.58	0.43	0.69	-0.31
1988	0.43	0.66	0.34	1.17	0.86	0.76	-0.24
1989	0.86	3.37	1.75	5.62	5.83	0.58	-0.42
1990	5.83	4.84	1.00	12.56	7.29	0.66	-0.34
1991	7.29	6.47	1.37	16.46	5.15	1.26	0.26
1992	5.15	3.73	0.60	9.84	0.80	4.69	3.69
1993	0.80	0.64	0.18	1.55	0.20	3.19	2.19
1994	0.20	0.38	0.16	0.68	0.19	1.95	0.95
1995	0.19	0.26	0.09	0.51	0.50	0.52	-0.48
1996	0.50	0.95	0.47	1.69	0.91	1.04	0.04
1997	0.91	1.39	0.62	2.66	2.06	0.68	-0.32
1998	2.06	1.82	0.58	4.01	2.78	0.66	-0.34
1999	2.78	2.24	0.92	4.48	4.27	0.52	-0.48
2000	4.27	2.96	0.78	6.96	3.63	0.82	-0.18
2001	3.63	2.06	0.42	5.13	2.21	0.93	-0.07
2002	2.21	1.32	0.42	2.91	0.53	2.47	1.47
2003	0.53	1.64	0.93	2.55	0.63	2.61	1.61

In 18 out of the 23 years, the observed stock size is within the 90% confidence interval of the predicted stock size (Figure 3). However, the confidence intervals are rather wide in most years, and the difference between predicted and observed values is quite large in many of the years. In half of the years the stock sizes are underestimated, in the other years they are overestimated. However, the sign of the residuals is not randomly distributed along the time series; it is evident that there is a trend in the data, where periods of overestimation alternate with periods of underestimation. With a few exceptions, the stock size is underestimated in periods when the stock is increasing, and overestimated in periods when it is decreasing (Figure 3). When the ratio between predicted and observed stock sizes are plotted versus observed stock size during the period, it is seen that the positive ratios (overestimation) are larger than the negative ratios, and there is seemingly a tendency for the highest ratios to occur when the stock size is at a minimum (Figure 4). This tendency is confirmed when the ratios are plotted versus observed stock size (Figure 5), but above an observed stock size of about 1 million tonnes, the relationship between the ratio and the observed stock size flattens out (linear regression, b=-0.03, R^2=0.02).

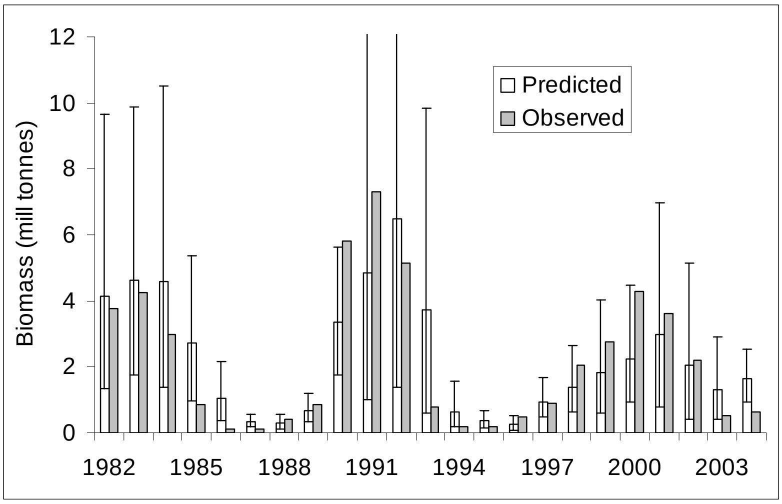

Figure 3. Predicted (with 90% confidence interval) and observed total stock sizes during the period 1982 to 2004

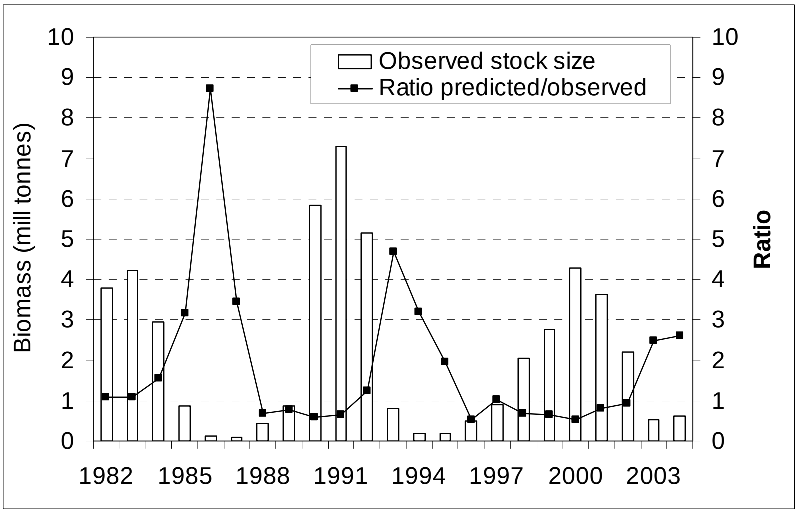

Figure 4. Time series of observed stock size and corresponding ratio between predicted and observed stock size during the period 1982 to 2004

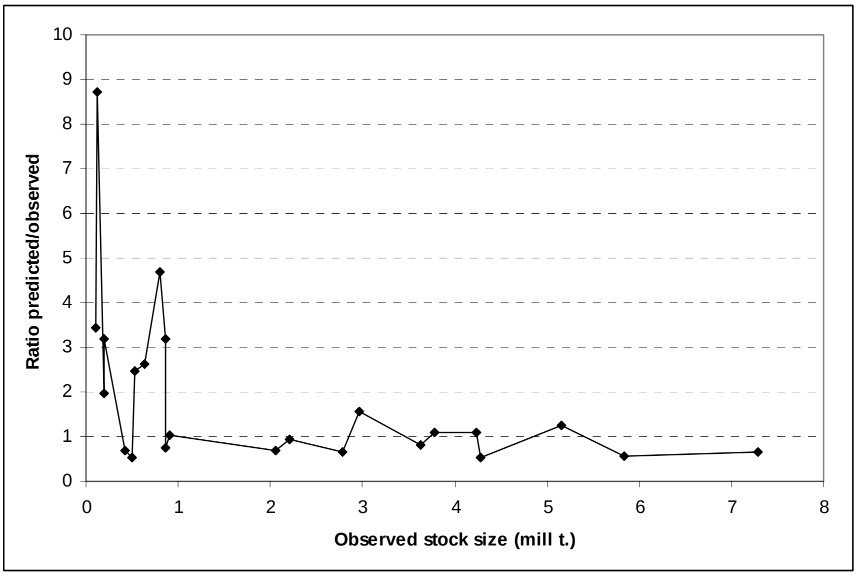

Figure 5. Ratio between predicted and observed stock size plotted versus observed stock size

There is no clear trend in the relative residuals ((predicted – observed)/observed) when plotted versus the observed stock size (Figure 6). The residual for the year 1985 is more than twice as large as any of the other residuals. That year, the stock collapsed and the predicted stock size for 1986 was almost 9 times as large as the observed stock size.

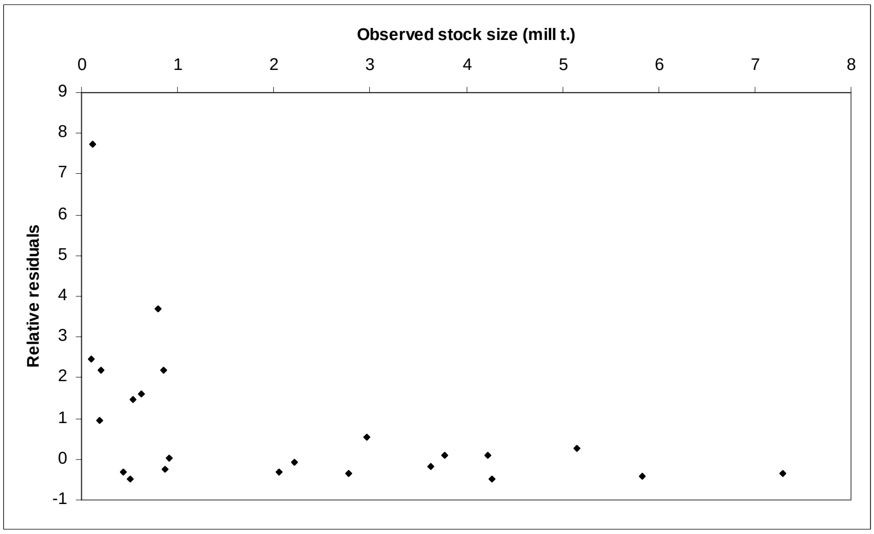

Figure 6. Relative residuals plotted versus observed stock size

3.2. Year class strength of the 1-year-olds

In addition to the simulations of total stock size of one-year-olds and older capelin, the part of the prediction constituting the one-year-olds was analyzed separately. The results are given in Table 2.

Table 2. Comparison of predicted (with confidence limits) and observed biomass of 1-year-old capelin during the period 1981-2003

Year	Predicted abundance of age 1 in year y+1 (million tonnes)	Lower Confidence Limit (5%)	Upper Confidence Limit (95%)	Observed abundance of age 1 in year y+1 (million tonnes)	Ratio predicted/ observed	Residual/ observed
1981	1.11	0.64	1.65	1.22	0.91	-0.09
1982	1.73	1.00	2.60	1.60	1.08	0.08
1983	1.04	0.61	1.55	0.57	1.81	0.81
1984	0.80	0.47	1.19	0.17	4.59	3.59
1985	0.38	0.21	0.60	0.02	16.23	15.23
1986	0.28	0.13	0.48	0.08	3.60	2.60
1987	0.17	0.03	0.36	0.07	2.40	1.40
1988	0.42	0.24	0.65	0.61	0.68	-0.32
1989	2.40	1.33	3.57	2.66	0.90	-0.10
1990	0.48	0.28	0.72	1.52	0.31	-0.69
1991	0.65	0.39	0.96	1.25	0.52	-0.48
1992	0.17	0.04	0.35	0.01	22.08	21.08
1993	0.18	0.03	0.37	0.09	2.04	1.04
1994	0.25	0.10	0.45	0.05	5.23	4.23
1995	0.18	0.04	0.36	0.24	0.75	-0.25
1996	0.58	0.33	0.86	0.42	1.38	0.38
1997	0.67	0.39	0.99	0.81	0.83	-0.17
1998	0.48	0.27	0.72	0.65	0.73	-0.27
1999	0.94	0.54	1.38	1.70	0.55	-0.45
2000	0.51	0.29	0.77	0.37	1.36	0.36
2001	0.22	0.08	0.41	0.23	0.92	-0.08
2002	0.35	0.18	0.56	0.20	1.74	0.74
2003	1.29	0.73	1.93	0.20	6.61	5.61

For the one-year-olds, the observed values are within the confidence limits of the predicted values in only 13 out of the 23 years (Figure 7). That means that the prediction of one-year-olds constitutes a “weak part” of the prediction of total stock size. Similarly to the predictions of total (1+) biomass there is also in this case a trend of overestimation in cases of an increasing stock and underestimation when the stock is declining. However, the trend is not as systematic as found for the total predictions. On average, there is an annual overestimation of about 21 thousand tonnes of one-year-olds during this period.

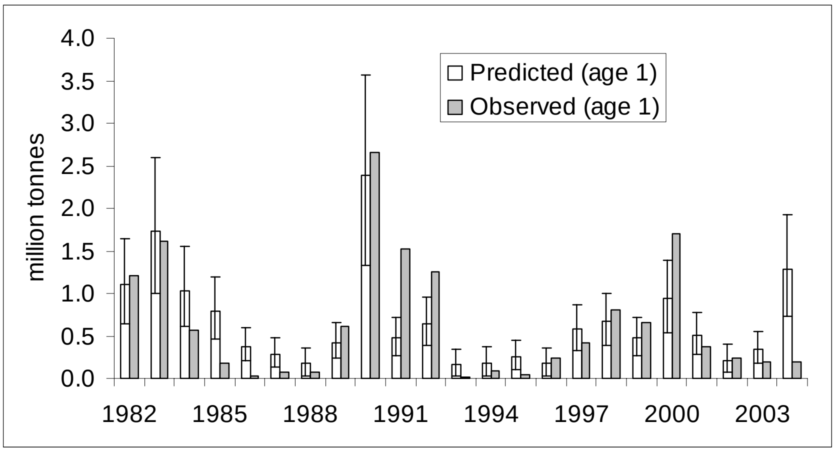

Figure 7. Predicted (with 90% confidence limit) and observed biomass of one-year-old capelin during the period 1982 to 2004

4. Discussion

4.1. Precision of predictions and time lag

The average overestimation of stock size is 96 thousand tonnes, out of which 21 thousand tonnes stem from the one-year-olds, showing that the model has had a slight tendency to overestimate stock size compared to observed values in this period. The predictions obviously "lags behind" the development of the stock, since the model overestimates the stock size when it is declining and underestimates the stock when it is increasing.

4.2. Effect of ignoring catch of immature capelin

Ignoring catch of immature capelin in 1981-1986, 1991-1993 and 2000-2003 leads to overestimation in prediction for these years. The amount of immature fish taken during these periods has varied considerably, but especially for the first of these catch periods catch of immature capelin was quite high, amounting to between 131 and 435 thousand tonnes annually. For 1981 and 1982, the catch of immatures was in fact 118% and 33% of the difference between predicted and observed stock size respectively. For the other years the catch of immatures makes up less than 15% of the difference. This clearly shows the need to take account of these catches, at least when analyzing historical data. Because it is quite time consuming to implement this in the model, it was not possible to do before this symposium. This is a task for the near future.

4.3. Year class strength of the 1-year-olds

The analysis of one-year-olds separately shows that there is a slight tendency for overestimation, but the sign and value of the residuals are less related to stock situation than those for the total predictions. It has not been possible to check the various components of the predictions of one-year-olds, so it is unknown whether it is the natural mortality or the growth that constitutes most of the residuals. Since the mortality is large and variable during this phase (see Figure 2), it seems probable that the rather low accuracy and precision in the predictions of one-year-olds mostly stem from the regression of one-year-olds on the 0-group index. The regression of one-year-olds on 0-group index has a positive intercept. This will inevitably cause a relative increase in overestimation for smaller stock sizes, and may partly explain the increase in ratio between predicted and observed stock sizes seen for smaller stock sizes in figure 5. Further work will include implementation of a regression through the origin, to avoid this effect.

4.4. Natural mortality

One possible reason that the predictions lags behind the stock development is the way the natural mortality is handled, by drawing at random a natural mortality (as observed by the decrease of one year class from one year to the next when fishing and spawning mortality is accounted for) observed during previous years. The rationale behind this method is that the natural mortality is unknown, but may vary randomly within the observed limits. However, it is observed that in periods of stock decline, the natural mortality is increasing and vice versa. If this could be taken into account, a better prediction for natural mortality could be made. However, it is not a straightforward task to implement this in the model, since it is unknown whether the stock will increase or decrease during the next year. One possibility would be to draw the natural mortality at random from e.g. the last 2-3 years, since the trends in stock size normally changes in a cyclic manner, and recent years would better reflect current level of natural mortalities.

An even better idea would be to model the natural mortalities with external factors as driving forces. The most obvious factors to try would be density dependence, predation pressure from cod, or rather, a combination of these. The most probable mechanism for an increased natural mortality when the capelin stock is decreasing is that a high predation pressure will exert a galloping mortality (M) as the capelin stock gets smaller. When the capelin stock is above a certain level, one may suppose that M would be inversely proportional to the cod/capelin ratio. When the capelin stock falls below this critical level, the cod may have problems with encountering capelin, and may even actively switch to other food sources. The hypothesized relationship would then break down. Unfortunately time has not allowed us to pursue these ideas further, so this is for the future.

4.5. Growth

The growth from year y to $y+1$ is implemented in an analogous way to the natural mortality. Assuming the actual growth is unknown, the growth rate is drawn at random from previously observed growth rates independently for each age group. In the future, this might be changed into drawing one year and use that year's growth for all age groups. It would be possible to compare the length frequencies in the predictions with those observed, but this is a quite laborious task and has not been done. However, if trends in these residuals could be demonstrated, a logical enhancement would be to model how individual growth from year y to year $y+1$ would depend on some or all of the following factors:

Mean length at age of immature capelin in year y
Total stock abundance in year y
Oceanographic variables in year y
Plankton abundance in year y

This was studied by Bogstad et al. (2005), who found that individual growth from age 1 to 2 was density-dependent, i.e. negatively correlated with the biomass of capelin in year y. They also found how the individual growth from year y to $y+1$ was correlated with the mean length at age of immature capelin in year y. These relationships will be built into the CapTool model.

1.6. Additional possible improvements:

- Use annual estimates of uncertainty of number at age in surveys (including how these numbers are correlated), to get more appropriate measure of uncertainty in survey estimate.
- Try to account for other uncertainties in survey estimate than those modeled by Tjelmeland (2002)

5. Acknowledgements

We thank Sigurd Tjelmeland, Institute of Marine Research, for help with implementing the 0-group/1-group regression in CapTool.

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RETROSPECTIVE REVIEW OF MANAGEMENT ADVICE FOR THE NORTHEAST ARCTIC COD

by

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Introduction

The history of fishery of the Northeast Arctic cod is almost a millennium (Rollefsen, 1966; Dyrvik et al., 1979), while the history of its management is much shorter. We reviewed 100 years period of managements measures development.

Currently for all commercially important fish stocks in the Barents Sea area, Norwegian and Russian management authorities receive annual advice from ICES on total allowable catches (TAC's) and other management measures. The advice is based on the stock monitoring and research carried out by PINRO and IMR.

Material and methods

All data are taken from the annual ICES reports (ACFM reports) as well as the Joint Soviet-Norwegian Fisheries Commission, later the Joint Russian-Norwegian Fisheries Commission protocols. Each year ICES produces an updated version of the assessment of all previous years, and we have compared the results from the annual assessments; i.e. the assessment that is the basis for the decision on next years TAC, with the results from the 2005 assessment for the same years.

Results

History of the management

First regulations of the cod fishery aimed at preventing the conflicts among fishers operating on the same fishing grounds are almost a century old. The development and practical application of regulatory measures began to be a more regular practice only from the mid-20th century. The need for development and subsequent implementation of regulatory measures on the cod fishery was called forth by an abrupt decline of the efficiency of this fishery in the second half of the 1950s.

Before that, a minimum mesh size established by the "Convention on regulation of the mesh size in fishing gear and minimal legal fish size" (London, 23 March 1937) was recommended for use to limit the cod fishery. However, decisions under this Convention were not binding for all nations exploiting the stock.

Under the next Convention, which was signed in London on 5 April 1946 and came into force on 5 April 1953, it was recommended that the minimum mesh size be increased to 110 mm (the USSR acceded the Convention in 1958 and ratified it in 1961). So, this technical regulatory measure was the first direct regulatory measure in the history of cod fishery.

A later history of exploitation of cod in the Barents Sea showed, that application of technical regulatory measures alone could not help avoiding sudden variations and repeated decline of the efficiency of fishery, variations in the size composition of catch and its decline.

Redused catch rates and disappearance of large cod from catches, near Lofoten including, in the second half of the 1950s gave grounds for the Russian and Norwegian researchers to conclude that the trawl fishery had a strong impact on the cod stock (Maslov, 1957a; Sætersdal and Hylen, 1964). It was formulated, that "a method to manage the biological processes in a water body lies in regulating the fishery by establishing science-based catch limits strictly complied with by the industry (Maslov, 1957b)".

A more effective measure to ensure rational exploitation is fishery regulation through establishing a science-based total catch limit (TAC) based on a stock status. Therefore, the subsequent history of the cod fishery management was based on giving the priority to establishing a TAC on the basis of scientific advice with simultaneous development of other regulatory measures for the fishery.

In 1958 the first meeting of the Arctic Fisheries Working Group (AFWG) under the International Council for the Exploration of the Sea (ICES) was held in Bergen, where for the first time assessment of the Barents Sea commercial fish stocks, cod including, was undertaken. Russian and Norwegian scientists Yu.Yu.Marti, V.I.Travin, G.Rollefsen, A.Hylen participated. After that the assessment of stocks was conducted on an annual basis. In 1964 to assess the cod stock the Virtual Population Analysis (VPA) was applied for the first time.

It should be noted, that before mid-1970s although the AFWG provided scientific advice on catch options, no binding decisions were taken to regulate the fishery by quotas. This left the total fishing effort unrestrained from increasing, as a result of which the fishing mortality of juvenile cod, not having used its potential for growth, increased in the 1970s, when even strong year classes could not support yet long-term mean, let alone high, catch rates (Ponomarenko, 1982).

Introduction of national economic zones and negative trends in the Barents Sea commercial fish stocks dynamics were major reasons for establishing the Joint Soviet-Norwegian Fisheries Commission, later the Joint Russian-Norwegian Fisheries Commission, in January 1976 with the objective to ensure a coordinated effective management of joint stocks.

Annual cod quotas have been setting up by the Joint Fisheries Commission since late 1970s. It should be noted that at some of its annual meetings the levels of commercial harvest adopted by the Commission were higher than recommended by Russian and Norwegian scientists. In addition, until mid-1980s there were no limitations for fishing of cod by net, line and jigger, which increased the harvest beyond recommended levels.

A revision of established limits in order to reduce them for critical status of the cod stock was needed only once – in 1988. The reduction of catch limits led to a reduction of fishing mortality (Jacobsen, 1992) and gradual growth of the stock. In 1992 the catch limit was revised with the aim to increase it.

Later on a higher accuracy of management advice for the cod fishery was achieved through refining the methodology for estimating a TAC, taking into account predator-prey relations and cannibalism.

The next step in optimizing the cod fishery was an agreement concerning "a 3-year harvest control rule" adopted by the 31st session of the Joint Russian-Norwegian Fisheries Commission and effective from 2004. Under this agreement, seeking to achieve a year-to-year stability of TACs and create conditions for high long-term yield from the stock the Parties decided:

- estimate the average TAC level for the coming 3 years based on Fpa. TAC for the next year will be set to this level as a starting value for the 3 years period;
- the year after, the TAC calculation for the next 3 years is repeated based on updated information about the stock development, though such that the TAC should not be changed by more than +/-10% compared with the previous year's TAC;
- if the spawning stock falls below Bpa, the Parties should consider a lower TAC than according to the decision rule above.

Simultaneously with the scientific advice for the management of cod stock being improved technical measures to regulate this fishery were also modified. For instance, minimum mesh size was revised several times (from 80/90 mm for Norwegian/Soviet trawlers in 1946 to 135/125 mm in 1982) and minimal landing size for cod as well (from 34 cm in 1964 to 47/42 cm for Norwegian/Russian fishing vessels in 1988/1990). Furthermore, in order to reduce the by-catch of juvenile cod sorting grids were made mandatory for use on the trawl fishery from 1997. In mid-1980s a limit for allowable by-catch of juvenile *Gadidae* on the shrimp fishery was established and in mid-1990s a mandatory use of sorting grids on this fishery was introduced.

Table 1. The history of alteration of management measures applied on the Northeast Arctic cod fishery

Year	Management measures
1961	Introducing minimal mesh size in trawls of 110 мм
1963	Introducing minimal mesh size in trawls of 120/130 мм
1978	Establishing annual TAC for trawl fishery
1979	Introducing measures to improve spawning conditions
1981	Introducing minimal mesh size in trawls of 125 мм
1982	Introducing minimal mesh size in trawls of 135 мм*
1983	Establishing annual TAC for the cod fishery (for all fishing gear, including fixed engines)
1984	Limiting the by-catch of juvenile *Gadidae* on shrimp fishery
1992	Limiting the by-catch of juvenile *Gadidae* on capelin fishery
1993	Introducing sorting grids on shrimp fishery
1997	Introducing sorting grids on cod fishery

**Applies to all vessels operating in the Norwegian economic zone.*

The use of unified management measures such as TAC, mandatory use of sorting grids and others, by all nations exploiting the cod stock is certainly advantageous. At the same time, differing minimal mesh size in trawls, minimal landing size of fish applied in different economic zones complicate the development of scientific advice. Therefore, a long-term objective for Russia and Norway would be the development and implementation of unified management measures for the cod fishery overall.

The current management system

The management system for cod stock is based on three sources of information about its status (Fig.1). The first is fisheries statistics, which includes information on catch, catch per effort, mean weight at age and age composition of commercial catch provided to ICES by all nations engaged in cod fisheries.

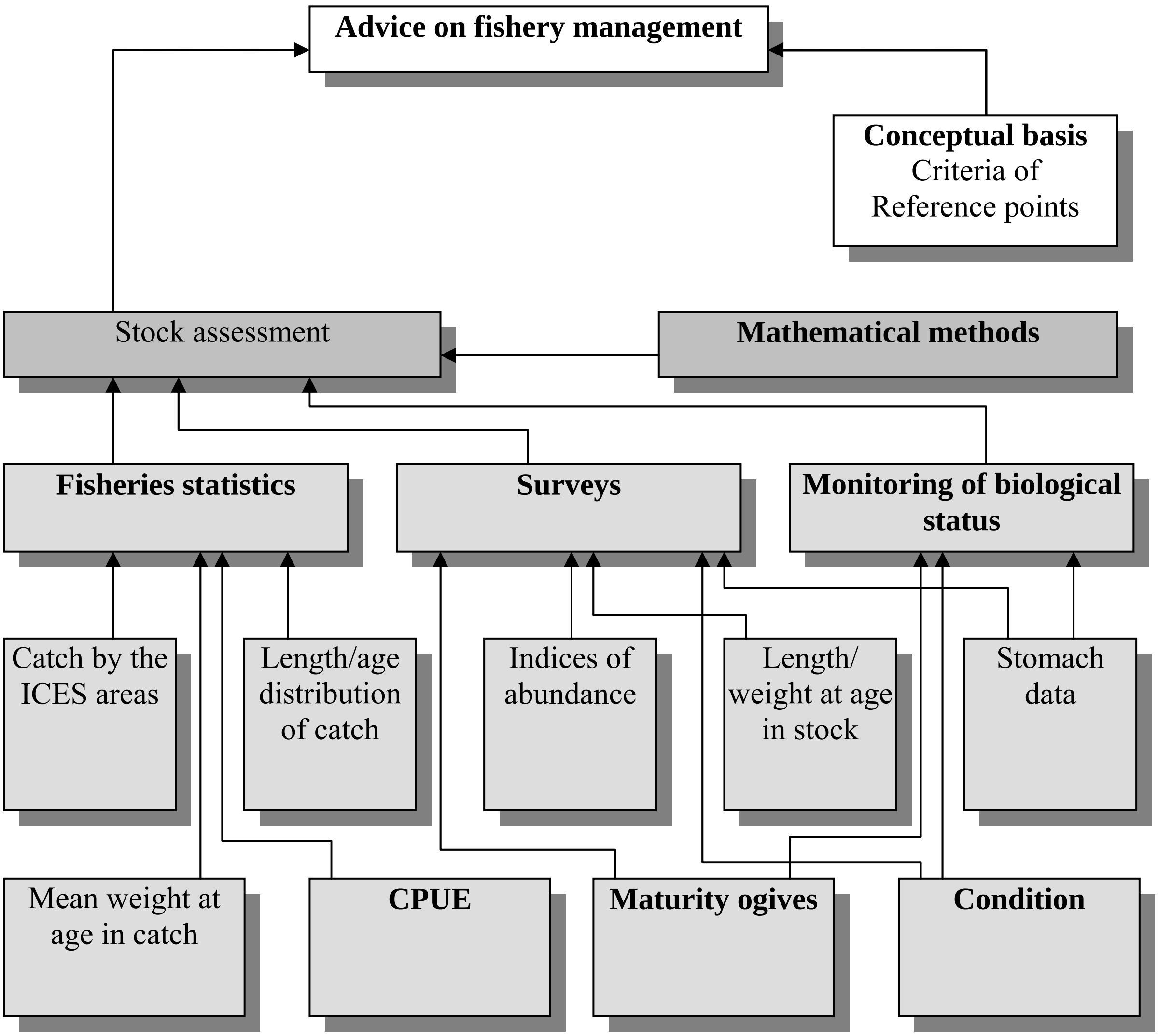

Fig 1. Diagram to show schematically how management advice for the Northeast Arctic cod is developed

The second important source of information is trawl-acoustic surveys conducted by Russia and Norway, which provides data for estimating the abundance indices, length and weight at age and maturity ogives. Survey data are supplemented by environmental data.

The third source of information is a year-round-run observer program on fishing vessels and coastal plants, which provides information on cod feeding conditions, maturation rate and abiotic conditions in its habitat.

All information compiled is used for stock assessment for which a variety of mathematical methods are applied, of them the key method is VPA. This method permits to develop a science-based advice on the level of fishing mortality (F).

In choosing the optimal fishing mortality rate various biological reference points set on the basis of the relationship between catch and F as well as recruitment and spawning stock biomass are taken into consideration. Some history of the ICES framework for advice given in Aglen et al. (2004). An optimal level of the chosen F means that a principle of maximizing the long-term yield is met (to prevent overfishing). Besides, the need to avoid excessive outtake of juvenile fish, recruits to the commercial stock, and maintain the spawning stock biomass (SSB) at the level preventing from impaired recruitment is taken into account.

Comparison of the annual and the most recent stock assessments

In a review of the exploitation and management of several stocks in the area some years ago (Nakken 1998, 2002) it was shown that agreed and actual catches frequently exeeded the advised ones. In addition, it was shown that the annual stock assessment tended to be biased, particularly for North-East Arctic cod; i.e. the annually estimated fishing mortalities were as a rule substantially lower than those arrived at in later assessments for the same year. On an average the fishing mortality rates seemed to be about 20 percent too low and consequently the stock estimate, on which the annual advice was based, was about 20 percent too high. Nakken (1998, 2002) therefore recommended that considerably more caution ought to be used by management authorities when deciding on TAC's in the future.

In the present paper we have updated the information on advised and agreed TAC's as well as actual catches, and we have also compared the annually estimated fishing mortalities, SSB and recruitment numbers (age 3) with the figures arrived at in the most recent assessment; i.e. the 2005 assessment. The results indicate that in recent years the errors in the annual assessments have been minor as compared with previous periods and than the large downward bias in fishing mortality rate (upward bias in stock estimate) has been absent since 1998.

Table 1 and Figure 1 present advised, agreed and actual catches of North-East Arctic cod in the period 1984-2004 as given by ICES. For some of the years ICES has advised on an upper limit of fishing mortality rate and we have calculated the corresponding TAC. The comparison (Fig.1) shows that since 1998 the TAC's decided on, have been much higher than the advised ones, and in most recent years the actual catches have also exceeded to a considerable extent the TAC's decided on by the authorities.

In Table 2 and Fig.2 are also showncomparisons of the main results (SSB, fishing mortality rate and recruitment) of the assessment carried out annually and those from the ICES' stock assessment in spring 2005. The figure 2 indicates that spawning stock biomass has been estimated "precisely" since 1998. It also appears that the gross underestimation of fishing mortality rate (and overestimation of SSB) in the annually estimated figures experienced in the mid 1980s and the period 1990-1997 has been absent since 1998, and there is a slight tendency to the opposite for 2000-2003. Apart for 2-3 years in the early 1990s recruitment figures seem to have been estimated with good precision (lower panel of Figure2).

Table 2. North-East Arctic cod: Adviced, agreed and actual catch (thousand tonnes), and assessment results, both from annual assessments and from the 2005 assessment. SSB is the spawning stock biomass (thousand tonnes), F is fishing mortality and R3 is recruitment at age 3 (millions spec.)

	Catch (000 tonnes)			SSB (000 tonnes)		F 5-10		R3	
Year	Adviced	Agreed	Actual	Annually	2005	Annually	2005	Annually	2005
1984	150	220	278	354	251	0.59	0.89	300	398
1985	170	220	308	407	193	0.62	0.8	677	524
1986	446	400	430	397	170	0.65	0.91	1000	1036
1987	645	560	518	275	118	0.96	1.01	443	286
1988	530	590	459	189	202	0.9	0.9	156	204
1989	335	300	351	151	194	0.67	0.72	175	173
1990	172	160	212	327	340	0.27	0.29	136	242
1991	215	215	319	680	674	0.19	0.34	227	412
1992	250	356	513	1047	869	0.39	0.44	642	721
1993	256	500	582	1024	737	0.43	0.55	808	896
1994	649	700	771	774	599	0.51	0.86	908	811
1995	681	700	740	570	499	0.58	0.79	717	655
1996	746	700	732	720	569	0.57	0.7	474	437
1997	993	850	766	694	564	0.79	1.04	763	717
1998	514	654	561	419	387	0.91	0.92	819	851
1999	360	480	485	266	256	0.96	1	585	599
2000	110	390	415	223	229	0.91	0.86	591	688
2001	263	395	427	298	334	0.84	0.71	462	542
2002	181	395	535	505	520	0.69	0.64	498	447
2003	305	395	552	643	585	0.46	0.5	502	502
2004	398	486	579	714	714	0.57	0.57	276	276

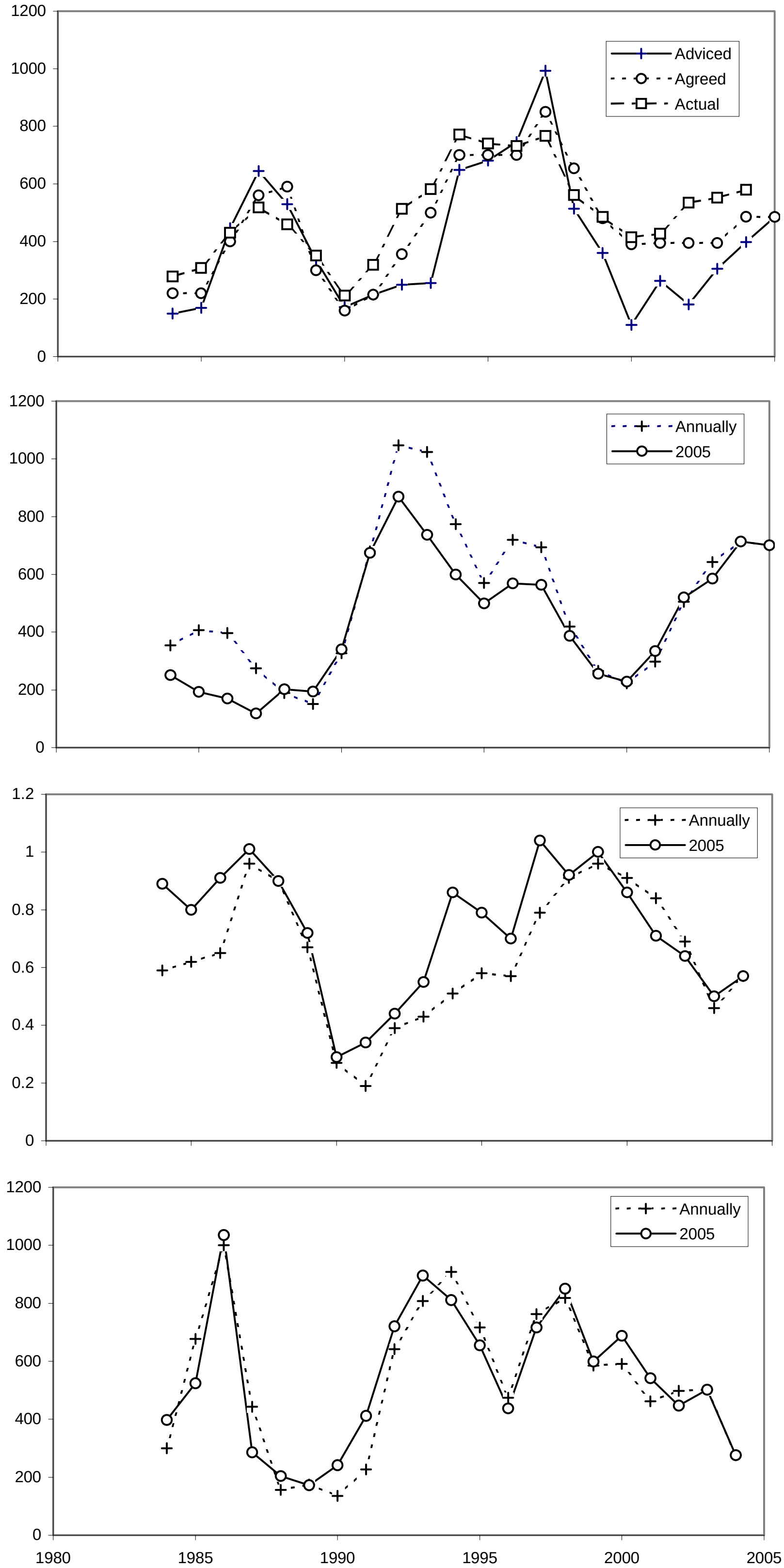

Figure 2. North-East Arctic cod. Panels from top: Catch (thousand tonnes), spawning stock biomass (thousand tonnes), fishing mortality, and recruitment at age 3 (millions spec.). Data as shown in Table 1

Statistical and political geography of the NEA cod's distribution range

There are several international and national schemes of division of the NEA cod's distribution range into areas, which directly or indirectly serve the purpose of management of biological resources, cod stock including.

For instance, the split into areas established by ICES aims at addressing a wide range of issues, such as catch statistics, assessment and distribution of stocks (Fig. 3A).

One of the reasons of establishing a system of economic, fishing and fish protection zones in the Barents Sea (Fig. 3B) in 1976 de jure and 1978 de facto was also a need for more effective management of stocks. All fishery regulations concerning fishing gears to be used, fishing seasons and areas, by-catch limits etc. are zone-specific or related to international agreements in force.

Russian trawl-acoustic and trawl surveys of stocks in the Barents Sea, cod including, use a map of fishing areas, which are in turn divided into rectangles of 10x10 n.miles^2 each (Fig. 3C). The same map is used for temporal closure of areas, when the by-catch of juveniles of commercial fishes on the trawl fishery of *Gadidae* and shrimp exceeds the established limit.

In Norwegian trawl-acoustic surveys of bottom fish a system of strata is applied (Fig.3D) and a system of statistical areas for harvest control.

This diversity of schemes, which serve to address a wide range of tasks, does not, at present, represent any impediment to accurate assessment of the cod stock. However, one of the steps towards deriving more accurate abundance indices by surveys could be establishing a unified scheme of division of the cod distribution area into strata.

Future of management

Despite a fairly long history of research on the Northeast Arctic cod and its extensive scope many aspects of the biology of this species still remain inadequately studied. To fill the gaps it is, for instance, important to undertake a more thorough analysis of the spawning stock/recruitment relationship with the focus on the phenomenon of skipped spawning, sex composition of the parent stock etc.

In our view, the stock assessment should place higher emphasis on biological aspects of cod's life history.

Moreover, some political problems has to be solved, such as

- unification ofishery management rules within the margin of cod area
- getting of reliable fishery statistics.

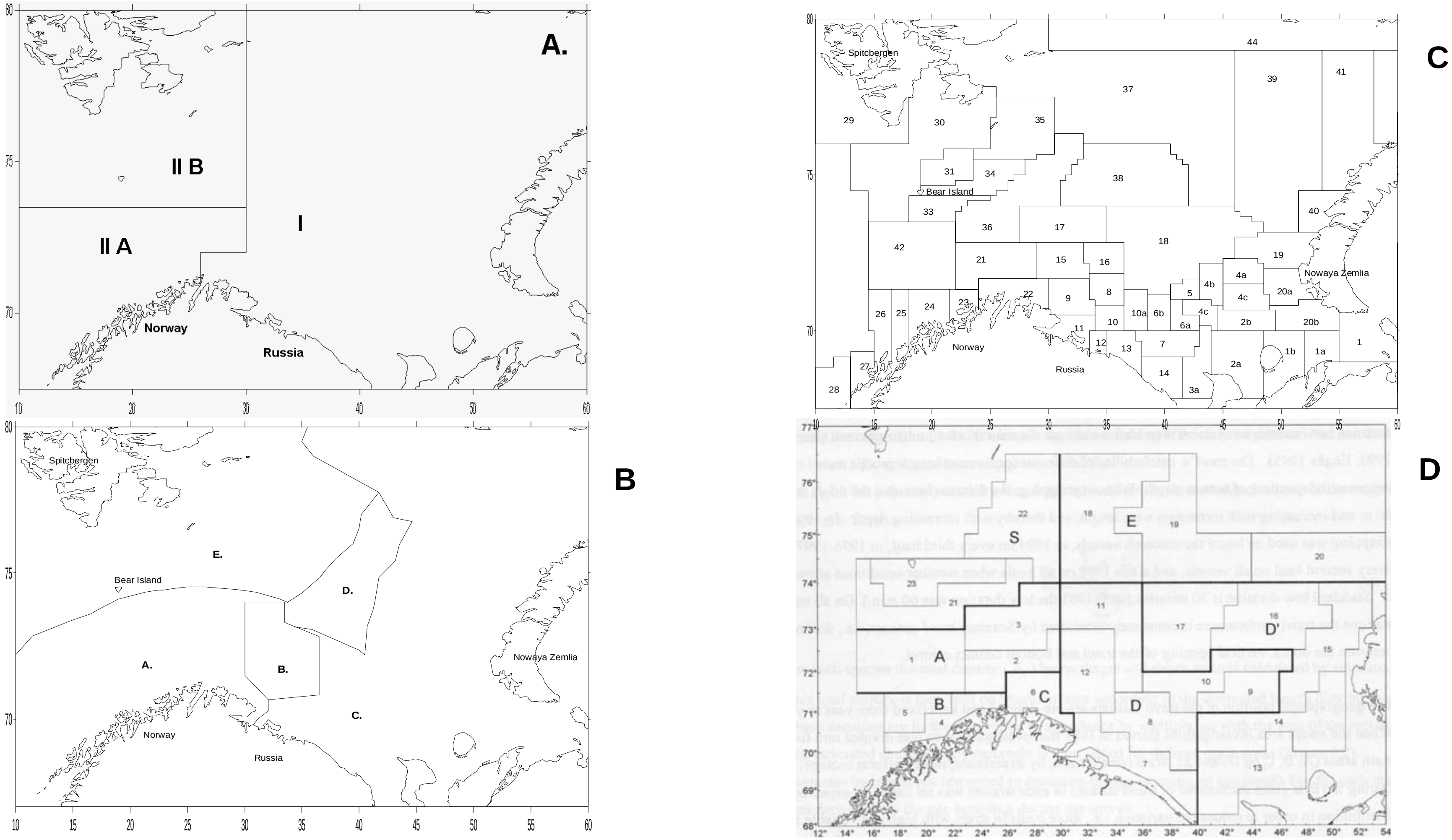

Fig.3. International and national division of the NEA cod distribution range into areas
(A – ICES areas; B – Economic and fishing zones; C – Russian fishery areas; D – Norwegian strata and main areas

Legend to fig 3:

Fig.3C. The Russian fishery areas (Trudy PINRO, vyp. 10, 1957).
Eastern areas (1; 1a; 1b; 2a; 2b; 3a; 3b; 20b).
Central areas (4a; 4b; 4c; 5; 6a; 6b; 7; 18; 19; 20a).
Coastal areas (12; 13; 14).
Western areas (8; 9; 10a; 10b; 11; 15; 16; 17; 21; 22).
Norwegian coast (23; 24; 25; 26; 27; 28).
Northwestern areas (29; 30; 31; 32; 33; 34; 35; 36; 37; 38; 42).
Northeastern areas (39; 40; 41).

Fig.3B. Economic and fishing zones in the Barents and Norwegian Seas

A. Exclusive Economic Zone of Norway;
B. Area of joint fisheries between Russia and Norway;
C. Exclusive Economic Zone of Russian Federation;
D. Area outside Economic Zones of Russia and Norway (Enclave);
E. Bear Island – Spitsbergen area.

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THE USE OF B_{PA} REFERENCE POINT WHEN DETERMINING TAC FOR THE NEA COD: HOW VALID IS IT?

by

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Abstract

Management of fishery using TAC constraint is intended to maintain such number of spawners (usually the term “spawning stock biomass (SSB)” is used), which would provide the stability, and preferably an increase, in the stock reproduction. In compliance with the precautionary approach (PA), considerable research efforts are made to determine the optimum level of SSB = B_{pa}, which supposedly can reduce to a minimum the risk of poor recruitment (R) when SSB ≥ B_{pa}. It implies the presence of the required direct or curvilinear positive relationship between SSB and R that does not contradict the logic. However, in fact, many numerous highly fecund species, to which the NEA cod belongs undoubtedly, do not show such a relationship. Apparently, in such species, recruitment depends on survival conditions at their early life stages rather than on quantity of eggs spawned. Therefore, with regard to each fishable population, before assessing the B_{pa} level it is necessary to evaluate contribution of SSB to R compared to that of the other factors. As for the NEA cod, the variance analysis showed that the effect of SSB on the number of survivors at age 3 is limited to the range of 4,3 to 14,7% (the significant estimate is 7,5 %). In our opinion, since the contribution of SSB to R is quite low, it makes no practical sense to establish B_{pa}, which can be just of theoretical interest. The primary emphasis should be placed on identification and prognosis of those environmental factors, on which survival of eggs, larvae and juveniles depends first and foremost.

Introduction

Scientific advice on the annual establishment of the Total Allowable Catch (TAC) for commercial fish populations is the most widespread sort of advice in the international practice of fisheries management. It is quite reasonable in the aspect of efficient fisheries, because the TAC limitation that takes into account the current status of the population helps to preclude both growth (biomass) overfishing, and recruitment overfishing.

The latter consideration (i.e. prevention of recruitment overfishing) is of particular importance because it is aimed at limiting catches of mature fish. Abundance of fish that escaped from previous fishing and is engaged in reproduction of potential spawners is usually associated with succeeding recruitment (R), e.g. which is to occur in 2, 3, or 4 years. It is expected that today's restrictions on catches will ensure recruitment increase in the nearest future.

Therefore for each relatively valuable fishery species, experts calculate spawning stock biomass (SSB) levels that are supposed to ensure success in reproduction (Serebryakov, 1990; Jakobsen, 1992; O'Boyle, 1993; Bondarenko et al., 2003). In accordance with the precautionary approach (pa) concept, considerable research efforts are taken to identify or specify an optimal level of SSB = B_{pa} to minimize risks of a poor recruitment.

There are no doubts about the biological validity of such an approach to fisheries management when we speak about species whose retrospective study confirms a connection between the spawning stock and the produced number of recruits to the fish stock. Conversely, other species do not reveal such connections and their recruitment seems to be determined by survival rates at the pre-recruitment stage rather than the original abundance of produced eggs.

We consider it inappropriate to determine B_{pa} for such populations. No matter how precautionary it is there will always be a risk that Nature may dispose of the yield of our conserved spawning stock. This raises doubts about propriety of establishing lower TACs mainly or only in order to maintain SSB ≥ B_{pa} as well as propriety of use the B_{pa} reference point to set up TACs.

Therefore it would be reasonable to check the SSB effect on the R formation against other relevant factors prior to determination of the fish population B_{pa} level and use the latter for TAC setting. This approach has already been taken to the north-eastern arctic cod stocks on the basis of dispersion analysis (Borisov et al., 2004). The results convince us that such studies should be expanded and intensified. Here we have systemized additional information on this issue.

Materials and Methods

The main source of the original data is reports of the ICES AFWG containing assessments of the cod annual spawning stock biomass since 1946 and abundance of year-classes that survived till the age of 3 (N_3) in each spawning stock (Anon., 2005). Correspondence between these indicators for both the entire data array (56 sets of SSB-N_3) and individual data groups was assessed by the correlation coefficient.

In order to identify the percentage of year-classes which abundance corresponded to small-sized, medium-sized, large-sized, and very large-sized spawning stock, (<300,000 tons; 300,000-600,000 tons; 600,000-900,000 tons; and >900,000 tons, respectively), the N_3 values were classified into four traditional groups (Boytsov et al., 2003): poor, medium, rich, and very rich year-classes (<300,000,000 ind.; 300,000,000-500,000,000 ind.; 500,000,000-900,000,000 ind.; and >900,000,000 ind., respectively). Figure 1 presents a diagram of this correspondence.

The spawning stock influence on abundance of the progeny is traced through five stages of the year-class formation (Figs. 2 and 3) with the help of: the estimated number of produced eggs or population fecundity (PF); the abundance indices for pelagic juveniles (Pel.j.) and young fish at the demersal stage, i.e. fish at the age of 0+, 1+, and 2+ (Borisov et al., 2001; Sokolov et al., 2004).

A single-factor dispersion analysis of the N_3 dependence on SSB was done with several variations (namely, 6 variations) because the results were influenced by the scope and number of the SSB groups (Table 1).

Practical advice on the commercial cod stock conservation and maintenance at a relatively high level takes into account the yearly average individual increase in weight and the average survival ratio for each age group. The original data are taken from the ICES AFWG reports (Anon., 2005); the indicators were averaged for the last ten year-classes (Fig. 5). The author thanks Dr. Tretyak (PINRO) for his help with the data fitting and extrapolation in this study.

Results

Study of correspondence between the cod spawning stock biomass and the respective recruitment-stock abundance revealed a virtual absence of such correspondence. The correlation coefficient calculated for 56 sets of SSB-N_3 data appeared statistically insignificant (0.23). An objection could be made that a small value of the total correlation coefficient was associated with implicit curvilinear relationship between these indicators with substitution of the positive correspondence (for some SSB values) for the negative one (for other SSB values).

For the sake of study, the entire range of the SSB values was divided into 2, 3, 4, 5, and 6 groups with respective sets of the N_3 data. Then individual correlation coefficients were calculated for each group (Table 1). Our results indicated that the SSB values of <250,000 tons and < 200, 000 tons were the only groups which correlation coefficients were significant (0.44 and 0.46, respectively, at the significance level of 0.05). The rest of the groups did not reveal any significant correspondence.

Even this simple analysis throws doubt on the claim that conservation of a large spawning stock through the TAC limitations would definitely bring about growth in the population. At least the statistics does not confirm that. Generally, however, it is a priori thought that a larger spawning stock has more chances to produce an abundant recruitment than a smaller one which often produces poor year-classes.

Studying correspondence between the number of three-year-old cods and various levels of the spawning stock biomass, we divided the SSB-N_3 coordinate field with 56 points into 16 squares (Fig. 1) in accordance with the classification described in *Materials and Methods*.

The picture shows that only one third of all year-classes comes into the zone of correspondence, while two thirds (37 out of 56 sets) lack correspondence between the number of three-year-old cods and the brood stock biomass. Out of 26 year-classes produced by a small-sized spawning stock (<300,000 tons): ten generations (38.4%) were rich and very rich, five generations (19.2%) were medium, and less than half the year-classes (42.4%) were poor and corresponded to a low SSB.

