

JOINT



**Long term bilateral Russian-Norwegian  
scientific co-operation as a basis for  
sustainable management of  
living marine resources in the Barents Sea**

**Proceeding of the 12th Norwegian-Russian Symposium  
Tromsø, 21-22 August 2007**

Edited by  
Tore Haug, Ole Arve Misund, Harald Gjøsæter and Ingolf Røttingen



### **Earlier Norwegian-Russian Symposia:**

1. **Reproduction and Recruitment of Arctic Cod**  
Leningrad, 26-30 September 1983  
Proceedings edited by O.R. Godø and S. Tilseth (1984)
2. **The Barents Sea Capelin.**  
Bergen, 14-17 August 1984  
Proceedings edited by H. Gjøsæter (1985)
3. **The Effect of Oceanographic Conditions on Distribution and Population Dynamics of Commercial Fish Stocks in the Barents Sea**  
Murmansk, 26-28 May 1986  
Proceedings edited by H. Loeng (1987)
4. **Biology and Fisheries of the Norwegian Spring Spawning Herring and Blue Whiting in the Northeast Atlantic**  
Bergen, 12-16 June 1989  
Proceedings edited by T. Monstad (1990)
5. **Interrelations between Fish Populations in the Barents Sea**  
Murmansk, 12-16 August 1991  
Proceedings edited by B. Bogstad and S. Tjelmeland (1992)
6. **Precision and Relevance of Pre-Recruit Studies for Fishery Management Related to Fish Stocks in the Barents Sea and Adjacent Waters**  
Bergen, 14-17 June 1994  
Proceedings edited by A.Hylen (1995)
7. **Gear Selection and Sampling Gears**  
Murmansk, 23-24 June 1997  
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8. **Management Strategies for the Fish Stocks in the Barents Sea**  
Bergen, 14-16 June 1999  
Proceedings edited by T. Jakobsen (2000)
9. **Technical Regulations and By-catch Criteria in the Barents Sea Fisheries**  
Murmansk, 14-15 August 2001  
Proceedings edited by M. Shlevelev and S. Lisovsky (2001)
10. **Management Strategies for Commercial Marine Species in Northern Ecosystems**  
Bergen, 14-15 August 2003  
Proceedings edited by Å. Bjordal, H. Gjøsæter and S. Mehl (2004)
11. **Ecosystem Dynamics and Optimal Long-Term Harvest in the Barents Sea Fisheries**  
Murmansk, 15-17 August 2005  
Proceedings edited by Vladimir Shibanov (2005)

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Institute of Marine Research  
Bergen  
February 2008

## PREFACE

2007 marked the 50-year anniversary for a formal and active cooperation between Norway and Russia in marine research. To mark this long period of collaboration, the Institute of Marine Research (IMR) in Norway and the Polar Institute of Marine Biology and Oceanography (PINRO) in Russia arranged a symposium in Tromsø from 21 to 22 August 2007. These two institutions have always been in the forefront of the cooperation, but other institutions in both countries have also participated.

The symposium was the 12<sup>th</sup> in a series of joint Norwegian-Russian symposia which started in 1983. Up to 1999, these symposia were attended mainly by scientists from IMR and PINRO. From 1999 on, a broader scope has encouraged attendance also from fisheries management and fishing industry. At the jubilee meeting in Tromsø, the prime scope of the symposium was: “*Long term bilateral Russian-Norwegian scientific co-operation as a basis for sustainable management of living marine resources in the Barents Sea*”. Contributions were organized under three theme sessions: I) Establishment and maintenance of long time marine data bases; II) Development and implementation of new methods and models; III) Long term changes in the Barents Sea ecosystem.

This gave participating scientists from IMR and PINRO good opportunity to summarize some of the results obtained and understanding reached in the course of 50 years of cooperation between the two institutions. They were also given the opportunity to look ahead, anticipating a trend towards different types of ecosystem studies and more cooperating partners. For this reason, also other institutions in Norway and Russia were invited to give presentations at the meeting.

It was agreed that many presentations at the anniversary meeting in Tromsø had a content and quality that would deserve more than merely printing in the traditional Proceedings. For this reason the steering committee of the symposium decided that 10 selected papers from the symposium would get the opportunity to be published in a peer reviewed scientific journal. The journal Marine Biology Research was chosen for this purpose. Consequently, a special issue of this journal, celebrating the 50 years of Norwegian-Russian research cooperation, will be published by the end of 2008.

These proceedings from the 12<sup>th</sup> Norwegian-Russian Symposium on Fisheries Research in Tromsø 2007 contains the written contributions from all participants. Some are comprehensive, others are just extended abstracts (e.g., the 10 presentations selected for publications to Marine Biology Research). The Power Point presentations from all contributors are included as pdf-files on the enclosed CD. Both the proceedings and the PP presentations are available on the IMR website, [www.imr.no](http://www.imr.no). As for earlier symposia, the contributions have not been subject to peer reviews. The editors are responsible for a few modest editorial changes for which it has not been possible to obtain the authors' approval. The editors are also indebted to Hugh M. Allen for correcting and improving the English text.

Tromsø/Bergen February 2008

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## Opening address

Ole Arve Misund

*Research Director, Institute of Marine Research (IMR), Bergen, Norway*

### Convenors welcome

State secretary, ladies and gentlemen, invited guests, dear colleagues.

It is a great pleasure for me to welcome you all to this jubilee here at the Polar Environment Centre in Tromsø to mark and celebrate fifty years of scientific cooperation on the exploration of the living marine resources in Northern waters, particularly in the Barents Sea.

The cooperation developed in the late fifties out of concern for the sustainability of the fisheries on Northeast Arctic cod and Norwegian spring-spawning herring. These fisheries were expanding substantially these days with larger and more efficient vessels, better gears, acoustic fish detection and better navigation.

Scientists on both sides began questioning the effects on these fisheries on the development of the stocks, and I have been told that a Russian delegation of scientists from the Polar Research Institute of Marine Fisheries and Oceanography (PINRO) in Murmansk came to Bergen in 1956 to express their concern about the development of the stocks of North East Arctic cod and Norwegian spring-spawning herring. This was followed by a revisit from scientists from The Institute of Marine Research in Bergen, lead by its Director, Gunnar Rollefsen, to Murmansk in 1957, during which the scientific cooperation was formally declared and protocollized.

Since then joint efforts have been extended and deepened, especially through joint surveys. So called 0-group surveys on the new year classes of the main commercially interesting fish stocks have been carried out since 1965, and this have now evolved to ecosystem surveys where five vessels during a coordinated program monitor the oceanography, climate, biomass, distribution and trophical interactions at the living resources in the Barents Sea quite synoptically in August – September every year. On this occasion, we have planned the Symposium to coincide with the change of crew and scientific personell on two of the Norwegian vessels here in Tromsø, so both “Johan Hjort” and “G.O.Sars” will be alongside the quay here in Tromsø today and until lunchtime tomorrow. And to stress the importance of the ecosystem surveys as the main method for common, standardized data collection so that we can have a common basis for studies and advices on sustainable development of the Barents Sea living marine resources, we will invite you to join in on the first part of the next cruise with “G.O.Sars”. We will go onboard there at 1400 tomorrow, and follow the vessel up to Skjervøy, get information on how the vessel operate and how the ecosystem surveys are reported. Subsequently, we take the coastal steamer (“Hurtigruten”) back from Skjervøy to Tromsø tomorrow evening.

But first of all we have planned the Symposium to show the scientific level of the Norwegian – Russian cooperation in marine research, and we have three themes to be covered

- Establishment and maintenance of long time saline databases
- Development and improvements of new methods and models
- Long term changes in the Barents Sea

We all look forward to the presentations to come during the Symposium, and I am sure you will join me in a hope that this Symposium will not only mark a successful jubilee for 50 years of Norwegian – Russian cooperation on the living resources in Northern water, but that it will underline the need for further and extended cooperation between our two countries is a basic for a sustainable future for the rich and clean Barents Sea and adjacent waters.