The medium SSB group showed still less correspondence between the number of three-year-old cods and the level of the brood stock biomass. Out of 22 year-classes produced only five generations (22.7%) were "medium". The medium SSB was most preferable for production of rich year-classes; they almost attained 59% in this range of the SSB values. The following SSB ranges, large-sized and very large-sized spawning stocks, did not show any obvious relationship with the recruit number. Only three out of eight year-classes came into the zone of correspondence. Figure 1 also illustrates the fact that five out of nine most abundant year-classes (>900 x 10^6 ind.), i.e. more than a half, were produced by the spawning stock that did not exceed 230,000 tons.

The presented attempts to find correspondence between the cod spawning stock and recruitment persuaded us of its absence rather than presence. However, it is hardly possible that SSB does not influence abundance of a year-class and, consequently, a number of three-year-old cods entering exploited stock. The question is how important will this influence be, compared to other factors?

A single-factor dispersion analysis allows us to assess a degree of the SSB effect on recruitment (Table 1). Because of sensitivity of the method not only to the number of groups differentiated in the data array, but also to the scope of individual groups, there were six variants of calculations. Only one of these calculations was statistically significant; the SSB values were divided into two groups (<600,000 tons and > 600,000 tons). The SSB effect on the recruitment formation made 7.55%.

Though the rest of the variants were insignificant and the SSB effect varied from 4.34% to 14.7%, we did not discard them. Taking into account the reservation made, we have to note that in the case of cod stocks the effect of spawners' biomass on formation of recruitment is not likely to exceed 10 %; the rest and, consequently the major driving force in recruitment formation belongs to a set of other factors which have no direct relations with abundance/biomass of the spawning cod. Let us leave identification of the actual causes that directly influence the young cod survival at the pre-recruitment stage beyond the scope of our discussion and concentrate our attention of the following.

The period from production of eggs till entrance of survived recruits into the commercial cod stock lasts three years at the least. During this period there occurs a significant "correction" of the year-class abundance that breaks the inherent relation with the spawning stock. A series of curves could answer this question (Figs. 2 and 3).

There could be no doubts that abundance of produced eggs depends on the spawning stock (Fig. 2a) not only because the PF calculations are based on SSB (i.e. on the number of females in each age group and their mean individual fecundity determined for the respective age group). The relation is objectively true because the higher SSB we observe, the more mature females will come to spawning grounds, and the more eggs will be produced.

Contrary to the conventional view that this relation is broken during the "critical period", i.e. at the stage when the yolk sac resolves and the larva transits to self-feeding (Hjort, 1926; Ellertsen et al., 1977; Last, 1978), the major correction of generation abundance seems to occur somewhat later. It is proved by a rather good agreement (r = 0.8) of the relative abundance of pelagic juveniles with the biomass of the respective spawning stock (Fig. 2b). The autumn-winter survey of demersal juveniles, however, showed that at the succeeding stage, abundance indices for young fish at the demersal stage did not correspond to SSB (r = 0.08; Fig. 3a). Naturally, there was no correspondence between SSB and the respective generations at the age of 1+ and 2+ (Figs. 3b and 3c). Here we should note that observations made during the autumn-winter survey were rather objective. It is indicated by a quite satisfactory synchronism in dynamics of juveniles from the same year-classes observed at different age (Fig. 4).

Comparison of abundance indices for various age groups of young cod with SSB rather definitely indicates the most vulnerable period in recruitment formation which occurs at the beginning of the juveniles' transition to the bottom life stage. Apparently, marine biology forecasters should pay attention to this stage of the cod life cycle and identify major factors causing massive elimination of demersal young cod at the age of 1+. To be more exact, we should use our modern technical and research capacity to continue studies which were actively carried out by our predecessors in the 1960s – 1980s.

The evidence presented supports our conviction about uncertainty of measures aimed at conserving some "indispensable" number of cod spawners today in order to provide a high level of the fish stock in three or four years. This approach should be treated as theoretical rather than applied.

The aim of the fish stock increase could be achieved through a more straight and efficient approach, i.e. introducing conservation measures for young fish which survived to the age of 2, 3, or 4 despite unfavorable habitat conditions. This age group contains relatively strong fish able to survive temporary food deficit and other poor conditions. At this age survival of the juveniles depends on frequency of their interactions with larger-sized cods, i.e. on cannibalism rates. Apropos the strategy of sustaining a high SSB brings about increase in cannibalism rates.

Another important cause of decline in number of the young fish and consequently the potential commercial stock is associated with practices of bycatch and discards (Dingsor, 2001; Sokolov and Tretyak, 2001).

According to Sokolov's studies (2003), annual discards of juveniles of non-target species or undersized fish often attained 15-20,000,000 individuals. We have attempted to assess effect of such discards on the total commercial stock for 13 years of a year-class participation in the fishery (Table 2). The assessment was performed with averaged weights and survival coefficients arranged by the cod age-groups (Fig. 5). An example of one generation with the initial number of two-year-old fish totaling 500,000,000 individuals shows a significant effect of the survival coefficient (*S*) for three-, four-, and five-year-old cods that grew from 0,657, 0,655, and 0,547 to 0.7, 0,7 and 0.6, respectively. Here the assumed *S* increase approximately totals 20, 15, and 10 mln. cods respectively. This is close to estimated discrards for these age groups. We can see that decrease in discards of these age groups only by 0.043 – 0.053 will increase the total biomass of all age groups in the commercial stock by more than 200,000 tons. If targeted conservation of young fish, including measures to decrease bycatch and discards, allow us to increase the survival coefficients for three-, four-, and five-year-old fish by 0.8; 0.8 and 0.7, respectively, the long-term total biomass of the commercial stock with the same initial abundance could be larger by 745,000 tons (Table 2).

Such strategy for the commercial stock increasing seems quite feasible. It is more realistic and effective than measures aimed at obligatory maintaining SSB ≥ B_{pa}.

Discussion

As it was shown in Figure 2, the B_{pa} strategy applied to cod stocks can sustain only population fecundity and abundance of pelagic juveniles. As for recruitment abundance, this measure is inefficient. Therefore it is inevitable that we doubt validity and expedience of the B_{pa} use to establish TACs. We believe that the B_{pa} importance as a biological reference point in fisheries management is also precarious. Unlike the parent indicator of B_{lim}, it is a statistical rather than biological indicator. While B_{lim} has actually got some biological meaning indicating the lowest safe SSB inherent to the given population, B_{pa} is only the upper statistically determined bound with the confidence coefficient of 95%: $B_{pa} = B_{lim} \exp(1.645\ s)$. However, the B_{pa} reference point is often considered a biologically sound optimal level of SSB which is almost mandatory for TAC establishment though the objective could be achieved through other ways.

Development of traditional production models (Schaefer, 1954; Fox, 1970; Shepherd, 1982) to forecast annual growth in biomass and yield seems more promising and biologically sound. At least, we could, with reason, regard the model annual growth of production (including increase, decrease, and variation forecasts for these indicators) as a true biological reference point to be used to establish TACs.

For the same purpose we could discuss the following scheme (Fig. 6) where SSB is only a part to the entire commercial stock rather than the major reference point for TAC assessment. Necessity of this forecast element is very doubtful. This is true not only for cod stocks, but also for many other abundant and highly fecund species with the population yield depending rather on survival conditions at early onthogenesis than on the initial egg production, i.e. the spawning stock biomass.

The presented scheme includes all traditionally measured principal features of the stock and the respective fishery output as well as analysis and forecast of factors determining state of the former and the latter. Special attention is given to studies of period and factors which play a key role in recruitment formation. The only novelty in the scheme is a special accent on attaining correspondence between annual relative variations in catches ($\Delta C\%$) and stock ($\Delta S\%$). The TAC for the next year is increased/decreased against previous years by the same percentage as the forecasted increase/decrease in the commercial stock.

On the other hand, correspondence between $\Delta C\%$ and $\Delta S\%$ should not be regarded as a dogma (compare: once determined precautionary reference point of the fishing mortality (F_{pa}) that is used for ages). On the eve and in years of positive trends in the stock development a reasonable excess of $\Delta C\%$ over $\Delta S\%$ could be possible, whereas in the case of negative forecasts $\Delta C\%$ should be decreased against $\Delta S\%$. In both cases, fisheries is a damper that helps maintain the stock at a relatively stable level.

The scheme allows us to implement a more sound approach at which stocks are not managed through fisheries, but current and forecast fluctuations of the stock make the fisheries change to fit them. Despite high ambitions of managers who claim that they manage fish stocks, this kind of management is at best an attempt to mitigate adverse anthropogenic impact which cannot be regarded as management of fish stocks. On the other hand, people are able and ought to manage fisheries in such a manner that negative anthropogenic impacts on fish stocks would inevitably be minimized and fisheries ultimately would not interfere with natural reproduction.

Concerning commercial stocks, it is realistic and extremely important for us to follow the principle, "no harm done". While the global task of fish stock management has always been and will remain within the scope of Nature.

Conclusion

The performed analysis shows that common use of the B_{pa} reference point to set up TACs is not always reasonable. At least in the case of species with R dependent on survival conditions for pre-fishery juveniles rather than SSB, this indicator cannot be regarded as properly biologically based. Therefore it would be reasonable to check the SSB effect on the R formation prior to determination of B_{pa} and use it for TAC setting.

According to statistics, the SSB effect on the R formation in cod stocks made 7.55%. The rest and, consequently the major driving force in recruitment formation belongs to a set of other factors.

Presence of relation between SSB and abundance indices for pelagic juveniles (the summer survey) and absence of such relation in the case of demersal young fish (the autumn-winter survey) support conclusions that young cod is most vulnerable at the onset of the first wintering and transition to the bottom life stage. The reasons for such changes need further detailed studies.

Cautious attitude towards young fish, including a ban on trawl fishing in areas of its highest concentrations and decrease of discards of undersized fish, should be considered a principal source of the commercial stock growth.

As to species with significant natural fluctuations in recruitment that are not connected with SSB, it is preferably to set TACs taking the "achieved level" as a start-point. The achieved level of catches is adjusted for the forecast year in accordance with the estimated growth/decrease in the stock. However, the degree of such accordance should account for annual and also much longer trends in the stock development.

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Table 1. Estimation of the SSB role in forming of the cod recruitment (N_3)
(data of one way variance analysis)

SSB groups	Correl. coef. by groups (r)	Generations in group (n)	Sum of devations' square: between groups (SSa)	inside groups (SSe)	total (SS)	SSB role for N3 SSa/SSx100%	Average sums of: mSa	mSe	Fisher's calculat. criterion (Fc)	Fisher's standart criterion (Fs)
< 600 > 600	0.13 -0.37	47 9	598553	7331635	7930188	*7.55*	598553.4	138332.7	4.32691*	4.02301
< 400 401-800 > 800	0.16 0.31 -0.17	39 13 4	361173	7569015	7930188	4.55	180586.6	145558.0	1.24065	3.17515
< 250 251-500 501-750 > 750	*0.44* 0.24 0.32 -0.17	23 20 9 4	343837	7586351	7930188	4.34	114612.3	148752.0	0.77049	2.78623
< 300 301-600 601-900 > 900	0.32 -0.03 -0.42 -0.73	26 21 6 3	665753	7264435	7930188	8.40	221917.5	142439.9	1.55797	2.78623
< 250 251-500 501-750 751-1000 > 1000	*0.44* 0.24 0.32 - -0.73	23 20 9 1 3	350802	7579386	7930188	4.42	87700.5	151587.7	0.57855	2.55718
< 200 201-400 401-600 601-800 801-1000 > 1000	*0.46* -0.29 -0.01 -0.35 - -0.73	16 23 8 5 1 3	1166624	6763564	7930188	14.71	233324.8	138031.9	1.69037	2.40438
Common	0.23	56								

Comments: SSa - factor mutability (for studied factor); SSe - variate mutability;
SS - total mutability; mSa - deviation of group averages of studied factor;
mSe - deviation of group averages of nonstudied factors; Fc = mSa/mSe; Fs for P=0.95;
blue figures are statistically significant;
* - Fc>Fs indicates the confidence of the effect of the factor considered

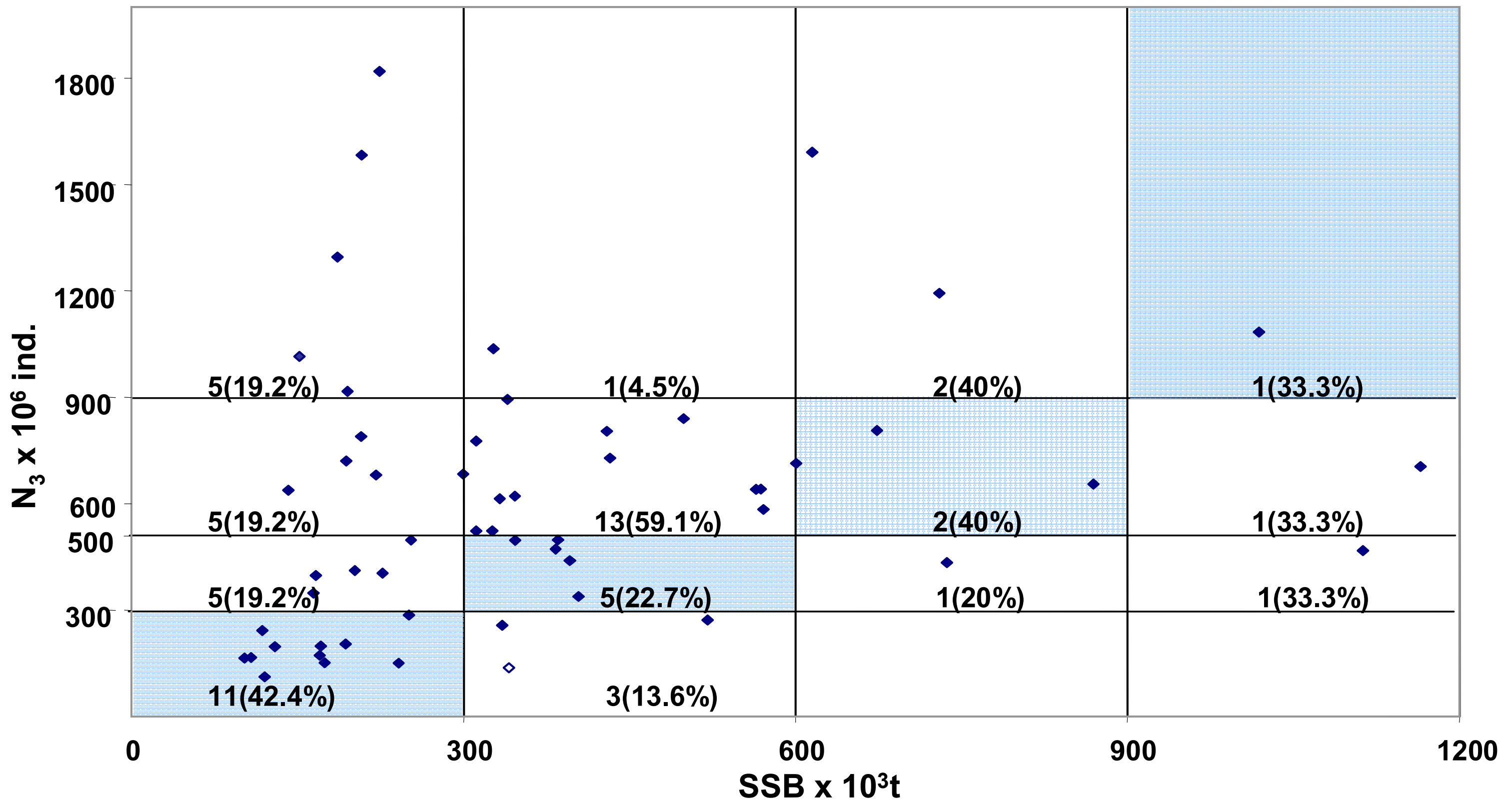

Fig. 1. Strength of the year-classes (N_3) born from different SSB levels. *Figures in the rectangles point quantity /percentage of the year-classes by N_3 groups in every SSB range. Shaded rectangles show the zone of correspondence among N_3 and SSB range.*

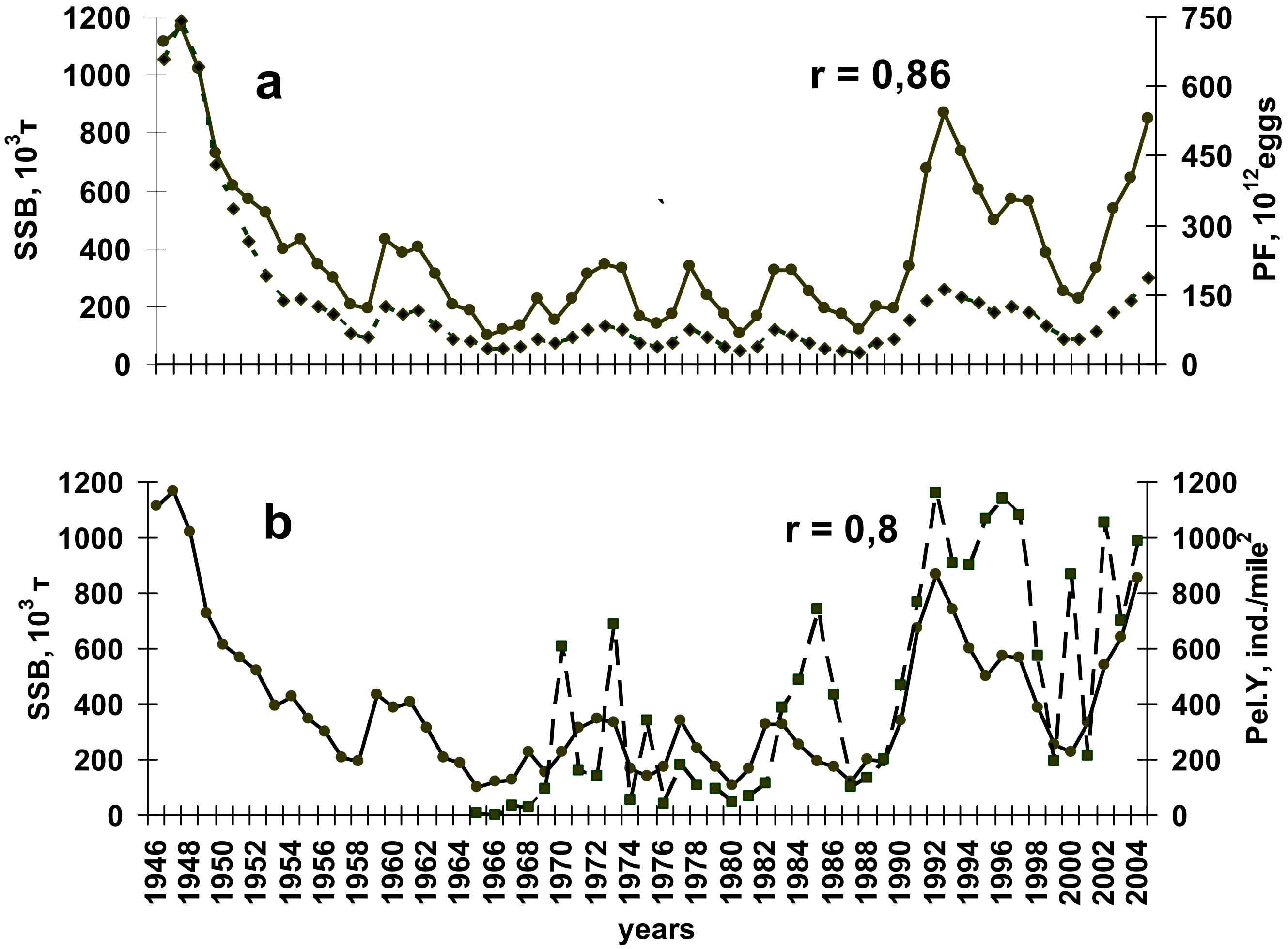

Fig.2. NEAcod. Spawning stock biomass (SSB), population fecandity (PF) and pelagic young (Pel.Y.) (-●- SSB; – -♦- – PF; —■— Pel.Y.)

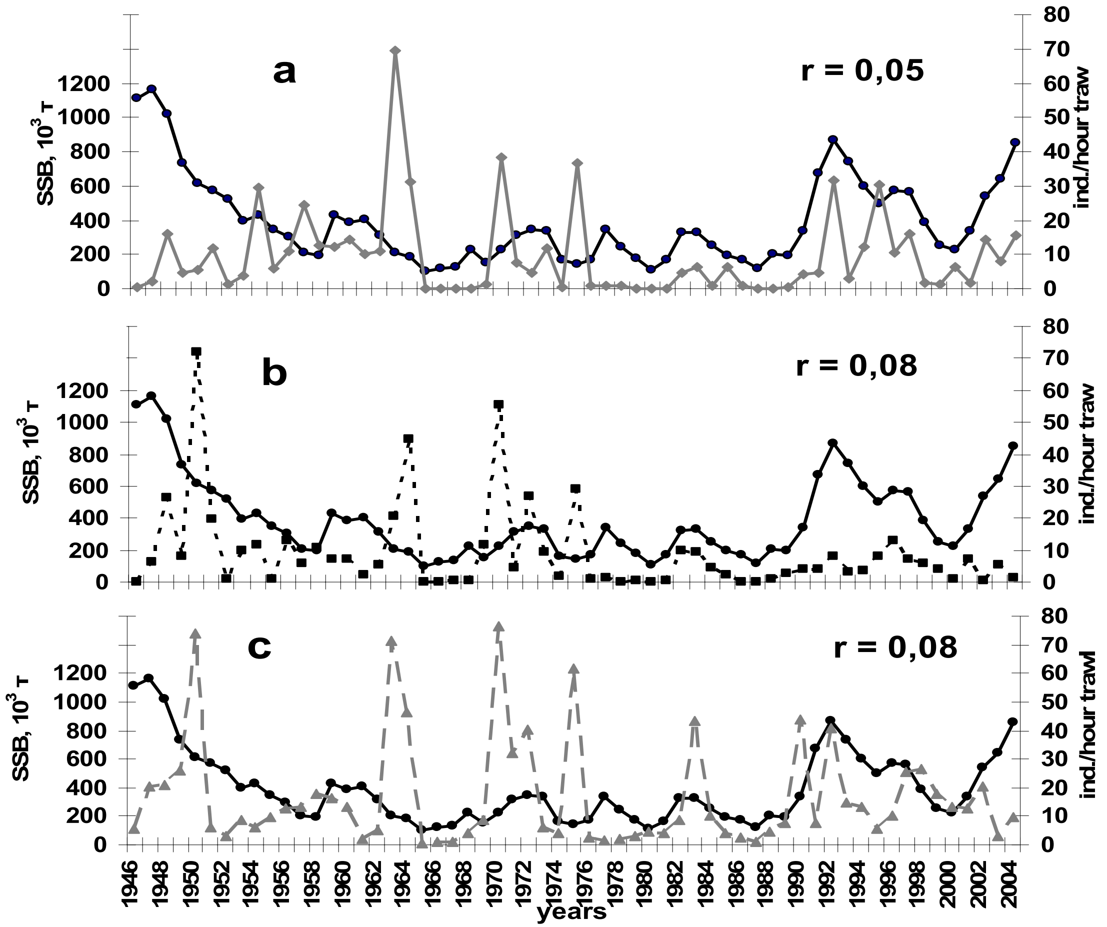

Fig.3. NEAcod. Spawning stock biomass and relative abundance of the benthonic young of age “0+”(-♦-); “1+”(-■-); “2+”(—▲—)

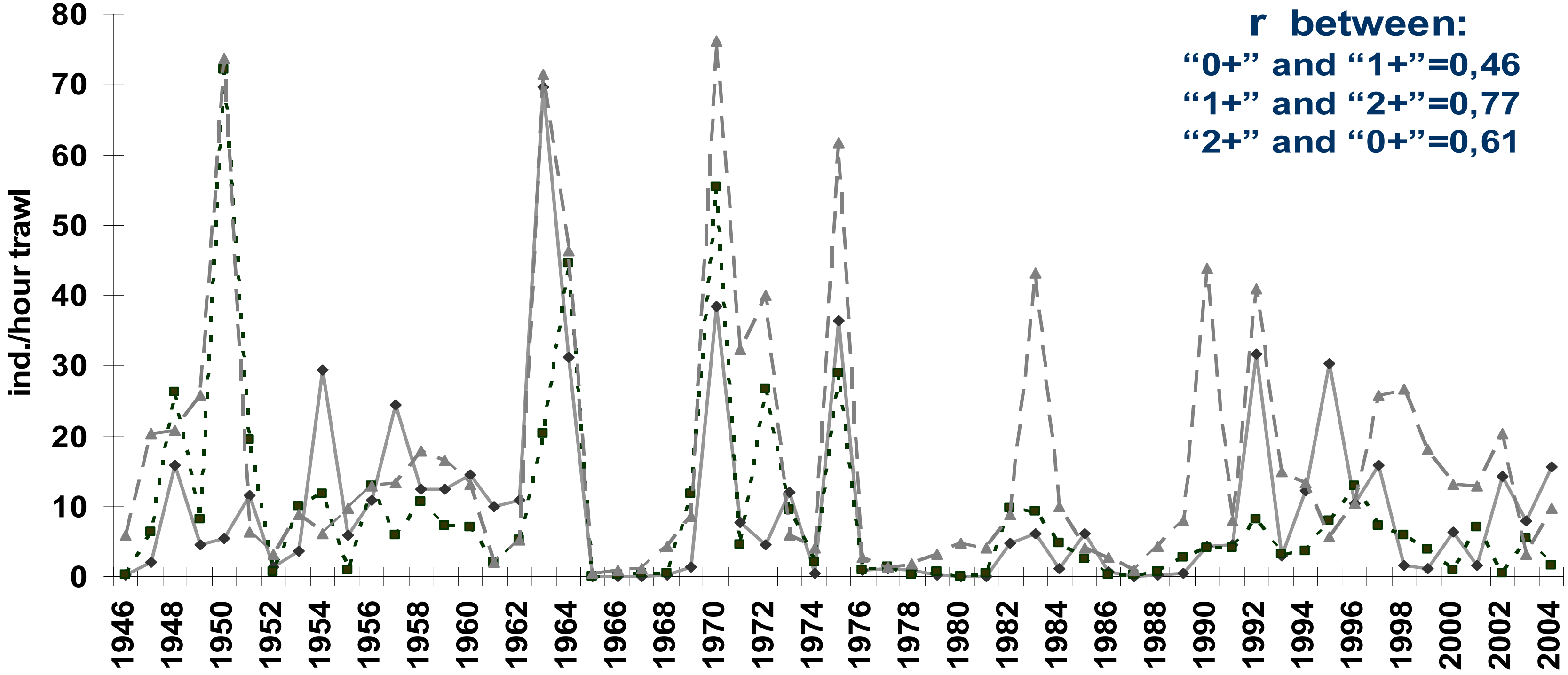

Fig.4. NEAcod. Relationship between relative abundance of the benthonic young at age “0+”(-◆-); “1+”(- -■- -); “2+”(—▲—)

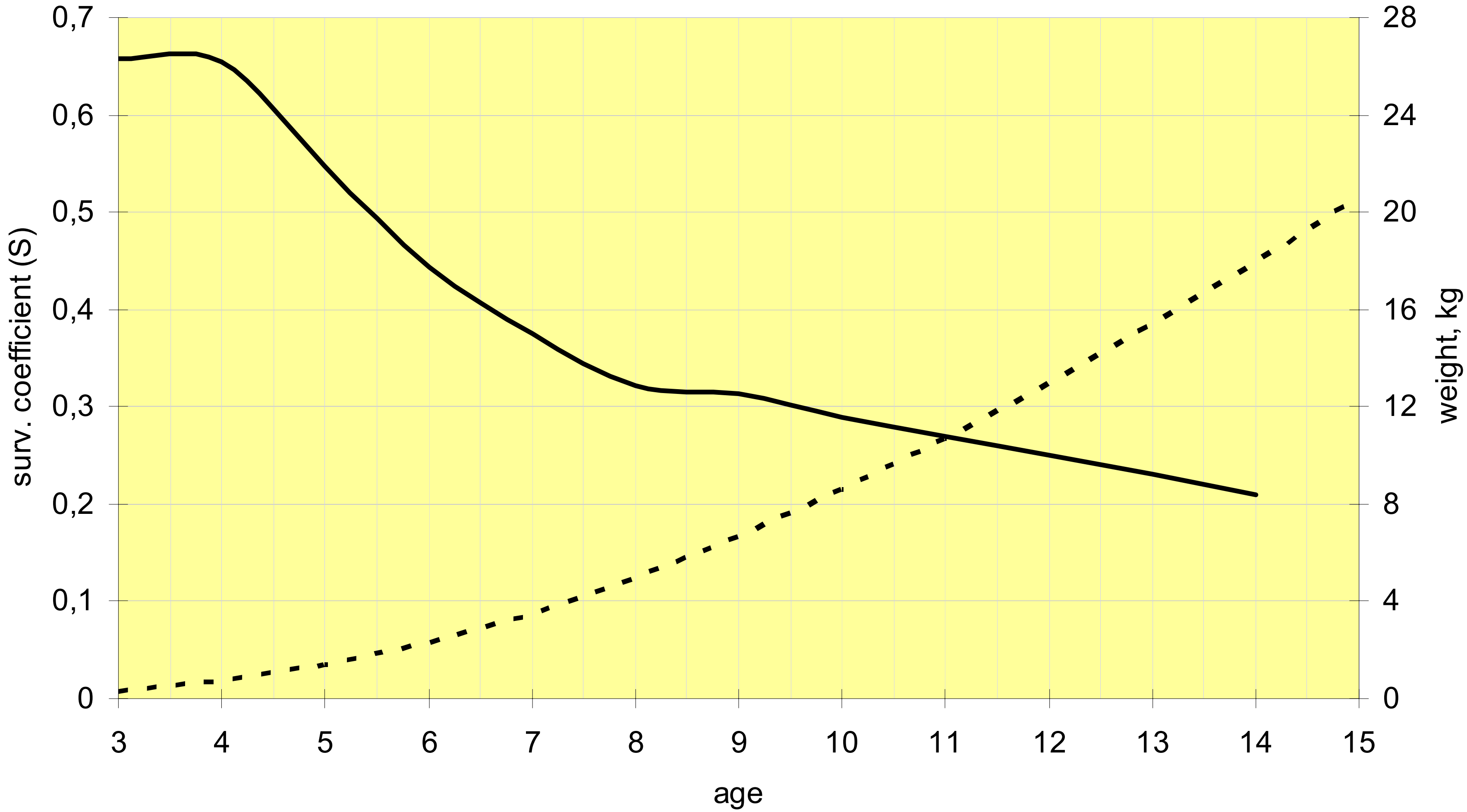

Fig.5. NEAcod. Survival coefficients (—) and weights (- -) at age 3-15

Table 2. Change in the fishing stock biomass (FSB) at different survival levels in 3-5-age cod

Age	Weight, kg	S_1	$N_1 \cdot 10^3$ ind.	FSB_1 10^3t	S_2	$N_2 \cdot 10^3$ ind.	FSB_2 10^3t	S_3	$N_3 \cdot 10^3$ ind.	FSB_3 10^3t
3	0.27	0.657	500000	135000	*0.700*	500000	135000	*0.800*	500000	135000
4	0.69	0.655	328500	226665	*0.700*	350000	241500	*0.800*	400000	276000
5	1.35	0.547	215167	290475	*0.600*	245000	330750	*0.700*	320000	432000
6	2.28	0.443	117700	268356	0.443	147000	335160	0.443	224000	510720
7	3.47	0.375	52140	180926	0.375	65121	225970	0.375	99232	344335
8	4.93	0.321	19552	96391	0.321	24420	120391	0.321	37212	183455
9	6.63	0.314	6276	41610	0.314	7839	51973	0.314	11945	79195
10	8.55	0.289	1971	16852	0.289	2461	21041	0.289	3751	32071
11	10.67	0.270	569	6071	0.270	711	7586	0.270	1084	11566
12	12.96	0.250	154	1996	0.250	192	2488	0.250	293	3797
13	15.39	0.230	38	585	0.230	48	765	0.230	73	1123
14	17.95	0.210	9	161	0.210	11	197	0.210	17	305
15	20.59		2	41		2	41		3	62
Sums FSB_i				*1265*			*1473*			*2010*
Difference between sums: FSB_2-FSB_1=208000 t FSB_3-FSB_2=537000 t FSB_3-FSB_1=745000 t										

MAIN ELEMENTS OF TAC

Analysis of previous and current status of the stock:
assessment of fishing stocks (S),
relative interannual changes (ΔS%);
Influence of S on recruitment (R_s), growth (W_s), natural mortality (M_s)

Analysis of previous and current status of fisheries:
catches (C), relative interannual changes (ΔC%);
assessment of CPUE, F, correspondence of ΔC% with ΔS%, influence of C on S

Forecast $\mathbf{S_{i+1} = S - C - M_s + R_s + W_s}$,
where R_s prognosis is based on surveys of young fish and assessment of conditions of its survival on the stages from eggs to R_s; M_s includes cannibalism, discards, and other accountable losses of S

Assessment of ΔS_{i+1}% ***based on $S - S_{i+1}$***

Choice of reasonable ΔC_{i+1}%
based on ΔS_{i+1}%, tendencies in S and CPUE assessments, and consideration of W_s and M_s trends

Setting of TAC_{i+1}
based on ΔS_i and chosen ΔC_{i+1}%

RETROSPECTIVE ANALYSES, IMPROVEMENT OF ASSESSMENT AND PREDICTION METHODS FOR THE NORTH-EAST ARCTIC HADDOCK STOCK

by

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Abstract

North-East Arctic haddock – given of methods used for stock assessment and prediction of haddock and an attempt is made to improve these methods by using alternative software and investigating part of the uncertainty in stock assessment and projection of haddock.

For uncertainty investigations (deviations in estimates of parameters) in stock assessment and projection, i.e. observation errors given a particular model specification, an ADAPT model is set up in Excel, similar to the one described by Gavaris (1988).

The retrospective estimates and forecasts of spawning stock biomass (SSB), recruitment (numbers of fish at age 3) at start of 1980-2007 and associated fishing mortality (F) in previous years from xADAPT and obtained by AFWG versus XSA estimates are slightly different for period 2001-2007. However, working group estimates lies within the bootstrap error distribution.

Terminal year estimates of SSB and F obtained by xADAPT model lie outside the limit reference points with high estimated probability, but the given model allows only part of the total uncertainty. The prototype of the used algorithm, program ADAPT, can be applied as an alternate approach for the estimation of population dynamics of haddock at AFWG.

Introduction

North-East Arctic Haddock (*Melanogrammus aeglefinus Linne*.) – the second main commercial species (after North-East Arctic cod) in the Barents Sea. Since 1960 the total annual catch of this species was ranged from 17 to 322 thou. t. In recent years Norway and Russia have accounted for more than 90% of the landings and total catches was about 100 thou. t. Fishery takes approximately 30 % of stock. The dynamics of haddock stocks are defined by productivity of its generations, which can differ considerably in number. The tendency of an increase in number of haddock was outlined in 2001-2004, due to the introduction of some strong yearclasses.

The divisions of ICES – Arctic Fisheries Working Group (AFWG) and Arctic Committee of Fisheries Management (ACFM) assess the haddock stock annually and give advises to decision makers – Joint Russian-Norwegian Fishery Commission (JRNFC). At present the ICES takes account of the uncertainty in assessment by making advice in relation to defined reference points. In principle ICES has defined B_{lim} as level of SSB which produces only poor recruitment, has been observed from 4 years of SSB < 50 000 t, and B_{pa} – as level of SSB which produces good recruitment with 95% probability. Corresponding values of F set as fishing mortality reference points.

The distance between Bpa and B_{lim} and Fpa and F_{lim} are 30 thou. t and 0.14 accordingly. Thus point estimates of SSB and fishing mortality are evaluated and advice is given in relation to pa-reference points. This is considered to ensure, given the uncertainty, that the adviced fishing mortality and resulting spawning stock biomass do not exceed the limit points.

But point estimates vary depending on data series used in assessment and model assumptions: tuning fleet's data series used as well as assumptions in the model configurations (F shrinkage and assumption about the relationship between survey indices and stock size (type of model)). E.g. changing from moderate (default) shrinkage (SE=0.5) to low shrinkage (SE=1.5) changes the perception of the 2003 SSB from 104 454 to 120 947 (16% increase) (Anon. 2004).

In this case it is necessary to investigate differences between reference points, because if possible variation in estimates is higher than that interval stock needs more detail analysis.

There are several categories of uncertainty in fish science: natural variation, observation errors in input data, model misspecification, uncertainty in transaction scientific advice into management, imperfect implementation of management strategies and others (Mace and Sissenwine, 2002). Current project aims at investigating a part of the uncertainty, i.e. observation errors given a particular model specification.

The AFWG states (Anon., 2004a) that the uncertainty may be underestimated and that difference between B_{lim} and B_{pa} may be too small. In this project an attempt will be made to investigate at least part of the uncertainty in the assessment by the use of bootstrap techniques. The overall objective is to investigate if current assessment and prediction procedures can be improved. Such improvements are expected to be incorporated in AFWG assessments in the future and hopefully improve the scientific advice for North-East Arctic haddock.

Data collection and current assessment and prediction methods for providing annual advice

This section provides short information about the previous and current data collection and assessment methods used by the AFWG.

Haddock are harvested throughout the year. In years when the commercial stock is low they are mostly caught as bycatch in cod trawl fishery. When the commercial stock abundance and biomass are high haddock is targeted directly by a specific fishery.

Bottom trawling accounts for approximately 75% of the catches on average. Conventional gears, mostly longline, used almost exclusively by Norway accounts for most of the rest of the catch. Part of the longline catches are from a directed fishery. National quotas from 1976 have restricted the fishery.

Data collection from commercial catches started from late 40s, but it was episodically observations, mostly land-based measurements of catches. As the regulation of the haddock stock was based on an assessment of the stock, more representative data were collected from the early 1980s.The current schedule sampling is described in detail in the Quality handbook for Standard Procedure for Assessment and available on ICES website (Anon., 2004b).

Table 1. Information from commercial catches different countries of NEA haddock used by AFWG in stock assessment

	Kind of data				
Country	Caton (catch in weight)	Canum (catch at age in numbers)	Weca (weight at age in the catch)	Matprop (proportion mature by age)	Length composition in catch
Norway	x	x	x		x
Russia	x	x	x	x	x
Germany	x	x	x		x
United Kingdom	x				
France	x				
Spain	x				
Portugal	x				
Ireland	x				
Greenland	x				
Faroes	x				

Annually, Russian scientists make length measurements and take age samples from catches onboard commercial vessels. Data on length distribution of haddock in catches are collected in areas of cod and haddock fishery by a "standard" fishery trawl (mesh size is 125 mm in the Russian Economic zone and Spitzbergen area and 135 mm in the Norwegian Economic zone) and summarized by three ICES sub-areas (I, IIa and IIb). Previously the PINRO area divisions were used, differed from the ICES sub-Divisions.

The main Norwegian sampling program is sampling the landings. Additional samples from catches are obtained from the coast guard, from observers and from crewmembers reporting according to an agreed sampling procedure.

All countries, which harvest haddock, send information on commercial catches to AFWG as input for estimating total nominal catch and additional information (see table 1).

At the AFWG all the data combined for recalculation age compositions of the landings: catch-at-age or catch in numbers and the mean weights-at-age in catches.

Survey measurements

Russian surveys of cod and haddock in the southern Barents Sea started in the late 1940s as trawl surveys of young demersal fishes. Since 1957 such surveys have been conducted over the whole feeding area including the Bear Island – Spitzbergen area during September-February.

Time of survey conducting has reduced from 5-6 months in 1946-1981 to 2-2.5 months (October-December) since 1982. AFWG used data from Russian bottom trawl – acoustic survey from 1983 (Figure 1A). The survey covers the main areas where fries settle down as well as the commercial fishery takes place in ICES areas I, II a and II b, including Russian coastal zone.

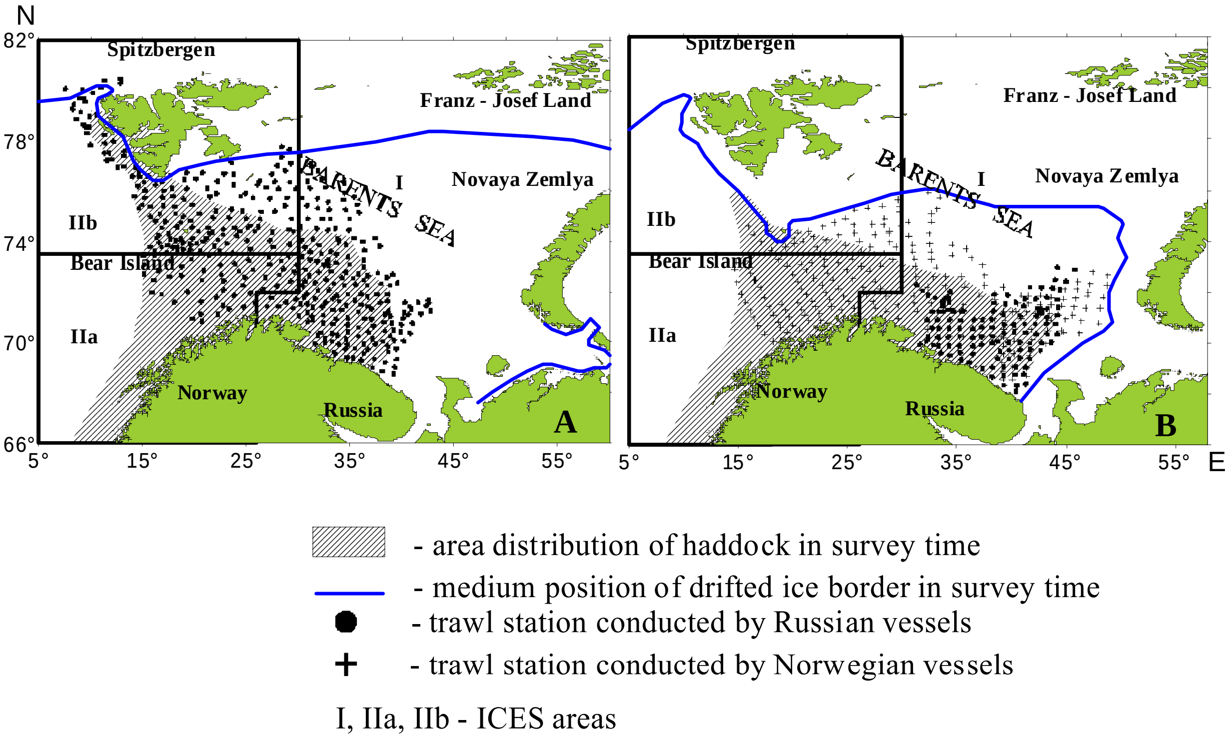

Figure 1. Area of Russian (A) and Norwegian (joint) (B)
trawl-acoustic scientific surveys in Barents Sea

Norway conducted sporadic surveys in the Barents Sea between 1970 and 1981. The regular survey started in 1981 and conducts bottom trawl and acoustic survey in the Barents Sea in January-March, which also covers the ice-free part of the Barents Sea in ICES areas I, II a and II b, including Norwegian coastal zone. Before 2000 this survey was made without participation of Russian vessels, while in the three latest surveys Russian vessels have covered important parts of the Russian zone (Figure 1B).

Data from survey provided estimation mean weights of fish in stock (weight at age), also survey data combined with data from catches to calculation proportion of mature haddock at age, numbers of consumed haddock by NEA cod using data from cod stomach samples, and survey “trawl indices”, calculated as relative numbers per age per hour and “acoustic indices” of absolute numbers (in thousands) computed from the acoustic registrations.

Assessment and predictions models

The haddock is assessed using a catch at age model Virtual or Sequential Population Analysis (VPA or SPA) was introduced in fish stock assessment by Gulland (1965). In common with computing machinery evolution the software for stock assessment and projection was changed but calculations were made on the same principal as previously (Anon., 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995a,b, 1996, 1997, 1998, 1999a, 2000a,b, 2001a,b, 2002, 2003a, 2004a, 2005). The table 2 shows the software used at the AFWG from 1978. All are standard ICES software based on catch-at-age analyses.

The classical VPA analysis that uses measurement of the number of fish caught in each age group and age. Given that the catches are treated as exact the historical part of the stock estimates (N-values) are principle the cumulative sum of catches given certain assumption of annual natural mortality. The VPA solves the Baranov (Baranov, 1918) equation directly by numerical methods and it is not a statistical analysis, however, it is an important basis for the ADAPT and other statistical methods. ADAPT, based on VPA, uses the fishing mortality of the terminal year and of the oldest age as the unknown parameters.

*Table 2. The standard software and methods used for stock assessment and projection of NEA haddock at AFWG**

<table>
<tr><th>Year</th><th>Assessment methods</th><th>Short-term projection catch and biomass</th><th>Recruitment projection</th></tr>
<tr><td>1978-1985</td><td rowspan="2">IFAP module (VPA)</td><td rowspan="5">IFAP module (management options table)</td><td>(Survey indices ratio)</td></tr>
<tr><td>1986-1991</td><td>RCRTINX2 (regressions of yearclasses)</td></tr>
<tr><td>1992-1993</td><td>VPA version 3.1(SVPA/XSA), ADAPT</td><td rowspan="4">RCT3 (regressions of yearclasses)</td></tr>
<tr><td>1994-1998</td><td>VPA version 3.11 (SVPA/XSA)</td></tr>
<tr><td>1999-2002</td><td rowspan="2">VPA version 3.2 - VPA95 (SVPA/XSA)</td></tr>
<tr><td>2003-2005</td><td>MFDP(management options table)</td></tr>
</table>

**In brackets – methods.*

At present, the AFWG uses VPA95 software package (Darby and Flatman, 1994), including Extended Survivors Analysis (XSA) (Shepherd, 1992), to estimate stock abundance and fishing mortality of cohorts that have entered the fishery. XSA method uses the number of survivors of the each age group as the unknowns.

Estimation numbers of fish, which have not entered the fishery in the assessment and two followed years, previously were estimated by VPA using survey indices are estimated using the RCT3 software package (Shepherd and Darby[*]).

Assumptions of weight-at-age in the catch and in the stock, maturity and selection patterns, which are needed in the projection, are derived from *ad hoc* expert judgment. These data are then the basis for short-term projection procedure (using MFDP software, Anon., 1999), which provides a management option table.

All outputs are point estimates and include estimates of SSB, recruitment, and catch under various fishing mortality scenarios. These point estimates in relation to defined reference points (that are considered to reflect uncertainty in the assessment) form the basis of the

[*] Work is in secretary ICES, year of the edition is unknown.

annual advice provided by the ACFM – department of International Council for the Exploration of the Sea (ICES).

The current uncertainty is reflected in the distance between the limit and the precautionary reference points (lim and pa points). B_{lim} is defined to be the limit SSB below which only poor year classes have been observed, B_{pa} is considered to be the minimum SSB required to provide a 95% probability of maintaining SSB above B_{lim}, taking into account the uncertainty in the assessments and stock dynamics. Flim is the fishing mortality associated with potential stock collapse and Fpa is considered having a high probability of keeping F below Flim (Anon., 2003). At the moment B_{lim}=50 000 t, B_{pa} = 80 000 t, F_{lim}=0.49 and F_{pa}=0.35. The reference points will, however, be revised in 2006.

Materials

Materials for investigation were input data for stock assessment and projection, which used in AFWG 2005 (Anon., 2005). These include catch at age, mean weight in stock and catch, maturity ratio for period 1980 – 2005 and survey indices for period 1981-2005.

Methods for improvement stock assessment and prediction of haddock stocks

Estimation of stock size

The estimates of stock numbers at age (Nay) and fishing mortality at age were made using an ADAPT model set up in Excel. In principle this model is similar to the one described by Gavaris (1988), where catches are treated as being measured without error. The ADAPTive Framework uses a non-linear least-squares fit to calibrate the cumulative catch, given assumption of natural mortality (the virtual population) against independent indices of abundance. The data used were the estimated catch-at-age from 1980-2004, with age groups 1-11+. The last age group contains all catches equal to and higher than that age and is thus treated as a plus group. The following survey indices were used in the tuning:

- Russian bottom survey (Fleet 1), year ranges 1991-2004, age ranges 0+-7 in survey time assumed as start of year 2005 year ranges 1-8, year range 1992-2005;
- Norwegian acoustic survey (Fleet 2), year range 1990-2005, age ranges 1-8 survey time as start of year;
- Norwegian bottom trawl survey (Fleet 4), year range 1990-2005, age ranges 2-9 survey time as start of year.

Estimates of predation of cod on haddock was added as natural mortality (M2) as done by the AFWG. This is in addition to the constant mortality assumption (M1) of 0.2.
In the Excel spreadsheet Pope's approximation (Pope, 1972) of the transformed Baranov (Baranov, 1918) equation was used:

$$N_{a,y} = N_{a+1,y+1} * e^{M_{a,y}/2+C_{a,y}} * e^{M_{a,y}/2} \qquad (1)$$

Fishing mortality of the oldest true age group (age 10) was derived recursively as the average fishing mortality of the theree younger age groups:

$$F_{10,y} = \frac{F_{7,y} + F_{8,y} + F_{9,y}}{3} \quad (2)$$

Fishing mortality of the plus group (age 11+) was set the same as for age 10. Population estimates of the oldest true age group (age 10) and the plus group where then obtained by the transformed Baranov equation:

$$N_{a,y} = \frac{C_{a,y}}{\frac{F_{a,y}}{F_{a,y} + M_{a,y}} * (1 - e^{(-(F_{a,y} + M_{a,y}))})} \quad (3)$$

For tuning the relationship between population size and survey was the same as that set by the AFWG 2005. Thus for ages 1-6 power relationship was assumed:

$$U_{a,y} = \alpha * N_{a,y}^{\ \beta}, \quad (4)$$

and for ages 7-9 – proportional relationship was assumed:

$$U_{a,y} = \alpha * N_{a,y} \quad (5)$$

Year class 1996 which has consistently been much lower in the survey than in the catches. The AFWG has resolved that by excluding it from tuning but here a special multiplier was added to the relationship between survey and stock size:

$$U_{a,y}^{YC96} = k^{YC96} \alpha_a * N_{a,y}^{\ \beta_a}, \quad (6)$$

where k is a parameter estimated by the model. The objective function in the model was:

$$SSE_{MIN} = \sum_{Surveys} \sum_{a} \sum_{y} \frac{\left(\ln U_{a,y} - \ln \hat{U}_{a,y}\right)^2}{\sqrt{2\sigma_a^2}}. \quad (7)$$

Surveys indices of different age groups are generally measured with different degree of precision. In the absence of direct information of variance in the survey a proxy for the survey errors were estimated internally in the model and was done as follows: 1) In the first run the denominator in equation x was set to 1 and an optimal fit was obtained. 2) The standard deviation of the residuals for each age group was calculated. 3) These estimates were then used as a proxy for variance (σ) in the objective function for the final fit of the model.