Thank you.

### **Statement from the Managing Director at IMR**

On behalf of the managing director at The Institute of Marine Research, Mr. Tore Nepstad, I wish once again to welcome all participants, the State Secretary and our Russian colleagues in particular to the Symposium here in Tromsø to celebrate the fifty years of cooperation between Norway and Russia in the exploration of the living resources and the oceanography and climate of the Northern waters.

Mr. Nepstad is expressing his sincere apology for not being able to be present, his absence have to do with the ongoing structuring of the Norwegian fishery and aquaculture research institutes, which from 2008 will be organized in management oriented institutes like IMR, and a business development oriented instituted named NOFIMA.

For IMR, the tasks outlined in the Research program being developed during the joint Norwegian – Russian Fisheries Commission, found as Appendix 10 in the Protocol, open to everybody through the web pages of the Royal Norwegian Ministry of Fisheries and Coastal Affairs, are priority no. 1.

These tasks are iterated in more general terms in the so called “Letter of allocation” from the Royal Norwegian Ministry of Fisheries and Coastal Affairs, and they are again stressed as being of main importance. We formulate these tasks as projects in our Research and advisory programs, and the total portfolio of projects related to our activities in Northern waters amounts to about 280 mill NOK annually, about 50 % of the resources channeled through our research and advisory programs. So like the Polar Research Institute of Marine Fisheries and Oceanography in Murmansk, which for the last fifty years have been our main foreign collaboration, IMR is also definely a Polar Research Institute.

And in this context it is interesting to know that our founding fathers, Nicholai Knipovitch in Russia and Johan Hjort and Fridtjof Nansen in Norway, had quite much contact. They met in 1889, and when Dr. Knipovitch lead the maiden voyage with the new, state of the art marine research vessel “Alexander Pervorzvany” from Germany where the vessel was built, to Russia, he visited Kristiania, the name of the city of Oslo in these days, to show the vessel to Nansen and Hjort, and the vessel was later a model for the first Norwegian vessel “Michael Sars” delivered I 1904. These gentlemen were also central in the establishment of the International council for the Exploration of the Seas (ICES).

As the fisheries and marine research cooperation have developed between Norway and Russia, it seems to me to have always been based on simple, but fundamental principles for peaceful regulation of interests between nations. From a scientific point of view this is:

Equality : common resources are shared on an equal basis, and the fundament for the division is a common knowledge about the resources.



Respect: formalized cooperation, showing of information and a common protocol for basic measurements, and not at least stick to the rules agreed upon.

Parity: equality in resource allocation to monitor development of common resources and in allowing access to each others territory for investigation of common interests.

These principles have been stressed in the reports of the national auditors in Norway and Russia which recently have evaluated the fisheries management systems in the two countries.

The IMR we know have the ambition to regulate and extend our cooperation with our Russian counterparts through memorandum of understandings, and we look forward to and will be prepared for such an extension, especially since the Northern waters are receiving increased attention. All the best for this jubilee Symposium, and for our relations in the years to come.

Thank you!

## **Opening address - Yuri Lepesevich**

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

Ladies and Gentlemen,

With my Norwegian colleague Ole Arve Misund, I have the honour to open the 12<sup>th</sup> Russian-Norwegian Symposium.

To hold the symposium successfully required a great and intensive work of the Steering Committee and the authors of papers. I would like to express a special gratitude to the Norwegian scientists and specialists, as a hosting party this year, for every effort they have exerted to make this traditional bilateral forum very useful and effective. I note with satisfaction that the Steering Committee has found the possibility to include the majority of submitted papers into the program since all of them are very interesting scientifically, and answer the goals and tasks of the symposium. However, the main merit in the submitted contributions belongs to the authors of the papers.

I would like to thank also all those present for their interest in this meeting and I hope that all the presentations, unexceptionally, will find grateful listeners and impress everybody.