Effectively this means that age groups with higher variance have lower influence in the final population estimates than those with lower variance.

The parameters estimated in the model where thus: Numbers of fish at age 1-10 at 2005 and α and β for each age group for each survey.

Predictions

The objective function provides the estimates of the population numbers in the start of 2005. Calculation of catch in 2005 and 2006 and population numbers in 2006 and 2007 were done by the use of the catch and stock equations. As input data for projection were used estimated values of mean weight in stock and catch as used in AFWG 2005.

The catches were constrained to yield of 117 thou. t. in 2005 and 112 thou. t. in 2006 as set by the AFWG. The selection patterns used was the average of the last three years and the assumed mortality (M1 and M2) set the same as set by AFWG.

It should be noted that the plus group in 2005 and onward was estimated using equation:

$$N_{a,y} = N_{a-1,y-1} * e^{(-(F_{a-1,y} + M_{a-1,y-1}))} + N_{a,y-1} * e^{(-(F_{a,y-1} + M_{a,y-1}))} \quad (8)$$

Estimation of uncertainty

Spreadsheets gave the possibility to characterize the uncertainty in model fit using a bootstrap method (Efron and Tibshirani 1993, Haddon, 2001) – resampling of the residuals from the observed-predicted tuning indices.

In nonlinear least-squares estimates (Haddon, 2001) of a solution estimates of population abundance were chosen that provided the best fit to the tuning indices. The residuals of that fit were bootstrapped 1000 times and new values of N produced. The distribution of the associated Fs and SSB provided an indication of variation and the bias (deviations).

Each data set has the same number of observation (n) as the original data set. Recalculating the model to each bootstrap data set receive the statistics of interest (probability profile, standard deviations, confidence intervals) from the results for each model fit. Thus the bootstrap samples were:

$$U^{b}_{a,y} = \hat{U}_{a,y}\left(\frac{U_{a,y}}{\hat{U}_{a,y}}\right)^{boot} . \quad (14)$$

The random sampling was maintained within each survey and each sample consisted of the whole residuals for the randomly selected year.

Spreadsheets gave a possibility to investigate also uncertainty in projection procedure. For this aim the same procedure as for stock assessment was used. For the projection period 2005-2007 calculation of parameters were based on total allowable catch (TAC) for 2005, which established JRNFC at November 2004. Fishing mortality at age calculated as “TAC constraint” according to algorithm used in standard ICES projection software MFDP (Anon., 1999). Using standard equations of stock and catch for projection period were estimated values of numbers of fish in 2006 and 2007 as well as spawning stock biomass and fishing mortality. Selectivity in the year 2005 and 2006 was randomly selected in each run from the selectivity pattern estimated in each year 2001 to 2004.

For all parameters confidence intervals were estimated and compared with point estimations of N at age 3, F and SSB obtained by AFWG in 2005 (Anon., 2005).

Results

Summary of the results of xAPAPT calculations, bootstrap estimations of fishing mortality, numbers of fish at age 3 (recruits) and SSB are given in figures 2, 4 and 6. The dark shaded areas shows 80% probability and the light shaded areas the 95% uncertainty. Cumulative distribution of the estimates are shown in figures 3, 5, and 7. These figures enable detail determination of the probability that the parameters exceed or are below a certain value.

The historical point estimates of SSB, fishing mortality and recruitment from xADAPT are, as expected, the same as estimated by the AFWG. Given the constraint in yield for 2005 (117 thou. t) and 2006 (112 thou. t) is expected that the SSB will most likely continue to increase from a low in 1999 (Figure 2). This is both due to an expected continous good recruitment (Figure 6) as well as reasonable fishing mortalities in recent years (Figure 4).

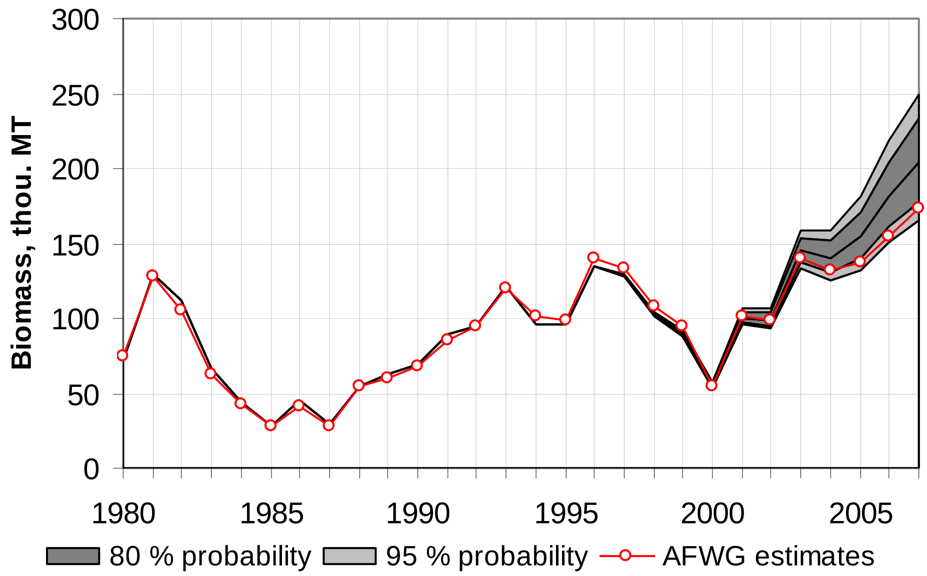

Figure 2. Dynamic of SSB estimated by AFWG and confidence intervals obtained from xADAPT for period 1980-2005 and forecast for 2006-2007

The uncertainties in the historical part of the time series are none since it is assumed that the catches are exact. The uncertainties in the more recent years increase, this because of reduced numbers of observations and a greater influence of the surveys on the current estimates. The point estimates from the final adopted XSA run by the AFWG are slightly different for the period 2001-2007, but working group estimates lies within the 95% bootstrap error distribution (Figure 2, 4 and 6).

Standard deviation (uncertainty) of estimated SSB value at the start of 2005 according to calculation using bootstrap procedure is about 50 thou t. (CV = 0.07). The medium estimate of SSB in 2005 is 150 thou. t and there the 95% bootstrap confidence interval is between 124 and 181 thou. t. The medium fishing mortality (F_{bar}) in 2004 was 0.32 and 95% bootstrap confidence interval is between 0.28 to 0.36 (CV=0.07), and the bias in the SSB and F bootstrap estimates was insignificant (below 1%).

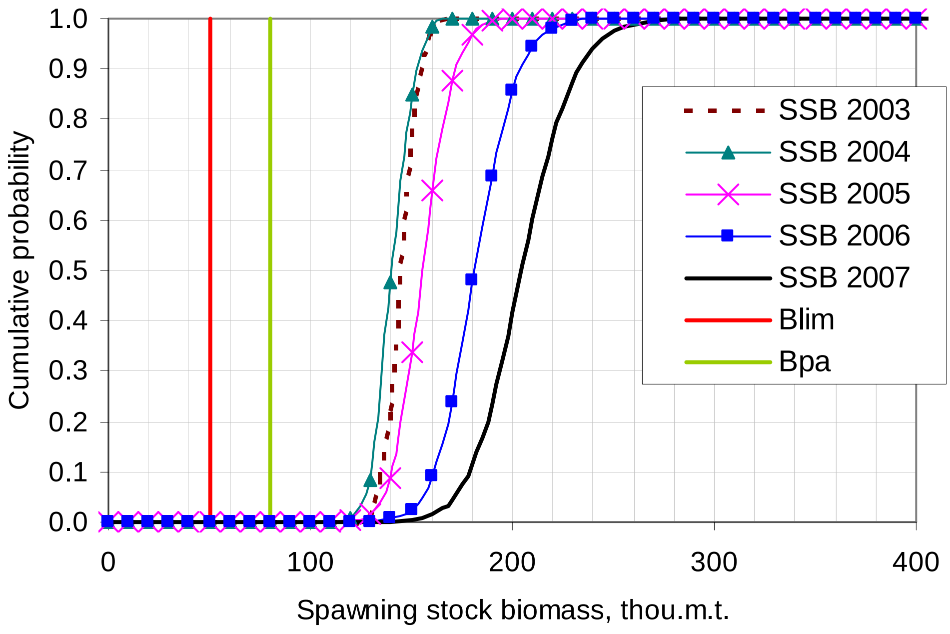

Figure 3. Cumulative probability distribution of SSB obtained from xADAPT for period 2003-2005 and forecast for 2006-2007 in relation with reference points

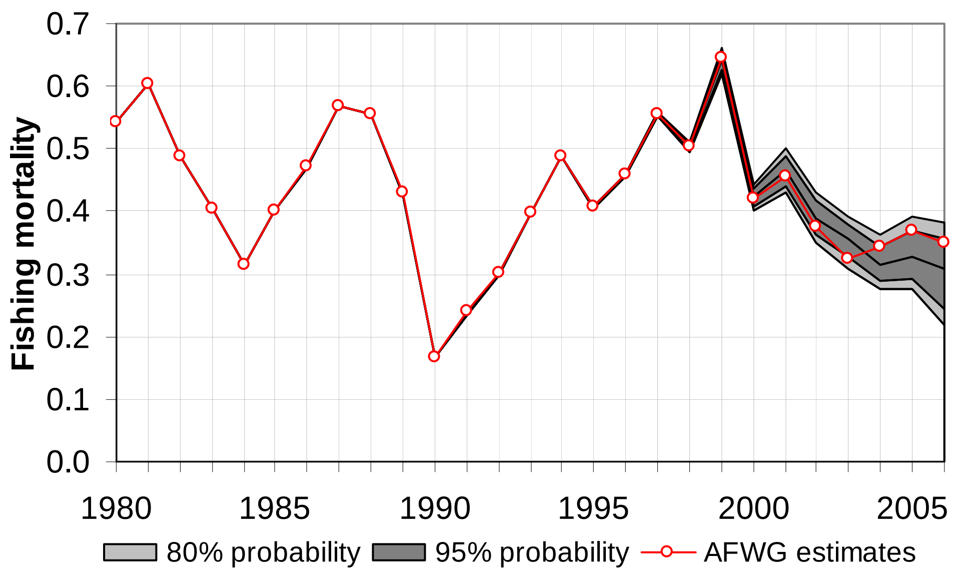

Figure 4. Dynamic of F (age 4-7) estimated by AFWG and confidence intervals obtained from xADAPT for period 1980-2004 and forecast for 2005-2006

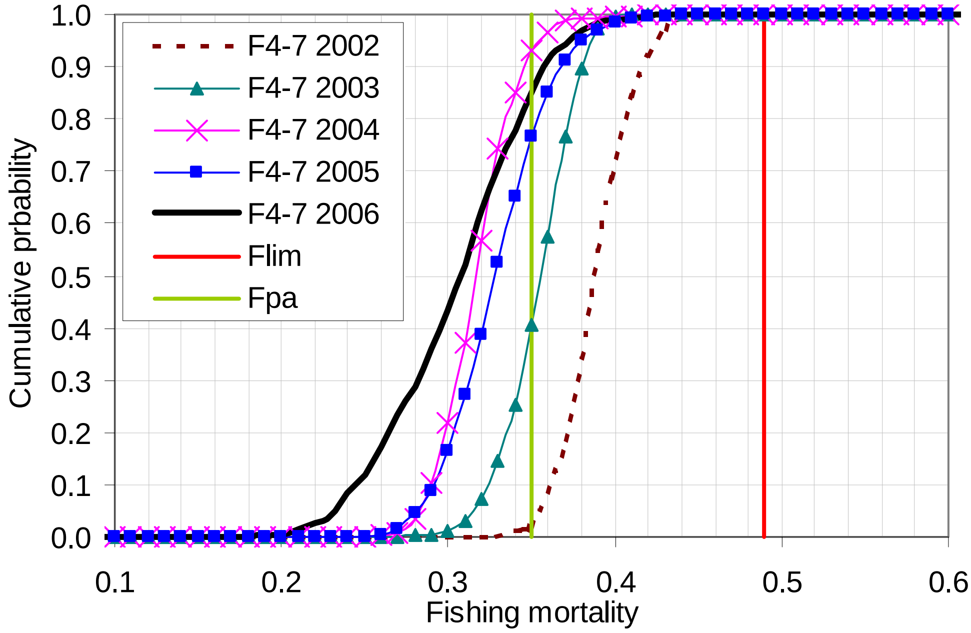

Figure 5. Cumulative probability distribution of F (age4-7) obtained from xADAPT for period 2002-2004 and forecast for 2005-2006 in relation with reference points

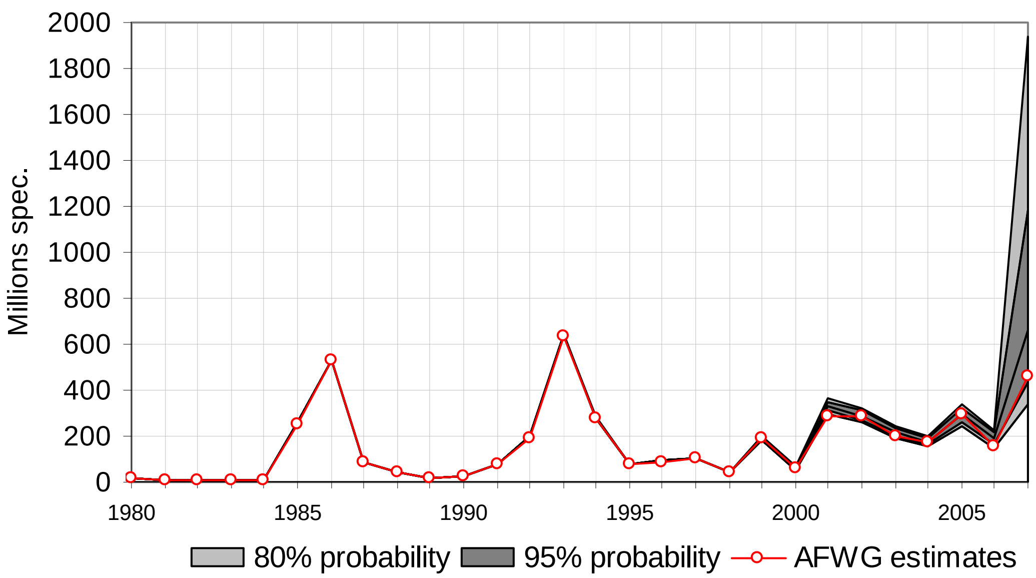

Figure 6. Dynamic of recruitment (N_3) estimated by AFWG and confidence intervals obtained from xADAPT for period 1980– 2005 and forecast for 2006-2007

The 95% bootstrap confidence interval indicate, given the yield constraint for 2005 (117 thou. t.), that the F_{bar} in 2005 is between 0.26 to 0.41 (mean is 0.33 and the bias in the F estimates is 4%, CV=0.11) and that accordingly the estimated SSB value at start of 2006 is expected to be between 142 thou. t. to 223 thou. t. (with median value 180 thou. t., CV= 0.12).

The 95% bootstrap confidence interval indicate, given the yield constraint for 2006 (112 thou. t.), that the F_{bar} in 2006 is between 0.21 and 0.38 (mean is 0.3 and the bias in the F estimates is 5%, CV=0.15) and that accordingly the estimated SSB value at start of 2007 is expected to be between 163 thou. t. to 271 thou. t. (mean value 211 thou. t., bootstrap bias 1.6%, CV= 0.13).

The results also show trends of mean estimates in F and SSB in recent and projection years. The fishing mortality after decreasing from 1999 to 2003 stayed on more or less the same level with high probability. Accordingly, spawning stock size shows a small tendency of an increase from 2000. Unsignificant decreasing at 2004 can be explained by increasing density of the population.

Increasing numbers of fish in population usually lead to decreasing mean weight of haddock in consequence of increased feed competition between individuals.

The 95% bootstrap confidence interval indicates that variances in recruitment estimates (numbers at age 3) increase during the time. In 2005 varyies from 273 to 397 mln. spec. with mean value about 332 mln. spec. Expected value of recruitment in 2006 varying from 152 to 254 mln. spec. with mean value about 200 mln. spec. and in 2007 from 339 to 1942 with mean 664 mln. spec. (Figure 6).

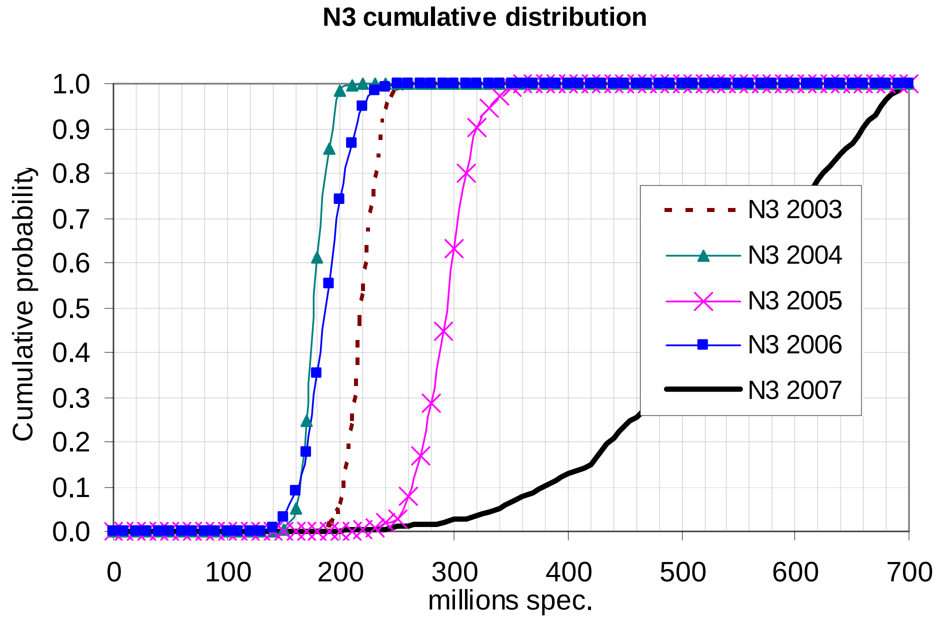

Figure 7. Cumulative probability distribution of recruitment (N_3) obtained from xADAPT for period 2003-2005 and forecast for 2006-2007

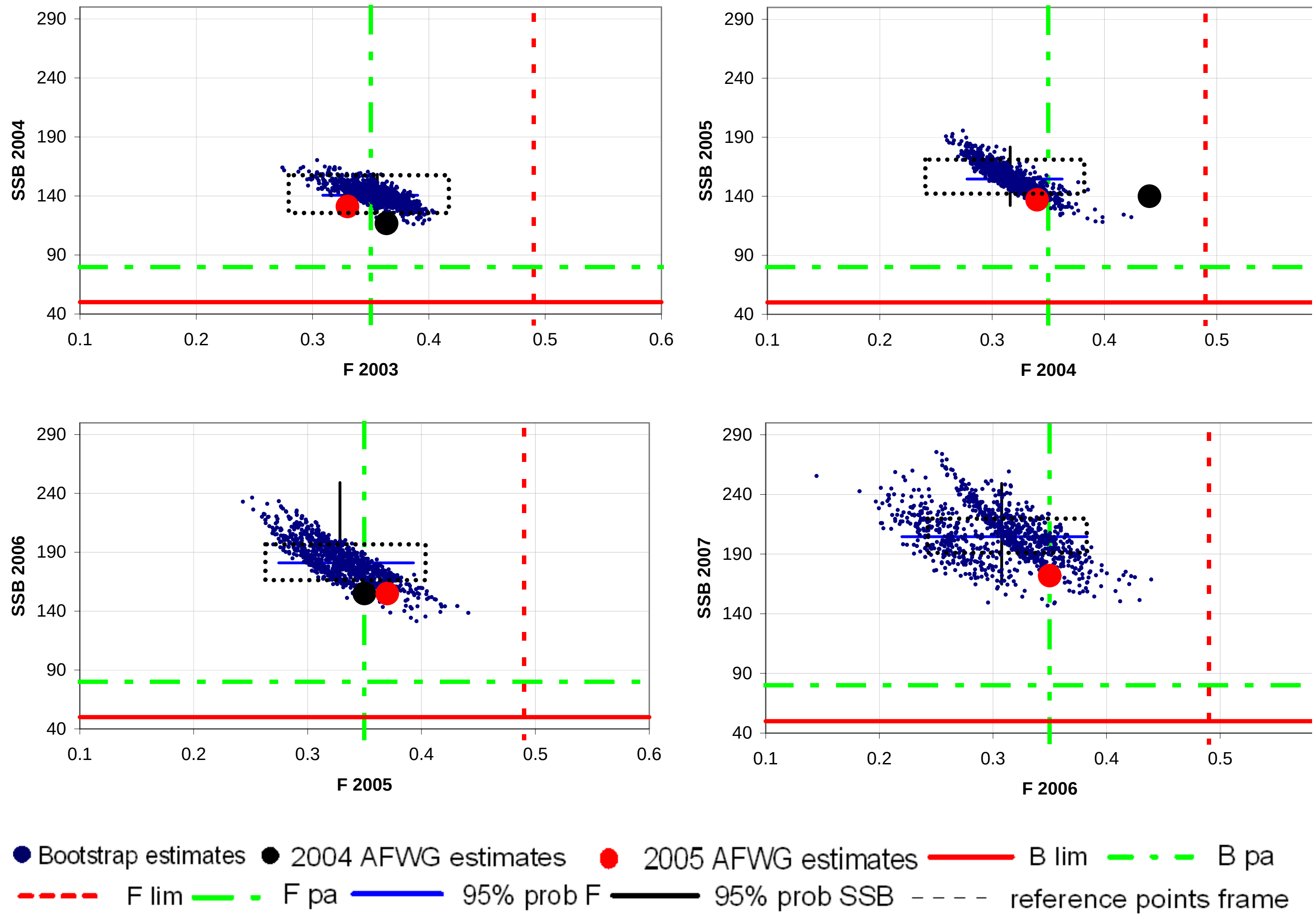

Figure 8. Point estimates of SSB and F in previous year made by AFWG and obtained by xADAPT with 95% confidence intervals in relation with adopted reference points for period 2002-2006

This mean that incoming yearclass 2004 has a very high abundance, 2003 has a lower abundance than yearclass 2002, but it is just preliminary estimates and can be changed using the new observation.The probability profile of estimates (Figure 7) shows that decreasing in recruitment from 2005 to 2006 is very likely but increasung in recruitment from 2006 to 2007 is not very likely. Figure 8 demonstrates the uncertainty in estimates of SSB and corresponding F associated with adopted reference points. Dotted line frame in pictures matched with imaginary frame between precautionary approaches values of F and SSB.

The 95% bootstrap confidence interval indicates that variances in that estimates also increase during the time, but most of point estimates lie inside imaginary "reference point's frame".

Conformably to estimates in terminal year (F in 2004 and SSB at start of 2005) which most important in assessment procedure we can suppose:
(1) estimates of spawning stock and F of NEA Haddock lies in adjusted by ACFM safe biological limits with high (95%) probability;
(2) investigated part of uncertainty given by observation errors comparable to distance between lim and pa borders of SSB and F.

Discussions

Mean estimates of SSB obtained by xADAPT are generally higher and estimates of F are somewhat lower than the finally adopted point estimates of SSB and F by AFWG. This is expected because there are differences in the handeling of data and in model configurations in the two models. The major differences are:

1) In XSA the estimates of the population parameters are done in two steps, the historical values are determined from observations of ages 3 and older but the estimates of the younger ages are determined from a separate software, RCT3. In xADAPT all the observations, both recruits and older were dealt with in the same model setup. The latter should be the preferred option because all available measurements are available for the terminal estimates.

2) XSA is used with shrinkage of the terminal F, but there is no shrinkage in the xADAPT. If there are changes in fishing mortality in the recent past, as observed for the NEA haddock, this by assumption of shrinkage will result in higher terminal (2004) F estimates in XSA. And consequently lower estimates of SSB.

3) The weighting of different survey indices is done differently in XSA compared with xADAPT. Further studies are needed to understand how this influences the terminal estimates.

4) The year class 1996 is treated as a missing value in the XSA but is modelled, albeit with a multiplier factor, in xADAPT. The influence of that was not evaluated in this study. It should be noted that although the point estimators differ beteween XSA and xADAPT, the XSA point values lie within the 95% bootstrap confidence interval of the xADAPT.

The 95% bootstrap confidence interval in terminal year estimates of SSB obtained by the xADAPT model lies within the distance between adopted reference points. It must however be stressed that the bootstrap confidence interval contains only one part of the total uncertainty in stock assessment, i.e. the uncertainty related to the precision in the estitmates of survey abundance given the model configuration.

However, all models of population dynamics have uncertainties that are related to the assumption that are made within any model. Uncertainty is unpleasant commonplace in stock assessment and how best to approach it is a growing and vital part of fisheries modeling (Haddon, 2001).

Main weakness of current methods for stock assessment and projection is in using several partly different, partly similar models, which turn to account more or less the same input data but receives different estimation of population numbers and fishing mortality, therefore level of uncertainty increasing with each step. Suggested method probably allows combining input data and receiving one and only one value for each parameter.

Using the algorithm of ADAPT framework with the bootstrap procedure allows to estimate at least some part of the uncertainty – from errors in measurements, uncertainty in stock assessment parameters and the statistics of interest (probability profile, standard deviations, confidence intervals) from the results for each model fit.

It thus provides an opportunity to make statistical tests of differences between model assumptions, like natural mortality or selection pattern.

One of the problems in the management of NEA Haddock stock is estimating the reference points, which will be revised in 2006. Estimated population parameters using standard models with a bootstrap procedure can be applied in stock assessment and projection. Estimated confidence intervals of parameters can be good candidates in estimating values and intervals between reference points!

This uncertainty analysis, using bootstrap, is only the first step in the construction of a full analysis of uncertainty in stock assessment. Additional work to more fully characterize all important sources of uncertainty in the assessment process, including modeling errors, should be used to estimate the applicability of the current biological reference points as well as any harvest control rules.

Conclusion

Suggested algorithm based on ADAPT framework allow to investigate part of uncertainty in stock assessment and projection procedure and its prototype – programm ADAPT can been applied as an alternative approach for the estimation of population dynamics of NEA haddock.

The framework should allow for a procedure making decisions more simple, objective and robust to criticism. Working Group members can then develop a process for weighting the risks and reaching an agreement on the best management actions given all of the inherent uncertainties in the analysis.

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POSTERS

STOCOBAR MODEL FOR SIMULATION OF THE COD STOCK DYNAMICS IN THE BARENTS SEA CONSIDERING THE INFLUENCE OF ECOSYSTEM FACTORS

by

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Introduction

Practical realization of the ecosystem approach to the management of marine bioresources requires development of multispecies and ecosystem based models designed for fisheries objectives. For the Barents Sea, specific research in this field began in mid-1980s. At that time the stocks of major commercial species and consequently catches dramatically decreased due to large-scale structural and functional changes in the ecosystem of the sea cased by both natural and human factors (Kovtsova, 1991; Nakken, 1998). One of the reasons of the fisheries crisis in the Barents Sea in the mid-1980s was ineffective fisheries management. The management strategy in the Barents Sea based on single species approach did not allow us to take into consideration the changes of trophic interactions between commercially important populations in the period of changing ecosystem conditions.

In 1996 the conceptual basis and general scheme of model design for commercial species in the Barents Sea were developed in the framework of PINRO plan of scientific researches. The work had several stages. Firstly, we planed to develop population models for main commercial species and then fuse them in one model. Cod as the most studied species that is of great importance for fisheries and functioning of biocenosis in the Barents Sea has to be the crucial element of this model.

The model of dynamics of the Northeast Atlantic cod stock reflecting both intrapopulational and interspecies relationships in the Barents Sea has been developed in PINRO since 1997. The model is intended for optimisation of management of cod fisheries and for quantitative estimation of cod predation on stocks of capelin, shrimp, haddock and polar cod in the Barents Sea.

In 2001, the first version of the model called STOCOBAR (STOck of COd in the BARents Sea) was created. This model is a successor of separate model blocks and two of those were designed as separate models that is CONCOD (to describe feeding and growth of NEA cod) and STRAFICOD (to analyse different harvest strategies for cod stock in the Barents Sea taking into consideration capelin stock dynamics) (Filin 2000; Filin, Gavrilik, 2001). The work on improvement of model structure and time discreteness of calculation was carried out in 2002-2004.

1. General characteristics of the model

STOCOBAR is a complex model that describes population parameters and species interactions of cod based on successive running of separate processes that are crucial for cod stock dynamics in the Barents Sea within one functional system. This model is designed to improve the harvest management of cod stock taking into account species interactions. It can be applied for prediction of cod stock dynamics and expected catch as well as for model analysis of effectiveness of different harvest strategies.

The conceptual basis of the model consists of the following:

- a proportion of prey species in a predator's ration reflects the proportion of these species in nature;
- maximum consumption by fish depends on a their body weight and environment temperature;
- a coefficient of proportionality between real and maximum consumption by a predator is the function of the biomass of available food;
- quantity of available food as a particular prey item is determined by the total biomass of prey in nature, a coefficient of its suitability as food and the coefficient of food competitiveness of the predator when consuming this prey;
- a coefficient of food suitability of prey for a predator is a coefficient of proportionality between prey portion in the predator stomach and their portion in nature in relation to all other categories of prey;
- a coefficient of a predator's food competitiveness reflects the relative rate of consumption of the prey in comparison with other predators;
- growth of cod is the function of body weight, water temperature and ration expressed as energy units;
- maturation rate of fish is determined first of all by their linear growth.

All calculations in the model are carried out in cohort mode. Time step of the model (discontinuity of calculations) can be established as equal to one year or half a year. The model is spatially unstructured, i. e. the processes are simulated without area differentiation.

The model includes seven prey species of cod (capelin, shrimp, polar cod, herring, euphausiids and juveniles of haddock and cod) that are divided in age groups except for shrimp and euphausiids (Table 1).

Table 1. Age composition of species included in the model

Species	**Age group, years**
Cod	1-15
Haddock	1-12
Capelin	1-5
Herring	1-4
Polar cod	1-6
Shrimp	Without regard for age
Euphausiids	Without regard for age

Euphausiids that occur in the Barents Sea in four commonest species are included into the model as one group without specification. Species structure of the model is not permanent and it is set according to the tasks of the model analysis and available input data. Therefore, based on common algorithms the model can be used in different structural modifications. It can be reduced from seven-species version to a simple modification where all prey species are considered as one food category. In this case, food resource of cod is considered as constant for the whole modelling period and thermal conditions and abundance of cod population become the factors that affect growth rate of fish.

A strategy of the management of the cod stock in the model is realized on the basis of a concept of the precautionary approach accepted in the ICES. In accordance with that, the rules of a control of the intensity of the cod stock exploitation in the model are based on biological reference points B_{lim}, B_{pa}, F_{lim}, F_{pa}.

The model can be run in three modes:

1) retrospective analysis;
2) prediction;
3) scenario modelling.

In retrospective analysis and prediction, the following parameters are calculated:

- portion of prey species included in the model in cod diet;
- cod ration expressed in kg;
- cod ration expressed in kilocalorie;
- cod ration expressed in % of body weight;
- total annual consumption of cod specified by prey species in thousand tonnes;
- annual growth of cod at age of 1 and older in kg;
- annual growth of cod at age of 1 and older expressed in % of weight;
- mean age based weight of cod in the beginning of year in kg;
- cod maturation ogive in the beginning of year;
- biomass of cod fishing stock in the beginning of year in thousand tonnes;
- biomass of spawning stock in the beginning of year in thousand tonnes;
- abundance of cod at age 1-3 in million individuals;
- biomass of cod at age 1-3 in thousand tonnes;
- cod juveniles mortality caused by cannibalism;

In prognostic calculations mode, the model also provides predicted annual catch of cod and coefficient of cod fishing mortality according to the set harvest level.

In scenario modelling mode, the model provides quantitative estimates of:

1) The effect on feeding, growth and maturation rate of cod by the following factors:
   - biomass dynamics of prey species included in the model;
   - abundance and age structure of the population;
   - water temperature.
2) dependence of cod cannibalism level on food resources and population abundance;
3) long-term effectiveness of different management strategies for cod in the Barents Sea taking into account species interaction.

A computers program of the STOCOBAR model is designed in programming language Delphi 7. Calculation results are produced as graphs and tables. When doing calculation with the use of several versions of the model tuning, the results are converted to the common graph and can be presented as a common table.

2. Input data

The model is based on monitoring data on species included in the model and water temperature in the Barents Sea as well as on fishing statistics.

The following data are needed to estimate the parameters of the model:

1) age based abundance of cod in the beginning of the year;
2) age based individual weight of cod in the stock in the beginning of the year;
3) age based mean annual weight of cod in catch;
4) annual age based coefficient of cod fishing mortality;

5) cod maturation ogive in the beginning of the year;
6) age based catch of cod in the first and second part of the year;
7) mean temperature (in one year or half of the year) on the Kola section;
8) abundance and biomass of capelin, herring and polar cod in the Barents Sea according to the results of acoustic survey;
9) abundance and biomass of haddock stock;
10) indices of shrimp abundance according to the data of trawl surveys;
11) indices of euphausiids abundance in the Barents Sea according to the results of macroplankton survey;
12) quantitative composition of cod stomachs content in each half of the year and by ages.

The following input data is used in prognostic calculations:

- abundance of cod at age 1;
- mean individual weight of cod at age 1 in the beginning of the year;
- coefficient of cod fishing mortality F_{bar} or TAC calculation rules;
- biomass (age composition if necessary) of cod's prey populations included in the model in the beginning of the year;
- mean annual (or mean in half of the year) water temperature on the Kola section at the depth of 0-200 m.

Sources of the data used in the model:

- report of ICES AFWG;
- joint Russian-Norwegian database on cod stomachs in the Barents Sea;
- results of trawl and acoustic surveys in the Barents Sea;
- fishing statistics;
- observation data on the water temperature on the Kola section.
-

In the mode of stochastic simulation, the input data is randomly taken from the corpus of retrospective data.

3. Model calculations

The general scheme of model calculations is given in the Fig. 1. The food resources of cod are included in the model in separate food categories that differ in species and age of prey. "Other food" covers all prey species except the species included in the model and it recognised as a separate category. The number of food categories for cod in different versions of the model differs according the number of species included in the model and their age structure. Each food category except for the "other food" is characterised by biomass and the coefficient of food suitability. The coefficient of food suitability of different prey categories was set according to age groups and it shows the relationship between the biomass proportion of prey species in cod stomachs and biomass proportion of populations of these species in the environment. The coefficients of food suitability are the parameters of the model and the values of these parameters vary from 0 to 1 and it is set in tuning of the model.

Calculation of proportion of other food in the diet of cod is not based on estimates of its biomass due to the lack of such data. It is based on comparison of total biomass of prey populations in the given year with the mean long-term value of this parameter. The calculated proportion of “other food” in cod diet cannot be lower than it is set according to the observed data of minimal value despite the prey biomass.

The rations of cod are calculated in the model according to the maximum ration and feeding level, which is a proportionality coefficient between maximum and true rations (Ivlev, 1955; Andersen, Ursin, 1977). The equation obtained by M. Jobling (1988) as a result of experimental work was used for estimation of maximum ration.

$$H = 0{,}7e^{0{,}104T-0.000112T^3}W^{0{,}8}, \quad (1)$$

where W – cod weight in kg;
T – water temperature

However, in the model calculations the experimentally obtained coefficients of equations (1) are substituted with model parameters that are estimated in the process of model tuning according to the observed data.

The level of cod feeding *f* was calculated as a function of available food that varied in the model depending on biomass of prey populations included in the model and abundance of cod. Since “other fish” category is ignored in this approach to the estimation of *f*, the parameter of minimum level of feeding f_0 is applied. The f_0 parameter does not depend on abundance of prey species included in the model but it depends on the size of cod population:

$$f_0 = Ke^{-\alpha B} \quad (2)$$

where K, α – coefficient;
B – biomass of cod stock in thousand tonnes.

Coefficient α that shows the effect of density factor on cod feeding level differs in the model for cod at age 1-3 and other age groups.

The experimentally obtained equation of Jones is used as a basic level for calculation of cod growths in the model (Jones, 1978):

$$E_d = 0{,}0075W^{0{,}8}e^{0{,}081T+0{,}76V} + 1{,}27\Delta W_d W^{0{,}15}, \quad (3)$$

where E_d – daily ration expressed in energy units;
W – body weight in kg;
T – water temperature;
V – mean relative (expressed in body length) swimming speed;
ΔW_d – daily growth.

In the model, this equation was transformed with consideration to time step (1 year or 6 month) and additional tuning of coefficient according to observed data.

The dynamics of cod abundance is calculated according to the coefficients of fishing mortality and natural mortality. The coefficients of fishing mortality are set in the model according to TAC calculation rules, while the value of the coefficients of natural mortality for all age groups is constant and it is equal to 0,2. Besides, mortality caused by cannibalism is also taken in to account for juveniles at age 1-5. For these age groups of cod, natural mortality includes two components that are mortality as a cause of cannibalism and remaining natural mortality.

4. Estimation of model parameters

The values of the model parameters are estimated in the tuning by minimizing the discrepancies between simulated and observed data. The parameterization of STOCOBAR model is based on algorithms realised in Excel (options for search of optimal solution). Total scheme of estimation of the model parameters is given in Fig. 2.

Model tuning is performed in several stages. At the first stage, the values of the parameters used in calculations of diet composition are set. These values are calculated by minimisation of the sum of squares of deviations between modelled diet composition and food composition based on observed data.

At the second and third stages of model tuning, the parameters of the equations used in calculation of ration and cod growth rate are estimated. This is done in the following way:
- maximisation of squares of correlation coefficient between modelled cod rations and corresponding values of mean annual weight of stomach content according to the quantitative feeding analysis;
- minimisation of the sum of squares of deviation between observed weight values of fish in the stock and the modelled ones;
- minimisation of the sum of squares of deviation between observed values of mean annual weight of fish in catch and the modelled ones;

At the fourth stage of model tuning, the parameters of equations that describe cod maturation rate depending on growth rate are estimated. These values are obtained by minimisation of squares of deviation between observed data on maturation at age and the modelled values.

The limits of parameters variations are of great importance for parameterization of the model. These limits are set according to the principles of truth or to avoid situation when further calculations are impossible (dividing by zero etc.). The following limits based on true principle were used in the model:
- total consumption of capelin shall not exceed the biomass of capelin stock in the beginning of the year;
- coefficients of food suitability for preys species of cod shall exceed zero;
- maximum proportion of prey in cod diet can not exceed a definite level, which means that cod cannot feed on one prey species in the whole year even if its abundance is very high;

The achieved correspondence between observed and calculated data on diet composition and mean weight of cod is given in fig. 3-4.

Conclusions

The developed model STOCOBAR is intended to improve the management of cod stock exploitation taking into account the effect of species interactions and ecosystems factors. It can be used both for the prediction of cod stock dynamics and for the model analysis of various fisheries strategies.

Besides, STOCOBAR model can be accepted as conceptual and structural basis to develop ecosystem model of the Barents Sea designed for fisheries purposes. The development of STOCOBAR based model that describes interactions between capelin and cod can be the first step forward. In this model, capelin stock dynamics shall expose not only the effect of harvest but also predation of cod. It will allow us to make both quantitative estimation of the effect of cod fisheries on capelin stock dynamics and estimation of effect of fisheries for capelin on cod stock.

It is suggested that the work on development of STOCOBAR model will be carried out according to the joint Russian-Norwegian research programme on estimation of long-term optimal yield of marine organisms in the Barents Sea taking into account species interactions and the effect of ecosystem factors. At the first stage of this programme, the developed model can be applied as analytical tool to analyse the variations of cod growth, maturation and cannibalism depending on capelin stock, water temperature and population abundance. The formalisation of these relationships based on model calculations will allow us to make relevant changes in the single species models that are used to analyse the effectiveness of harvest strategies for cod, which in its turn will make these models more true to life.

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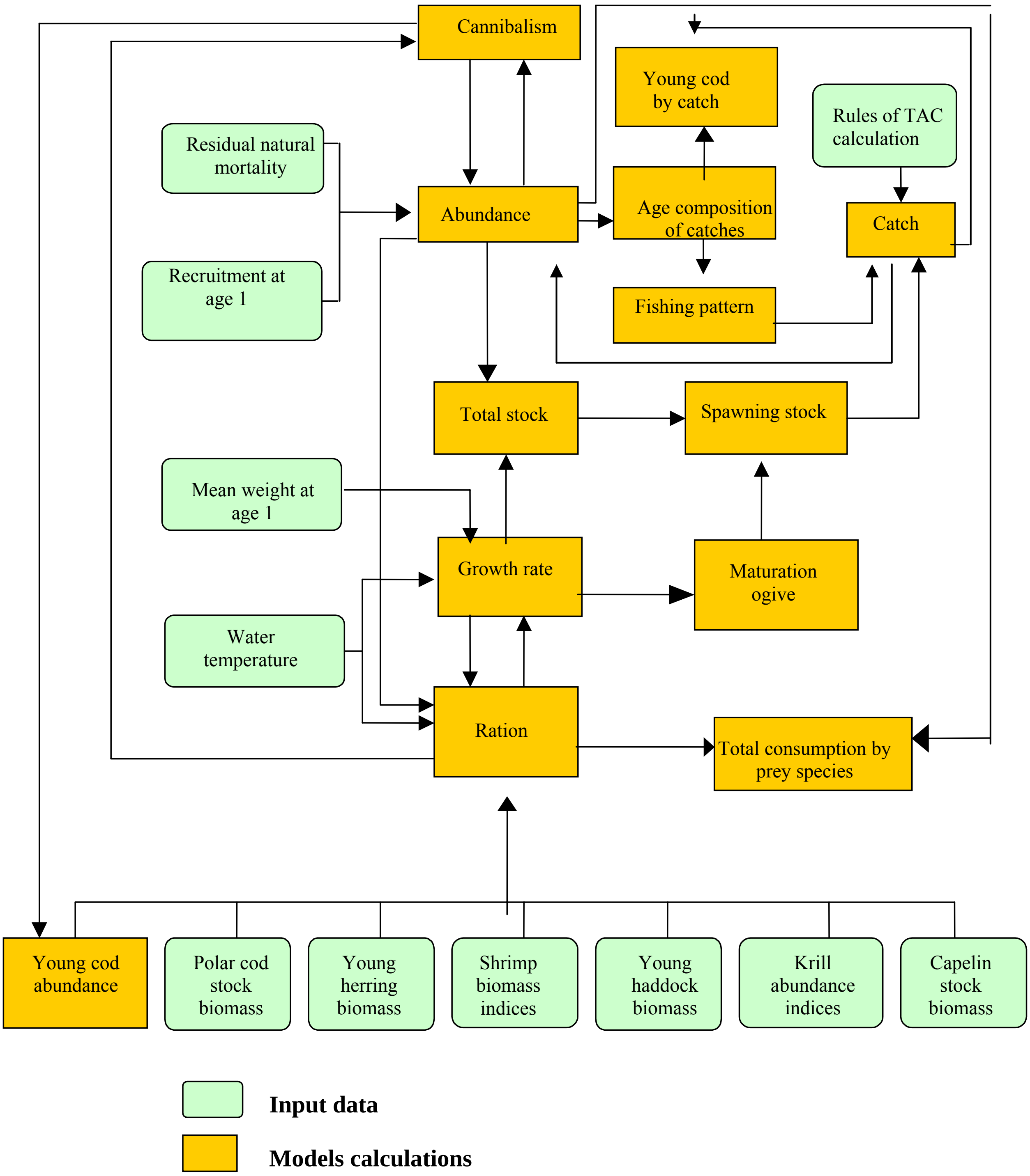

Fig. 1. A scheme of functional links realized in the STOCOBAR model

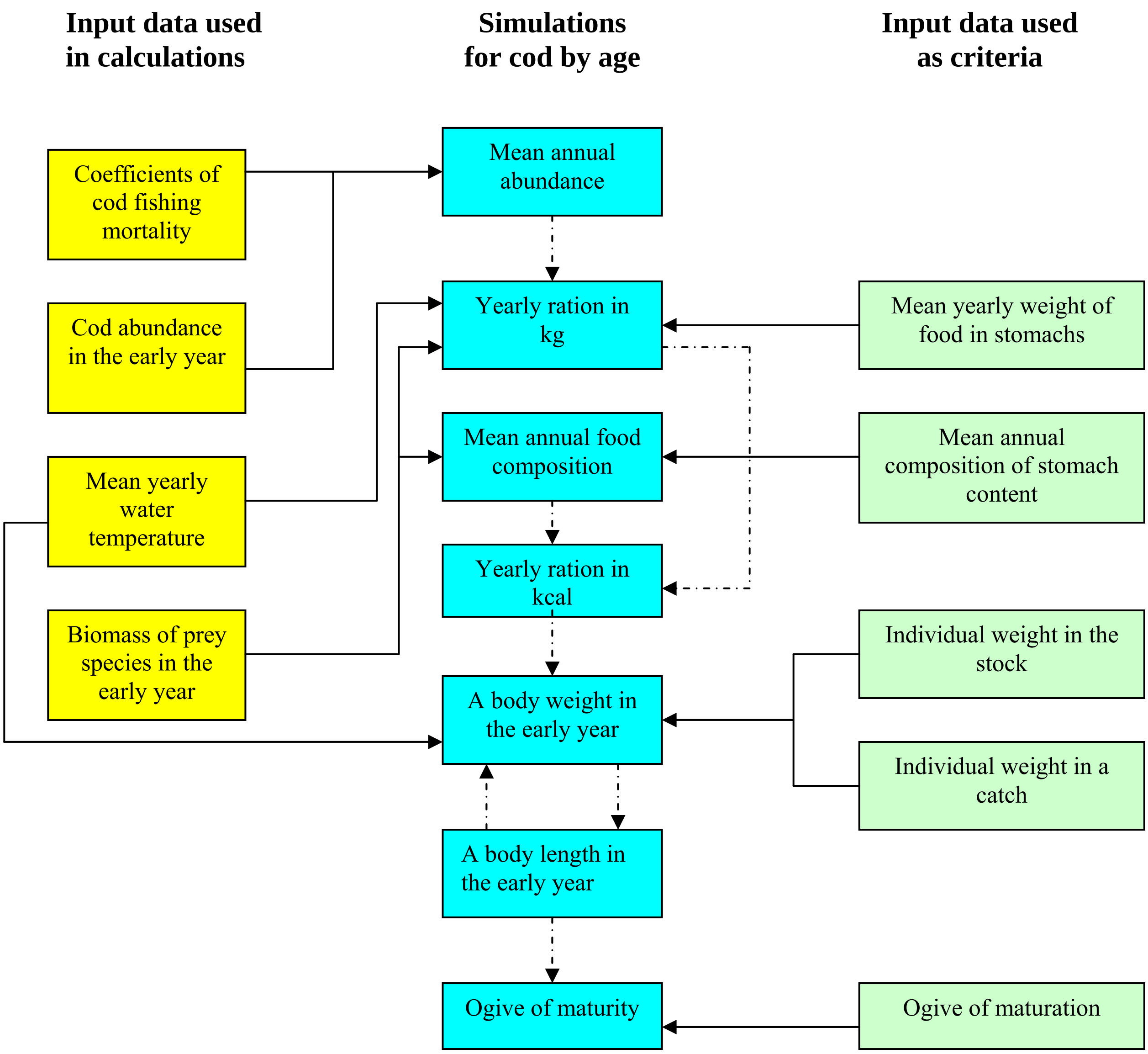

Fig. 2. A scheme of calculations and input data used at the model tuning with 1-year time step

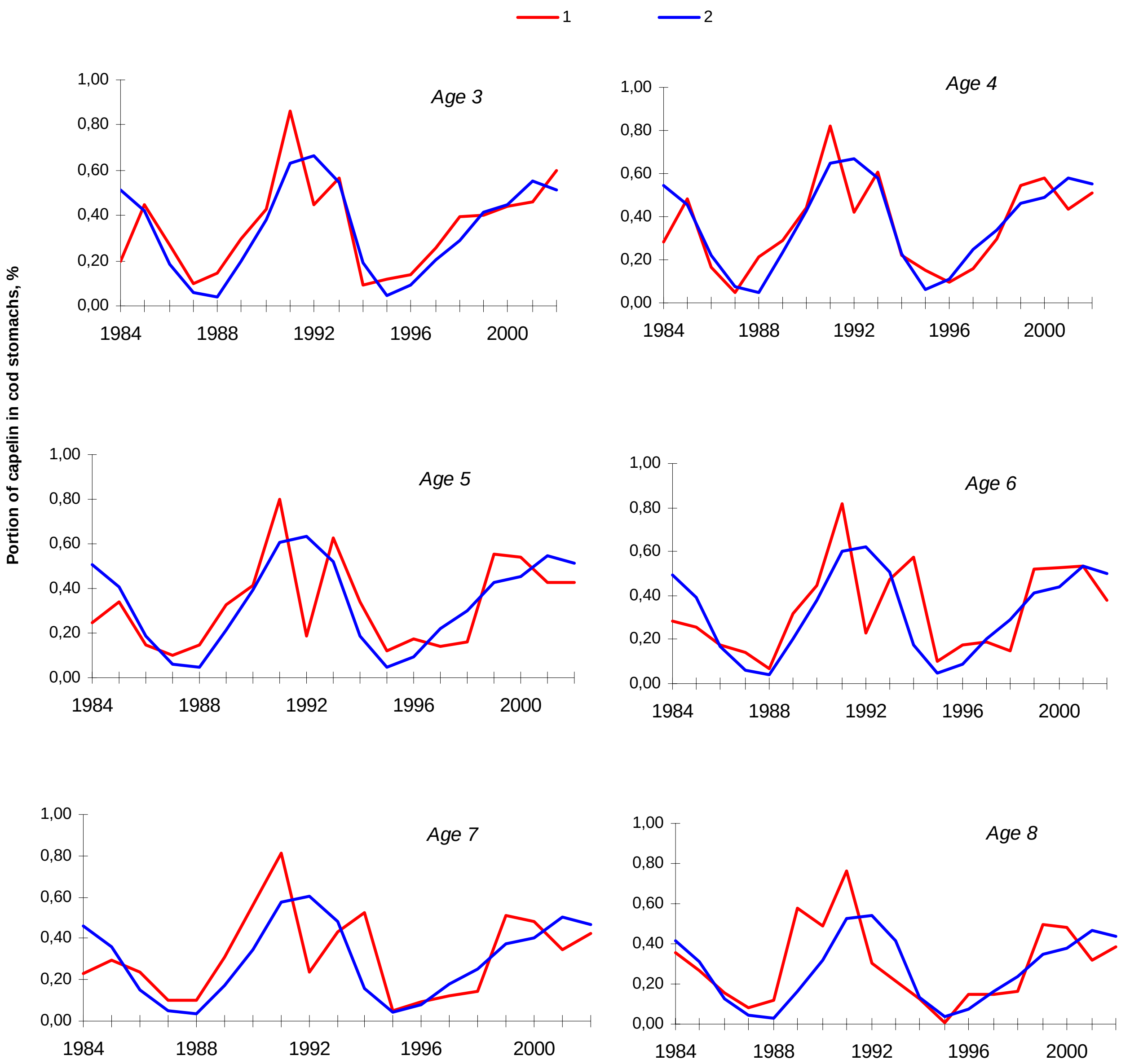

Fig. 3. Consistency between the observed and simulated portion of capelin in cod stomachs: 1– observed, 2 – simulated

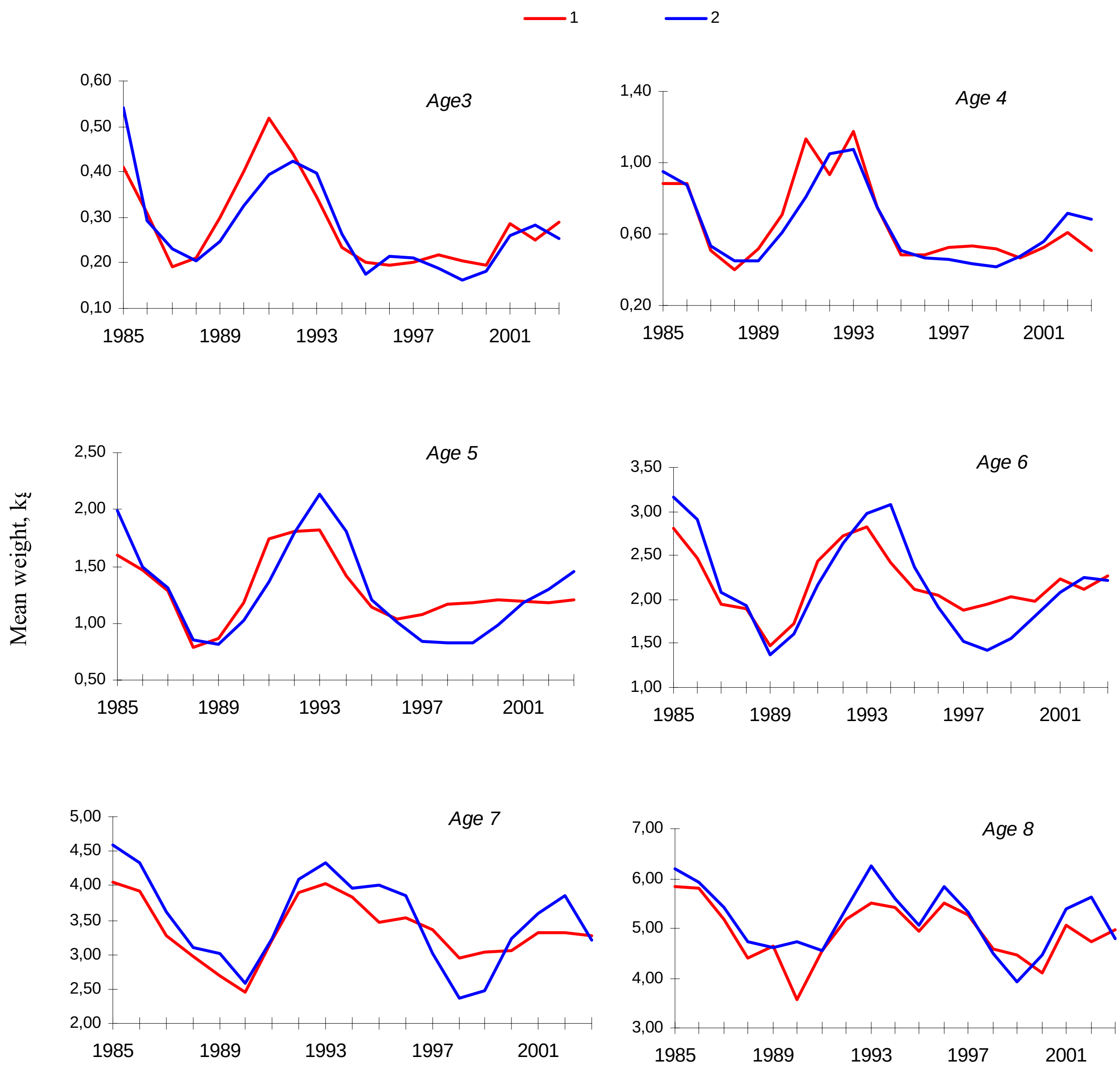

Fig. 4. Consistency between the observed and simulated cod growth rates achieved during tuning the model: 1 – observed, 2 – simulated

STRUCTURAL CHANGES IN THE PLANKTON COMMUNITIES OF THE BARENTS SEA UNDER THE INFLUENCE OF BIOTIC AND ABIOTIC FACTORS

by

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When studying biological resources of seas, plankton is historically considered as a part of the pelagic biota, trophically connected with the latter one. Analysis of the component composition of the zooplankton community is paramount at determining of its functioning system, the production level, as well as at the assessment of the mass plankton-eaters' food base, the most of which are the commercial objects or serve as a food for organisms of the higher trophic levels. The most mass groups in the Barents Sea are copepods, euphausiids, amphipods and chaetognaths.

Objects of the traditional investigations are copepods and euphausiids. The first ones are the main food for larvae and young commercial fish, including herring, as well as for adult plankton-eaters (capelin, polar cod and blue whiting). Euphausiids have a wider circle of consumers, as follows: young and adult Gadoidae, pelagic fishes, marine mammals and birds.
Hyperiids were investigated to a less extent. Only in the end of the previous-beginning of the present century they attracted the attention in connection with the increase of abundance and a role in the feeding of marine organisms of various trophic levels (Drobysheva and Nesterova, 1992; Dolgov, 2000, 1995; Dalpadado, 2002; Orlova et al., 2003, 2004a,b).

There are a lot of data on the population structure and abundance of chaetognaths and on the local and seasonal differences of life cycles of these animals in the Arctic seas (Kaufman, 1967; Bogorov, 1974; Mishin and Adrov, 1980; Pearre, 1981; Timofeev, 1990, 1994; Falkenhaug, 1993). The food requirements of chaetognaths were investigated under different temperature conditions (Mironov, 1960; Cosper and Reeve, 1975; Falkenhaug, 1991). Morphological peculiarities of the *Sagitta* digestive tract structure permit them to use large prey as a food, which exceed in size the *Sagitta* themselves. They are very active and gluttonous predators, and their influence on the plankton community is quite big. The main prey species of *Sagitta* are copepods and tunicates. A daily consumption of copepods by the adult individual of *Sagitta elegans* can reach 75 mg in dry weight (Falkenhaug, 1991). At the same time, *Sagitta* themselves very rarely become prey.

The aim of the given paper is to investigate the long-term dynamics and structural peculiarities of the Barents Sea plankton communities and a role in them of both biotic and abiotic factors.

Materials and Methods

Materials of annual surveys of macroplankton carried out in the Barents Sea in autumn/winter with the use of a pre-trawl net in the pre-bottom layer (6-10 m from the bottom) are used. Under the quantitative assessment the index of abundance was calculated as a mean arithmetic value of catches expressed in individuals/1000 m^3 per 1 trawling hour.

Results and Discussion

The abundance of macroplankton organisms fluctuated very much during the recent 20-year period. The largest fluctuations were observed in euphausiids both in the southern and northwestern sea (Fig.

1). Maxima and minima of euphausiids' abundance coincided with the sharp fluctuations of the stock size of their main consumer – capelin. Besides, large-scale climatic fluctuations also influenced the dynamics of abundance of warm-water and cold-water species and their spatial distribution. Beginning from 1999-2000 a quite high and stable abundance of these crustaceans has formed. Probably it was a result of the influence of two mentioned above factors: large-scale decrease of the capelin stock value (at the simultaneous diminishing in the population of a portion of fish of older age groups, which are the main consumers of euphausiids) and a stable warming up accompanied by the intensification of the Atlantic waters advection.

In spite of the lower concentrations of euphausiids in the autumn-winter period of 2003 (compared to warmer year of 2002), the distribution of crustaceans was wider (Fig 2). Density of their concentrations in the northwest was comparable with that in the southern sea including the most productive coastal areas. Minimal concentrations of euphausiids were traditionally registered on the Great Perseus Bank and the Eastern Basin. At the same time, it should be mentioned that sampling in two latter areas in all years of investigations was insufficiently complete that influenced the concentrations values. This is proved by data for 2004. When investigating the northern areas (78°N), the density of the euphausiids concentrations exceeded 5 000 individuals/1 000m^3 (Fig. 3).

Recent years, data on the species composition of euphausiids also prove a large importance of the warm-water species inflow. In 1999-2000, a big inflow of the boreal species *Meganyctiphanes norvegica* in the southern part of the sea was registered (Drobysheva et al., 2003). A big number of crustaceans of this species was observed in the southern part of the sea in 2001 as well. In 2002 and 2003, diminishing of the *M. norvegica* portion under the simultaneous increase of abundance of the other warm-water species *Thysanoessa longicaudata* (9-12 % in 2003) was observed. The relative abundance of *T. longicaudata* was approximately at the same level in 2004 (Fig. 4).

Dense local near-bottom euphausiids concentrations (> 1000 ind./1000 m^3) were observed in the northern part of the Hope Island area in October 2004. The maximal catch was recorded at 77° N 28° E (6806 ind./1000 m^3), the minimal one – at 76° N 25° E (14 ind./1000 m^3). On the whole, in the area, the abundance of wintering stock of euphausiids was at the high level. The mean index of euphausiids abundance made up 771 ind./1000 m^3.

Thysanoessa inermis was a dominant species among euphausiids – 92 % of the total abundance of euphausiids in samples. Relative abundance of *T. longicaudata* made up 5 %, *T.raschii* – 3 %, and *M. norvegica* – 0,3 % (Fig. 5).

Individuals of *T. inermis* and *M. norvegica* at age 2+, with the length of 20-28 and 30-40 mm, respectively, and of *T. longicaudata* aged 0+, 8-11 mm in length, prevailed (Fig. 6). The population of *T. raschii* was represented by one-year-old and two-years-olds (15-26 and 22-27 mm, respectively). The youngest age groups of *T. inermis*, *T. raschii* and *M. norvegica* were not observed virtually in the catches by a net attached to the trawl net.

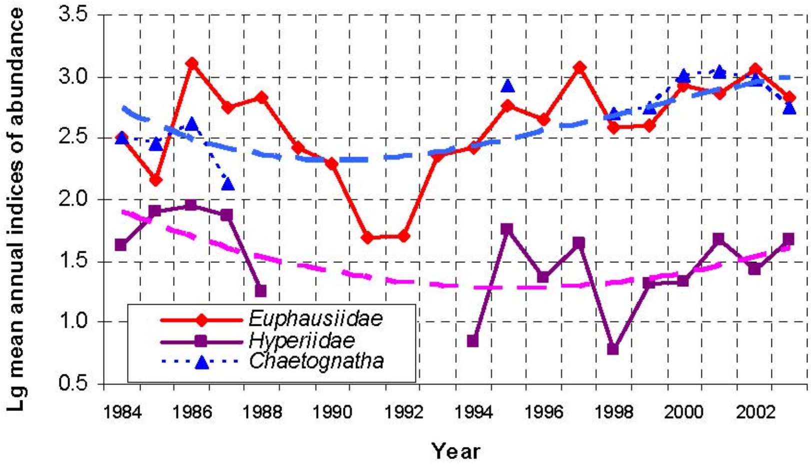
By data of the pre-trawl net, the abundance of hyperiids (*Themisto*) is lower than that of euphausiids (Fig. 1). Two species dominate in the Barents Sea: a smaller one *Th. abyssorum* and a large Arctic species *Th. libellula*. The largest abundance fluctuations of this group of crustaceans were registered in the southern sea, where the first species dominates. However, there are two reasons to believe that catches in the low layers reflect the density of hyperiids concentrations inadequately. Firstly, the large *Themisto* are able to avoid the fishing gear; secondly, they stay for a long time in the water column. There, hyperiids feed on *Calanus* and compete with capelin because of them. Therefore, at a disastrous decrease of capelin stock in 1986-1987 an outbreak of hyperiids abundance took place. This influenced the cod feeding. Cod consumed regularly the grown young and adult crustaceans *Th.*

libellula in autumn 1987 (Table 1). In the other years a high level of consuming of *Themisto* by cod was registered in the northwest at their values of 25-29 % (1986,1987 and 1996) and 6-10 % by weight (1984, 1993-1995, 1998 and 2000). By data of recent years (Figs. 2 and 3) and in warm years, hyperiids have quite high abundance, especially in the northern areas, where *Th. libellula* dominate.

The well-expressed nonlinear trends are present in the interannual dynamics of Euphausiidae and Hyperiidae abundance indices (transformed by finding of the decimal logarithm) for the southern part of the sea. Their contribution into the total variability of these indices constitutes 30-32 %. It is possible that the similar tendency was in the fluctuations of the Chaetognatha index of abundance (Fig.1). In the northwestern part of the Barents Sea, a linear trend was revealed only in the Euphausiidae variability. It takes about 40 % of the summarized dispersion. The rest species of the macroplankton have no such a trend.

The macroplankton abundance nearby the bottom in September has well-expressed intra-daily fluctuations. In all three species the largest abundance is observed in the morning and daytime (Fig. 7). At night, their quantity is much less, that can justifies on their migration into the water column. However, data collected in October-November show that the expressed differences in the macroplankton abundance between the dark and daytime are absent (Fig. 8), that means that migrations of the main mass of crustaceans are terminated. In that period their availability for fish is maximal.

Compared to euphausiids and hyperiids, which play an important role in the trophic structure of the plankton community, chaetognaths are weakly used as food by plankton-eaters (capelin, herring). It probably is connected with a high level of their provision with more favourite food (copepods and euphausiids) under diminishing of fish abundance and with a sharp decline in the capelin population of fish of older age groups. In the mature capelin chaetognaths constituted up to 20 % of the mass of food in the feeding period in the northern areas (the 1970’s). By our data (Fig. 9), which prove the data of S. F. Timofeev (1994), the population of *Sagitta. elegans* in the northern areas (76-78°N) is characterized by the 3-year life cycle, farther to the south – by the 2-year cycle that supposes the presence of larger individuals in the north.



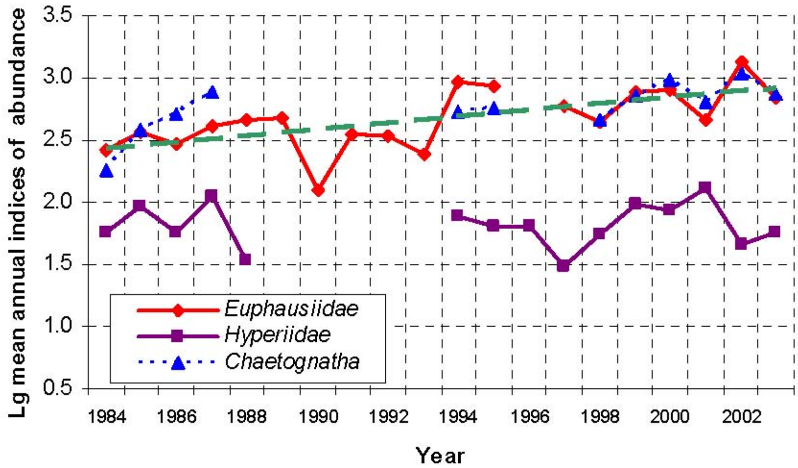
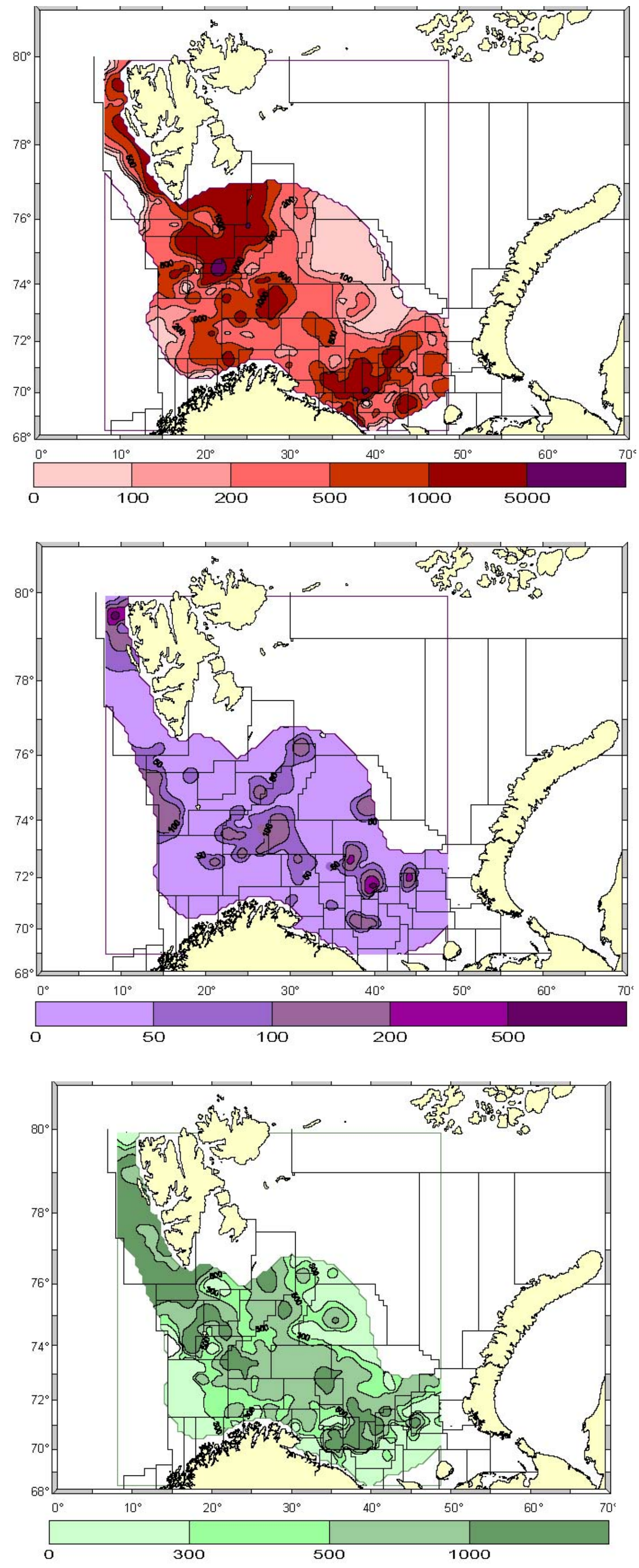


Fig.1. Dynamics of mean annual indices of macroplankton abundance in the Southern (A) and Northwestern (B) parts of the Barents Sea in October-February



A

B

C

Fig.2. Distribution of euphausiids (A), hyperiids (B) and arrowworms (C) in the near-bottom layer in October-February 2003/04, ind./1000 m^3 (by the data from the catches by a net attached to the trawl)

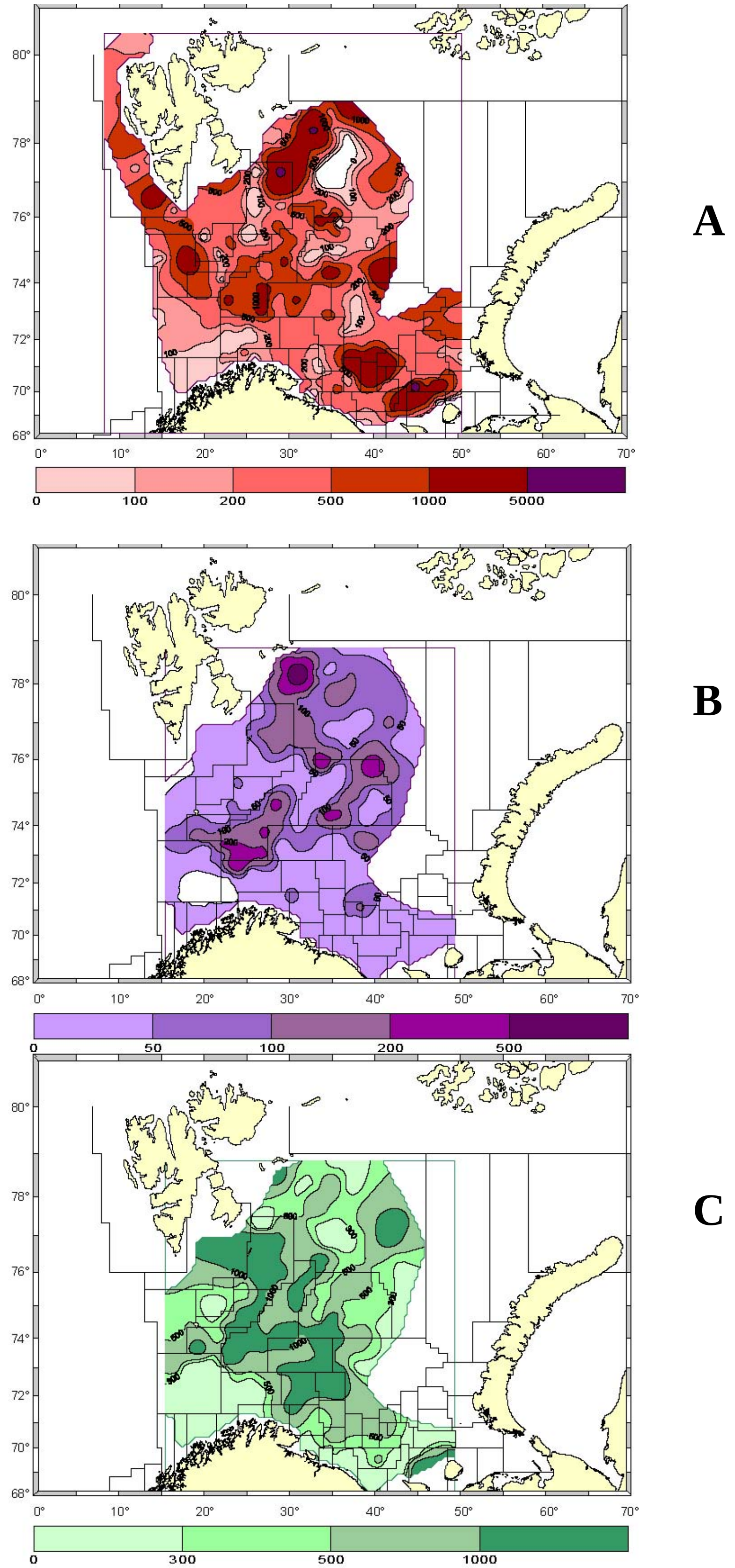


Fig.3. Distribution of euphausiids (A), hyperiids (B) and arrowworms (C) in the near-bottom layer in October-February 2004/05, ind./1000 m^3 (by the data from the catches by a net attached to the trawl)

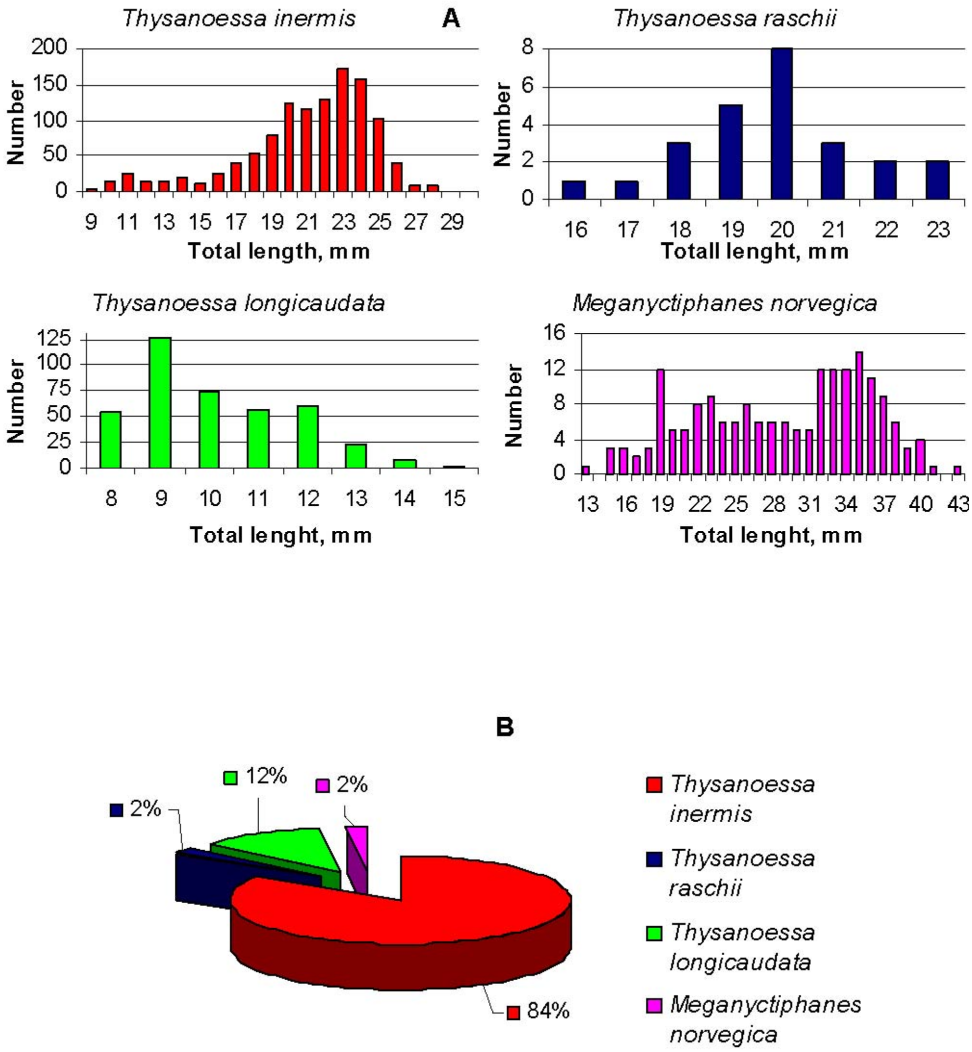


Fig.4. Size frequency (A) and species composition (B) of krill in the Northwestern areas of the Barents Sea in October-February 2004/05

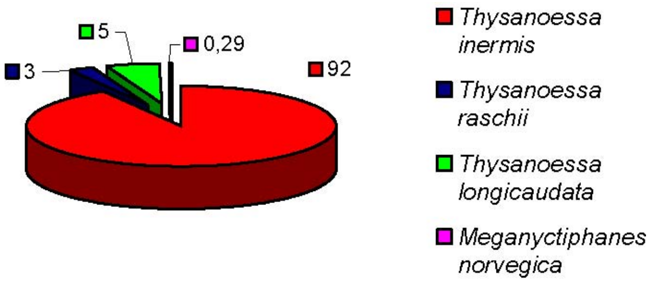


Fig. 5. Species composition of euphausiids in the area of the Hope Island in October 2004

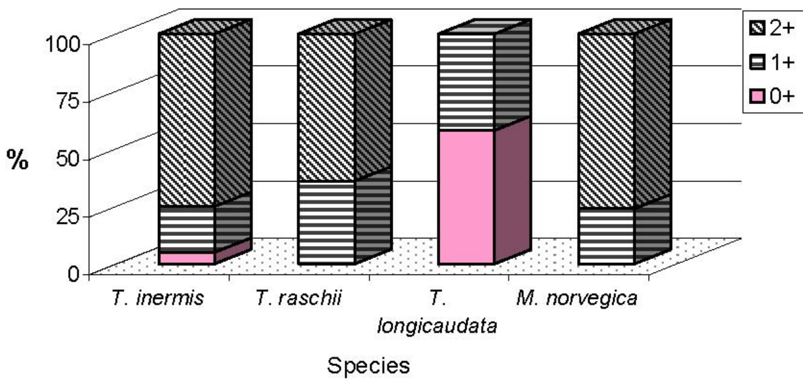


Fig.6. Age frequency of euphausiids in the area of the Hope Island in October 2004

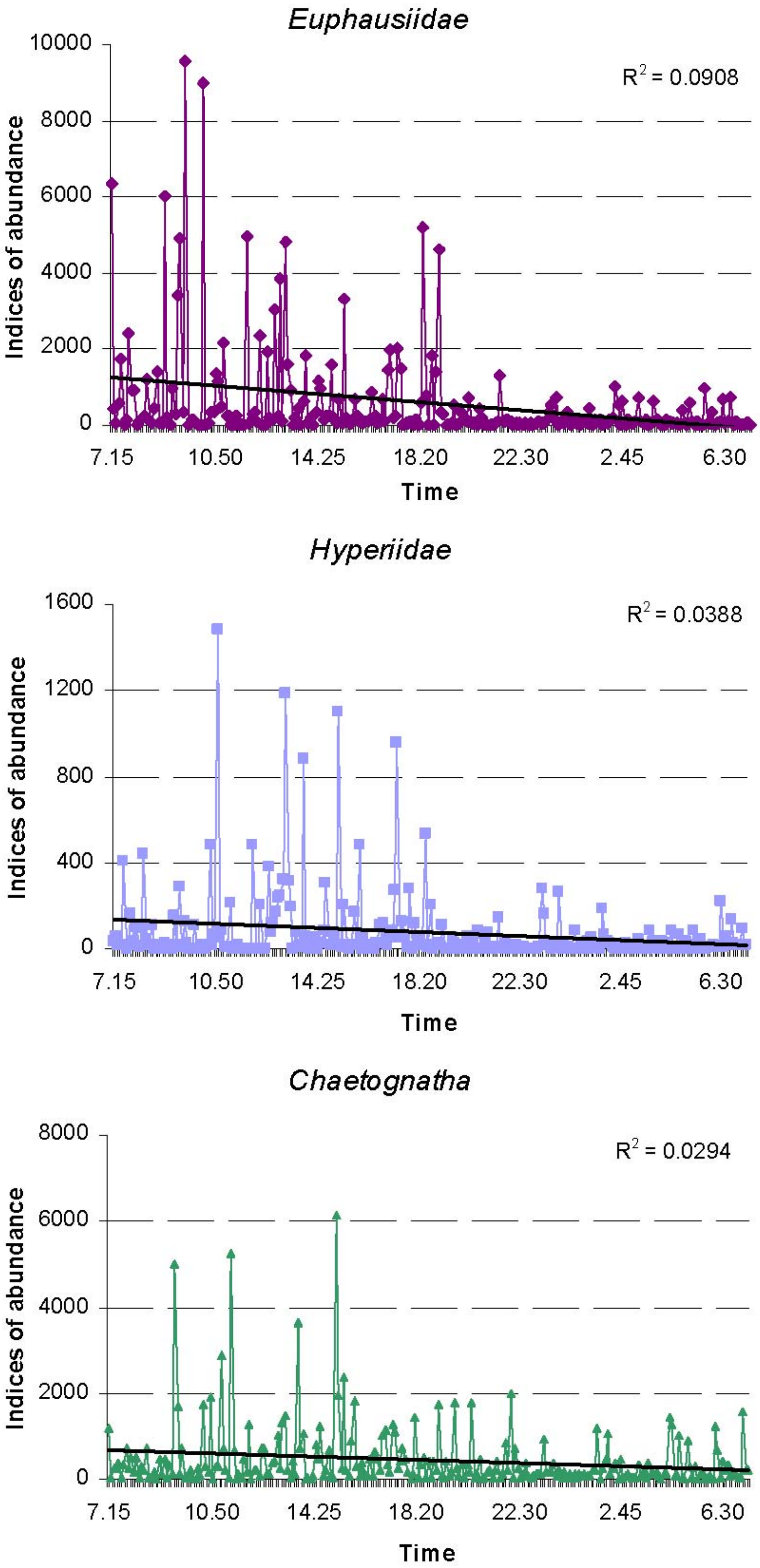


Fig.7. Distribution of macroplankton in the near-bottom layer in different time in September 1987 (by the data from the catches by a net attached to the trawl)

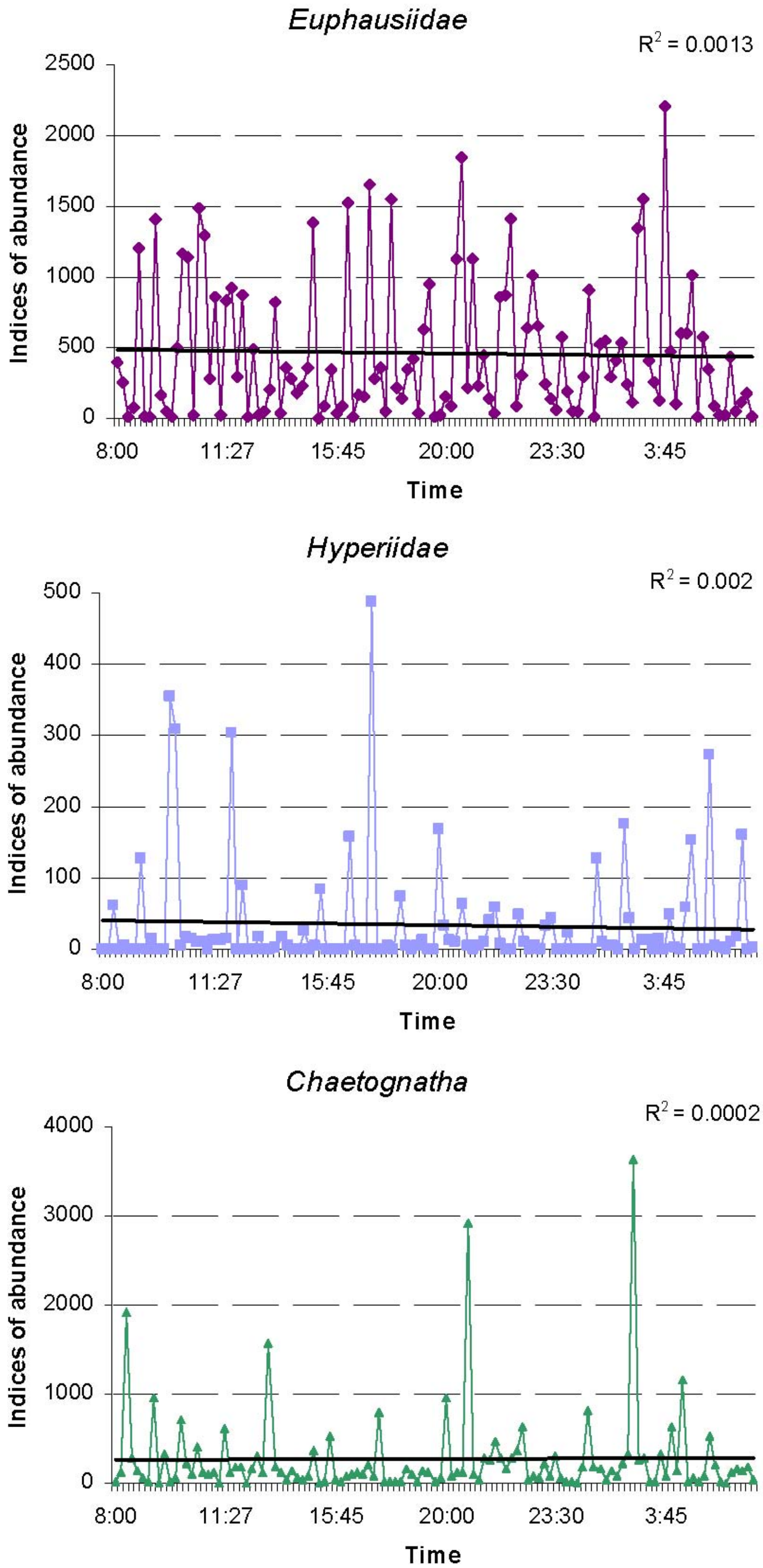


Fig.8. Distribution of macroplankton in the near-bottom layer in different time in October-November 1987 (by the data from the catches by a net attached to the trawl)

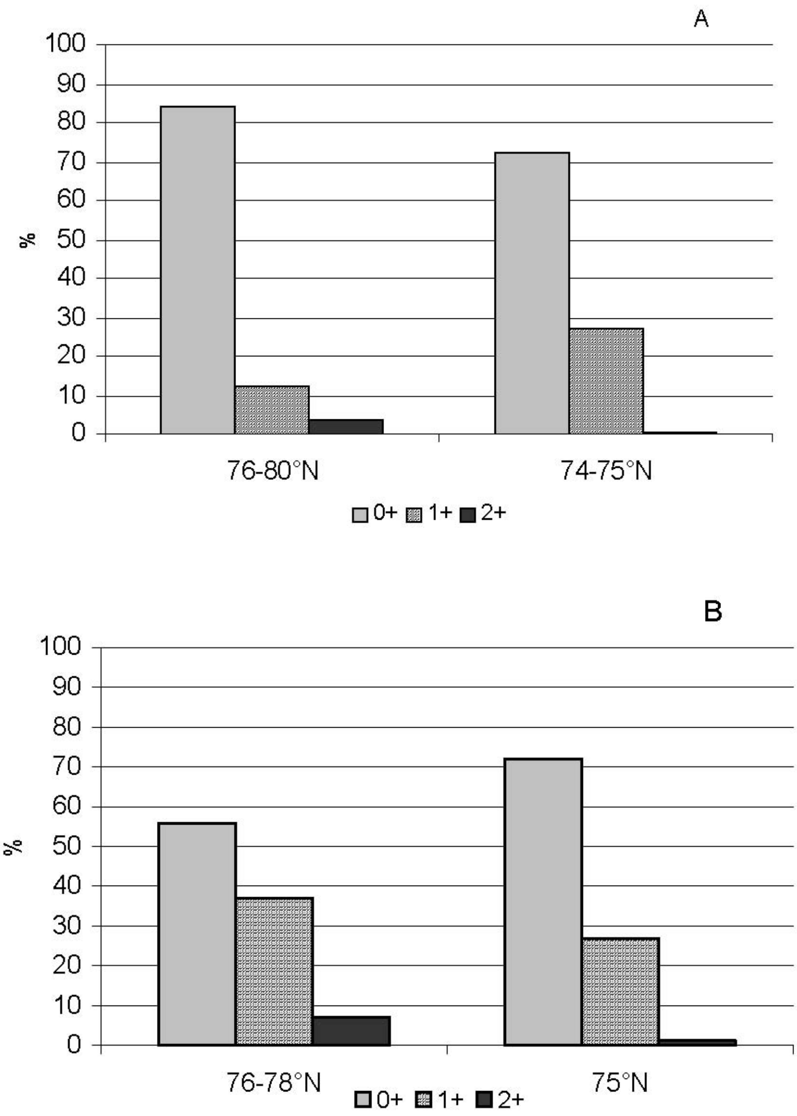


Fig 9. Age composition of Chaetognatha (0+ – youth, 1+ – growth youth, 2+ – adults) in the western part of the Barents Sea in July 1983 (A) and 1987 (B)

The significance of Th. libellula in the food of different size cod in 1985-1988

Month	Areas	**20-40 cm**			**41-60 cm**			**61-80 cm**		
		% of frequency	% by weight	Average length, cm	% of frequency	% by weight	Average length, cm	% of frequency	% by weight	Average length, cm
					1985					
November	Western area	-	-	-	36.1	0.1	15	50.0	0.1	11
August	North-western area	28.6	6.3	15	61.1	34.4	13	22.2	0.3	10
August	Central area	63.6	7.6	10	57.1	1.9	11	-	-	-
August	Murman coast	100.0	47.2	20	13.3	5.8	10	-	-	-
					1986					
August	Western area	14.0	2.0	10	17.0	1.7	10	-	-	-
August	North-western area	23.6	4.9	5	28.2	8.2	10	-	-	-
					1987					
September	Western area	-	-	-	44.8	32.5	21	12.6	37.6	24
October		40.0	87.9	30	61.5	83.1	30	55.6	74.0	28
November		-	-	-	30.8	35.5	28	28.6	33.3	30
August	North-western area	40.0	93.8	20	55.3	52.7	19	71.4	22.0	17
September		25.0	91.0	20	42.1	44.4	21	-	-	-
September	Central area	-	-	-	-	-	-	25.0	13.2	25
November		-	-	-	6.2	0.2	16	3.1	0.1	15
October	Eastern area	66.7	47.6	30	69.7	51.9	28	50.0	38.8	30
					1988					
August	Central area	5.5	0.7	20	23.9	10.4	17	33.3	10.5	20
August	Murman coast	14.3	1.0	18	-	-	-	-	-	-

Means lack of data.

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE YEAR-TO-YEAR PECULIARITIES OF FEEDING, GROWTH AND SURVIVAL OF THE BARENTS SEA JUVENILE COD

by

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Introduction

It is known that the abundance of year-classes entering fishery depends on juvenile cod survival at the stage from 0+ to 2+ (Ponomarenko, Mukhina, 1998). Fish survival at some stages of life history is different. The most critical periods in the life of fish are: the period of embryo emergence from eggs, larva transition to independent feeding and the biotope change by juveniles. Cod fry going from pelagial to the sea bottom layers starts in August-September. At present, the questions on rates and duration of juvenile cod settling period, the change of its biological parameters at this time, feeding and others have remained to be under discussion (Sysoeva, 1972; Wiborg, 1949).

The paper is aimed at studying biological parameters and their variability, feeding and survival of cod fingerlings from 2002-2003 year-classes when fish change the pelagic mode of life to the bottom one.

Material and methods

In August-September 2002 and 2003, Russian data from international survey for assessment of 0-group fish abundance were used. In October-December 2002-2003, analyzed were the data from Russian TASs to estimate the stocks of the main commercial fishes in the Barents Sea. In February 2003 and 2004, Russian data from TAS for joint Russian-Norwegian methods were applied.

Length, weight and their increments, food composition, stomach fullness index (SFI), fatness and Fulton's condition factor of fingerlings were studied separately by seasons (from the first ten-day period of August to the late September, from the last ten-day period of October to the late December and for February). The stomach content of 3740 fish was analyzed.

To analyze growth chosen were the two time intervals: from 15 August to 15 November and from 15 November to 15 February if we assume that fish grew with a constant rate within the studied period (Ozhigin et al., 1996).

The paper uses Russian the data on the abundance of cod fingerlings from 2001, 2002 and 2003 year-classes (Anon., 2003). Calculations of the survival of fingerlings aged to three and the forecast of their abundance at this age were made according to the equation proposed by I.Ya.Ponomarenko (1979).

To analyze the effect of water temperature on growth and feeding of cod fingerlings the fishing areas were integrated into groups by distribution of dominating water masses entering the Barents Sea (Fig.1).

Weighted means of water temperature in 0-50 m (August-September) and bottom (October-December, February) layers were calculated and the charts of spatial distribution of temperature were made for the area groups separated. The thermal condition was estimated on the whole and separately by seasons and water masses in 2002-2003 and 2003-2004 and they were compared by the difference of average temperatures.

The paper uses statistical methods of correlation analysis. All the initial data were processed applying software “Surfer”, “Excel” and “Statgraf”.

Results and discussion

Biological data on fingerlings of cod from 2002 and 2003 year-classes by seasons

When fish grow their biological parameters change. From August to February the increase in mean length and weight of fingerlings against the decrease in their fatness and condition was observed (Fig.2). Fish index of fullness (IF) was also reducing from August-September to October-December (especially intensively in fingerlings from 2002 year-class) and somewhat rising by February. Average length and weight of 2002 year-class fingerlings were higher while their condition was lower than of those ones from 2003 year-class.

The greatest difference between maximal and minimal biological parameters of fingerlings was recorded in October-December (Fig.3). Such variability is connected with a quality of fish from a single year-class (Drebuadze, 2001) and the environment impact (Aleev, 1980). The population of the northeast arctic cod has a multiage structure of spawners and a long spawning period that, undoubtedly, affects all the biological processes of the following year-classes. In our opinion, the decrease in the range between the minimal and maximal biological parameters of fingerlings from the stage of a pelagic fry (August-September) to the true bottom juveniles (February) is a result of adaptation to the new conditions of living that leads to the natural selection of more adaptable individuals. Usually in a year-class having survived are larger fish that results in smaller range of mean biological parameters. Variations of cod fingerling biological parameters are connected with the change of their growth.

The growth of cod fingerlings when biotope changes

Cod is characterized by isometric growth, which is the most intensive in the first year of life. The closest links between weight and length of cod fingerlings were observed in April-September and February (Fig.4). This relationship becomes weaker in October-December. Different factors may be the reason of such variations. We calculated a relative increment of length and a specific rate of fingerling weight growth by each season in different water masses of the southern Barents Sea (Table 1). The analysis of the data revealed the total trend in changes of parameters of cod fingerlings from the given year-classes. Linear weight increments of fingerlings abruptly reduced in all the water masses from November to February. The highest values of growth were registered in the areas of coastal and main branches of the Murman Current influence. A relative length increment and the weight growth specific rate of 2003 year-class were somewhat higher than those ones of 2002 year-class.

To clarify the reasons of the reduction in linear-weight increments and other biological parameters of fingerlings we studied food and temperature factors.

Food composition of fingerlings in different seasons

From August to February, euphausiids, fish, hammarids, hyperiids, polychaetes and copepods occur in cod feeding the most often (Figs.5, 6).

In August-September, the diet of fingerlings consisted of, mainly, euphausiids and different juvenile fish among which larvae and juveniles of capelin, herring, polar cod, sand eel, gobies and eelblennies prevailed. The diet was quite various: the category of "other marine organisms" (to 25 %) was represented by juveniles of different shrimps and crabs, mysids, cladocerans, mollusks, chaetognates, appendicularies, ctenophores.

In October-December, in the ration of fingerlings the representatives of bottom fauna – gammarids and polychaetes appear. Hyperiids were a secondary feeding object since their weight portion in the stomachs of juveniles from both year-classes did not exceed 12% though the frequency of occurrence corresponded to 15%.

In February, the specific composition of fingerlings did not significantly change as compared to the previous period, having changed were only a qualitative ratio of food components in year-to-year aspect and the significance rate of some kinds of food.

Water temperature and biological parameters of fingerlings in the period of the biotope change

The influence of water on growth of cod and their juveniles was noticed by many authors, at this, the most of them pointed out to the presence of positive links (Anon., 1996).

From August to November an abrupt reduction in growth rates of cod fingerlings was observed. In these periods an active cooling of the Barents Sea water masses takes place (Tereschenko, 1999) that is traced well by seasons (Fig.7).

From August to February, water temperature reduced in all the water masses. The most intensive cooling was in the effect area of the central branch and along the main one in the Murman Current from August-September to October-December. In 2002, in the Central Current and the main branch of the Murman Current the difference in temperature between August-September and October-December reached 5.29ºC and 4.44ºC, in 2003 – 5.43ºC and 4.15ºC, respectively.

In 2002 and 2003, from August to February, in the southern Barents Sea, the most favourable temperature conditions were observed in water masses of the coastal branch in the Murman Current (Fig.7b). There, a high positive water temperature was registered in all the seasons. The most unfavourable temperature conditions for the life of fingerlings in the southern part of the sea were in the influence areas of the Central Current.

Table 1. Linear and weight growth of cod fingerlings from 2002-2003 year-classes in different seasons.

Currents	2002 year-class				2003 year-class			
	Relative length increment, %		Specific rate of weight growth		Relative length increment, %		Specific rate of weight growth	
	от 15.08.02 до 15.11.02	от 15.11.02 до 15.02.03	от 15.08.02 до 15.11.02	from 15.11.02 to 15.02.03	from 15.08.02 to 15.11.02	from 15.11.02 to15.02.03	from 15.08.02 to 15.11.02	from 15.11.02 to 15.02.03
Murmansk (coastal branch)	43,4	2,7	0,097	0,001	58,2	0,1	0,119	0,001
Murmansk (main branch)	44,4	6,7	0,097	0,011	41,4	5,0	0,109	0,011
Novaya Zemlya and Kanino-Pecherskoe	34,6	1,9	0,065	0,011	24,4	2,6	0,033	0,022
Central	31,3	5,5	0,076	0,001	34,2	5,1	0,076	0,001
North Cape (north and central branches)	28,9	-*	0,054	-	16,7	-	0,033	-
Average by areas	34,2	3,8	0,076	0,005	35,6	4,5	0,087	0,008

**Data were not collected.*

In the southern Barents Sea, in the seasons of 2002-2003, the temperature conditions, on the whole, corresponded to the level of the normal ones, in the seasons of 2003-2004 – to that one of anomalous warm years. There is a considerable positive relationship between water temperature in the different water masses of the Barents Sea and the growth of fingerlings (Fig.8). The more water temperature in the previous season, the higher growth rates of fingerlings. The highest linear weight increments of fingerlings were observed in the areas of the Murman Current coastal and main branches.

Temperature affects fish growth through the changes in the intensity of metabolism, which, in its turn, determines fish behaviour. By our data, in the period of biotope change, as a result of sharp reduction in water temperature, the physical activity of cod fingerlings decreases that leads to the feeding intensity decline and the rise of the non-feeding fish portion. In October-December, these two parameters are the lowest (Fig.2). We assume that in October-December fingerlings have not adapted to the sharp change of temperature conditions. Growth rate deceleration and lowering of mean biological parameters are often observed both in natural conditions, and in aquaculture (Brett, 1983).

Calculation of three-year-old cod abundance using the data from the assessment of their fingerlings

The north-east arctic cod is characterized by a high mortality during the first three years of life (Mukhina, Marshall, Yaragina, 2003). The ratio of the average catch of three-year-olds per a hauling hour to the mean catch of fingerlings from the same year-class was taken as an index of juvenile survival in some year-classes. This index does not characterize absolute survival of year-classes, but allows us to give a comparative quantitative estimate of different year-class survival in the same period. Used was a forecast equation of multiple correlation (1) including only biological arguments:

$$Y = 15.05x1+1.112x2+0.017x3-16.789 \quad (1)$$

$$Ry(x1x2x3)=0.854\pm0.06$$

where Y – the index of juvenile cod survival at the stage of from fingerling to three year old age;

x1 – mean condition factor of fingerlings in October-December;

x2 – mean fatness of fingerlings in October-December, %;

x3 – the rate of fish containing food in the stomachs

Applying this equation the survival indices of juvenile cod from 2001, 2002 and 2003 year-classes were obtained and then their abundance at age 3 was determined (Table 2).

Table 2. Survival indices (K_B) of cod juveniles and its abundance at age 0+ and 2+ in the southern Barents Sea (Area I)

Year-class	True abundance of fingerlings, ind. per hauling hour	Forecasted abundance of three-year-olds, ind. per hauling hour	K_B
2001	1	2	1.67
2002	20	23	1.15
2003	8	23	2.87

Obtained estimates of the three-year-old cod recruitment showed that 2001 year-class was poor, those ones of 2002 and 2003 were moderate in abundance. Considering favourable temperature conditions in the Barents Sea and a good state of fingerlings one may hope that the year-classes of 2002 and 2003 will remain at the level of year-classes, which are moderate in abundance.