This year we are already holding the 12<sup>th</sup> symposium. Exemplifying the topics of the previous ones we see the development of our concept concerning the optimal way to manage biological resources of the Barents Sea, the sea which feeds our countries and is our fortune. The first symposia were rather strictly specialized, practically considering only one species at the time, and they were devoted to the most abundant fish species (cod, capelin, blue whiting, herring) and their habitat, as well as to methods and gears to estimate stocks. Later, new concepts relating to the dynamic mechanisms of stock functions and more available data has made scientists from Russia and Norway turn their attention more closely to the relations and interference among populations. At last the latest symposia were devoted to the problems of management of not only separate stocks, but of the Barents Sea ecosystem as a whole.

The changing of topics at symposia, a gradual transition from simpler problems to more complicated ones has had an impact on the composition of participants. Scientists primarily dominated in the first symposia, whereas later both managers and fishermen became full participants at our forum. Their interest in the meeting has caused changes and improvements both in the symposium structure and the mechanisms to develop decisions and approve them. And, probably most essential, the practical importance of the topics addressed and results presented increased.

I believe that responsibility is the most suitable word to characterize the cooperation of Russia and Norway in fisheries. And although our joint decisions to exploit stocks were not optimal sometimes, we had the courage to recognize our mistakes and, owing to that, found the way out of difficulties.

The topic of our symposium is not accidental. The assurance of our countries that conducting research and obtaining the most full scientific data is the best guarantee for a successful fishery remains unchanged. The mechanism of cooperation between our scientists, formed over decades, is unique both with respect to research volume, level of cooperation and the

intensity of comprehension of collected scientific data. This is the scientific justification of the decisions taken by the Joint Russian-Norwegian Fisheries Commission that ensures sustainable resources available to the fisheries in the Barents Sea and serves the main objective of our cooperation - sustainable long-term fisheries.

In a certain sense this symposium is a summarizing one and I think it include very important papers which present our achievements and summarize the results of bilateral cooperation between Russia and Norway. We must solve both the problems which we have had lately and which, obviously, will appear. Our success in the future will mainly depend on our ability to evaluate critically and improve the joint activity in the management of the Barents Sea stocks. I am sure that only open public discussion of problems by scientists, managers and fishermen will provide the successful solution.

I believe that, by our joint efforts, and based on accumulated positive experience, we will be able to overcome difficulties without the damage for our national interests and successfully solve the tasks put on us by fishermen from both countries. I wish all of you a fruitful work.

## **Opening address - Vidar Ulriksen**

*State Secretary, Norwegian Ministry of Fisheries and Coastal Affairs, Oslo, Norway*

Ladies and gentlemen,

Thank you for the invitation. I am delighted to greet you all here at the opening of this symposium.

The symposium is dedicated to the fifty years of active scientific cooperation within the field of marine research. Fifty year is certainly a long time, but I am told that the cooperation between Norwegian and Russian marine scientists has a much longer history.

From what I have learned, Johan Hjort and Fridtjof Nansen discussed marine science and research equipment with Nikolai Mikhailovich Knipovich more than hundred years ago. The collegial friendship between Hjort and Knipovich lasted their lifetime. Professor Knipovich came to Norway on the maiden voyage of the world's first specially equipped vessel for fisheries research; "Andreij Pervozvonnyj". The research vessel was built to expand on the fisheries research that professor Knipovich already had started in the Barents Sea.

To underline the long tradition of cooperation in marine research, the establishment of the International Council for the Exploration of the Sea, ICES, in 1902, has to be mentioned. In 1903, as part of the expanded international cooperation, Johan Hjort established international courses in marine science in Bergen. Among the 27 scientists participating in the first course seven were from Norway and five from Russia.

In spite of the fact that Russian and Norwegian marine science actually is based on different scientific tradition, the cooperation has been systematic through dialogue and development of expertise thorough several generations. This has contributed to a mutual understanding of each others' point of view, which is of vital importance to provide a common scientific understanding for Russian and Norwegian fisheries managers.

The scientific cooperation between Russia and Norway is not based on solving random problems that occur, but is a long-term officially agreed and recorded cooperation. This shows that it is possible to maintain valuable scientific cooperation through different political regimes, from the cold war till today.