Conclusions

1. When cod fingerlings change the biotope, starting is the period of adaptation, which shows itself in the decrease of feeding activity, fatness and condition of fingerlings that leads to deceleration of their growth. The indices of linear-weight increments of fingerlings sharply decrease from November to February.
2. One of the reasons of noticeable changes in the life activity of fingerlings is an abrupt change of temperature conditions in the period of their going from pelagial to the bottom layers. October-November should be considered as one of the critical periods in the life history juvenile cod in the first year.
3. From August to February predominating food objects in diet of fingerlings from 2002 and 2003 year-classes were euphausiids, fish, gammarids, hyperiids, polychaetes and copepods. Their ratio in feeding depended on season.
4. Based on the indices of fingerling condition and fatness, as well as the role of feeding fish the survival indices of fingerlings from 2001-2003 year-classes were obtained. The obtained estimates of the three-year-old cod commercial stock recruitment placed the year-class of 2001 as being poor while those ones of 2002 and 2003 as to be moderate in abundance.

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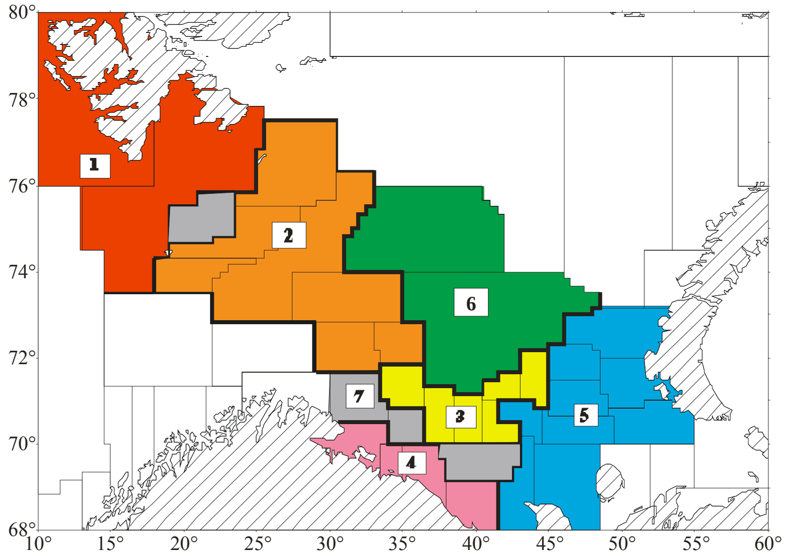

Fig.1 Areas of cod fingerling distribution by the main branches of the Barents Sea currents (Tantsura, 1973): 1- the Spitsbergen Current; 2 – the North Cape Current (northern and central branches); 3 – the Murman Current (main branch); 4 – the Murman coastal current; 5 – the Novaya Zemlya and Kanino-Pecherskoe Currents; 6 – the Central Current; 7 – areas not included into analysis

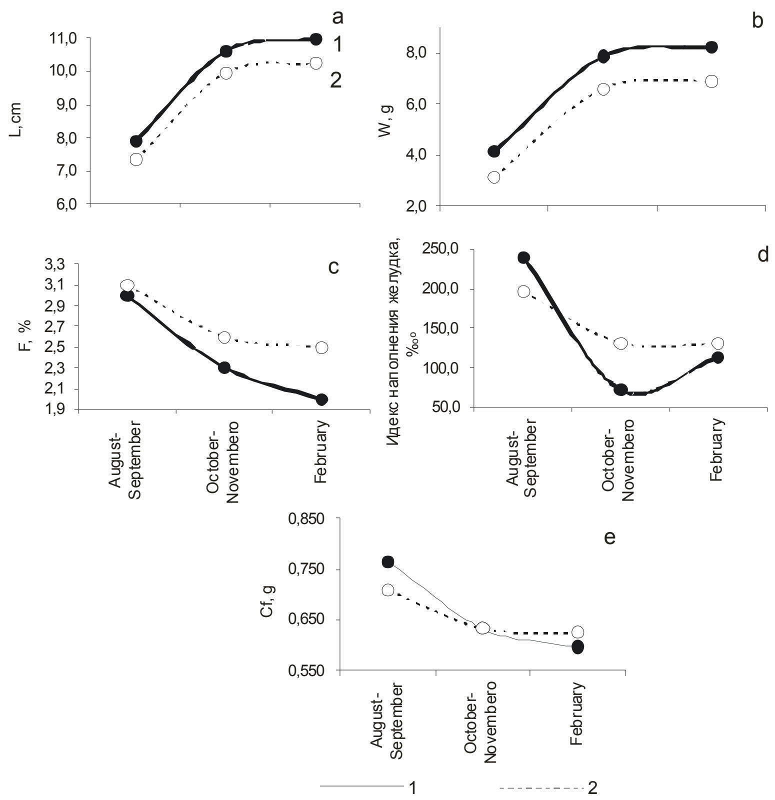

Fig.2.Variations of mean length (a), weight (b), fatness (c), stomach fullness index (d), condition (e) of cod fingerlings from 2002 and 2003 year-classes at the first year of life from August to February

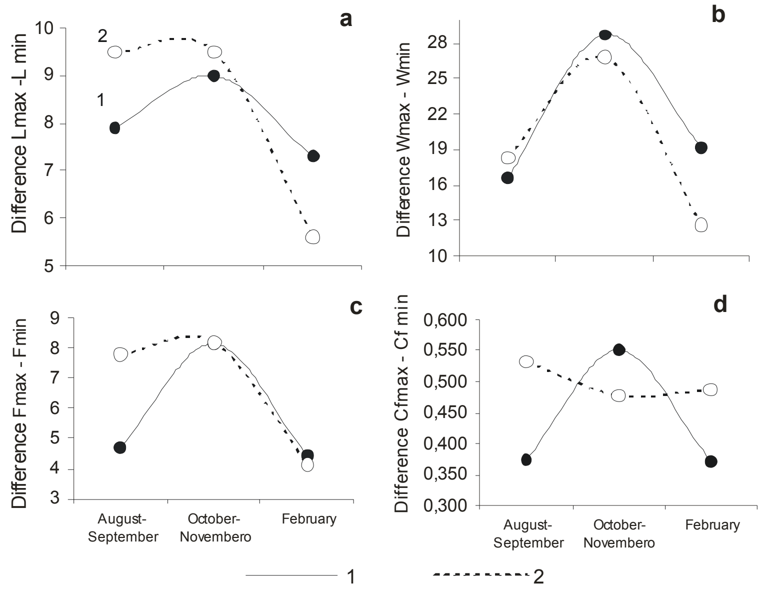

Fig.3. Dynamics of difference between maximal (max) and minimal (min) length (L, a), weight (W, b), fatness (F, c) and condition (Cf, d) of cod fingerlings from 2002 (1) and 2003 (2) year-classes

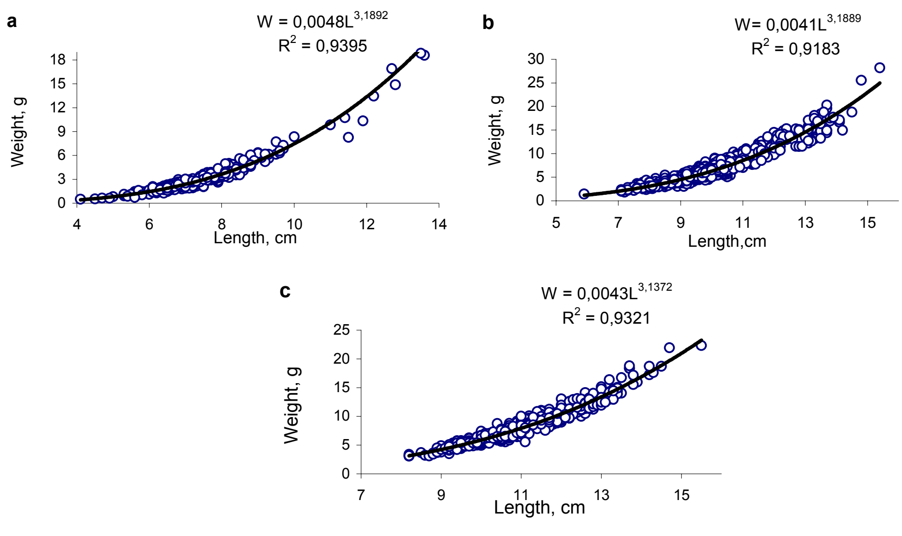

Fig.4. Dependence of cod fingerling weight on their length in August-September (a), October-December (b) and February (c)

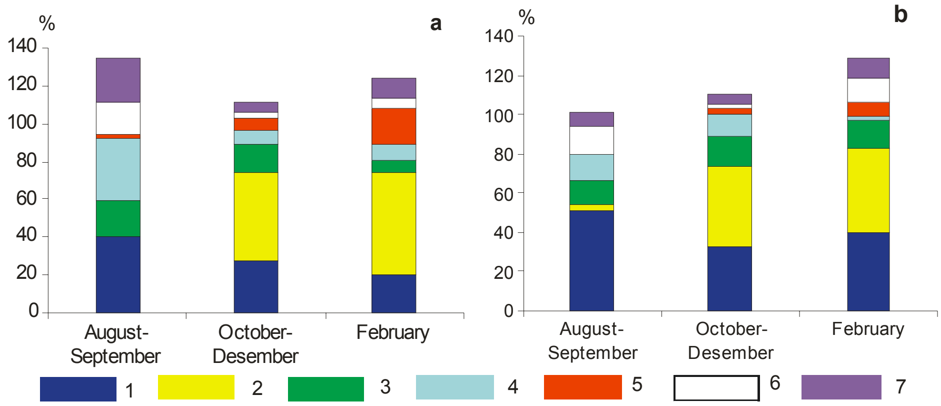

Fig.5. Food item occurrence frequency in stomachs of cod fingerlings from 2002 (a) and 2003 (b) year-classes in different seasons: 1 – euphausiids; 2 – gammarids; 3 – hyperiids; 4 – fish; 5 polychaetes; 6 – copepods; 7 – other marine organisms

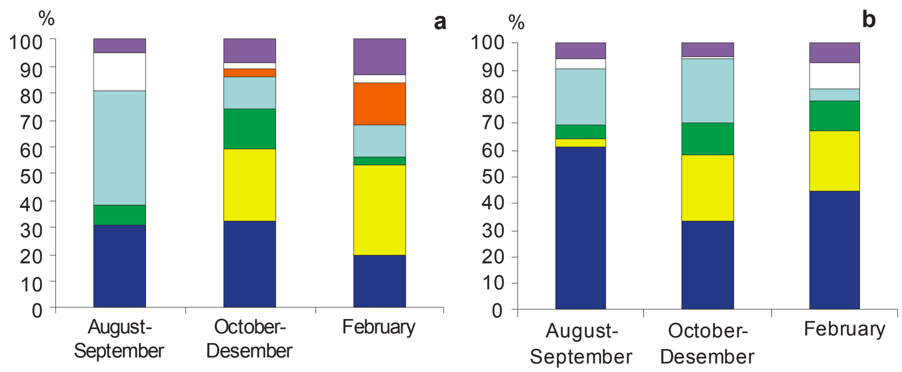

Fig.6. Ratio of main food items in stomachs of cod fingerlings from 2002 and 2003 year-classes in different seasons, % by weight in a bolus. Legends in Fig.5

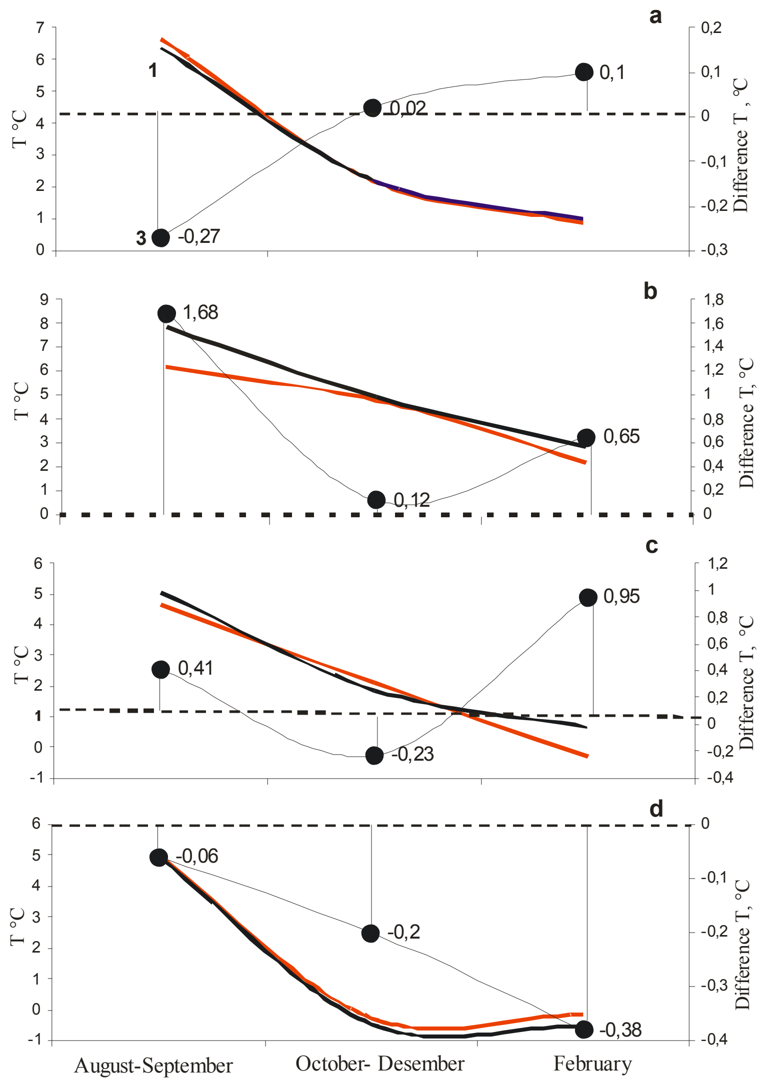

Fig.7. Seasonal dynamics of mean water temperature along the main (a) and coastal (b) branches of the Murman Current, in the Novaya Zemlya and Kolguevo-Pechyorskoe (c) and Central (d) Currents in the layers of concentration of fingerlings: 1 – year-class of 2002; 2 – year-class of 2003; 3 – difference of water temperature between seasons in 2003-2004 and 2002-2003

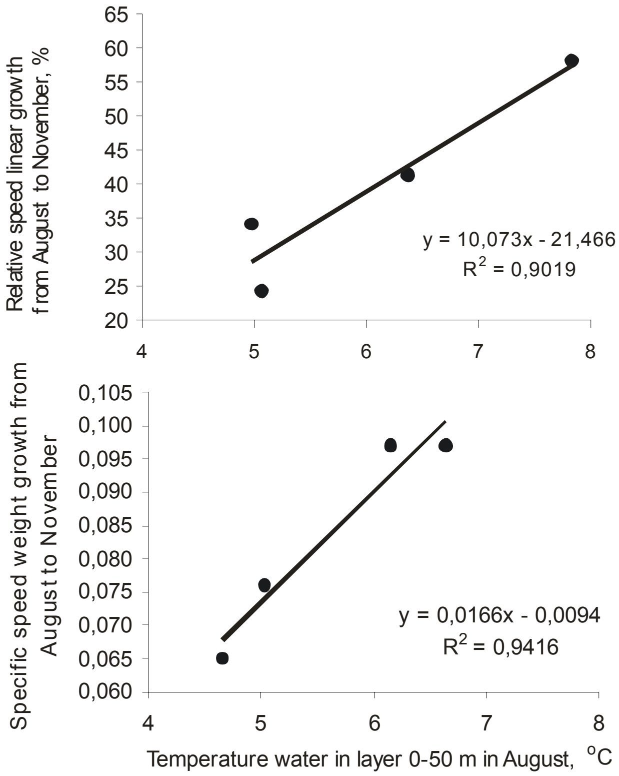

Fig.8. Relationship between water temperature and growth of cod fingerlings in different water masses when the biotope changes

SPECIFIC FEATURES OF DISTRIBUTION AND ABUNDANCE OF THE MOST ABUNDANT PISCIVOROUS SEA BIRDS IN THE BARENTS SEA IN RELATION TO THE DISTRIBUTION OF THEIR PREY IN 2003-2004

by

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The objective of this study undertaken on the basis of data from aerial surveys conducted by research aircraft AN-26 "Arktika" in summer and autumn 2003 and 2004 is to investigate the distribution of the most abundant sea birds – northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*) in relation to the distribution of abundant pelagic fish in the Barents Sea – capelin and polar cod. Abundance estimates for these species of sea birds are given as well as those ones of potential consumption of fish by them.

A comparison of the distribution pattern of sea birds in the Barents Sea in 2003 and 2004 showed considerable differences in the character of their distribution in the Barents Sea area which might probably be related to varying abundance of their main prey, capelin, in particular.

Introduction

Investigations of food relations at the level of highest vertebrates have been one of the priority topics in studies of marine ecosystems over the past 10-15 years. Against the background of intensive exploitation of fish resources in the Barents Sea more and more important becomes the issue of effective management of stocks of commercial fishes, and hence potential outtake, which cannot, in fact, be possible in the absence of reliable information about main organisms impacting on their abundance.

Understanding of the trophic role of those organisms in the ecosystem and assessment of their abundance is of particular importance. Unfortunately, against man's activities in utilizing the aquatic biological resources the populations of sea birds still undeservedly receive too little attention.

At present, fairly well studied are species composition of sea birds in the Barents Sea, location and approximate abundance of their breeding colonies (Belopolsky, Shuntov, 1980; Uspesky, 1959; Krasnov et al., 1995). However, virtually absent or very scarce is information on their distribution and diet beyond their breeding season (Borkin et al., 1992; Erikstad, 1990; Erikstad et al., 1990; Barrett et al., 2002). It is exactly in that period of their life, which encompasses a larger part of the year, the sea birds are distributed over large areas, perform extensive migrations, and gather sometimes in large numbers in areas with rich availability of food. The papers by a number of researchers (for instance, Greenstreet et al., 1999) showed that the abundance of sea birds as well as successful reproduction are mainly caused by productivity of the marine systems, i.e. the available food supply (primarily, crustaceans and fish species). The influence of abundant populations of sea birds on fish resources (direct or indirect, through fish food supply) may be, thus, enough great.

This paper contains results from observations carried out by research aircraft AN-26 "Arktika" in summer and autumn 2003 and 2004. Analysis of the distribution of the most abundant piscivorous sea birds – northern fulmar (*Fulmarus glacialis*) and black-legged kittiwake (*Rissa tridactyla*), and reasons behind them gathering in aggregations of high density is made. The relationship between distribution of these birds and their main prey – abundant pelagic fishes in the Barents Sea – capelin (*Mallotus villosus*) and polar cod (*Boreogadus saida*) is analysed. Estimates of abundance of northern fulmar and black-legged kittiwake and potential consumption of fish by them are given.

Material and methods

Surveys of birds to assess their numbers were undertaken from the research aircraft AN-26 "Arktika" under the program of integrated aerial surveys in the Barents Sea in the period from 22 August to 1 October 2003 and from 22 August to 30 September 2004. Specially trained observers (by two specialists from each board) carried out visual control of the sea surface parallel with board research equipment. The observations were made through standard bubble windows without using optics. The vertical angle of observation was equal to 45 degrees, on the average.

With survey altitudes between 150-200 m, flight speed 250-350 km per hour the width of visual strip was between 200-400 m. In subsequent data analysis this parameter was flight-specific. Observers' reports about observed objects, including species, number, observer's aircraft side, additional information, were sent via intranet to an operator of the onboard automated data collection system. The operator recorded all data into automatically logged flight log-book. During the flight all data were linked to positions and time by using information from satellite navigation system in real time.

In 2003, the survey area was 792 000 km^2 and, in 2004, it was 680 000 km^2. Fig.1 shows survey tracks.

In visual surveys all birds were counted and their species identified. It should be noticed that all the gulls (black-legged kittiwake, herring and great black-backed, glaucous gulls and others) and *Procellariformes* (northern fulmar) are differentiated well and identified to species under different illumination and vision. It is more difficult to assess *Alcidae* (murres, Atlantic puffin, black guillemot and others), which may be hardly identified from the aircraft board by different reasons.

The routes of aerial observations are given in Fig.1, the numbers of assessed birds and their percentage – in Table 1.

Results from aerial surveys of sea birds were analysed using a special software, by which the transect width was determined on the basis of flight altitude information and the number of birds of each species per 10 km^2 of the transect area was estimated. A major requirement to survey design was a uniform coverage of the survey area by transects, the spacing between them was no more than 50-70 km.

Table 1. Sea bird species registered during the aerial observations, the numbers of assessed birds and percentage of occurrence

Species		2003		2004	
		ind.	%	ind.	%
Great cormorant	*Phalacrocorax carbo*	6	0.0	0	0.0
Glaucous gull	*Larus hyperboreus*	88	0.1	4	0.0
Common eider	*Somateria mollissima*	0	0.0	0	0.0
Northern fulmar	*Fulmarus glacialis*	31549	52.1	11709	69.1
Murre	*Uria spp.*	5675	9.4	2310	13.6
Black-legged kittiwake	*Rissa tridactyla*	16734	27.7	1769	10.4
Great black-backed gull	*Larus marinus*	5	0.0	6	0.0
Gannet	*Sula bassana*	3	0.0	4	0.0
Pomarine jaeger	*Stercorarius pomarinus*	107	0.2	296	1.8
Herring gull	*Larus argentatus*	9	0.0	6	0.0
Common gull	*Larus canus*	0	0.0	0	0.0
Swan	*ordo Anseriformes*	2	0.0	0	0.0
Unid.gull	*fam Laridae*	33	0.1	382	2.3
Unid.bird	-	6286	10.4	452	2.7
Total		***60497***	***100.0***	***16938***	***100.0***

Aerial surveys were undertaken at the same time and over the same area as an annual joint Russian-Norwegian multispecies trawl-acoustic survey involving a number of vessels. Data on capelin and polar cod provided by this survey were used in analysing the data on the distribution of sea birds.

The results of calculations presented in Table 2 show significant difference between abundance and distribution density values by years. This fact is probably indicative of not only a great heterogeneity of bird distribution in the area, but of their evident underestimation in the northwestern sea, where higher biological productivity of the sea is usually noticed annually, in 2004.

Table 2. Abundance (10^3ind.) and average density (ind./km^2) of northern fulmar and black-legged kittiwake in the Barents Sea in August-September 2003-2004

Year	Northern fulmar		Black-legged kittiwake		Total	
	10^3 ind.	Ind./km²	10^3 ind.	Ind./km²	10^3 ind.	Ind./km²
2003	14074	17,8	3483	4,4	17657	22,3
2004	4555	6,7	499	0,7	5054	7,4

Results and discussion

Aerial surveys conducted in summer and autumn of 2003 and 2004 showed that despite a general diversity of species in the open part of the Barents Sea the avian fauna there was dominated by northern fulmar, black-legged kittiwake and guillemots (89.2-93.2%). Northern fulmar accounted for 52-69%, black-legged kittiwake 10-28% of the total number of sea birds observed.

The analysis of survey findings showed that in both years northern fulmar being a dominant species was observed almost everywhere in the area surveyed (Figs. 2,3). However, the density of its distribution was different. The densest aggregations of this species in 2003 were found in the central and northwestern part of the sea near Hope Island and on the Great Perseus Bank. The density of abundant flocks was occasionally as high as 1000 – 2000 birds per 10 km^2 and more at some locations. In the southeast of the sea the aggregations were less dense and observed on slopes of the Goose Bank near Novaya Zemlya.

In 2004 most abundant flocks of northern fulmar were observed only in the central part of the sea.

The distribution of black-legged kittiwake was on the whole similar to the distribution of the species reviewed above (Figs. 2,3). However, in both years it was predominantly distributed in the north and northwest of the sea, mainly to the east of the Hope Island. Average densities in those areas were more than 50 birds per 10 km^2, occasionally as high as 1000-2000 birds per 10 km^2. Less significant aggregations were observed in central areas and in the east near Novaya Zemlya.

Since the occurrence of abundant aggregations of birds in the areas with concentrations of prey is a well-known fact (Shuntov, 1972; Belopolsky, Shuntov, 1980; Borkin, 2004) we undertook analysis of data from the international multispecies trawl-acoustic survey (Anon., 2003; 2004).

A comparison of distribution maps showed that most dense aggregations of northern fulmar in 2003 were found in areas, where capelin was concentrated, with 2-year-olds of prevailing length of 8-10 cm predominant in its population (79%). In 2004, when the abundance of capelin dropped dramatically, aggregations of birds were mainly observed in areas with polar cod concentrations (Figs. 4,5).

Overall, the distribution of black-legged kittiwake was very well correlated with the distribution of capelin, which was indicative of a stronger relationship between the two. At the same time, in 2003 abundant flocks of black-legged kittiwake were also noted in central parts of the sea, where schools of juvenile Atlanto-Scandian herring were distributed in the surface layer of the frontal zone. While in 2004 black-legged kittiwake was observed together with northern fulmar in aggregations near Novaya Zemlya, in the areas, where polar cod massed with 2-year-olds of 8-11 cm being predominant (79%) in its population (Figs. 3,5).

Estimating the potential consumption of fish by these sea birds in the Barents Sea is of big practical value. To this effect we undertook preliminary calculations according to which the abundance of northern fulmar and black-legged kittiwake in areas surveyed in the Barents Sea in 2003 was 14.1×10^6 and 3.5×10^6 birds and in 2004 – 4.6×10^6 and 0.5×10^6 birds, respectively (Table 2).

Unfortunately, the 2004 aerial survey did not cover the northwestern part of the sea, where major aggregations of birds were, as a rule, found, this was the reason why the abundance of northern fulmar and black-legged kittiwake was considerably underestimated compared to 2003.

According to the evidence currently available the abundance of northern fulmar and black-legged kittiwake in breeding colonies along the coast and on islands in the Barents Sea can be roughly estimated at around 2 x 10^6 and 1.8 x 10^6 birds, repectively (The status of…, 2000). Taking into consideration that young birds spend most of their life migrating and mature only at age 3-6 years (seldom at age 1-2), the estimates we have derived for the open part of the sea suggest the possibility that they could well be close to real abundance.

It is known, that the diet of northern fulmar is predominantly composed of small fish (polar cod and capelin), 10-35%, and invertebrates, mostly crustaceans and cephalopods, around 50% (The status of…, 2000). Therefore, on the basis of daily consumption of food in the range of 200-300g, according to different sources, the proportion of fish in the diet can, on the average, be estimated at 50-75 g.

The diet of black-legged kittiwake is by 50-100% composed of fish (capelin, herring, polar cod, cod, sand eel) with capelin being predominant in the majority of cases. On the basis of daily consumption of food of 100-140 g, the proportion of fish in the diet of this sea bird can be estimated at 75-105 g.

Simple calculations showed that consumption of fish, capelin and polar cod in the first place, by birds in the open part of the Barents Sea could be quite considerable. For instance, in 2003 the consumption of fish by the population of fulmar was, on the average, 257-376 x 10^3 t, by the population of black-legged kittiwake – 83-125 x 10^3 t (Table 3).

Table 3. Consumption of fish by northern fulmar and black-legged kittiwake in the open part of the Barents Sea in 2003 and 2004

Species	Year	Abundance of birds, x 10^3	Daily consumption		Yearly consumption	
			By one bird, g	By population, t	By one bird, kg	By population, x 10^3 t
Northern fulmar	2003	14074	50-75	704-1056	18,3-27,4	256,9-375,8
	2004	4555	50-75	228-342	18,3-27,4	83,1-124,7
Black-legged kittiwake	2003	3483	75-105	261-366	27,4-38,3	95,4-133,5
	2004	499	75-105	37-53	27,4-38,3	13,7-19,1

Conclusions

Studies undertaken have shown that northern fulmar and black-legged kittiwake prevail in the avian fauna in the open part of the Barents Sea. Total estimated abundance of these species in 2003 was around 18 x 10^6 birds (14.1x10^6 and 3.5x10^6 birds, respectively), in 2004 it was 5x10^6 birds (4.6x10^6 and 0.5x10^6 birds, respectively). Unfortunately, it was not possible to estimate the abundance of guillemots for scarcity of data and difficulties with conducting an aerial survey of these birds.

These findings together with other evidence on the abundance of birds in breeding colonies along the coast in the Barents Sea currently available in the literature suggest the possibility to acknowledge that the estimates we have derived are close to real abundance.

Analysis of the distribution of northern fulmar and black-legged kittiwake has shown, that the occurrence of the largest aggregations of these birds in the open part of the Barents Sea is largely linked to the presence of concentrations of small pelagic fish, capelin and polar cod, there, which are their main prey. The largest overlap between the distribution of sea birds and the distribution of fish was noted for capelin feeding in the northwest of the sea in summer-autumn and black-legged kittiwake, which prefers to feed on exactly this fish for the most part of the year.

Consumption of fish, capelin and polar cod in the first place, by birds could be quite considerable. According to Barret et al. (2002) northern fulmar and black-legged kittiwake annually consume around 124 x 10^3 t of fish in the Barents Sea (39 x 10^3 t and 86 x 10^3, respectively). Total yearly consumption of fish by sea birds in the Barents Sea is estimated at 621 x 10^3 t, of which 52% by guillemots (the same source). According to our estimates in 2003 the population of northern fulmar consumed 257-376 x 10^3 t of fish and of black-legged kittiwake between 83 x 10^3 and 125 x 10^3 t, however, these estimates were much higher than those given in Barret et al. (2002). Therefore, further studies are needed to refine the estimates of consumption of fish by sea birds.

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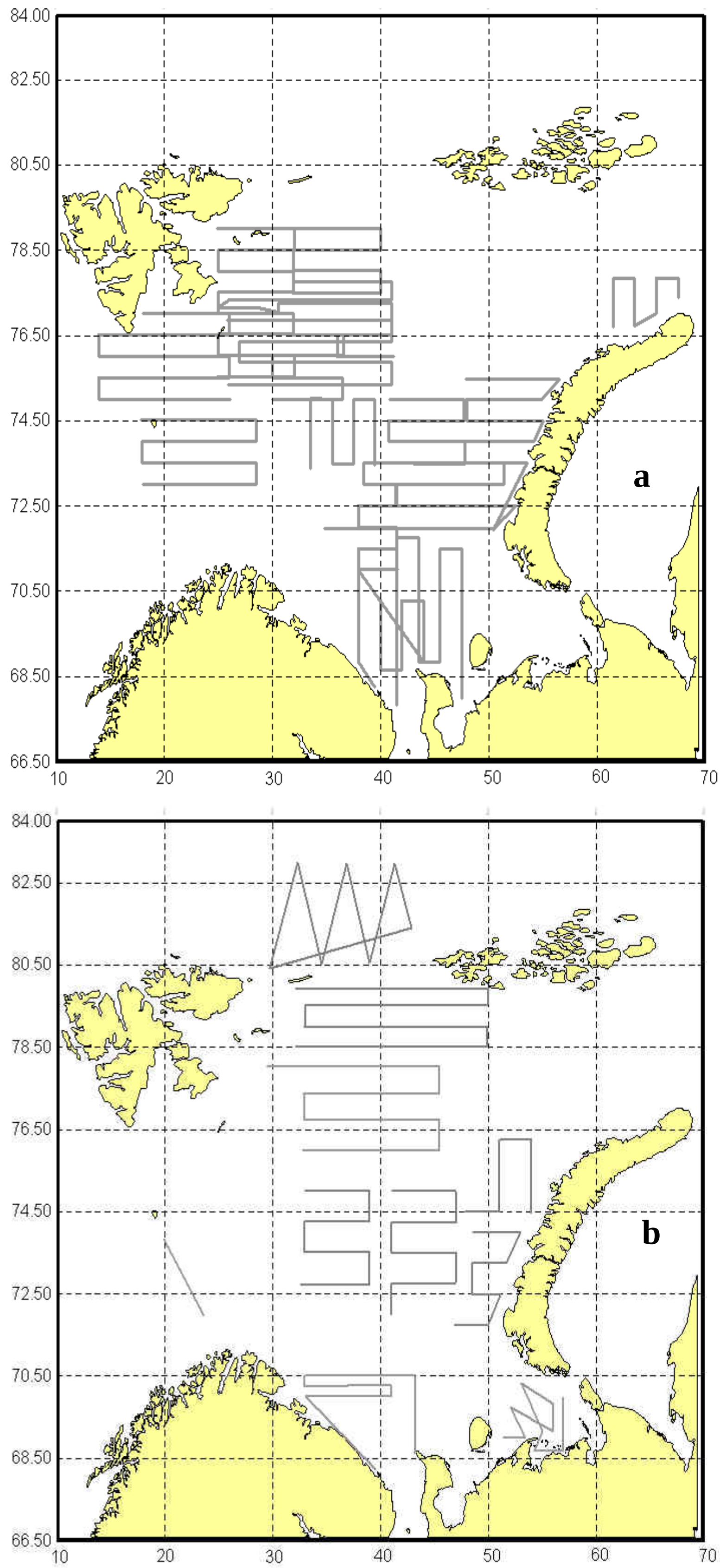

Fig.1. Areas and position of transects in the aerial survey by An-26 “Arktika” in autumn 2003 (a) and 2004 (b)

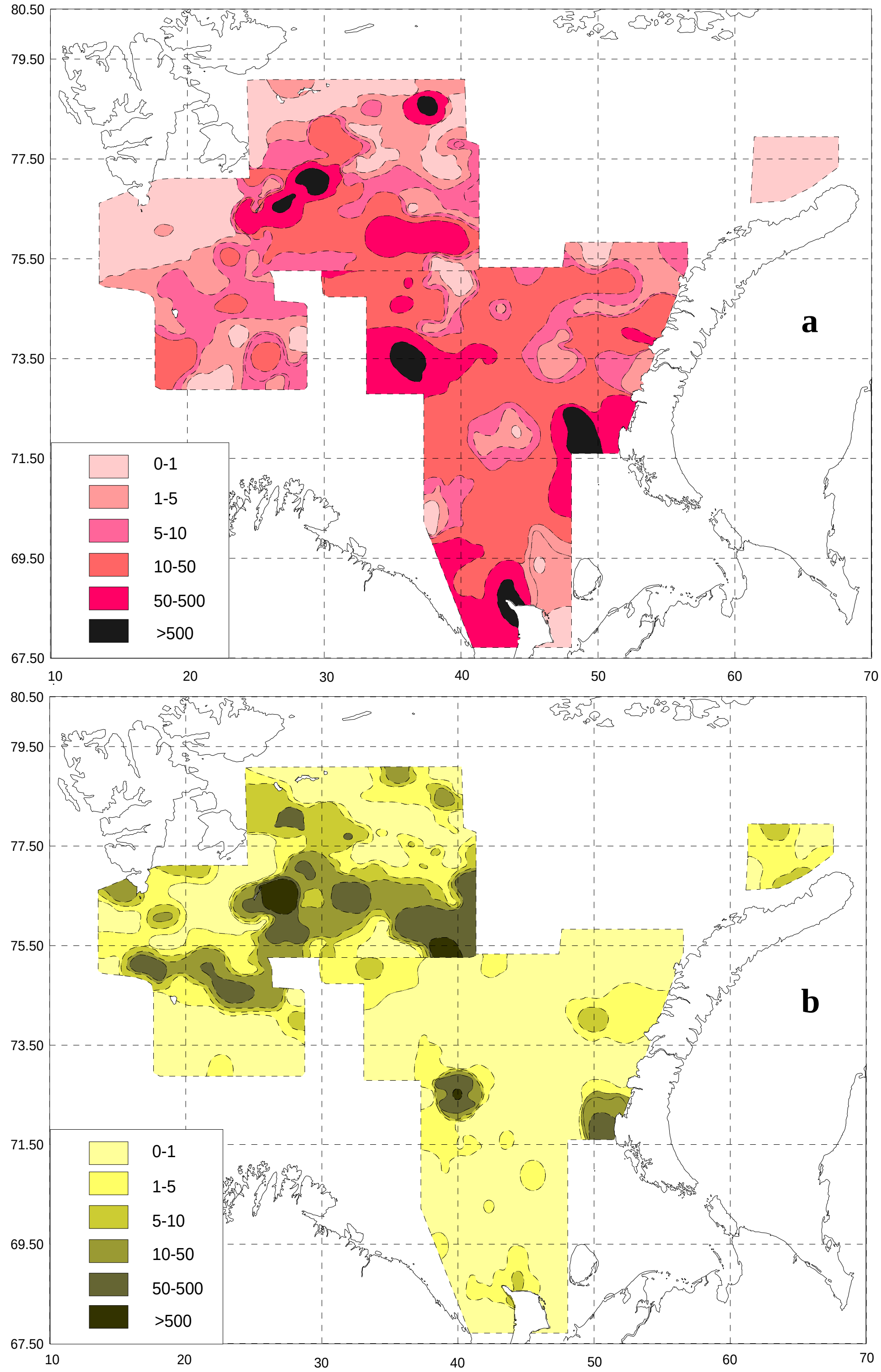

Fig. 2. Distribution of sea birds in the Barents Sea in summer and autumn of 2003, birds per 10 km^2: a – northern fulmar, b – black-legged kittiwake

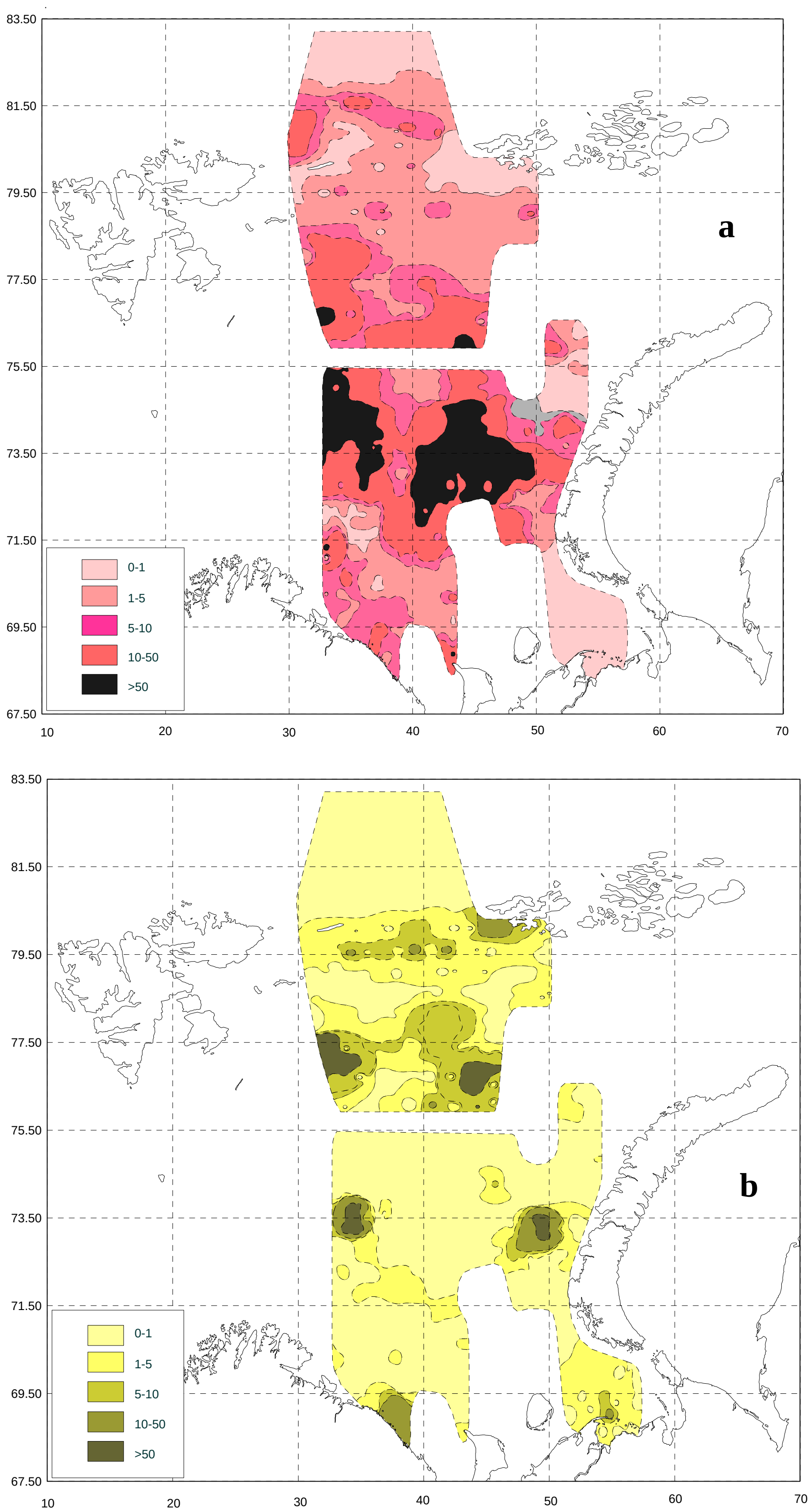

Fig. 3. Distribution of sea birds in the Barents Sea in summer and autumn of 2004, birds per 10 km^2: a – northern fulmar, b – black-legged kittiwake

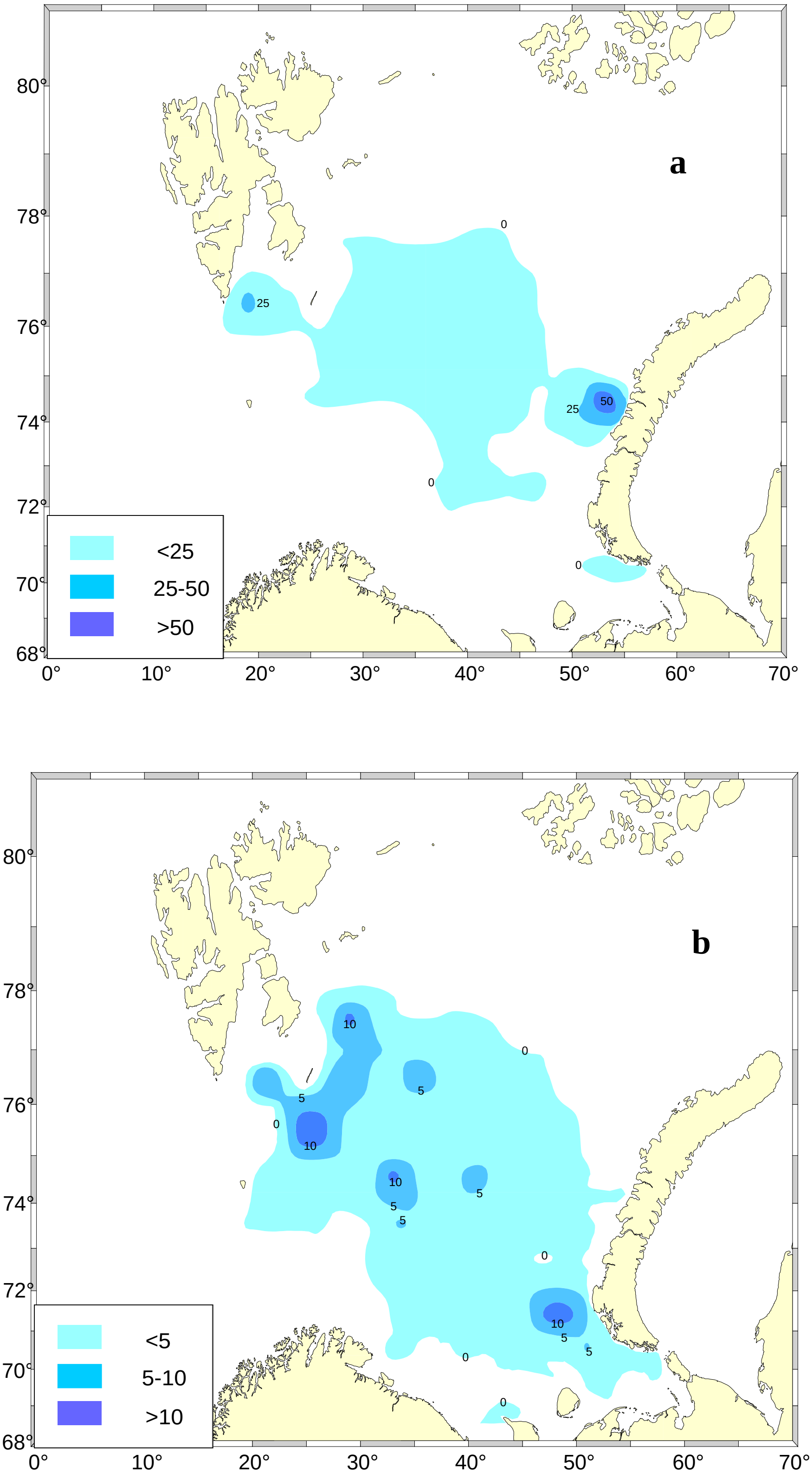

Fig. 4. Distribution of polar cod (a) and capelin (b) as mapped by the trawl-acoustic survey in September-October 2003, t per sq.mile

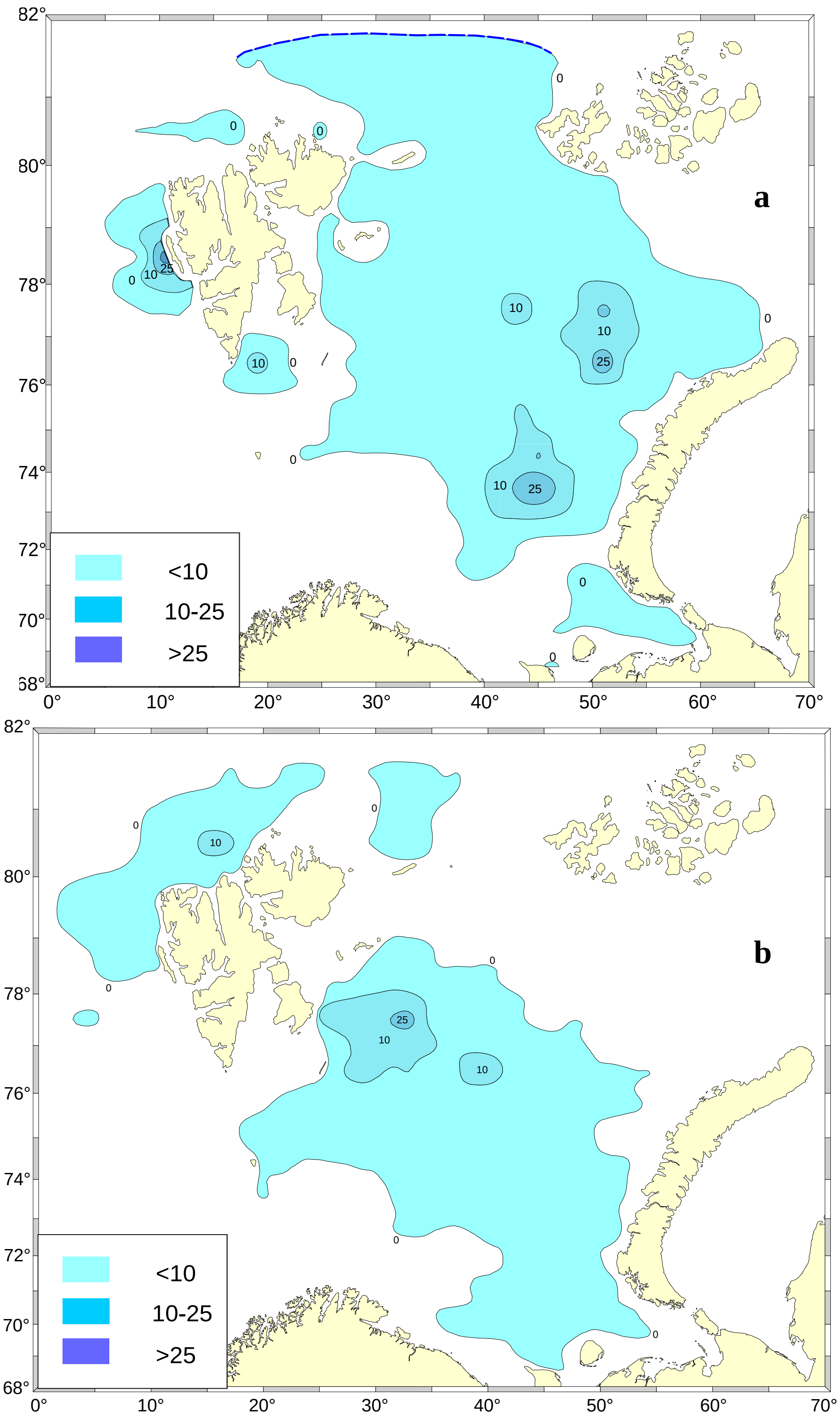

Fig.5. Distribution of polar cod (a) and capelin (b) as mapped by the trawl-acoustic survey in August-September 2004, t per sq.mile

IN THE BARENTS SEA

by

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Primary productivity in the Barents Sea ecosystem depends on structural and functional characteristics of four principal phytocenoses: phytoplankton, macrophytes, ice algae, and microphytobenthos. Productivity peculiarities of these phytocenoses are directly associated with hydrological and climatic conditions which have considerable variations in different parts of the sea. Variations in biocenoses structure and climatic conditions of the Barents Sea allow us to identify there the Arctic area with the Polar front as the southern boundary, and the Boreal area located in the south-western part of the sea. In their turn, these areas could be divided into subareas which essentially make transition zones.

The distribution area of the mentioned phytocenoses is determined by their adaptability to particular habitats. The microphyte distribution in the Barents Sea is limited to the littoral zone free of the ice coverage and the sublittoral zone up to the photic layer boundary whose depth varies in different areas from 10 to 30 m. Microphytobenthos inhabits the littoral zone down to 15-20 m. Ice biotope covers almost two thirds of the sea surface. Phytoplankton has the largest biotope among the mentioned phytocenoses (Table).

The Table shows that the principal role in primary productivity within coastal waters belongs to microphyte communities. Generally speaking, all coastal phytocenoses make a rather significant contribution to the total PP of the Barents Sea ecosystem.

With the biotope 23 times less than the one of the open-sea phytoplankton, coastal phytocenoses synthesize 11 % of the total PP in the Barents Sea.

Nutrient stocks accumulated as a result of bacterial metabolism and convection mixing provides favorable conditions for an intensive photosynthesis of the autotrophs. The only factor restraining this process is the solar energy deficit in winter and early spring. Autotrophs which are the first to start intensive primary production through photosynthesis are macrophytes from the south-western part of the Barents Sea. Already in February when the solar radiation totals 50-70 cal/cm^2 daily, photosynthesis of the principal representatives of this phytocenosis attains considerable rates. Macrophytes from the Arctic area of the Barents Sea (e.g. coastal waters of the Franz Josef archipelago) undergo more rigorous climatic conditions. Lightness and temperature are considerably lower in these areas, compared to the southern Barents Sea. Therefore, the arctic macrophytes are characterized by a much more primitive community structure and species composition than the boreal macrophytes (Makarov & Shopina, 1986). Because of the climatic conditions photosynthesis and respiration rates of coastal macrophytes off the Franz Josef archipelago are lower by 20% and 50%, respectively, compared to those in the southern Barents Sea (Kusnetsov et al., 1994).

Productivity Characteristics of Phytocenoses in the Barents Sea

Area of distribution (biotope)		Phytocenosis	The biotope area (ths km^2)	Production mln.tC/year
Sublittoral (the 20 m isobath)	The Cola Peninsula	Phytoplankton Microphytobenthos Macrophytes	5.4 5.4 5.4	0.324 0.189 2.700
	Novaya Zemlya (western part)	Phytoplankton Microphytobenthos Macrophytes	5.2 5.2 5.2	0.101 0.077 0.691
	Franz Josef Land	Phytoplankton Microphytobenthos Macrophytes	14.0 14.0 14.0	0.234 0.177 1.862
	Svalbard (eastern part)	Phytoplankton Microphytobenthos Macrophytes	15.8 15.8 15.8	0.263 0.201 2.101
	The Pechora Sea	Phytoplankton Microphytobenthos	20.5 14.5	0.246 0.087
TOTAL: (coastal area)			60.9	9.253
Pelagic waters		Phytoplankton	1438.4	60.400
Ice		Ice algae	1078.8	10.700
TOTAL:				80.020

In spring the earliest intensive photosynthesis starts in coastal waters and at the ice edge where a highly productive marginal zone develops. This process usually starts in April that is two months later than in the case of macrophytes. The solar radiation level required to trigger the phytoplanktonic photosynthesis approximates 150 cal/cm^2 daily (Bobrov, 1982; Kusnetsov, 1988). The phytocenoses of ice algae and microphytobenthos join intensive photosynthesis simultaneously with phytoplankton or a bit earlier. The phytoplankton productivity rates in the open Barents Sea differ considerably from those in the coastal area. Seasonal dynamics of the phytoplankton photosynthesis in the open sea are characterized by one peak in spring and the following decline which is associated with depletion of nutrient stocks (they are almost completely consumed during the short spring). The subsequent input of nutrients from deep waters is limited by density stratification in the water column; therefore, the photosynthesis rates are limited by nutrient recycling. Upwelling areas characterized by a continuous nutrient input from deep waters make the exception. Similar zones comprise the Polar front, coastal and shallow waters where advection can be caused by tidal and inward/downward currents. The spring maximum of phytoplankton photosynthesis in the coastal zone is followed by several other peaks in the phytocenosis development. According to observations presented by Kuznetsov and Volkovskaya (1994), the vegetation period was characterized by a continuous nutrient influx from the bottom biotopes to the pelagic community; this input sustains high rates of the phytoplanktonic photosynthesis in the coastal zone.

Ample stocks of nutrients developed in the process of metabolism of local bacteria and heterotrophs can sustain high rates of microphytobenthic production during the entire vegetation period. Additionally, studies of the seasonal dynamics of chlorophyll “a” in the microphytobenthic community indicated that the coastal microphytobenthos preserves photosynthetic biomass all the year round. It suggests that in absence of light during the polar night benthic microalgae change their feeding regime to the mixotrophic-heterotrophic one.

The ice algal photosynthesis is limited in the Barents Sea by the short spring. PP of this phytocenosis can attain very high rates and be comparable to the spring PP rates of phytoplankton. Effects of environmental factors, such as the snow thickness that limits the light penetration or the ice thickness and texture, can produce a significant effect on production rates of the ice phytocenosis. For this phytocenosis, the period of intensive vegetation ends with destruction of the ice biotope during the ice melting.

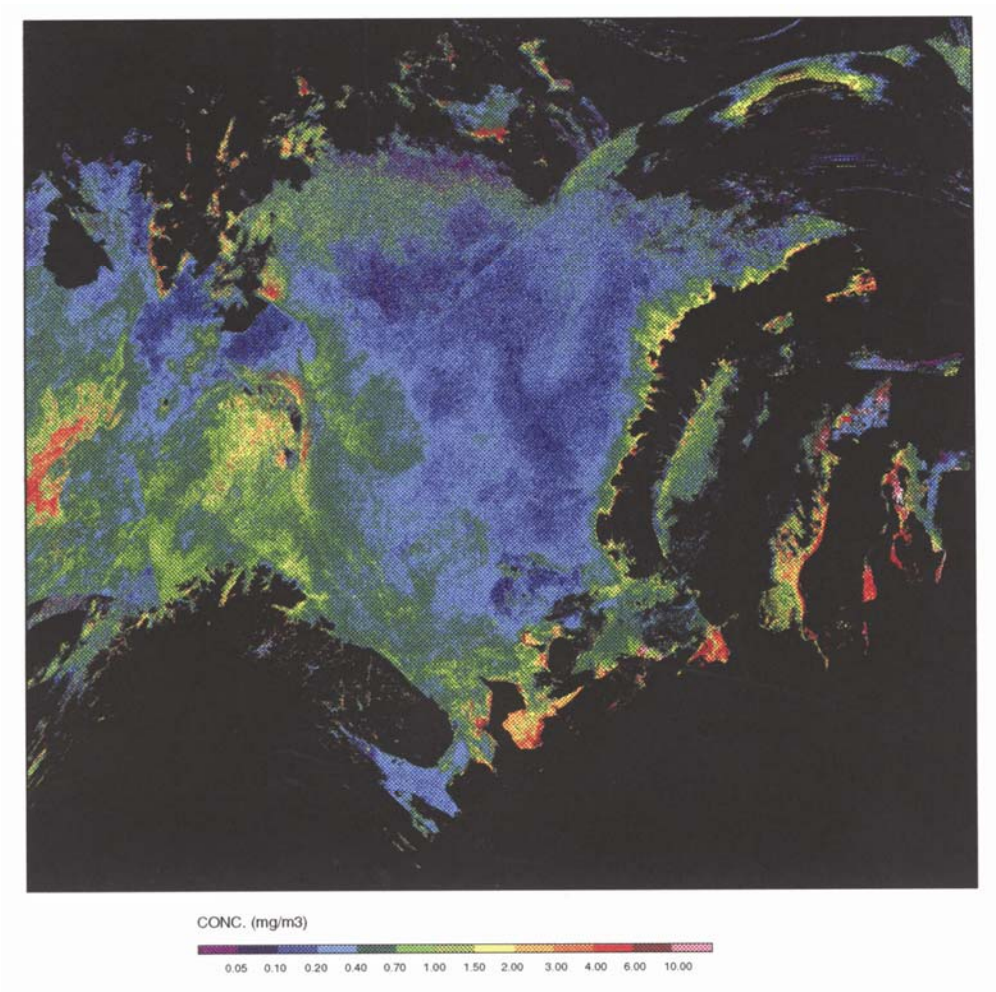

Fig.1. CZCS composite over the Barents Sea for July
(Average estimate of chlorophyll-like pigments)

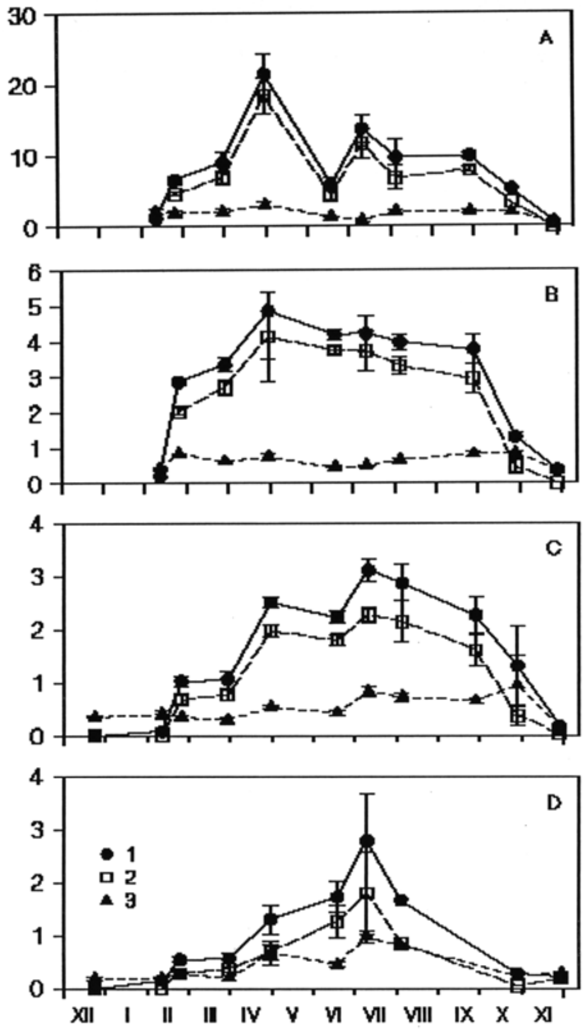

Fig.2. Seasonal dynamic of production-destruction characteristic of some macrophytos (Ulvaria (a), Palmaria (b), Lamunaria (c, d))

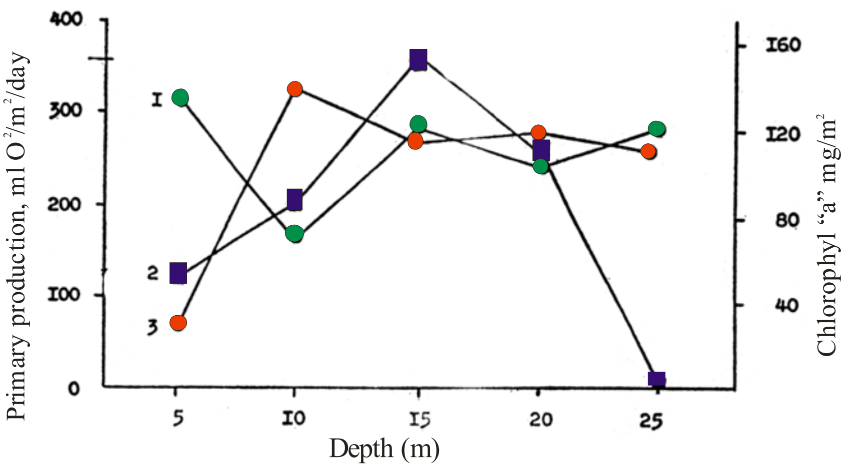

Fig.3. Production-destruction characteristics of microphytobenthos
1 – oxygen consumption; 2 – primary production; 3 – chlorophyll "a"

FROM REPRODUCTION TO RECRUITMENT IN NORTH-EAST ARCTIC COD

by

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Introduction

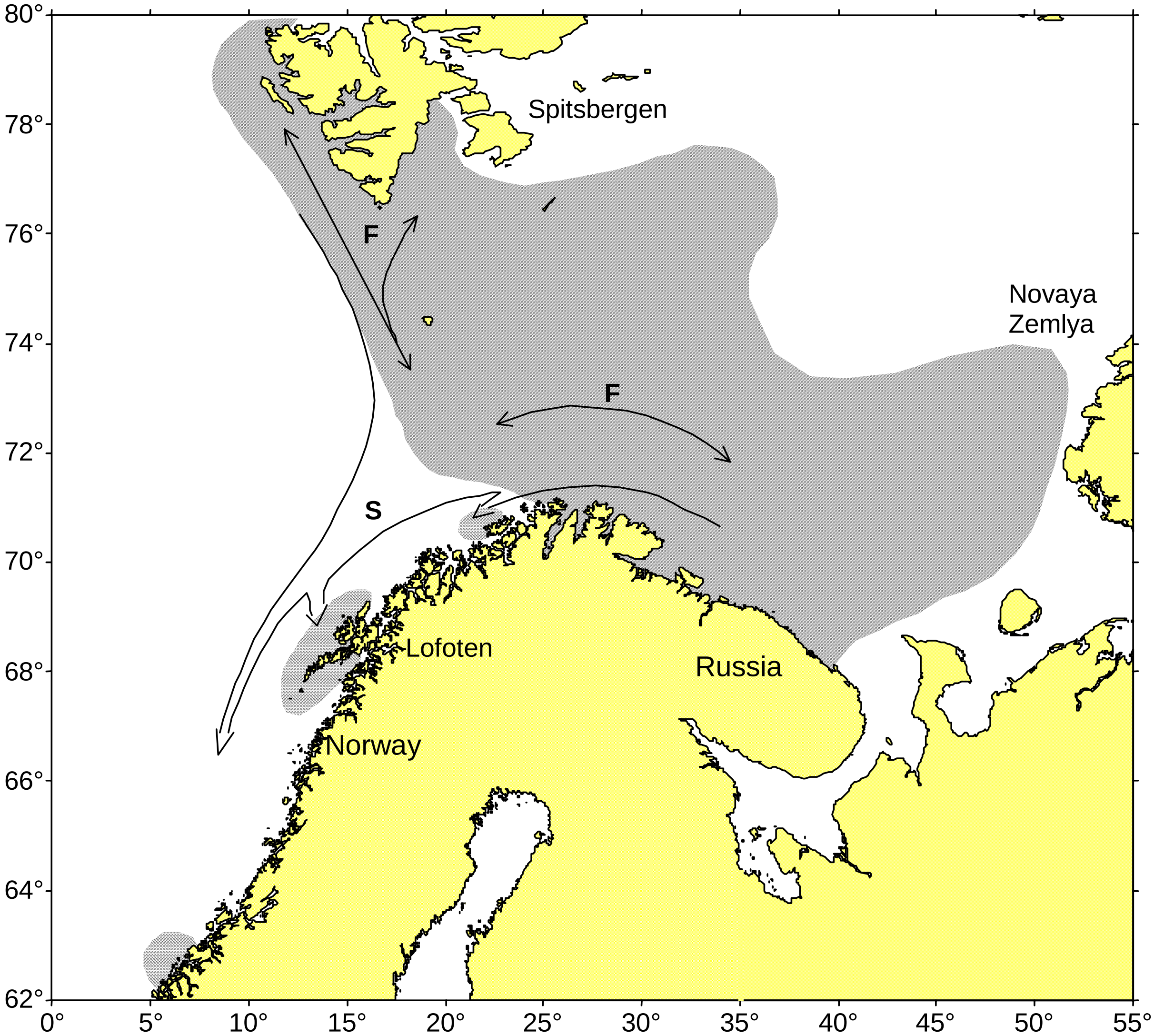
Most current fisheries management models do not include biological detail for processes occuring between spawning and recruitment. This means that temporal trends present in biological or environmental factors can and have been ignored.

The temporal and spatial trends in stock reproductive potential (SRP) have been largely ignored, however, variation in SRP can have a fundemental influence on recruitment. However, there are many processes occurring between spawning and recruitment that are not influenced by the parental stock.

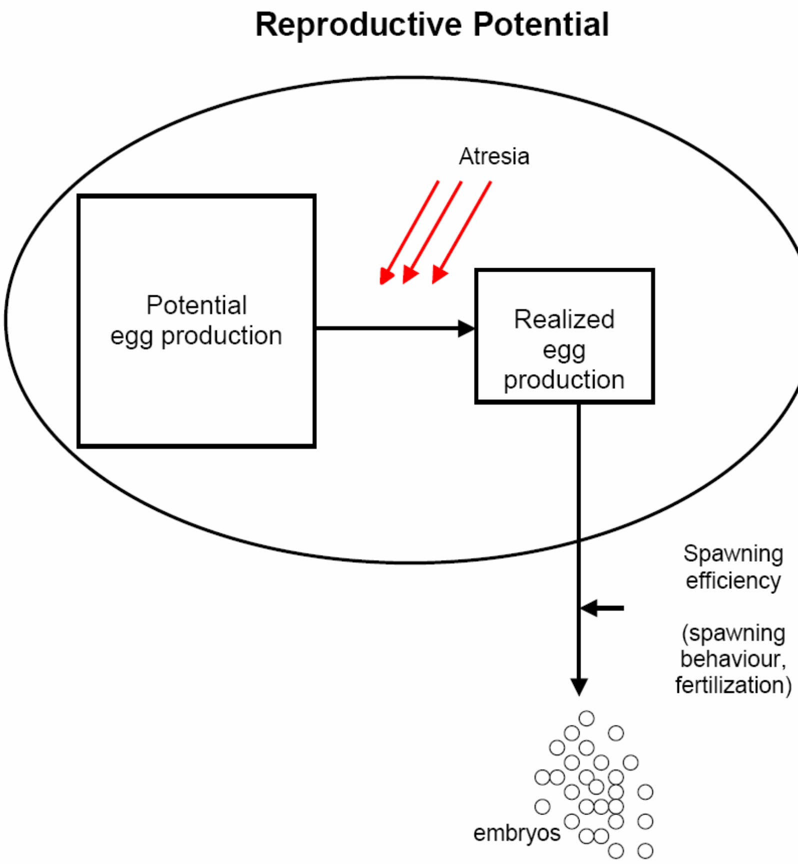
Materials and methods

North-east Arctic cod biomass/abundunce estimates, obtained by analytical methods (VPA, XSA) and trawl-acoustic surveys, were used (ICES CM 2003/ACFM:22). Portion of mature fish were taken from the Arctic Fisheries Working Group report, whereas sex composition from Norwegian database. Individual fecundity was calculated using C.T. Marshall and co-authors method (submitted). Potential fecundity was calculated for each year, taking into account length-age composition and mean length/weight.

Spawning and feeding grounds



Stock Reproductive Potential (SRP)



The transition from potential to realized egg abundance is a critical stage in the evolution of year-class strength of NA cod (connected with atresia, influenced by condition of spawners).

Furthermore, the signal in year-class strength undergoes substantial modification between the egg and larval stages. Thus, the signal in year-class strength of NA cod is determined in the earliest life history stages (Sundby et al., 1989; Mukhina, Marshall & Yaragina, 2003) before young fish settlement.

Stock Reproductive Potential (SRP)

Spawning Stock Biomass (SSB)

· number of mature fish at age
· mean weight of mature fish at age

Stock Reproductive Potential (SRP)

Maternal reproductive experience
– Condition factor
– Length

Female
· proportion mature at age
· non-annual maturation of adults
· egg production (fecundity at length, age)
· viable eggs (fertilization, hatching success)
· sex ratio
· body size at age
· other factors
– spawning duration
– egg size, larval size
– egg nutrient and lipid content
– time to starvation
– larval activity
– first feeding success
– compensatory growth

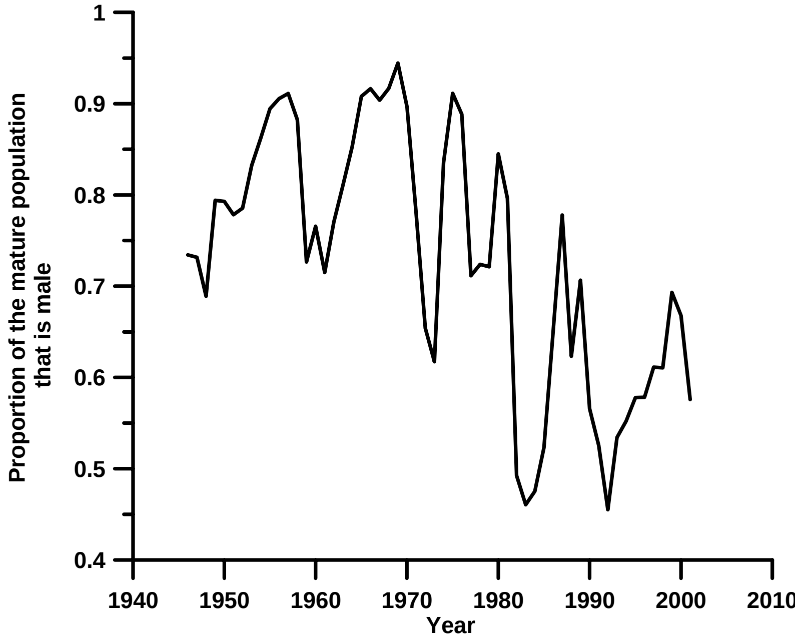
Paternal reproductive experience
– Condition factor
– Length

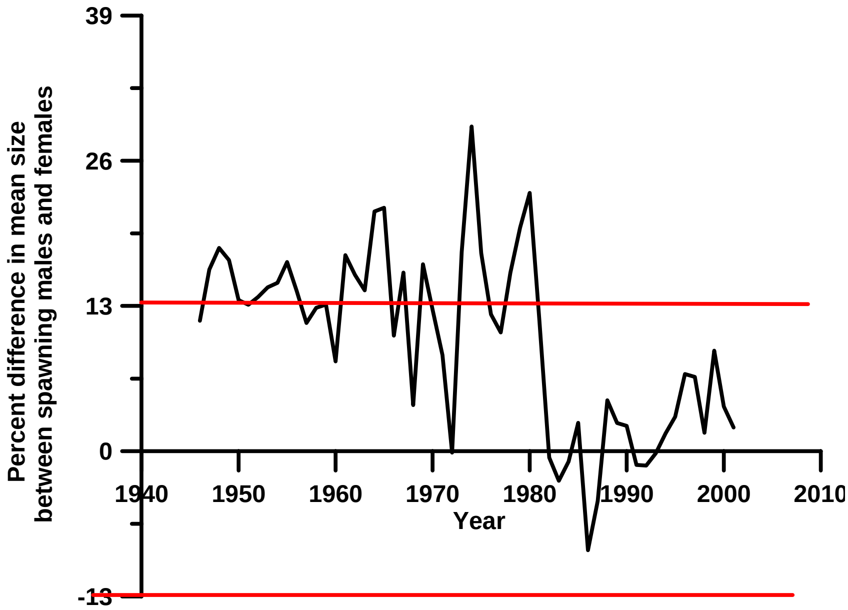
Male
· proportion mature at age
· non-annual maturation of adults
· testes weight
· sperm motility
· effect of male on larval fitness and early life survival
· sperm density
· fertilization rates, pairedmatings, in vivo sperm competition

Other factors
Stock-specific values
Water temperature interaction/effects
Maternal-paternal interactions

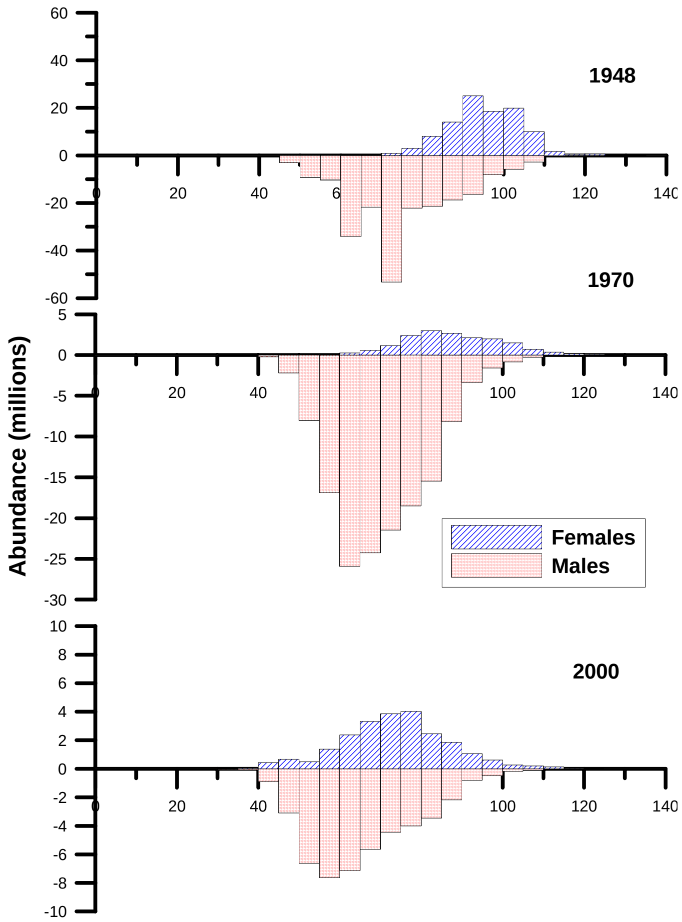
From: Trippel 1999

Males



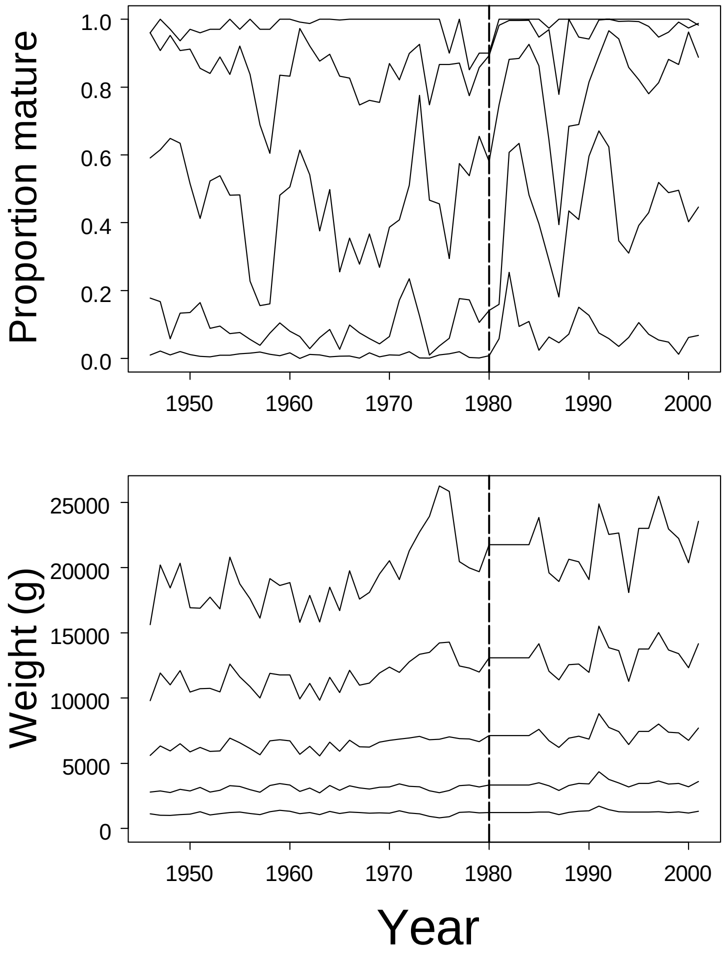


Should be worry about the male part of the population?
Figures to the left show fairly substantial changes in the sex ratio of the mature part of the population and illustrate fairly major changes in the relationship between mean size of mature males and females. Could this have an influence on reproductive success? Do we know enough about fertilisation success and maternal and paternal effects on survivorship in early life history stages?

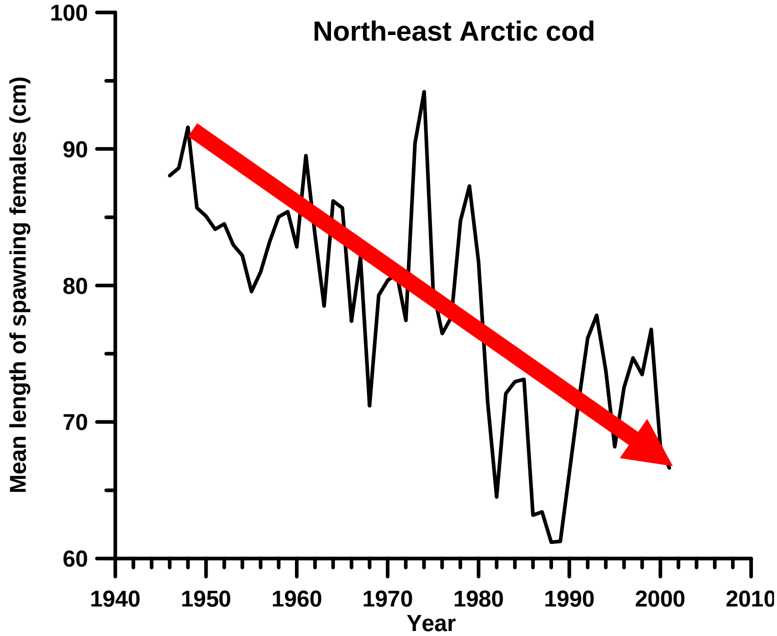


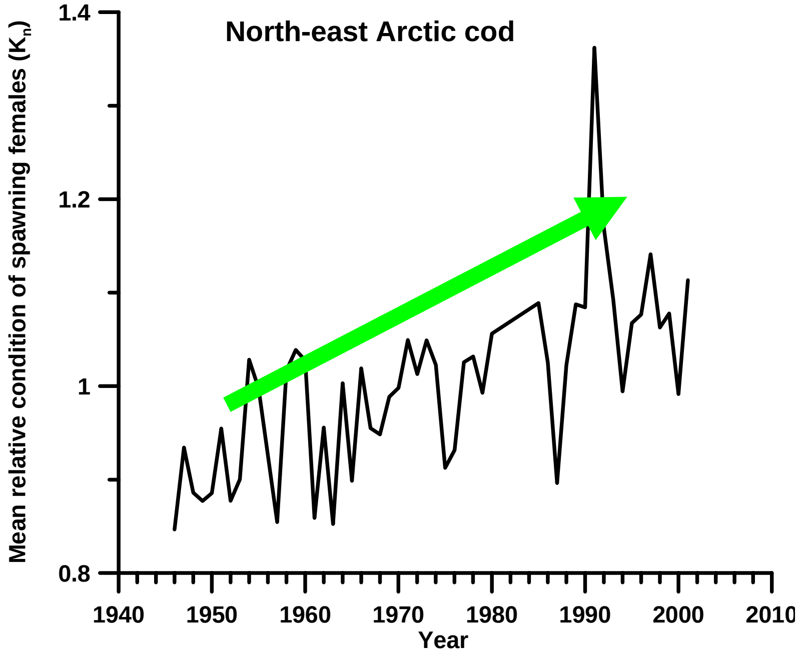
The figure above illustrates the changes in length frequency that have occurred in this stock. At present mature males and females are more similar in length

Females

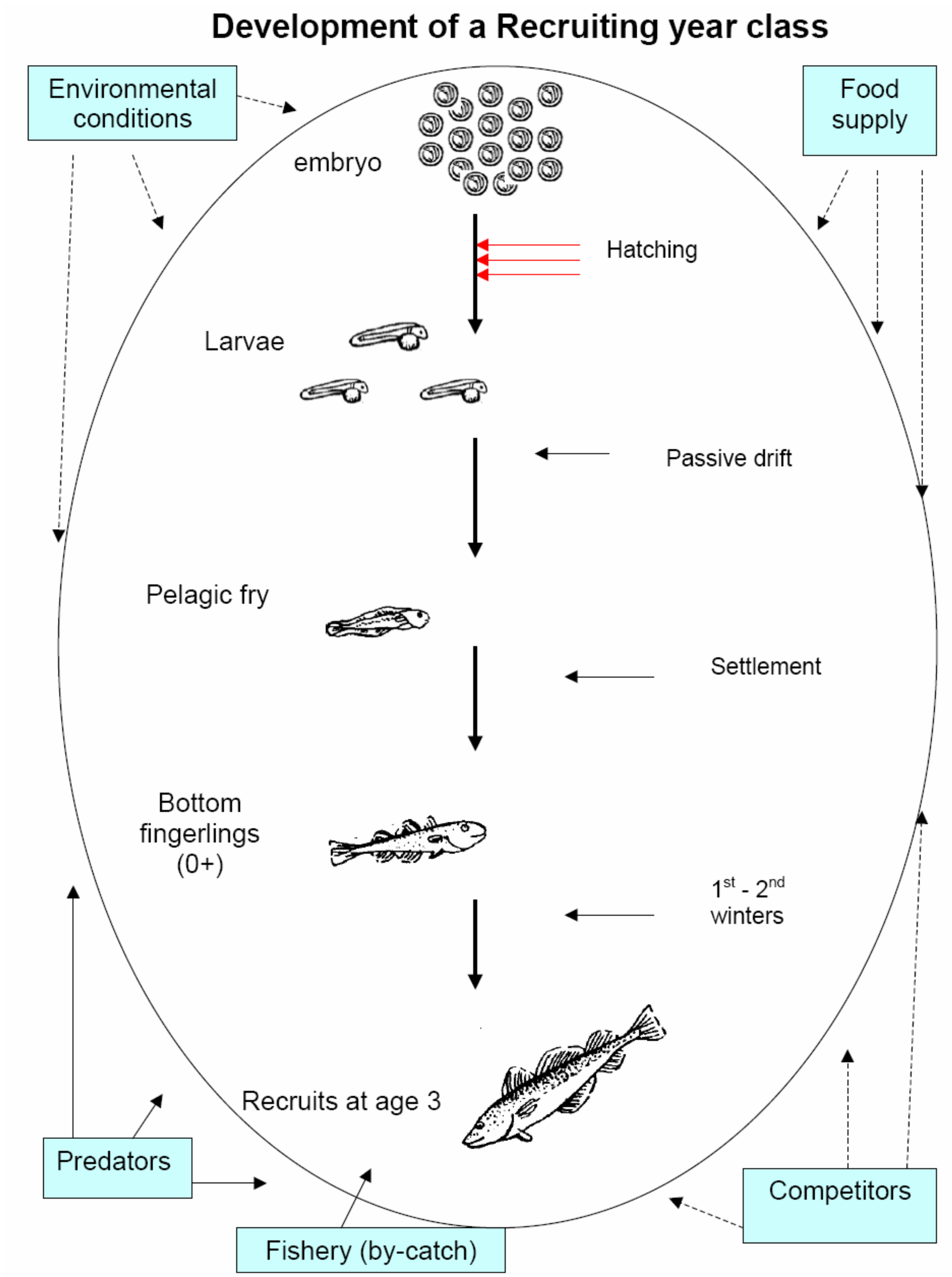


Interannual variation in maturity ogive and mean weights at length: verical line separates pre and post 1980.

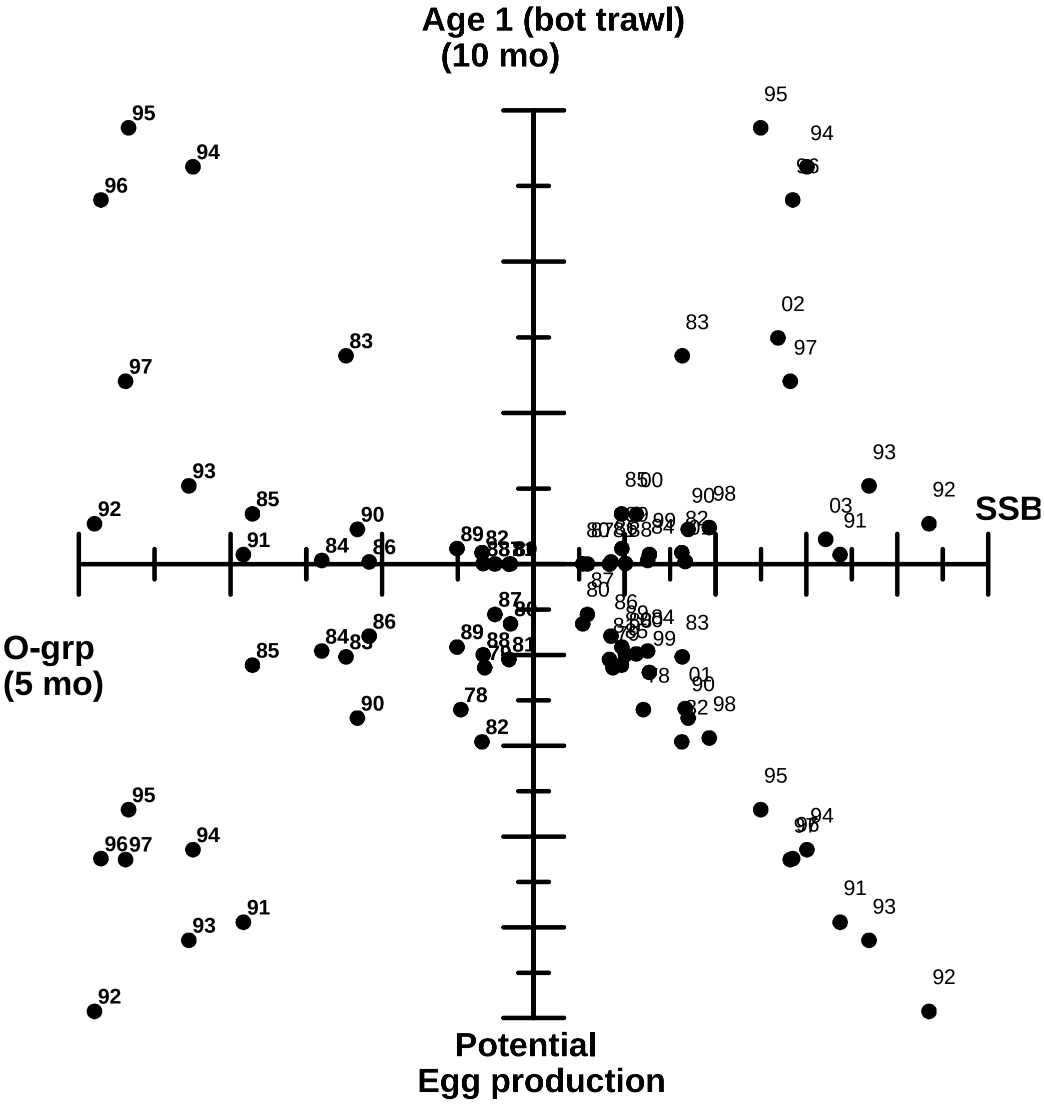




In general there has been a decline in mean length of mature females over time, however there has been a corresponding increase in mean condition . The consequence is an apparent 'compensatory' response in the egg production per unit SSB (see bottom right panel below).



Development of a Recruiting year class
Environmental conditions
Food supply
embryo
Hatching
Larvae
Passive drift
Pelagic fry
Settlement
Bottom fingerlings (0+)
1st - 2nd winters
Recruits at age 3
Predators
Fishery (by-catch)
Competitors

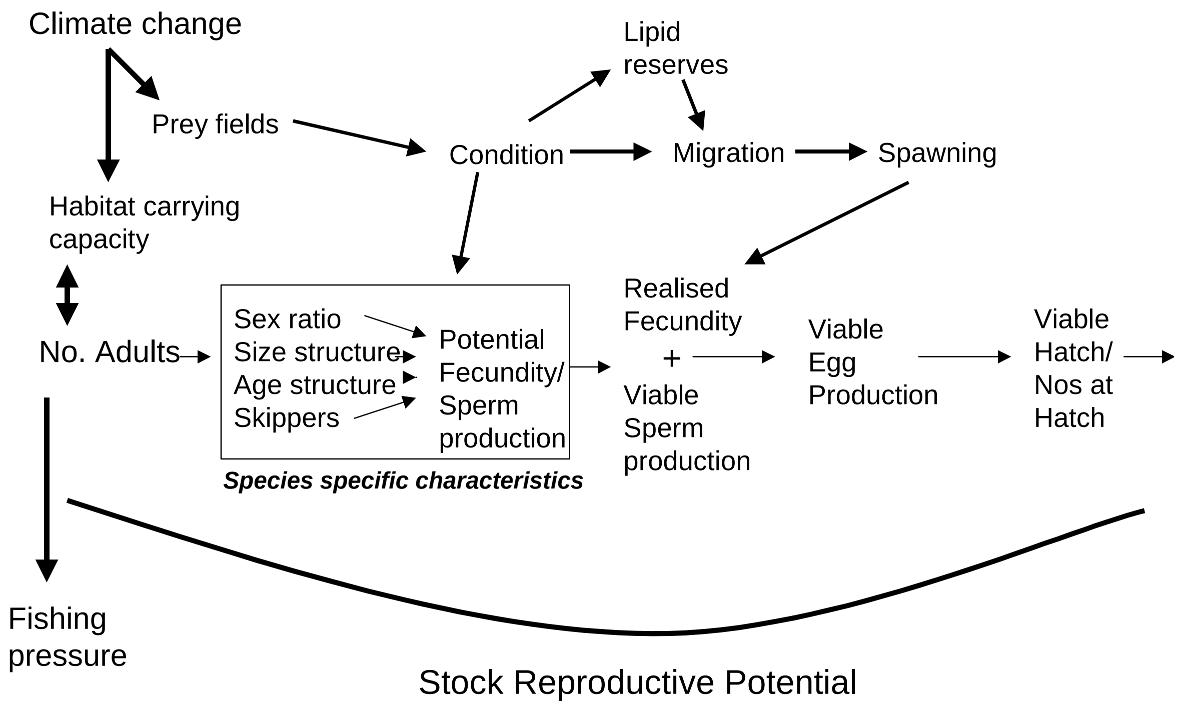


Life-history model or Paulik diagram for North-east Arctic cod. The SSB data are from the VPA, egg production data calculated from relationships determined by Marshall et al. (submitted) and O and 1 group abundances from surveys.

Some variability is generated in the transition from adult population to eggs, however, very large variability is generated through subsequent life-history stages which ultimately results in the classical stock and recruitment relationship by three years old.

These diagrams/models rely on being able to estimate the abundance of individuals at the transition boundaries e.g. metamorphosis, settlement, I year old etc.

The challenge for stock to recruitment studies



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Sundby S., Bjørke H., Soldal A.V., Olsen S., 1989. Mortality rates during the early life stages and year-class strength of Northeast Arctic cod (*Gadus morhua* L.). *Rapport Permanent verbeaux Reunion Conseil International pour l'Exploration de la Mer*, 191: P.351-358.

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ON THE EFFECT OF RED KING CRAB ON SOME COMPONENTS OF THE BARENTS SEA ECOSYSTEM

by

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Introduction

For the 40 years of successful adaptation elapsed since the red king crab introduction to the Barents Sea its distribution area and abundance have expanded (Figure 1). Trawl surveys showed that by 2003 the red king crab stock only in the Russian Economic Zone in the Barents Sea reached 20 million crabs. A start on its commercial fishery was made in 2002 in Norway and in 2004 in Russia.

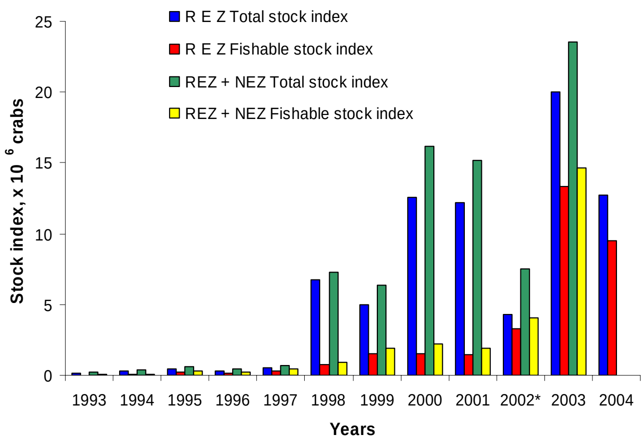


Fig. 1. Dynamics of the red king crab stock in the Barents Sea.
2002* – underestimation in the result of anomalous crab distribution during the survey period

However, it is well known that the appearance of fisheries objects extrinsic to the ecosystem is open not only to commercial benefits but also to ecological hazards. Examples of that in the world practice are numerous. Russian researchers greatly experienced in works on species introduction are aware of it quite well.

In this relation, a concern about ecological implications of the red king crab introduction has greatly increased in recent years and not only in the scientific circles. At the same time, a lack of reliable information on this issue gives cause for predictions that are not always justified and provokes the most fantastic publications.

A steep increase in the red king crab abundance in the Barents Sea during the recent decade gave rise to a deep research into this problem by a large number of scientific institutions in Russia and abroad.For a number of years this problem has been addressed to the Shellfish Laboratory of PINRO.

Implications of the red king crab introduction are being studied at both population and biocenosis levels. At the level of biocenosis, the object of the study are bottom communities; at the level of population, the study includes populations of commercial marine organisms in relation to which the red king crab acts as a direct predator (capelin and Iceland scallop) and a food competitor (haddock) (Figure 2).

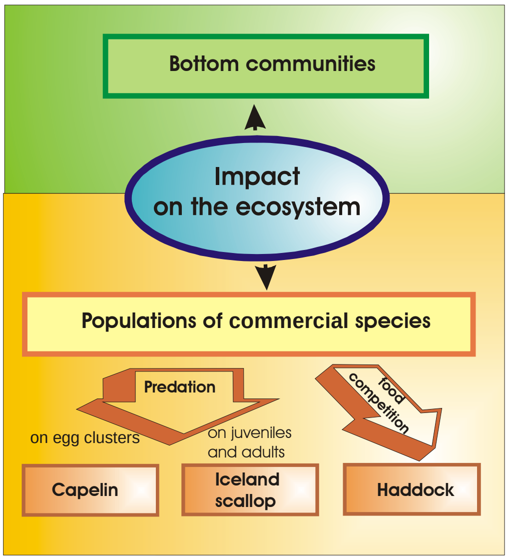


Fig. 2. The main directions of the study of the red king crab effect on the Barents Sea ecosystem being developed in the Shellfish Laboratory of PINRO.

Materials and methods

Material to evaluate the effect of the king crab on the indigenous communities was collected in the Motovsky Bay of the Barents Sea in 2003 during the cruise of R/V "Romuald Muklevich" (Figure 3). The standard methods were used for sampling (Rumohr, 1999).

To estimate the dynamics of community state the analysis of its biodiversity by the comparison of the most widely used indices (Table 1) and the relative abundance curves (ranked species biomass curves, k-dominance curves) was made; the community state was also tested by Warwick's ABC-method.

1

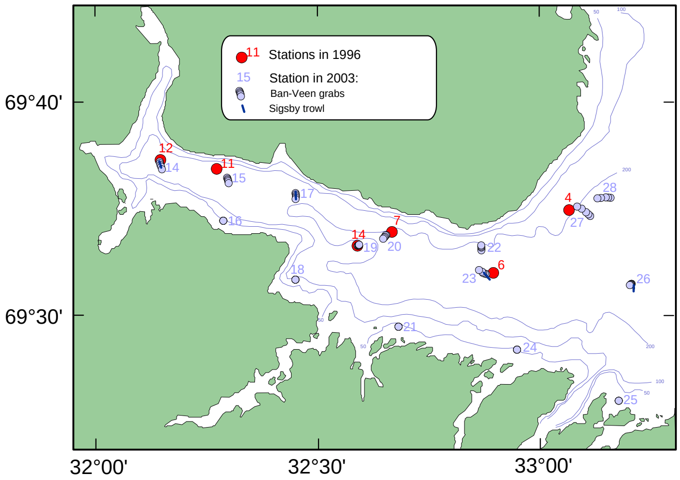


Figure 3. Location of stations during benthos survey by PINRO in 2003 onboard R/V “Romuald Muklevich” in the Motovsky Bay of the Barents Sea and stations during the survey in 1996 (Frolova et al., 2003) used for comparative data analysis

Table 1. Indices of biological diversity and density used in the analysis of the Motovsky Bay fauna

Indices	**Formula**	**Reference**
Margalef’s index of species richness (d)	$d = (S-1)/\ln N$	Margalef, 1958
Simpson domination index (c)	$c = \sum (b/B)^2$	Simpson, 1949
Shannon-Wiener diversity index (H)	$H = -\sum {}^{b}\!/_{B} (\log_2 {}^{b}\!/_{B})$	Shannon, Weawer, 1949
Pielou eveness index (J)	$J = H \log_2 S$	Pielou, 1966
Density index (D)	$D = \sqrt{b * \%}$	Brotskaya, Zenkevich, 1939; Leibson, 1939

Note: S – number of species (taxons); N – number of individuals; B – total biomass; b – average biomass of species (taxon) in the community; % – frequency of species occurrence in the community, %.

To evaluate the effect of the crab on scallop settlements, stomach content of 58 crabs captured at the exploited scallop settlements and 79 crabs caught at the non-exploited settlements was analyzed. To estimate the importance of main food items, the index of importance was used which was defined as the product of frequency of the item occurrence in stomachs and the average partial index of stomach fullness.

To evaluate the effect of the crab on capelin eggs, stomach content of 554 crabs taken from March to Mai in 1994-2003 in the West Murman waters (the Kola Peninsula coast from the Norwegian border to 35° E) was analyzed.

To evaluate the effect of the crab on haddock feeding, stomach content of 30541 of haddocks was analyzed. To make a comparison, 1971-1977 were chosen as reference periods (the first stage of the king crab acclimatization) and 1995-2002 (the period of the growth in the king crab abundance).

Results

Bottom communities

The effect of the red king crab on the bottom communities was studied in the Motovsky Bay of the Barents Sea. This area was chosen for the study because the Motovsky Bay and adjacent waters is the "oldest" part of the present area of the red king crab in the Barents Sea. By the present, the red king crab has been dwelling in this area for about 40 years and a part of the population inhabiting it is at the stage closest to naturalization.

The study was based on published data from benthos surveys in the Motovsky Bay in 1931-1932 (Leibson, 1939) and in 1996 (Frolova et al., 2003) as well as on other benthos samples collected by PINRO in 2003 (Figure 3). The available series of observations permitted us to analyze the bottom fauna of the Motovsky Bay before the red king crab introduction (the survey in 1931-1932), in the period of its low abundance (the survey in 1996) and upon reaching the highest abundance (PINRO survey in 2003) (Figure 4).

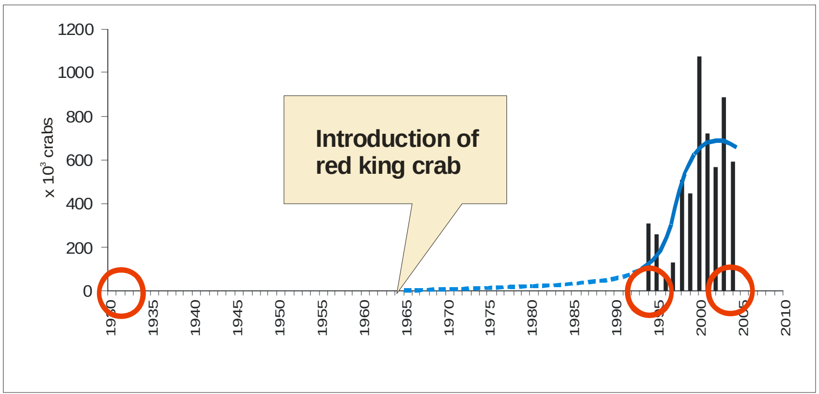


Fig. 4. Dynamics of the red king crab (legal males) abundance in the West Murman waters and benthos surveys in the Motovsky Bay

To make an analysis, a community dominated by a sedentary polychaete *Maldane sarsi* typical of the soft bottom in deep waters of the Motovsky Bay was chosen. This community is the most widespread in the Motovsky Bay and occupies almost the whole deepwater part of it. The adult red king crabs are abundant and feed intensively within this community throughout the year.