The Norwegian Institute of Marine Research and Russian PINRO have until now mainly worked through the Joint Norwegian-Russian Fisheries Commission. Today, other tasks like environment, climatic changes, oil activity etc. are set on the agenda.

Last year the Norwegian government presented to the Parliament (Stortinget) in report no. 8 (2005 – 2006), an integrated management plan for the Norwegian part of the Barents Sea and the sea areas off Lofoten.

This report is translated into Russian and I have brought some with me to the symposium.

The management plan is based on several different scientific reports, and as some of you may remember also Russian scientist took part in parts of the work.

However, the plan – as presented in the report to the Storting – is a political document, which after it was adopted by the Norwegian parliament in June 2006 regulates our various activities in the area. An important part of the follow up of the management plan is the establishment of three research/discussion groups, one monitoring group, one risk-assessment group and a scientific forum.

The task of the monitoring group is to coordinate the various Norwegian monitoring activities in the actual areas and report about the activities to the government. In report no. 8 to the Storting you will find as appendix 3 tables for elements of the monitoring system. But as you certainly know water-masses and biota are not aware of the boarder lines we have drawn on the map of the Barents Sea. Therefore we hope that a broader monitoring programme covering the whole Barents Sea can be established in the good spirit of scientific cooperation between Norway and Russia. In that connection, I find it obvious that an extended Norwegian-Russian scientific cooperation is based on the already existing long-term cooperation between the Norwegian Institute of Marine Research and PINRO. The cooperation in the field of fisheries may very well be a model for further cooperation.

Long time scientific series have shown its value for research of today and future research, and again I will mention professor Knipovich and the establishment of the Kola-section monitoring. More than hundred years of monitoring temperature have given unique time series and I believe that the scientists that have kept this continuity throughout the years have to be honoured.

Having said that, I regret that the research cooperation agreed under the Joint Norwegian-Russian Fisheries Commission to some extent has not been carried out according to plan. A part of the reason is the lack of access to the Russian economic zone for Norwegian research vessels. I sincerely hope that such obstacles will be removed in the future, in order to pave the way for marine research valuable for both Russia and Norway.

Our management of the living marine resources is based on good scientific advices. As we work against an ecosystem based advisory process, international scientific cooperation seems to be even more important than before. There are several different ways of influence on the various ecosystems, for example will it be important to follow the water-masses and what it may contain from the North Sea to the Barents Sea. This can give a better understanding of processes that may influences and have an impact on our common harvest of the marine living resources. Another example is to distinguish and understand effects of climate change and the warming of the sea on marine ecosystems.

There are several scientific challenges that will keep you occupied for many years. And in addition, the biggest challenge may be to present the results in a manner that are understandable for politicians and the public as well.

On behalf of the Norwegian Ministry of Fisheries and Coastal Affairs I would like to congratulate on fifty years of scientific cooperation!

## Has man learned to manage cod?

Guðrún Marteinsdóttir, Key-note speaker

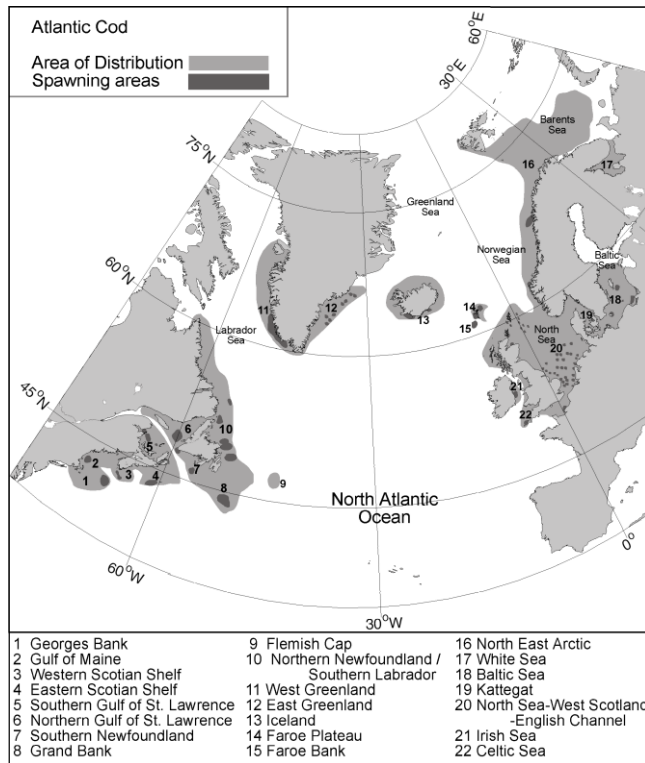
*Department of Biology, University of Iceland, Sturlugata 7, 101 Reykjavik*

Of all fish in the North Atlantic, cod has supported the greatest commercial fishery of the last centuries. Through centuries, or since the 15-16<sup>th</sup> century, cod has been caught in great numbers in the Barents Sea, Icelandic waters, on the banks between Nova Scotia and Labrador and in the waters of the coast of Maine and Massachusetts. (Cushing, 1988; Jonsson, 1994; Oiestad, 1994; Serchuk, et al., 1994; de La Villemarqué, 1994). The majority of the cod fishery at these locations was operated by Basque, French and English fishermen but also Dutch as well as locals (Palmadottir, 1989; Cushing, 1988). The cod were either salted or dried for local consumption or exported to foreign markets (Jonsson, 1994; Cushing, 1988).

A total of 22 cod stocks have been routinely assessed in the North Atlantic by ICES and NAFO (Figure 1). In addition to those listed in Figure 1, five other fishing stocks have been historically recognized. These include: Coastal cod, Norway; East Greenland; Faroe Bank and Bay of Fundi-Scotian Shelf (4X). Assessment information on stock size and structure exist back to 1946 for the Northeast Arctic, 1950 for the Icelandic cod stock, and the 1960s-1970s for most of the other stocks. All of these stocks are distinctly different with respect to size as well as structure, growth and other population dynamic characteristics (Table 1; see also articles in ICES Cooperative Research Report, No 274). During the recent assessment periods, only 5 stocks, Northeast Arctic, North Sea, East Baltic, Icelandic and Northern cod, have attained the size of one million tonnes. Most of the stocks have been considerably smaller or below 100-140 thousand tonnes, on the average, including the Irish Sea, Celtic Sea, West of Scotland, West Baltic, Faroe Plateau, George Bank and the Grand Bank. In terms of spawning stock biomass, only three stocks, North Arctic cod, Icelandic cod and Northern cod, have attained a size close to or above 1 million tonnes. Most stocks (Celtic, Irish Sea, W-Scotland, Faroe and W-Baltic, Grand Bank and George Bank) have been characterised by a considerably smaller spawning stock, or only 11-60 thousand tonnes on the average while the size of the E-Baltic and North Sea spawning stocks were at an intermediate levels of approximately 130-300 tt on the average and a maximum size of 250 (North Sea) and 700 tt (East Baltic).

Like stock sizes, catches have also varied distinctly among the stocks. Within the recent assessment time period, the greatest landings have been obtained from the largest stocks with maximum landings reaching as high as 1343, 810, 585 and 545 tt from the Northeast Arctic, Northern cod, North Sea and the Icelandic stock, respectively. Additionally, high landings have also been obtained from the East Baltic (max 392 tt) and Grand Bank (max 227 tt). For the remaining stocks, maximum landings have ranged from 15-60 tt (Table 1).

In all of the stocks, fishing pressures increased gradually throughout the 1950s-1990s. As a result, fishing mortality varied annually however in a gradually increasing manner, reaching levels of 0.8-1.8 during the last quarter of the 19<sup>th</sup> century. In most stocks, fishing pressures declined in the beginning of the 20<sup>th</sup> century, although regrettably, in many stocks the enforcing of lowering fishing mortality was due to drastically declining stock levels (e.g., North Sea, Irish Cod, W-Scotland, East Baltic, Northern Cod, Grand Bank and George Bank).