In the period from 1996 to 2003, within *M. sarsi* community, the mean biomass of benthos insignificantly, but reliably decreased from 77.4±15.3 g/m^2 to 63.8±11.6 g/m^2 (Table 2). More detailed by-station analysis showed that the reduction in biomass was only typical for the open north-west part of the bay. At the stations of central and inner parts, the biomass kept at the previous level and even increased a little at some of them.

Table 2. Total biomass of the benthos and biomass of the main taxa in community M. sarsi in 1931-1932, 1996 and 2003, g/m^2

Taxon	1931-1932	1996	2003
Total biomass, g/m2	71,5	77,4±15,3	63,8±11,6
Sipuncula	**11,92**	**10,64**	**5,57**
Polychaeta	**27,83**	**48,13**	**45,39**
Echinodermata	**12,68**	**8,88**	**0,98**
Bivalvia	**12,61**	**8,18**	**5,13**
Crustacea	**0,27**	**0,22**	**0,36**
Varia*	**6,21**	**1,34**	**2,71**

Varia – Gastropoda, Spongia, Bryozoa, Tunicata, Coelenterata, Nemertea.*

In the period of observations, in the area surveyed, the biomass ratio of main benthos taxonomic groups significantly changed. The biomass of echinoderms, bivalves and sipunculans noticeably decreased. In 2003, in comparison with 1996, the absolute abundance of polychaetes insignificantly reduced, and the relative one considerably increased.

Registered changes indicate that the decrease of the total biomass in the north-eastern part of the Motovsky Bay in 2003 as compared with 1996 and the reduction in biomass of echinoderms, bivalves and sipunculans in 1931-2003, most likely, are caused by different factors. One of the most probable reasons of general decrease in biomass of echinoderms, bivalves and sipunculans may be the presence of red king crab for which the mentioned groups of animals are favourite objects of feeding. A number of facts allowed us to assume that the local reduction in total biomass of benthos is caused by fishing which is the most intensive in the north-eastern bay. At that, benthos biomass is directly dependant on its intensity.

Thus, the data obtained permit us to assume that the growth of red king crab abundance is less important for benthos biomass regulation than such anthropogenous factor as fishing.
By the results of taxonomic identification of data on 2003, within *M. sarsi* community, 225 taxons (177 species) were found that was 33 taxons (33 species) more than in 1996 and 97 species more than in 1930-1931. The data obtained are surely indicative of maintaining species richness of the community.

The comparison of biodiversity indices at the level of community on the whole, showed insignificant decrease of Shennon-Wiener H′ and Pilow evenness indices and the increase in the Simpson’s dominance from 1996 to 2003. Index changes, nevertheless, are so insignificant that do not allow us to be fully confident of real negative changes in the community structure.

Relative abundance curves were analyzed for the entire surveyed area in 1996 and 2003, for the inner and open part of the bay in 2003, for the open part of the bay in 1996 and 2003, for the inner part of the bay in the same years. A mutual disposition and character of plotted curves for the inner part of the bay, insignificant influenced by fishery, indicate the absence of negative changes in the community structure from 1996 to 2003.
The results of ABC-testing also have not revealed the evident indications of stress disturbances at the stations of the inner part of the bay. In the open part of the bay, in the zone of bottom fishing influence poorly expressed indications of stress variations in the community structure were found.

A comparison of listed species predominating in the community in 1931-32, 1996 and 2003, showed significant changes. Of 20 species prevailing in the community in 1931-32 only a half maintained in 1996 and only 6 ones (*Maldane sarsi, Golfingia m. margaritacea, Edwardsiidae g.sp., Nephtys ciliata, Galathowenia oculata, Yoldiella tenticula*) dominated in 2003. At that, by 2003, all the feeding objects of red king crab accounting for 60% of leader specific list in the 1930s (6 species of the first 10 dominants) stopped their dominating.

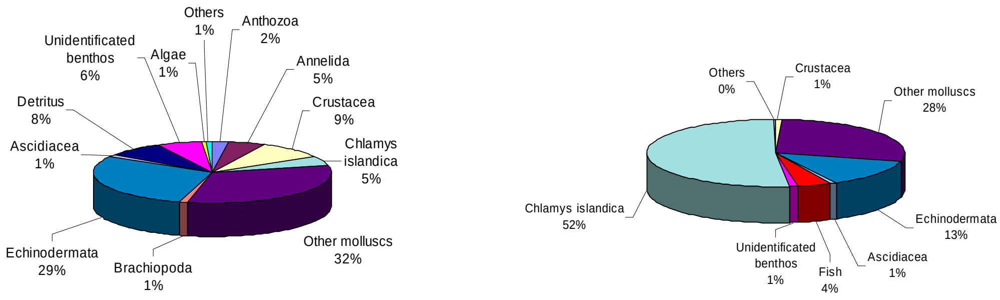
The analysis of stomach content of crabs caught in the Motovsky Bay at the depths of more than 200 m in 1994-2003 showed that within *M. sarsi* community distribution limits the main invertebrate groups consumed by crabs were echinoderms (44% of benthos consumed), polychaetes (21%) and bivalves (9%). The decrease in mean biomass that was more significant for echinoderms and bivalves and less expressed for polychaetes was recorded for all mentioned taxons in 1996-2003. A significant reduction in mean biomass was registered for predominating majority of benthos organisms actively consumed by crab.

Thus, the research did not reveal any evident effect of the red king crab on the total biomass of benthos and biological diversity of the studied *M. sarsi* community. However, a selective consumption by the crab of some groups of bottom organisms led to a considerable decrease in abundance of its food objects and to changes in the order of species domination within the community.

Iceland scallop

The effect of the red king crab on the population of Iceland scallop was studied by analyzing the crab feeding in the non-harvest areas of the scallop settlements and on the harvested scallop banks.

Analysis of the crab stomach content showed that the crab feeding on the harvested and non-harvested scallop settlements differed greatly (Figure 5). On the harvested scallop banks the crab fed on them actively. Partial index of stomach fullness was estimated at 1.5‱, frequency of scallop occurrence made up 20.7% and percentage of the scallop in the crab diet accounted for 51.2%. The same indices under conditions of no harvesting were far less and made up 0.4‱, 15.2% and 4.9%, respectively. In the non-harvested areas the scallop was less important in the crab diet compared to other food items. So, index of the scallop importance was equal to 6, while, for instance, that of echinoderms was 100. In the areas of the scallop harvesting its index of importance was 32, while that of echinoderms was just 16. The food spectrum of the crab on the harvested grounds was not so wide as in the non-exploited areas.



A B

Fig. 5. Food spectrum of the crab and weight percentage of food items in the diet on the unexploited (A) and exploited (B) scallop settlements.

Examination of the scallop fragments in the crab stomachs suggested that in the areas (and in the period) of the scallop harvesting the crabs consumed mostly wastes of the scallop processing and individuals damaged by a dredge. In the areas where the scallop settlements were not harvested the crabs mainly consumed young mollusks and almost did not use the adult part of the population.

Thus, it is evident that in the wild, the red king crab predominantly consumes young scallops and almost do not affect the adult part of the population. Thereby, the red king crab having no considerable effect on the reproductive potential of the scallop population, nevertheless, can be a cause of its extra natural mortality due to elimination of juveniles.

Capelin

The fact that the red king crab in spring feed on fish eggs in the period of their mass spawning is documented. However, the long-term observations showed that on the average frequency of occurrence of fish eggs in the crab stomachs in spring was not higher than 6% and its percentage in the crab diet accounted for not more than 2%.

The most frequency of occurrence of fish eggs in the crab stomachs was noted in 2001 (19.4%). At the same time, the proportion of capelin eggs in the crab diet made up 1.2%. A rough estimation showed that in 2001, March through May, the crabs had consumed about 37 tonnes of the capelin eggs.

Is it much or not much? An approximate estimation of the damage caused by the crab to the capelin spawning grounds looks as described below.

The spawning stock of capelin in the REZ constitutes one third of the total spawning stock, which in 2001 was estimated to be 99.5 billion individuals. Weight of one clutch of eggs laid by one female capelin constitutes 8 grams on the average. Therefore, total quantity of eggs laid by capelin in 2001 in the Russian part of the Barents Sea could be approximately estimated at 130 thousand tones. A simple arithmetical calculation showed that in 2001 the red king crab consumed 0.03% of eggs laid by capelin. The figure obtained is rather rough but adequately indicates the insignificance of damage caused by the red king crab to the spawning potential of the capelin population.

Haddock

The long-term research showed the king crab diet in the Barents Sea to be dominated by echinoderms, mollusks and worms.At the same time, all these groups are food objects of haddock; therefore, the food competition between haddock and the red king crab should manifest itself primarily in the decrease of frequency of occurrence and quantity of these objects in the haddock stomachs (Figure 6).

Analysis of the long-term data on the haddock feeding (1971-2002) allowed us to follow the haddock feeding dynamics in different periods of formation of the red king crab population in the Barents Sea. A comparative analysis of the haddock feeding in the period of the red king crab low abundance (1971-1977) and in the period of its increased abundance (1995-2002) was made. Taking into account that haddock feed on benthos in the second half of a year, the analysis was based on data for July-September. The study area was limited to the Norwegian border in the west, to 72°N in the north, to 45°E in the east and by the coastal line in the south. Within the study area such parameters as haddock catches, mean individual length in catches, feeding intensity, frequency of occurrence of plankton, worms, mollusks and echinoderms were analyzed.

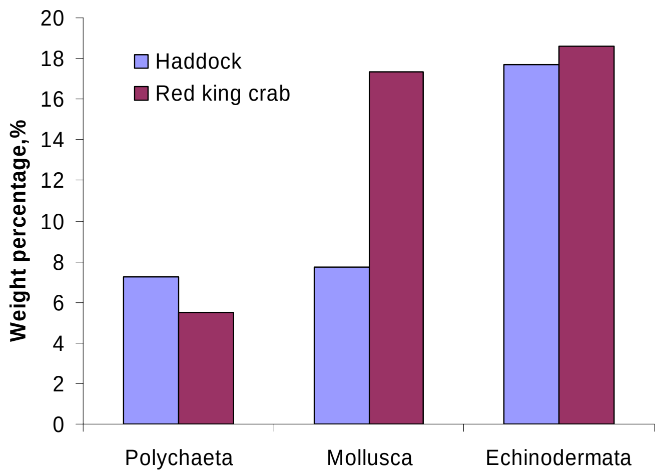


Fig. 6. Weight percentage of main benthic food items in the diets of red king crab and haddock in the coastal waters of the Kola Peninsula

The analysis made did not reveal any effect of the trophic competition from the side of the red king crab on the haddock feeding in the Russian part of the Barents Sea.

Conclusions

The research did not reveal any evident effect of the red king crab on the total biomass of benthos and biological diversity of the studied *M. sarsi* community in the Motovsky Bay. However, a selective consumption by the crab of some groups of bottom organisms led to a considerable decrease in abundance of its food objects and to changes in the order of species domination within the community.

The red king crab predominantly consumes young scallops and almost do not affect the adult part of the population. Thereby, the red king crab having no considerable effect on the reproductive potential of the scallop population, nevertheless, can be a cause of its extra natural mortality due to elimination of juveniles.

It has been shown and documented haighestregistered Capelin eggs consumed by the crabs made up 0,03% of all capelin eggs laid in 2001. Thus, the negative effect of the king crab on the capelin recruitment can be considered as insignificant.

Such parameters as haddock catches, mean individual length in catches, feeding intensity, frequency of occurrence of plankton, worms, mollusks and echinoderms in the haddock stomachs were analyzed in the period from 1971 to 2002. The analysis made did not reveal any effect of the trophic competition from the side of the red king crab on the haddock feeding in the Russian part of the Barents Sea.

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THE INFLUENCE OF THE ENVIRONMENTAL FACTORS AND A NUTRITIVE BASE ON THE DISTRIBUTION AND BIOLOGICAL STATUS OF THE BARENTS SEA CAPELIN

by

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In the end of the 1950's – early 1960's the water temperature of the Barents Sea exceeded the norm, and capelin were widely distributed over the sea. However, the main area of feeding was in the north, where capelin fed on euphausiids, copepods and hyperiids. A peak of feeding was in July. In September-October, the fatness of capelin reached 19-21 %. In the capelin population, there was a big number of fish of older ages (4-5) that promoted a stable level of their reproduction. In the second half of the 1960's, the increase of capelin abundance was observed during the sufficient cooling of water masses. In connection with that the investigation of that species was widened, and the commercial exploitation of the capelin stock was initiated. In the 1970's, the catches of capelin amounted to 3.0 mill. t.

As a result of studying capelin food migrations, feeding behaviour and peculiarities as well as the growth, a quite clear picture of capelin feeding cycle was obtained. It was different for mature and immature fish under the different sea temperature. At present, the main attention is paid to studying the conditions of capelin nutritive base formation, peculiarities of its distribution dependending on abundance and age structure of the population and feeding relationships between capelin and the other plankton-eaters, as well as the effect of the trophic factor on capelin population status.

The aim of the given paper is studying a long-term and seasonal dynamics of capelin feeding, a process of accumulation of fat and their influence on the maturation rate in the conditions, when the food supply is different in different areas of the central latitudinal zone of the Barents Sea.

Material and methods

To characterize feeding of capelin, the data on field and quantity-weight analysis (own and archive materials) for 1976-1978, 1982-1985, 1987, 1992, 2002-2003 (about 17 thou. stomachs) were used. Feeding potential of fish was estimated by the biomass of the copepod plankton (mg/m^3 of wet weight) for 1982-1985, 1987, 1992, 2002-2003. Those data were obtained by PINRO during the complex survey in the central latitudinal zone of the Barents Sea (Fig. 1) and the survey for 0-group pelagic fish. In total, about 600 samples were analyzed. Percentage by mass (m) (% of the stomach contents mass) and frequency of occurrence (f) (% of feeding fish) were used as feeding indices. Stomach fullness was visually determined using a five-point scale: 0, empty; 1, low fullness; 2, mean fullness; 3, full stomach; and 4, full stomach with walls stretched by food. An index of fullness was calculated as the stomach contents mass divided to the fish mass and multiplied by 10 000 ($^0/_{000}$). Capelin fatness was determined by a standard method (Lazarevsky, 1955). The data on capelin abundance were taken from the ICES (Anon., 2000, 2003), and the fish distribution was analyzed by the data from the fishery statistics and the trawl-acoustic surveys.

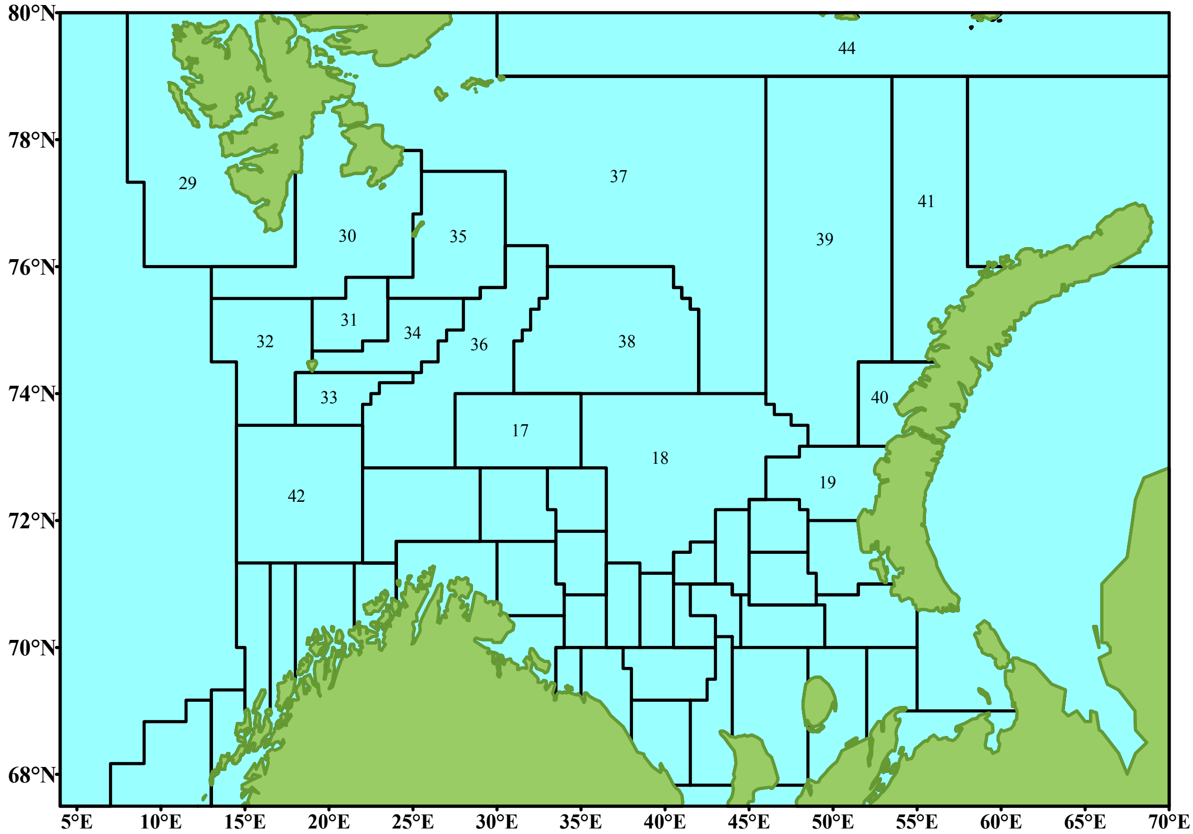

Fig. 1 Chart of the Barents Sea fishing area:
17-the Demidov Bank; 18-the Central Deep; 19-the Northern part of the Novaya Zemlya Shallows; 29-the West Spitsbergen; 30-the South Cape Deep; 31-the Spitsbergen Bank; 32-the Bear Island Bank Western slope; 33- the Bear Island Bank Southern slope; 34- the Bear Island Bank Eastern slope; 35-the Hopen Island area; 36-the Western Deep; 37-the Perseus Elevation; 38-the Central Elevation; 39-the Novaya Zemlya Bank; 40-the Sukhoy Nos area; 41-the Admiralteistvo Peninsula area; 42-the Kopytov area; 44- the Franz Josef Land area

Results

Formerly, estimating capelin food supply in 1972-1984, only the development of the North Atlantic species *Calanus finmarchicus* was taken into account. A role of the Arctic species was not estimated. However, a sufficient role of the arctic species in the formation of biomass in the high latitudes has been shown recently. *Calanus glacialis* is the most abundant species among them. Besides, during the discussed period the capelin population was changing that, probably, also influenced the distribution and conditions of capelin feeding.

A period of 1976-1978 is characterized by a high abundance of capelin and the presence of a great number of older fish (3+ and 4+) in the population. Their portion was high in the moderate and cold 1976-1977 (Fig.2). In those years, the capelin distribution was the widest. Their area reached 78-80°N in the north and the Novaya Zemlya in the east (Røttingen and

Dommasness, 1985). In the anomalous cold 1978, the feeding area of capelin reduced and shifted south and westwards. It was probably caused by the hydrological conditions, the decreased abundance of capelin and a drop of a portion of fish at the age of 3+ and 4+ in their population.

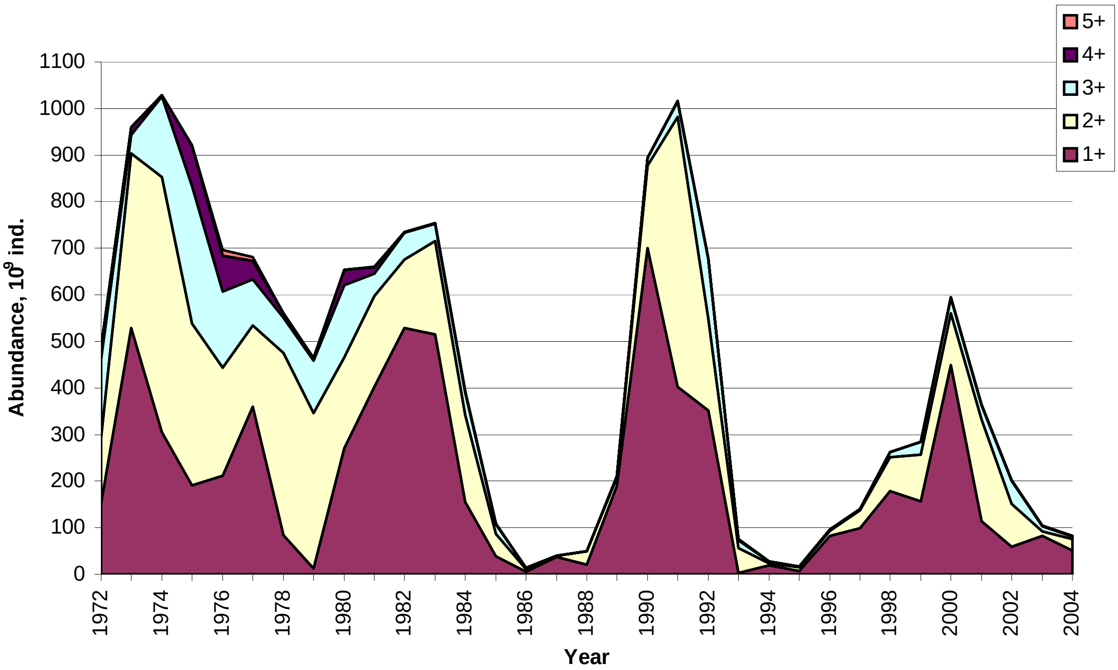

Fig 2. Dynamic of capelin abundance in the Barents Sea according to the TAS data

In the moderate 1976 capelin began to feed early. In that year, there was the high biomass due to the euphausiids (overwintering copepods) in the eastern and northeastern sea (Anon., 1991) that favoured the intensive feeding of the large capelin on them already in the first ten-day period of June. There, the consumption of copepods by the small fish (the mean length – 12 cm) was recorded (Fig.3a). In the early August, a part of capelin formed dense concentrations in the Hopen Island area, at 76º38′ N, where the fish fed moderately on copepods and euphausiids. In the northeast, capelin predated on copepods in the end of August-the first half of September. Already in July, the level of capelin fatness (10.2%) was unusually high for summer. Fish fatness increased in August-September (11.3-11.7%).

In the cold 1977, regular feeding of capelin began in May-June in the fish migration area (the Demidov Bank), as well as in the wintering ones (the Central Deep). First, it was connected with euphausiids, then (June-July) - with the copepods also (Fig. 4). Fish aged 2+ - 3 were noticed to prefer those crustaceans in feeding. In August-September, the center of capelin feeding shifted to the areas with the arctic water masses – to the Hopen Island area (76-77ºN) and the Perseus Elevation (76-78ºN), as well as to the northeast. In some areas in the west and east, capelin also fed on euphausiids and, to a less extent, on hyperiids and *Sagitta*. By the end of July, the fatness of capelin made up 6 %. In August-September, a sudden increase of capelin fatness (to 11-15 %) happened, and, in October, they stopped to feed.

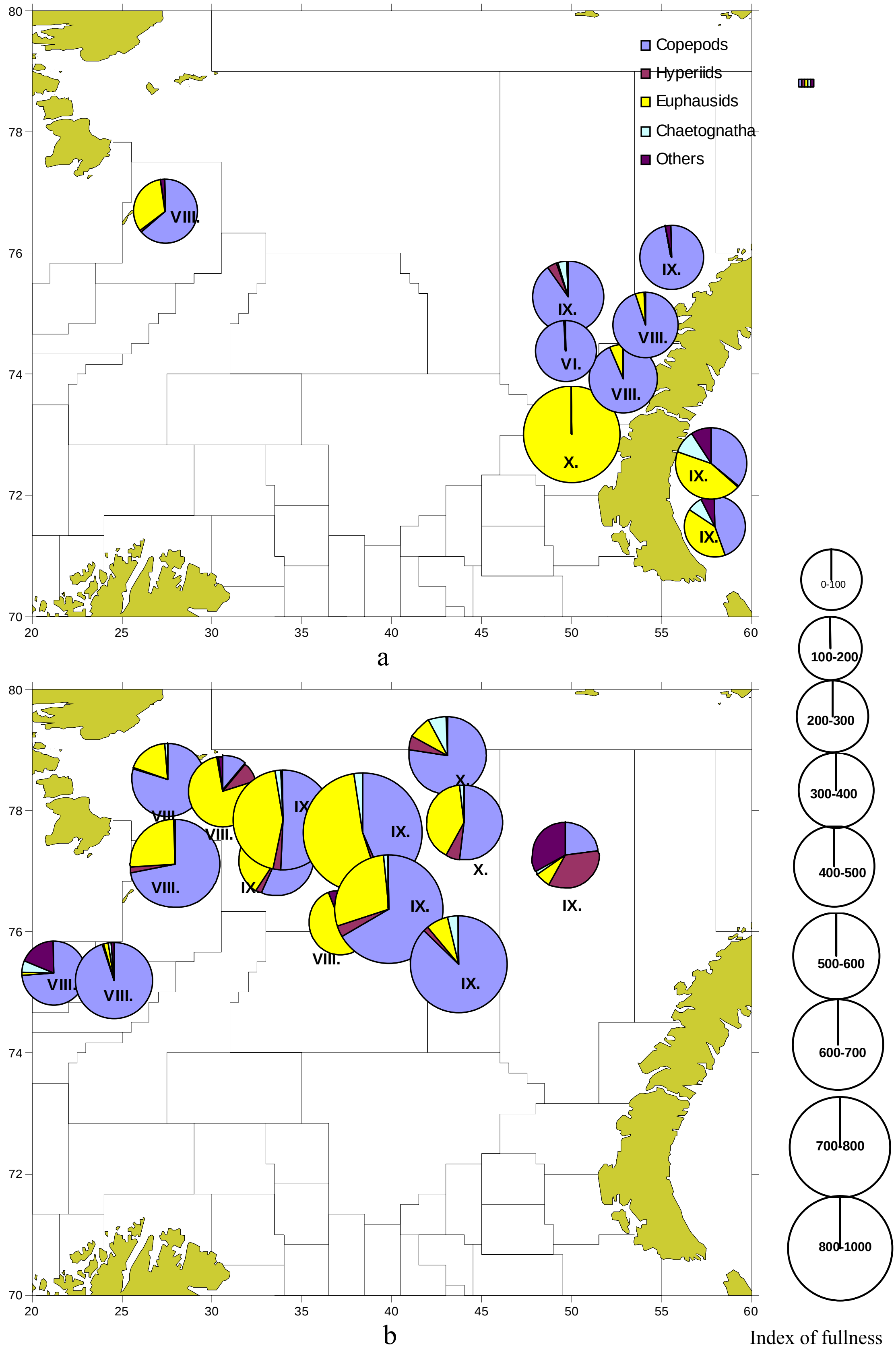

Fig. 3. Food composition (% by weight) and the intensity of consumption (Fullness $^{0}/_{000}$) in 1976 (a) and 1978 (b)

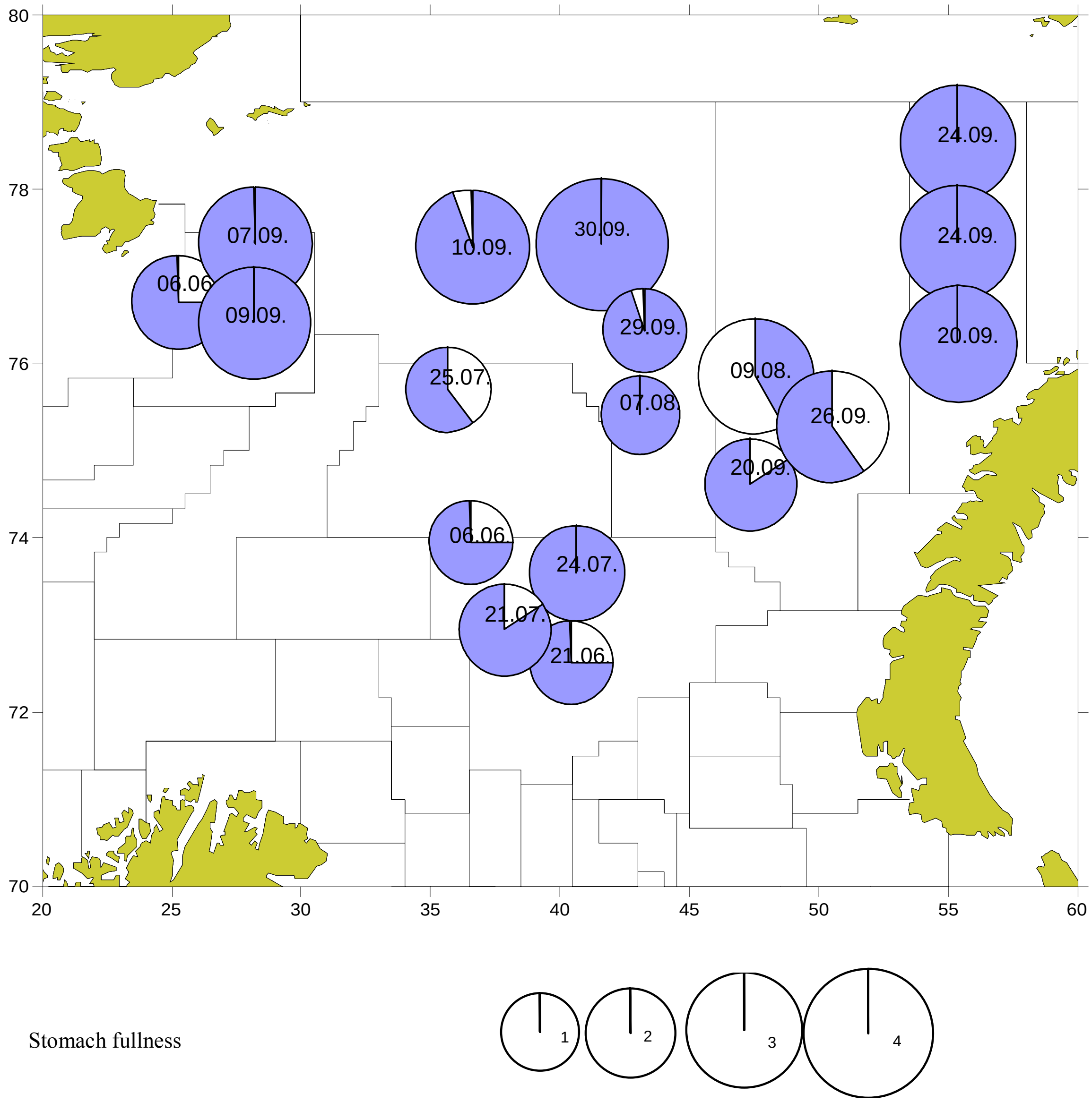

Fig. 4. Copepods frequency (%) in the food of 3+ years capelin in June-September 1977

The anomalous cold 1978 was characterized by the highest concentrations of the euphausiids in the northwest. Dense concentrations were also formed due to a wide distribution of coldwater *Th.raschii* alongside with the warm-water species (*Th.inermis, Th.longicaudata*). Rather poor, but prolonged (during the entire June) feeding of capelin was noticed on the ways of that fish migrations (the Western Deep), where capelin aggregations overlapped those ones of the euphausiids with a high density (100-1000 ind./1000 m^3). In that period, the two-year-olds primarily fed on copepods and the diet of the three-year-olds was mixed with a prevalence of euphausiids. The main feeding of capelin from all the age groups started in August-the first half of the month in the Bear Island Bank, in the Hopen Island area (76-77ºN) and the Perseus Elevation (76ºN). In the second half of the month, the feeding went on in the same areas, but the capelin was gradually migrating to the north and northeast. In the capelin feeding, the age differentiation by the specific food composition (copepods predominated in the small fish diet and the euphausiids were preferred by larger capelin), which also varied depending on the capelin feeding area, was observed well. In the late September-early October, in the northern borders of the capelin feeding area (77º35′-77º55′ N), in the Perseus Elevation, capelin started feeding on hyperiids though the consumption of copepods (mainly, *Calanus finmarchicus*) and euphausiids (primarily *Th.inermis*) remained to be high and those species predominated in capelin diet by weight (Fig. 5). At that, capelin index of fullness was high. Practically, all the fish fed. On the Novaya Zemlya Bank, hyperiids were the main food object. As a result of intensive feeding, in August, capelin fatness was already 11 %, and, in September, it reached 16.7 %.

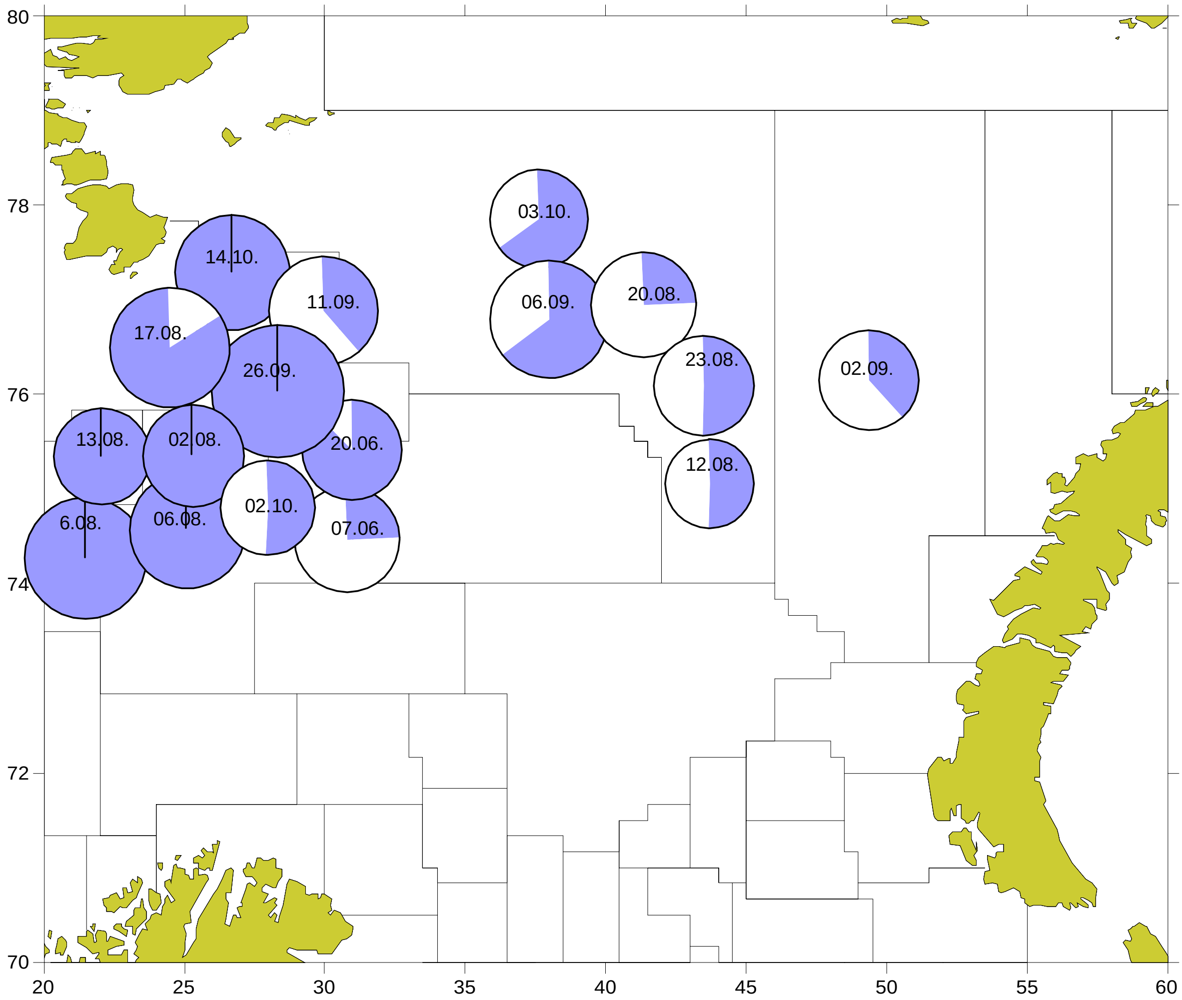

Fig. 5. Copepods frequency (%) in the food of 3+ years capelin in June-October 1978 (see legend Fig. 4)

The second group of years (1982-1987 and 1992) differs sufficiently from the previous one. At that time, capelin stock changed its status from stable (1982-1984) to collapse (1985-1987) and then it was recovered in 1992 (Fig. 2). Besides, at that period, a portion of older fish reduced much in the population compared to 1976-1978, and since 1984 fish aged 2 and 3 predominated. In 1982-1987 and 1992, unlike the previous years, the data on the food supply were available in the majority of cases, that permitted to analyze a role of this factor in feeding and dynamics of capelin fatness.

In June of warm 1983, all over the Barents Sea, the reproduction of copepods was mainly completed. In the western areas, nauplia and young copepodites from the North Atlantic species *Calanus finmarchicus* predominated. The Arctic species were also in plankton in the north, among which *C.glacialis* predominated. In the second half of July, in the central part, the spawning of *Calanoida* was in progress only at 77°N. The Arctic species predominated among older copepodites in the north, and *C. finmarchicus* prevailed in the southern areas. In the northeastern part of the sea the copepods kept high abundance till the end of July. The abundance of young copepods continued to be high in the northeastern sea to the end of July. On the Novaya Zemlya Bank, the individuals of *C. finmarchicus* at Stages I-II predominated. *C. glacialis* prevailed in the Sukhoy Nos area and was represented by copepodites at Stages III-V.

In July, in the layer 0-50 m, the total biomass of plankton did not exceed 100-200 mg/m^3, and only in the northern areas, to the east of Spitsbergen, the biomass was not higher than 500 mg/m^3. The contribution of each species was different (Table 1).

Table 1. Copepods biomass in 0-50 m layer in the central latitudinal zone of Barents Sea July-August 1983 (mg/m^3)

Fishing area	*C.finmarchicus*		*C.glacialis*		*C.hyperboreus*	
	July	August	July	August	July	August
Western Spitsbergen	56	135	47	6	29	0
South Cape Deep	174	33	159	7	10	12
Spitsbergen Bank	33	47	434	3	2	1
Eastern slope of the Bear Island Bank	-	6	-	0	-	0
Hopen Island area	41	94	172	17	6	2
Western Deep	13	17	0	0	0	6
Perseus Elevation	72	56	91	149	50	1
Central Elevation	28	48	5	1	0	1
Novaya Zemlya Bank	28	-	33	-	11	-
Sukhoy Nos area	7	-	75	-	44	-
Admiralteistvo Peninsula area	3	-	15	-	6	-

Plankton mass maturation and sinking to the depth took place in August. The copepods were consumed, probably, in that period. In the Arctic waters, the biomasses in the upper layer were low and formed owing to *C finmarchicus*. Only on the Perseus Elevation, they reached maximum (150 mg/m^3) due to *C. glacialis*.

In autumn-winter 1982/1983, in the northwest, the aggregations of euphausiids were also scattered, obviously, because of the intensive consumption of them by capelin in summer 1982 (further).

Since the rates of plankton development differed in the different water masses, the feeding of capelin in 1983 was irregular. In July, in the western areas, feeding of the large capelin predated on young *Themisto* and copepods (*C. finmarchicus* at Stage V and *M. longa*) was the most intensive. However, obviously, there was a small amount of food. Capelin fed more intensively in the end of July, in the Central Elevation (Fig. 6), where the diet by weight mainly consisted of euphausiids and copepods (predominantly cold-water species *C. glacialis*, *C. hyperboreus* and *P. minutus*). In August, capelin concentrations remained to be stable due to the mass passing into feeding on copepods. In that period, higher biomass in the low water layers was caused by mature *C. finmarchicus* and plenty of the Arctic species. The latter ones (*C. hyperboreus,* predominantly), as well as warm-water species of euphausiids (*Th. inermis*, *Th. longicaudata*) and chaetognaths (*Sagitta spp.*) predominated in capelin diet. In accordance with the seasonal order of the development of copepods and euphausiids, capelin fed the most intensively in the Central Elevation (August), the Perseus Elevation (August-September), in the Hopen Island area (September) and on the Novaya Zemlya Bank (August) (Fig. 6). Due to the intensive feeding, capelin reached high fatness in the first days of September already. In September and October of that year, fatness indices were equal to 10.8 and 10.7%, respectively.

A character of the capelin food supply formation in the warm 1992 was close to that one in 1983. The main feature of capelin feeding was irregularity connected with many factors: a character of their distribution, spatial differences in the plankton species composition and biomass, and the level of plankton consumption. In 1992, there was a food competition from the side of the polar cod, the abundance of which increased almost in six times as compared to 1990. The food competition between those fish species was the largest on the Novaya Zemlya Bank, where the polar cod had advantages in food consumption. A limitation of capelin diet influenced their fatness. In September 1992, that index was only 5.7 %, and in October – 6.6 %, that was much lower than for the same period of 1983 under the favourable feeding conditions for capelin.

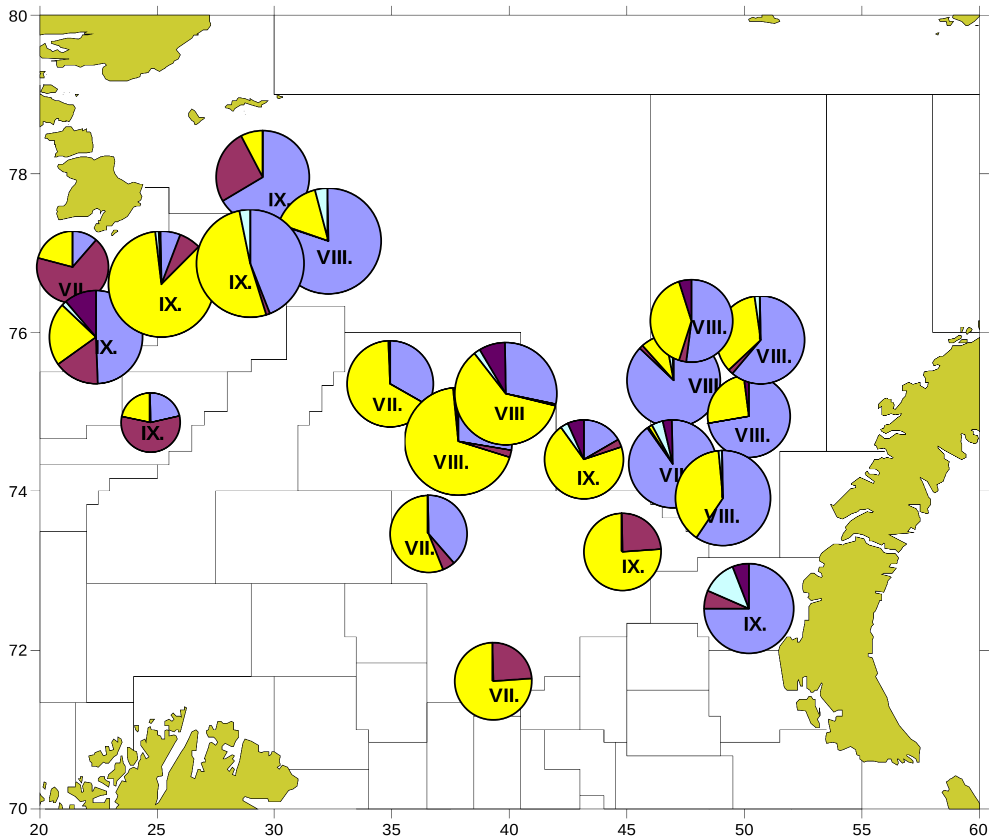

Fig. 6. Food composition (% by weight) and the intensity of consumption (Fullness $^{0}/_{000}$) by capelin in 1983 (see legend Fig. 3)

A situation with the formation of capelin food supply in the moderate years (1982, 1984 and 1985) was quite different. In 1982, under a big value of the capelin stock and the lowered portion of fish older age groups (Fig. 2), capelin had the northwestern distribution. *C. finmarchicus* predominated in the plankton composition there. In the end of August, a considerable part of crustaceans, predominantly in the south of the area, reached Stages IV-V, but in higher latitudes, nauplia and copepodites at Stages I-III were found. In the Arctic waters, the aggregations of *C. glacialis*, a portion of which was the highest in the area of the Hopen Island area and in the South Cape Deep (25-45 % of the large copepod total abundance) were registered. Large amounts of *C. hyperboreus* were also observed there. In August, the biomass formed mainly due to older stages of *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*. There mean values equaled to 227 mg/m^3 in the area of 72-75°N and to 203 mg/m^3 at 76-78°N. A great food potential in those areas had been existing for a long time that conditioned capelin stay in most those areas till October-November. In the northwest, the aggregations of the euphausiids were quite poor.

In the mid-June 1982, in the Hopen Island area (at 75°45′ N), 3-4 year old fish traditionally fed on euphausiids. In August, in the northwest, the main concentrations of capelin overlapped the increased biomass of zooplankton. In the middle of the month, their percentage in the diet of 3-4 year capelin abruptly increased. Copepods predominated in September as well, however, the change of food was not synchronized in time, and, in that area, the condition factor was low (Fig. 7).

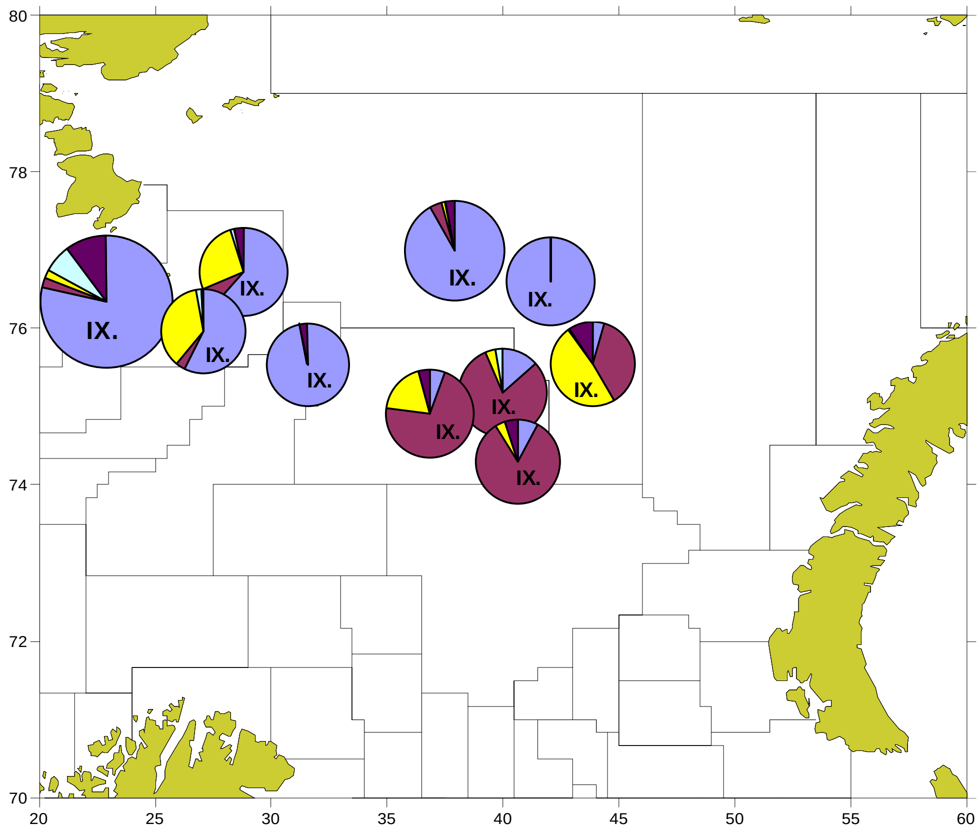

Fig. 7. Food composition (% by weight) and the intensity of consumption (Fullness $^0/_{000}$) by capelin in 1982 (see legend Fig. 3)

In the Perseus Elevation (76º55′ N), the feeding of capelin on copepods began in August, but was not intensive. In September, in the northern areas, *C. finmarchicus* and *C. hyperboreus* at Stages IV-V predominated in diet. At that, in the early September, small-sized capelin (the average size – 11.5 cm), which reached the northern borders, fed on crustaceans there. The role of *C. hyperboreus* in the feeding of large fish was especially great in the end of the month. In the south of the feeding area, their diet was mixed (Fig. 7). The capelin aggregations were distributed for a long time in the Central Elevation, where fish at age of 2-5 fed intensively on the mixed food in August. The shortest period of the intensive feeding of capelin on copepods (September-October) was in the cold waters of the South Cape Deep with a maximum in the first half of September. Since the feeding of capelin in 1982 was irregular, fish reached a high fatness (more than 10 %) in the first-second ten-day periods of September in the Perseus Elevation and in the end of September in the South Cape Deep.

The environmental conditions had the main influence on the feeding in 1985. The lowered heat content of waters in the west (right up to July) caused the slow development of plankton. However, the intensive warming up of waters in August favoured the quick maturation of plankton and their sinking to the bottom. In that year, the euphausiid community also appeared to be poor, probably, owing to the conbsumption of copepods in the previous years. Since zooplankton biomass on the migration ways of capelin was very low in July-August, fish almost did not feed. In August, despite feeding on euphausiids (the Western Deep, the Hopen Island area) the capelin index of fullness was very low (it does not exceed 7-25 $^0/_{000}$). In September, in the surface layers, plankton was also scanty. Compared to warm and normal years, when the intensive feeding of capelin began already in July-August, in 1985, a peak of capelin feeding was in September, when the main part of the food plankton was near the bottom (the fullness index increased up to 142-275 $^0/_{000}$). In that year, the euphausiids were not prevailing in the diet due to their low abundance in the northwest.

The area of the capelin feeding on copepods was very wide. At that, in the South Cape Deep, the Hopen Island area and in the Central Elevation, the intensive consumption of those copepods began in early September and stopped in early October (Fig. 8). Feeding of capelin in the Perseus Elevation lasted to October. In 1985, capelin feeding was characterized by the consumption of mainly copepods of the older copepodite stages in the lower layers and the lack of vertical migrations. A portion of *C. glacialis* in the capelin diet was the highest (58 % by quantity or 65 % by weight), and, as a whole, the Arctic species dominated. The consumption of euphausiids (primarily, of grown up juveniles) was mainly recorded in the northwest, in September. The disturbance of a seasonal rhythm of capelin feeding caused the lowered accumulation of fat supply. As a result of the poor feeding in August, in September, the fatness had been low (5.7 %), and only in October the index increased to 8.2 %.

In the cold 1987, at the low abundance of capelin and predomination of the two year old fish in the population, the formation of feeding concentrations was late, and, in the end of August, the capelin were yet in the Norwegian Channel. On the Demidov Bank, there were small and larger capelin migrating for feeding to the northwestern areas. Their feeding was moderate and the food was diverse. In addition to *C. finmarchicus* and *Th. inermis* composing the basis of capelin feeding, the Arctic species *M. longa* and *C. glacialis* were found in the small numbers. The main feeding of capelin took place in the areas with the increased concentration of copepods and euphausiids, in September. The index of capelin stomach fullness was high, in the most areas, the diet was dominated by euphausiids (55-95 % by the frequency of occurrence) and, only in some parts, the increased number of copepods was registered. In some areas, capelin fed quite intensively in the beginning of October, when their small concentrations moved forward to the Perseus Elevation. There, capelin started consuming mainly hyperiids, whereas in the west the feeding was the same. The late beginning and early termination of feeding in 1987, as well as the predomination of young individuals in the population and the limited feeding area could lead to the low fatness of fish.

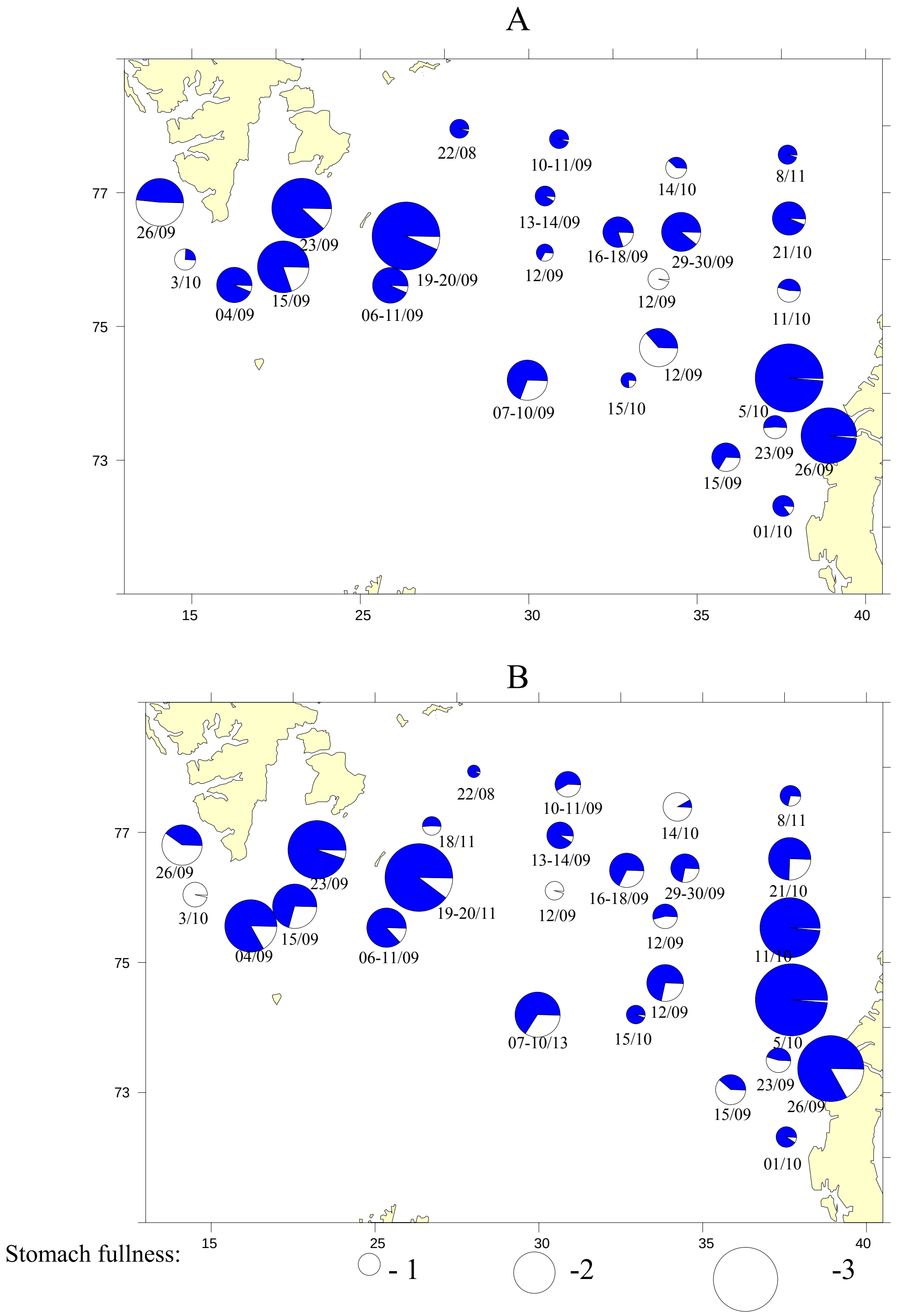

Fig. 8. Significance (blue sector frequency) of copepods in the 2+ years capelin (A) and 3+ years capelin (B) feeding in autumn 1985

Peculiarities of capelin feeding have been recently studied taking the warm 2002 and 2003 as the examples. In that period, with a relatively low stock size and a sufficient percentage of young fish in the population, the feeding area of capelin was small. In 2002, young fish distributed further to the south with the border in the north along 78°N. Mature capelin were distributed further to the north, but the main concentrations of fish from all the age groups were located in the Perseus and Central Elevations. In 2003, their distribution was further to the south and not so wide. The main concentrations were in the area of the Hopen Island area, the Perseus Elevation and the Central Deep reaching 78°30′ N in the north.

In 2002, in the end of August-early September, *C. finmarchicus* and *C. glacialis* at the early stages (I-III) predominated in zooplankton in the areas having recently become free from the ice and along the ice edge. In 2003, the similar situation (the availability of eggs, nauplia and young copepodites) in the areas further to the south in the Perseus Elevation was observed in the middle of September, but *C. finmarchicus* predominated there. Specially should be mentioned a big abundance of this Atlantic species at Stage V on the Novaya Zemlya Bank.

In 2002, the biomass fluctuated at the level of 50-200 mg/m^3, on the average, in the north, and they reached 300-750 mg/m^3 in the northernmost areas. In 2003, the biomass was lower and amounted to 100-300 mg/m^3 in the main areas of capelin feeding at 76-77°N. Thus, the feeding conditions of capelin in autumn of 2002 were more favourable.

In 2002-2003, capelin began to feed in July-August, but the peak of feeding was in September, although in 2003, in some areas, capelin continued to feed in October-November as well (Figs. 9,10). In 2002, the capelin distribution depended more on the copepod plankton because of the wide distribution and prolonged production of *C. finmarchicus* and *C. glacialis*, especially in the northern areas (78-80°N). In that year, the intensive consumption of copepods was registered in the Perseus Elevation, under a big importance of older copepodites in the capelin diet. It is important to notice that the individuals of older age groups of C*alanus* selected by capelin did not predominate in the plankton (Fig. 11) that can be explained by insufficient taking *Calanus* by the Juday net. Macroplankton organisms (the boreal species of euphausiids *Thysanoessa inermis* primarily) were also important in the distribution of capelin concentrations.

Capelin reached the highest fatness in 2002 in the northern areas of the Perseus Elevation (10.4-13.6 %) and on the Novaya Zemlya Bank (8.1-10.8 %). In 2003, the capelin fatness was somewhat lower, but the increased values (7.6-8.1 %) were also registered when the large individuals appeared at the northern borders of the feeding area on the Perseus Elevation. The latter fact is connected with the consumption of the Arctic species of copepods, which are characterized by a high content of lipids.

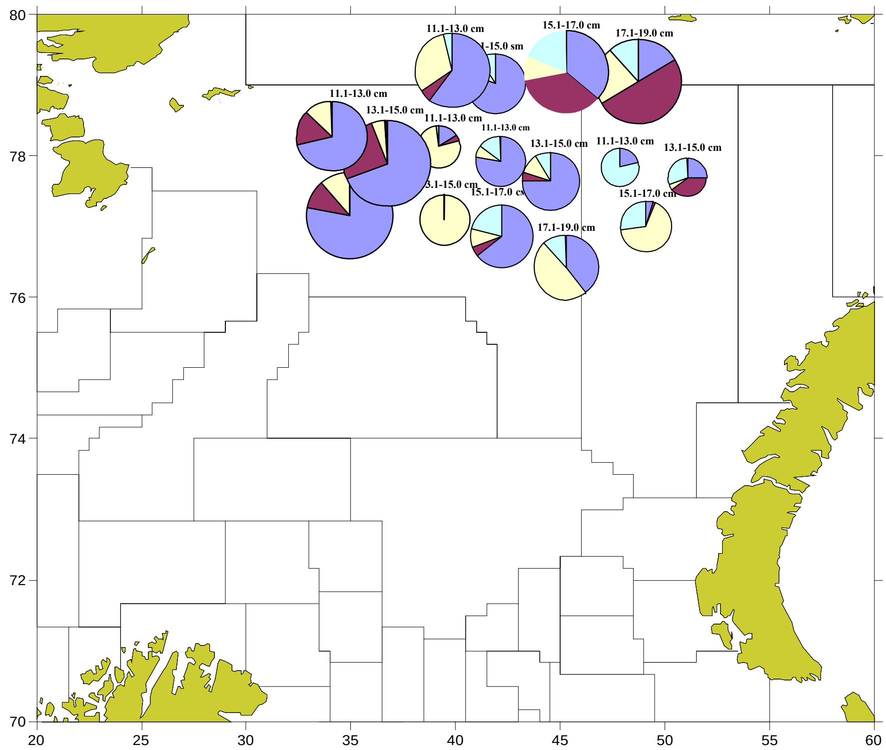

Fig. 9. Food composition (%) and the intensity of consumption (Fullness $^{0}/_{000}$) by different length capelin in 2002 (see legend Fig. 3)

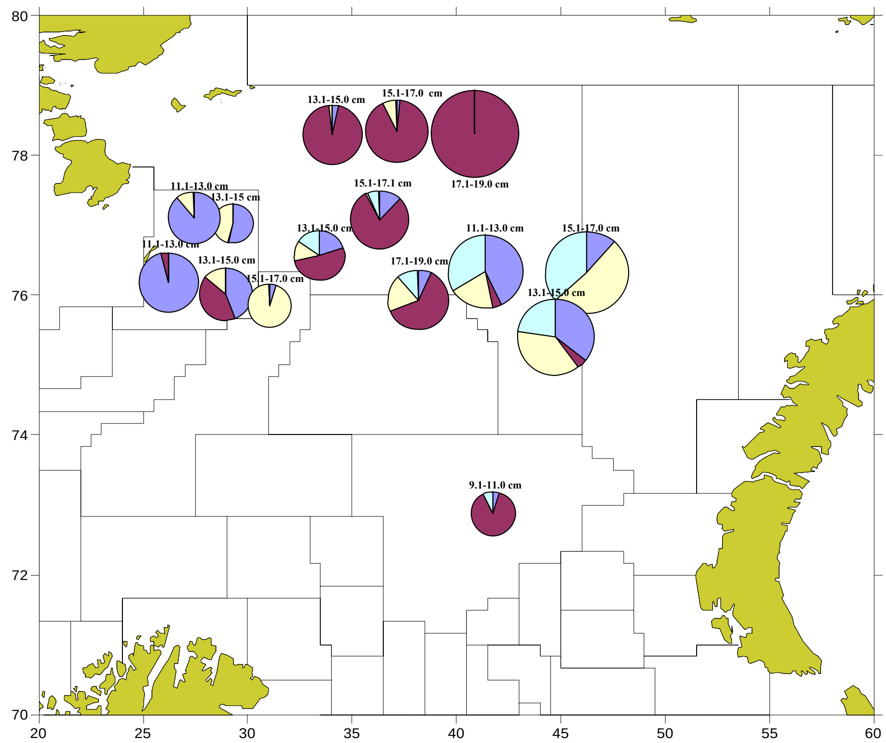

Fig. 10. Food composition (%) and the intensity of consumption (Fullness $^{0}/_{000}$) by different length capelin in 2003 (see legend Fig.3)

In accordance with the dependence of a maturation rate of capelin on their fatness level (Oganesyan and Dvinin, 1988), in 2002 a mass maturation of the second- and third-year females characterized by a high fatness was registered mainly in the Perseus Elevation, whereas males were immature with the little exception there (Table 2). In 2003, a portion of mature individuals in the mentioned age groups of capelin was lower.

Table 2. Abundance of mature capelin (%) and fatness of different lenght capelin in September 2002-2003

Fishery area	Date	Length group, cm	Fatness, %	Mature capelin, %					
				2+		3+		4+	
				female	male	female	male	female	male
2002									
Perseus Elevation									
78°50′N43°01′E	09.09.02	14.0-17.5	13.6	100	-	100	-	75	-
78°30′N44°52′E	10.09.02	12.0-16.0	10.7	100	-	100	-	-	-
77°35′N34°15′E	12.09.02	11.5-15.5	10.4	100	100	100	100	100	100
76°15′N45°15′E	16.09.02	14.5-18.1	8.7	-	-	96	40	-	-
Novaya Zemlya Bank									
77°25′N47°15′E	14.09.02	13.1-18.2	10.8	-	-	-	92	-	-
76°55′N49°45′E	15.09.02	14.0-17.6	8.1	-	25	100	27	-	-
77°15′N50°45′E	15.09.02	13.1-17.2	10.4	-	-	100	100	-	-
2003									
Perseus Elevation									
76°18′N 37°01′E	18.09.03	9.9-13.7	5.2	13	0	-	-	-	-
76°48′N 43°34′E	21.09.03	12.0-16.5	7.6	100	-	100	-	100	-
77°10′N 38°12′E	22.09.03	14.6-17.5	7.1	-	-	100	0	83	14
77°55′N 30°35′E	23.09.03	14.5-17.0	6.6	100	-	100	0	100	0
76°40′N 32°48′E	27.09.03	13.0-15.7	8.1	100	0	100	100	100	-
Hope Island area 77°39′N 26°37′E	25.09.03	14.0-17.0	6.3	100	0	80	0	33	0
77°02′N 29°02′E	27.09.03	12.2-14.3	6.0	64	-	67	-	-	-
76°39′N 28°59′E	29.09.03	12.8-16.0	6.8	92	-	85	-	100	-

Conclusions

Thus, an effectiveness of capelin feeding depends on hydrological conditions, abundance of their population, age composition of fish and a character of their distribution. The abiotic conditions indirectly influencing the specific composition of zooplankton communities have a great influence on the distribution and the development of zooplankters that determines the periods and duration of the fish feeding. The accessibility of food organisms and their abundance changing as a result of the biotic press are of decisive importance. The lack of food is felt to the utmost in the abnormally warm years (1983 and 1992), especially in the western areas, when the upper layers were very much depleted in connection with the intensive development and sinking of copepods. In the moderate years, under the slowed development of the copepod plankton and later spawning of the euphausiids, fish of all ages are better supplied with food, especially in the northern areas, where the most part of plankton consists of copepodites of older stages of *C. finamrchicus* and the cold-water species, *C. glacialis*, first of all (1982). More distinct dependence on the mentioned factors is expressed in the abnormally cold and cold years, but in this case the abundance of capelin and the availability of fish of older ages in their population are of a big importance. In the abnormally cold year of 1978, capelin were characterized by a wide distribution that was accompanied by their intensive feeding all over a vast area from August to early October. At that, the euphausiids forming the abundant concentrations, when the aggregations of ecologically different species *(Th. inermis, Th. longicaudata, Th. raschii*) overlapped, played greater role in the capelin feeding. In 1987, under the minimal abundance of capelin, their food migration was late, and the feeding area was very narrow. As a result, capelin poorly used food resources of the northern areas. The main feeding period of capelin on copepods (as well as on the euphausiids) shifted to September and was very short-term.

A condition favouring the prolonged feeding and the achievement of a high level of fatness and mass maturation by capelin is their migration to the north, where a high food potential is kept for a long time in the zone of the floating ice due to the continuing reproduction of copepods there. Such a possibility is realized under the presence of fish from older age groups migrating for a long distance in the capelin population; this appears to be both in the warm and cold years.

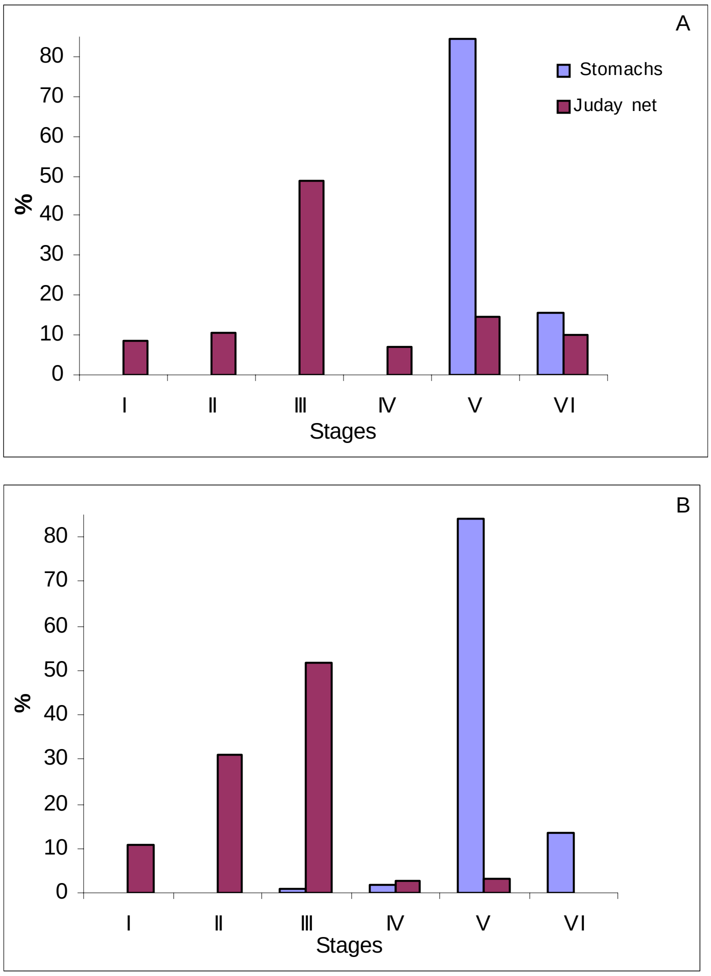

Fig. 11. Stage composition of *C. glacialis* in capelin stomachs and Juday net catches in the Franz Josef Land area (A) and Perseus Elevation (B) in September 2002

PREDICTION OF CAPELIN GROWTH FOR USE IN CAPTOOL

by

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Background

Since 1999, a 1-year prognosis of capelin has also been made during the assessment, using CapTool. The prognosis gives the abundance of 1+ capelin during the survey in year *y+1*, based on the survey of 1+ capelin in year *y*, as well as the 0-group survey in year *y*. The temperature and the cod stock abundance are also taken into account in this prediction. Since capelin is a key species in the ecosystem, e.g. as food for cod (*Gadus morhua*) and other predators, such a 1-year prediction is important for predicting the development of other important stocks in the ecosystem. It also gives some indication of whether the stock will be large enough to support a fishery in year *y+2*. An evaluation of the prediction methodology is given in Gjøsæter et al. (this symposium).

A key element in the 1-year predictions is the growth. In this poster, we make regressions in order to improve the 1-year predictions for capelin length growth, which are used in CapTool**.**

Results of regressions

$$L_{y+1,1} = 0.36 L_{y,0} + 8.10$$ ($r^2=0.20$, $p< 0.05$)

$$L_{y+1,2} = 0.49 LI_{y,1} - 0.26 \mathrm{Cap}_{y,1+} + 9.29$$ ($r^2=0.66$, $p< 0.05$)

$$L_{y+1,3} = 1.37\, LI_{y,2} - 1.39$$ ($r^2=0.34$, $p< 0.05$)

- ***$LI_{y,a}$: Mean length (cm) of immature capelin of age a in year y, from capelin survey***
- ***$L_{y+1,a+1}$: Mean length (cm) of (all) capelin of age a+1 in year y+1, from the capelin survey***
- ***$L_{y,0}$: Mean length (cm) of 0-group capelin, as observed during the 0-group survey in year y***
- ***Cap_y: Biomass (million tonnes) of capelin (1+) in year y***

The following variables were tested, but found not to improve the models:

- Kola temperature January-September or August-September.
- Plankton abundance by size fraction or total, from autumn survey.

Conclusions

- Length of age 1-3 capelin depends on length of age 0-2 capelin the year before.
- Growth from age 1 to 2 seems to be density-dependent.
- For growth from year y to y+1, no relationship was found to temperature or plankton abundance in year y.
- The equations given will be implemented in CapTool.

Further work

- Break the data (temperature, plankton etc. down by area/water mass.
- Check correlation with ambient temperature and with inflow of water to the Barents Sea.

LONG-TERM PROJECTION OF WATER TEMPERATURE TO BE USED IN THE ADVANCE ASSESSMENT OF THE BARENTS SEA PRODUCTIVITY

by

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Water temperature is one of the main characteristics of seawaters. It is widely used for estimation of heat content in water masses, dynamic processes, intensity of interaction between the ocean and atmosphere and other physical phenomena. Water temperature is of crucial importance for marine ecosystems. Therefore, study of its spatial and temporal variability and development of projection methods with different time in advance is an important scientific and practical problem.

The effect of variability in the heat content of the Barents Sea water masses on the ecosystem manifests itself at all trophic levels. In years with low water temperature in the upper 50-m layer in April-June in the southwestern Barents Sea 64% of cod yearlasses at the age of 0-group were poor and only 36% of the yearclasses were of average strength. In cold years rich yearclasses never appeared. Rich yearclasses of cod at the stage of pelagic juveniles formed only in years with high (58%) and average (42%) water temperature (Figure 1 and 2).

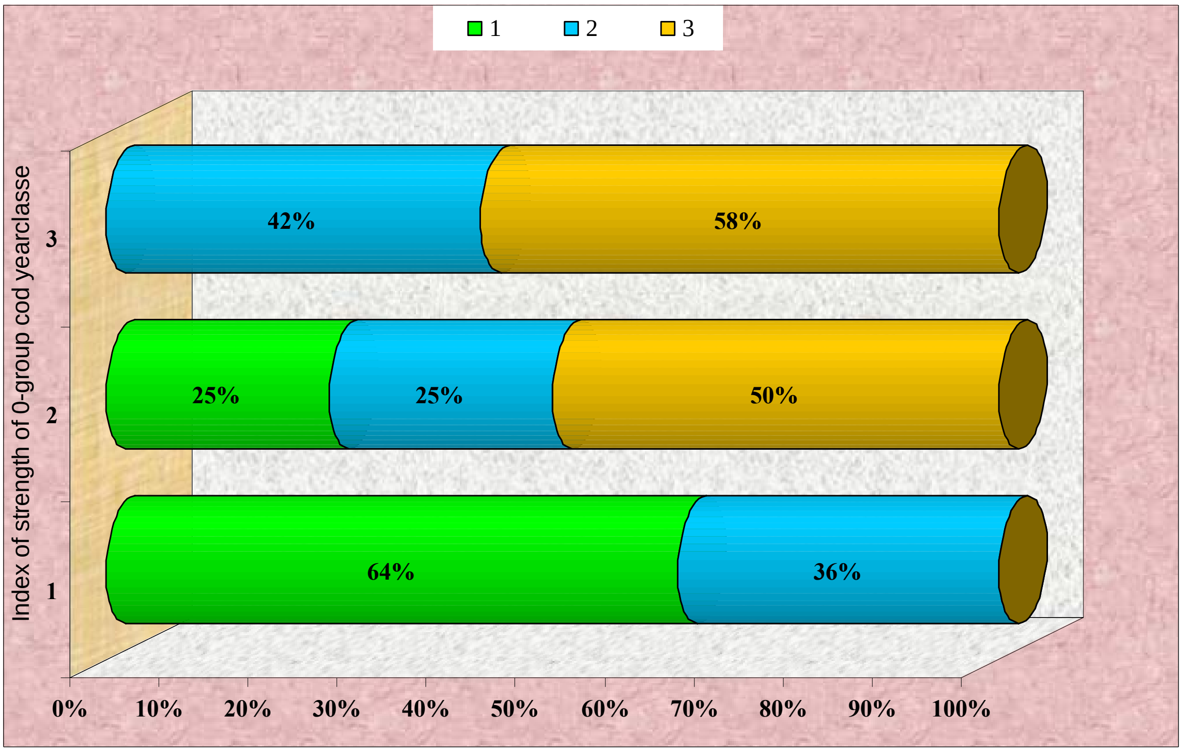

Figure 1. Frequency of occurrence of 0-group cod yearclasses of different strength at low (1), average (2) and high (3) water temperature in the Barents Sea

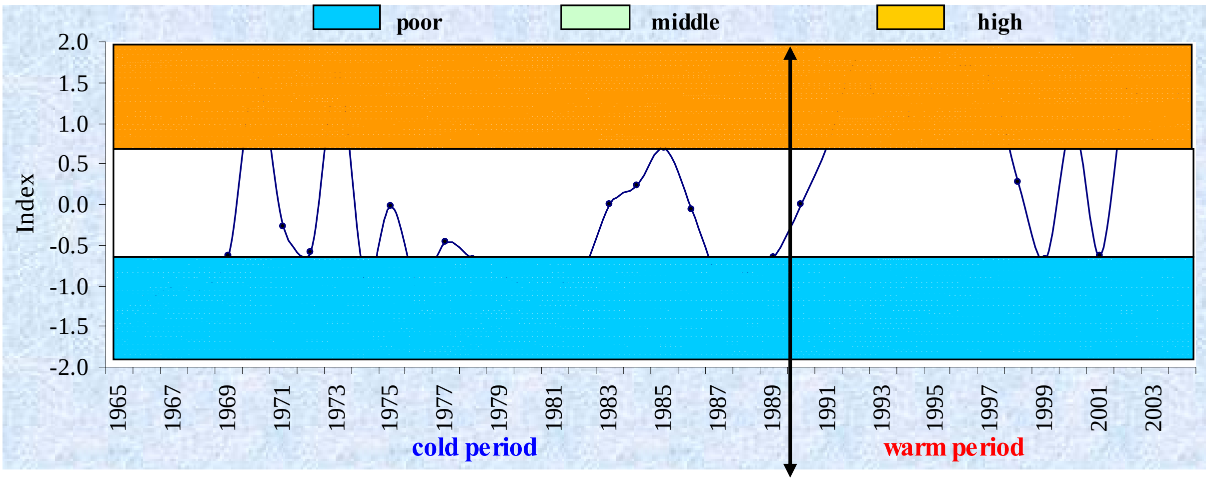

Figure 2. Variation in abundance index of 0-group cod

Year-to-year temperature variability in the Barents Sea correlates well with biomass dynamics of the main demersal species such as cod and haddock. Over a long period of water temperature decrease in 1960-80's, their total biomass also reduced (Figure 3). Under overall rise of water temperature in the Barents Sea, cod and haddock biomass was observed to increase. These examples demonstrate the importance of long-term temperature prognoses as they are taken into account in the advance assessment of expected changes in the Barents Sea ecosystem including recruitment and fishable stocks of the main fish species.

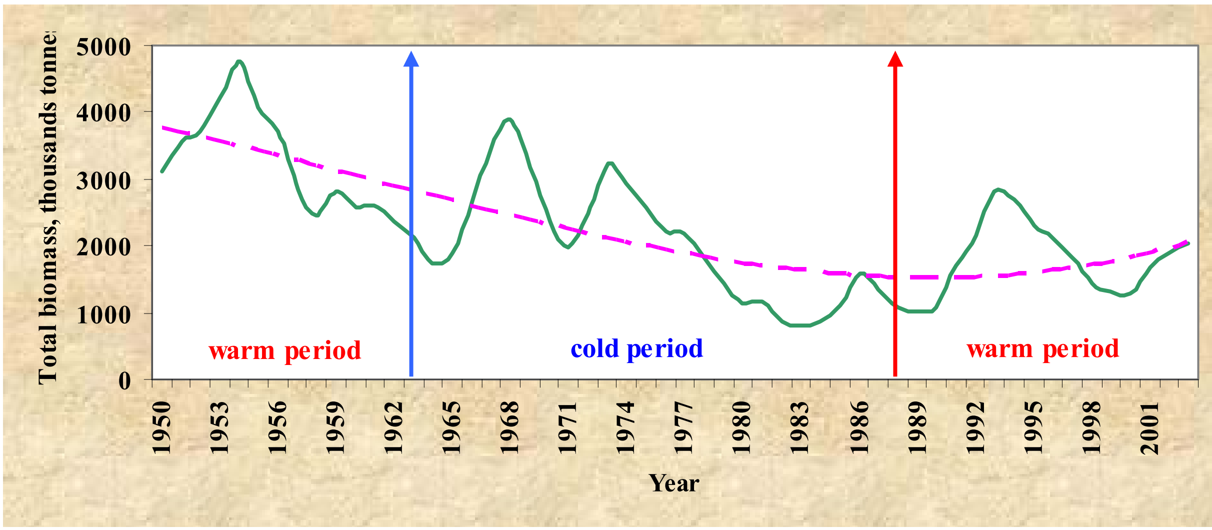

Figure 3. Year-to-year variability in total biomass of cod and haddock in the Barents Sea

Water temperature temporal variability in the Barents Sea has a complicated structure. The spectrum of year-to-year fluctuations in water temperature is rather wide, from short-term 2-3-year fluctuations to a trend component, which can be a part of the long-term cycle. The polycyclic nature of water temperature fluctuations is determined by numerous cause-and-effect relationships between oceanographic, meteorological and heliogeophysical conditions. Due to various reasons it is not always feasible to formalize and use such relationships in the long-term prediction of water temperature with the accuracy required for practical purposes.

Therefore, at present, the major task when developing new methods of the long-term water temperature prognoses in the Barents Sea is to take into account frequency structure of its fluctuations and instability in time of amplitudes and phases of cyclic components. In the present study, the cyclic components were identified in water temperature fluctuations within the 0-200 m layer of the Kola Section using periodogram analysis, spectral analysis, integer and non-integer harmonics identification and wavelet analysis. All the methods used showed almost the same ensemble of year-to-year fluctuations in water temperature. Its main components were a trend and cyclic components with average periods of 14-18, 8-10, 5 and 2-3 years (Figure 4). In 1951-2000, their contribution to the variance accounted for 18, 18, 34, 10 and 15%, respectively. The rest of power was due to noise effects.

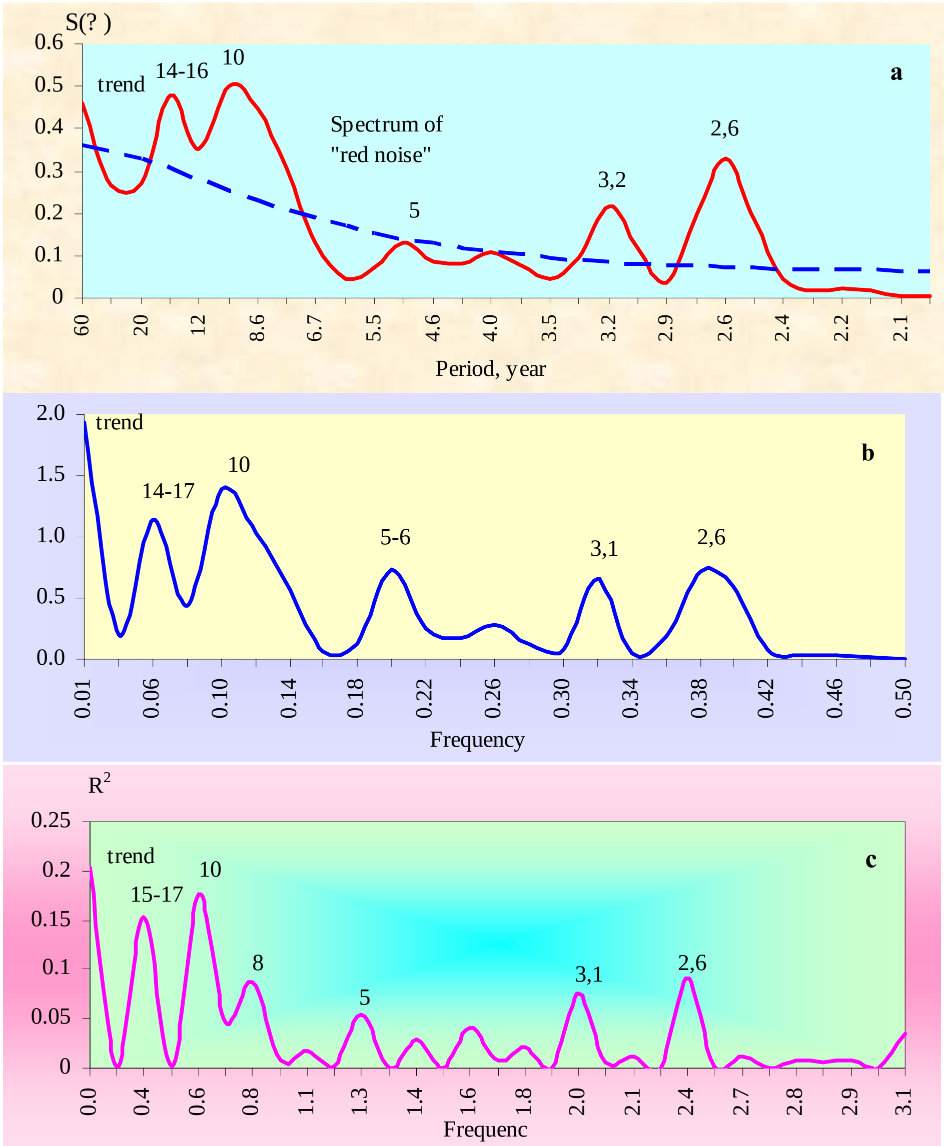

Figure 4. The spectrum (a), periodogram (b) and harmonicogram (c) of mean annual water temperature fluctuations in the 0-200 m layer in the Kola Section based on data of 1900-2000 (above the peaks – period in years; in the top panel a dashed line shows “red noise” spectrum; in the bottom panel a dashed line indicates threshold significance level of coefficient of determination)

A great problem is that year-to-year temperature fluctuations in the Kola Section are non-stationary. If this feature is ignored in methods being developed for temperature projections, errors will be inevitable in the future. Non-stationary frequency structure of water temperature fluctuations makes itself evident in the fact that in the second half of the XX century compared to its first half the period of low-frequency components increased from 12-15 and 8 years to 14-18 and 8-10 years, correspondingly. Amplitude instability of some cycles was also revealed. In 1951-2000, spectral power of the trend decreased while contribution of high-frequency fluctuations increased compared to the prior 50-year period (Figure 5).

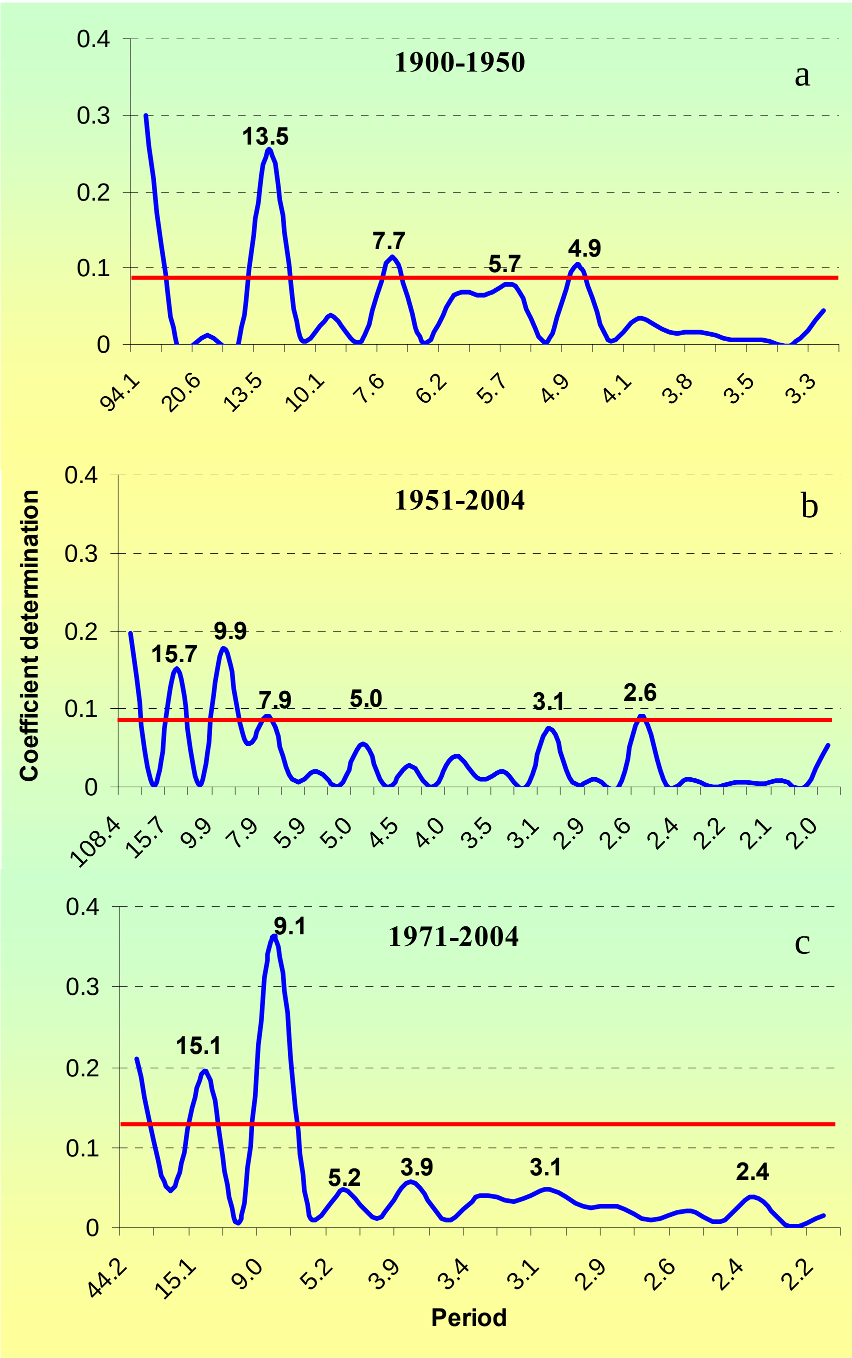

Figure 5. Periodograms of water temperature in the Kola Section in the 0-200 m layer for the periods 1900-1950 (a), 1951-2004(b) and 1971-2004 (c)

Analysis of water temperature fluctuations in 0-200 m layer of the Kola Section since 1971 until the present showed that variance of the short-term quasi-cycles decreased greatly again, while proportion of low-frequency components increased (Figure 5). The up-to-date pattern of water temperature fluctuations in the Kola Section was used for temperature projection by extrapolation of trend, 14-16 and 8-10-year quasi-cycle components. Such projections are proved to be correct in about 90% instances (Figure 6).

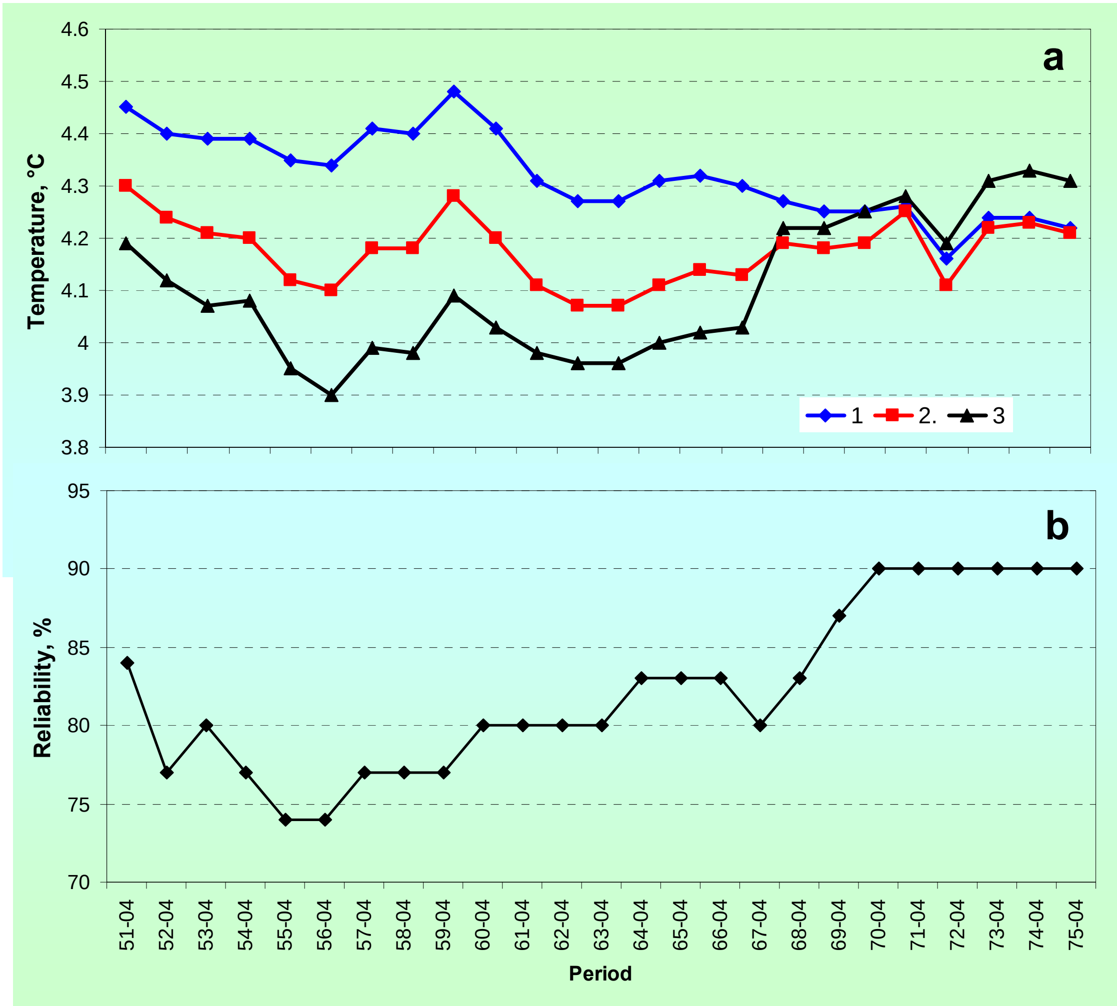

Figure 6. Projections of water temperature in the Kola Section in 0-200 m layer (a) for 2005 (1), 2006 (2) and 2007 (3) based on time series of different length and their reliability (b)

One more method of the water temperature prediction was also based on extrapolation of its cyclic components, which were identified based on data of 1941-2000 using a method of bandpass filtering. For each of them in the time interval, within which the cyclic recurrence appeared not less than 2 times, the Non-Integer technique was used to select those harmonics, which in sum described its variability to a closest possible approximation (no less than 95%). To arrive at more reliable results, one more way of analytical description of variability of the identified components was applied. With the least-squares method, polynomial functions approximating their last cycle were selected. This permitted us to minimize the frequency and amplitude instability in each cyclic component (Figure 7).

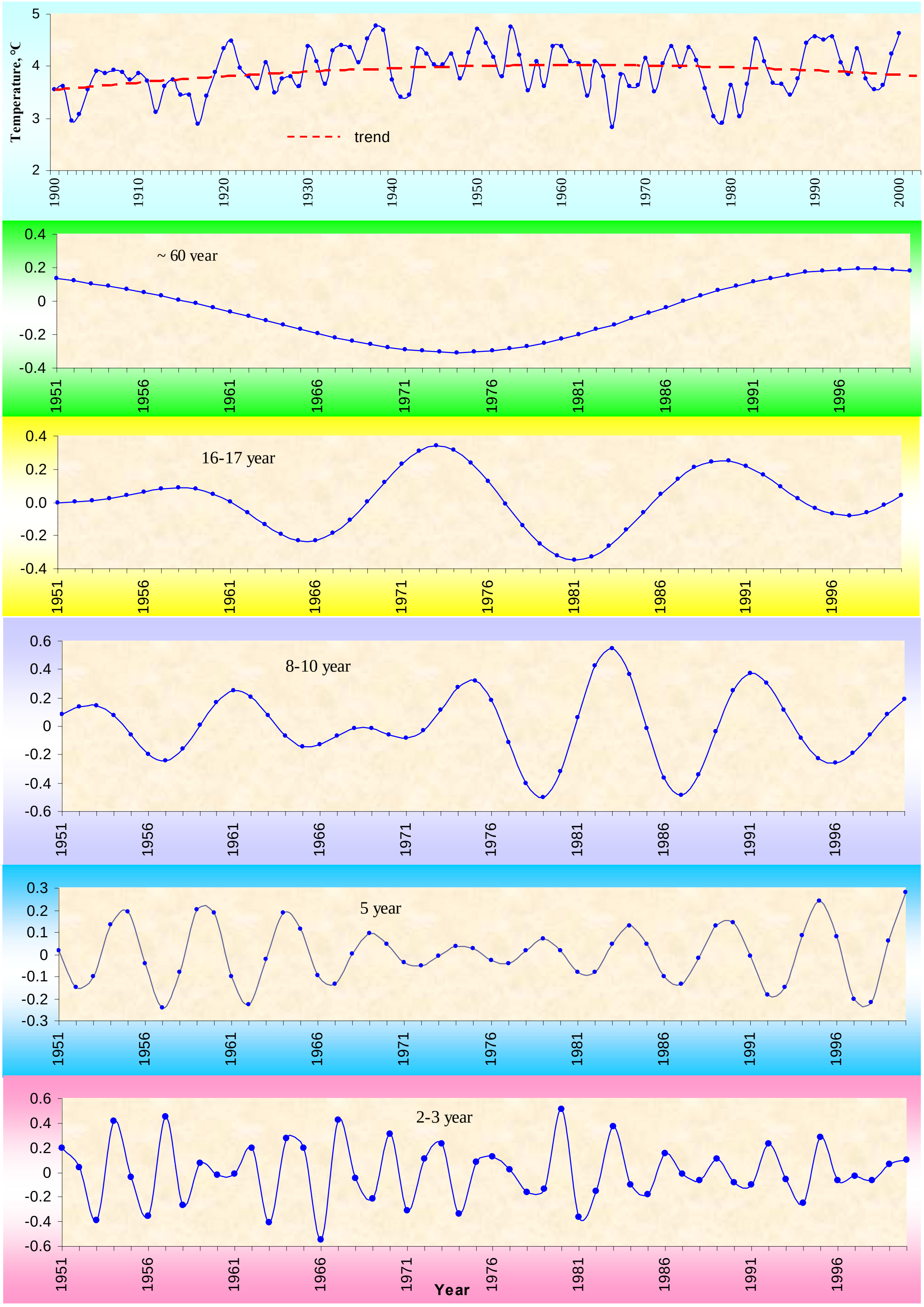

Figure 7. Cyclic components of water temperature variability in 0-200 m layer in the Kola Section

Water temperature was projected in several steps. Using the obtained analytic formula of the trend component based on data over the whole period of observations (1900-2000), its values were calculated for two years ahead. Having excluded the trend from the initial time series within the interval from 1951 to 2000 and using the method of sequential bandpass filtering, values of the main cyclic components were estimated and differentiated. Then, each estimate was extrapolated two steps forward with the use of the selected approximating polynomial functions and a set of non-integer harmonics. Estimates of all the components were summed up with regard to the sign that gave two projected estimates of water temperature. Each of the projected estimates was obtained for one and two-year periods in advance. Mean value of the two projected estimates in each of the above periods served as prognosis of water temperature in the 0-200 m layer in the Kola Section (Figure 8).

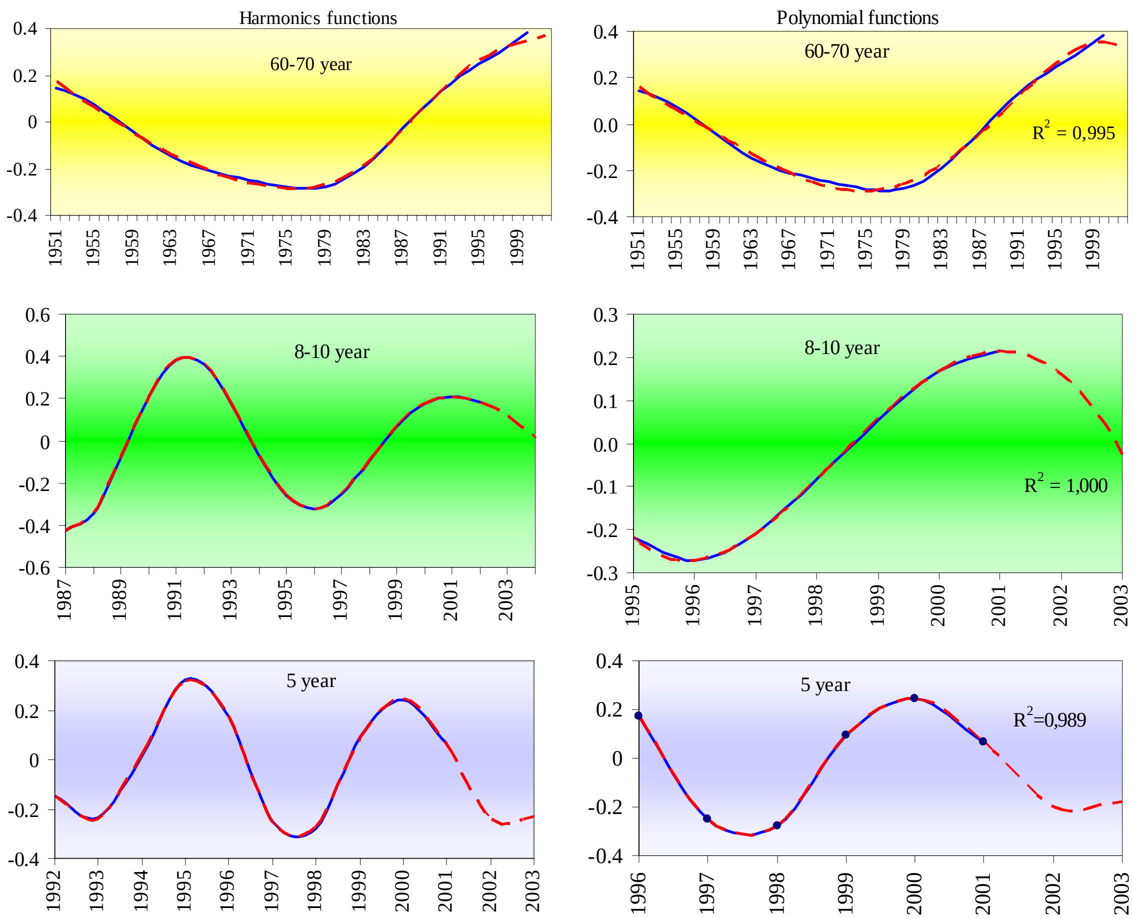

Figure 8. Approximation examples of cyclic components in the Kola Section water temperature in 0-200 m layer by the two methods and projection two years in advance

The method used was examined for quality based on independent data (2001-2004). All projected water temperature values did not exceed the standard deviation, in other words, were proved to come true. Efficiency of the method made up 75%.

According to the prediction made using the aforementioned methods, it is expected that in the nearest future water temperature in the Barents Sea will remain above long-term mean.

JOINT REPORT

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