**Figure 1.** Location of cod distribution and spawning areas in the NW and NE Atlantic including the Barents Sea, Baltic and North Sea (Sundby 2000).

Of the 22 cod stocks in the North Atlantic that are presently assessed, only three (NEA, ICE, FAROE) are considered to be inside safe biological limits. Of those that are considered to be outside safe biological limits, 7 stocks are currently collapsed (Northern cod, Flemish Cap, Grand Bank, St. Pierre Bank, North St. Lawrence and North Scotian shelf; Table 1). For all of these stocks the management advice has been to close the fishery and today, most of these are closed to all directed commercial fishery.

Table 1. Information on stock status, landings (thous. Tonnes), stock size (thous. Tonnes), recruitment (millions), age groups and time periods used in assessment of the major cod stocks in the North Atlantic.

	NAC <sup>1</sup>	W-BALT <sup>2</sup>	E-BALT <sup>3</sup>	KAT <sup>4</sup>	NS <sup>5</sup>	CE <sup>6</sup>	IR <sup>7</sup>	WSCOT <sup>8</sup>	FAROE PLAT <sup>9</sup>	ICE <sup>10</sup>	GREENL <sup>11</sup>
Present status	ISBL	OSBL	OSBL	OSBL	OSBL	OSBL	OSBL	OSBL	ISBL	ISBL	Collapsed
Fishing status <sup>21</sup>	Open	Open/ Open <sup>22</sup>	Open	Closed/ Open	Closed/ Open	Open	Closed/ Open	Closed/?	Open	Open	Closed
Years of Assessment	1946- 2003	1970- 2003	1966- 2003	1971- 2003	1963- 2003	1971- 2003	1968- 2003	1978- 2003	1961- 2003	1955- 2003	1924-2003
Mean landings	660	38	168	11	245	9	8	14	25	352	128
Range landings	212- 1343	17-54	45-392	2-22	66-580	3-19	1.8-15	1.3-28	6-40	169- 545	0.7-478
Mean Total Biomass	2026	72	459	20	579	17	19	31	93	1091	1197
Range Tot. biomass	739- 4168	27-116	136- 1057	3-45	164-1146	9-34	6-30	9-54	29-155	536- 2282	0.2-4129
Mean SSB	379	33	292	15	139	11	11	21	64	320	
Range SSB	102- 1165	9-57	95-697	3-37	37-253	6-24	2-21	6-40	21-117	121- 932	0.1-3200
Mean R	579	99	304	13	612	4	6	16	17	181	
Range R	53- 1819	18-286	83-829	0.1-37	88-2517	0.34-16	0.8-18	1.3-92	4-48	63-350	0.1-620
Age groups	3-13+	1-7+	2-8+	1-8+	1-11+	1-7+	0-7+	1-7+	2-9	3-14+	3-11+

OSBL = Outside safe biological limits (or below biomass referenc points (Kattegat, Celtic, Irish,  
ISBL = Inside safe biological limits

Table 1. Continued.

	Northern <sup>12</sup> cod	Flemish <sup>13</sup> Cap	Grand <sup>14</sup> Bank	St. Pierre <sup>15</sup> Bank	South St- Lawrence <sup>16</sup>	North St- Lawrence <sup>17</sup>	N-Scotian Shelf <sup>18</sup> 4vsw	Gulf of Main <sup>19</sup>	George Bank <sup>20</sup>
Present stock status	Collapsed	Collapsed	Collapsed	Collapsed	OSBL	Collapsed	Collapsed	OSBL	OSBL
Fishing status	Closed 1992	Closed 1999	Closed 1994	Closed 1993	Reopened 1998	Closed 1995	Closed 1993	Open	Open
Years of Assessment	1962-1993	1972-2001	1959- 2002	1959-2003	1971-2003	1974-2003	1970-2003	1982- 2001	1978- 2001
Mean landings	256	12	49	41	41	49	30	9	29
Range landings	0.3-810	3-57	0.17-227	0.6-80	1-69	0.1-106	0.01-61	1.6-18	8-57
Mean Total Biomass	1001	44	131		206	270		25	73
Range Tot. biomass	100-3000	2-113	6-395	65-250	92-473	36-603		15-42	25-135
Mean SSB	583	15	49		151	143	51	16	53
Range SSB	33-1552	2-40	4-125	45-125	63-354	13-379	5-171	11-24	17-92
Mean R	389	28	53		108	84	106	7	15
Range R	23-1196	0.03-134	0.4-252	11-80	30-322	10-206	9-332	0.5-25	1.5-43
Age groups	3-15+	1-8	2-12	3-14	3-15	3-13	3-13	1-7	1-10+

1) ICES 2004a, 2-4) ICES 2004b, 5) ICES 2004c; with discard, 6) ICES 2004d, 7-8) ICES 2005, 9) ICES 2004e, 10) ICES 2004e, 11) West Greenland, offshore and inshore combined; Wieland and Storr-Paulsen 2004; Buch, et al., 1994; ICES 2004e, 12) Lilly et al., 1998; Smedbol et al., 2002, 13) Cervino and Vázquez, 2004, 14) Healey et al., 2003, 15) Bratney et al., 2003, 16) Chouinard, et al. 2003, 17) Fréchet et al., 2003, 18) Clark and Hinze, 2003; Fanninig et al, 2003, 19) Mayo and Col 2002, 20) O'Brien et al., 2002, 21) (status as advised by ICES/current action), 22) The absence of separate TAC for the eastern and western Baltic stocks limits the ability to restrict fishing activity by TAC (ICES 2004b)

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## ***Theme Session 1: Establishment and maintenance of long time marine data bases***

### **Variability in cannibalism in Northeast Arctic cod (*Gadus morhua* L.) during the period 1947-2006**

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#### **Extended abstract**

*(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation.)*

Cannibalism is likely the most important and also the most variable cause of natural mortality for age 1-4 Northeast Arctic cod (Korzhev and Tretyak, 1992; Bogstad et al., 1994). It was shown previously that incorporation of the data on North-East Arctic cod cannibalism into the VPA model improves the overall quality of its assessment and accuracy of recruitment estimation (Kovalev and Korzhev, 2004). Nevertheless, for the younger cod age groups, there is an inconsistency in the time series of (VPA) number at age from 1946-present, as cannibalism is only taken into account in 1984 and later years, when quantitative stomach content data are available. To improve the understanding of the population dynamics of Northeast Arctic cod (especially stock-recruit relationships) it would be of great value to have estimates of the abundance including cannibalism through the entire time series.

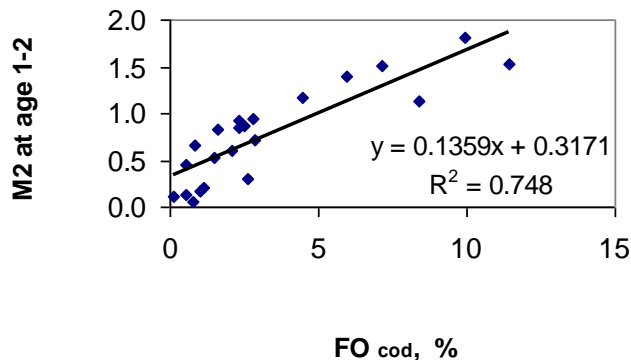
Long time series describing diet composition are available for the stock (qualitative stomach content data for 1947-2005 and quantitative data for 1984-2006). We intended to hindcast natural mortality of age 1-4 cod due to cannibalism based on combined qualitative data for 1947-2005 and quantitative data for 1984-2006, using the same approach as in the paper of Marshall et al. (2000) with regards to capelin abundance. The data obtained were analysed together with survey indices/XSA estimates for young cod, and abundance of capelin, the most important prey item for cod.

The mean frequency of cod occurrence in cod stomachs ( $FO_{\text{cod}}$ ) from the qualitative and quantitative data from 1984-2005 demonstrated similar patterns; the correlation between these  $FO_{\text{cod}}$  time series was strong ( $r^2 = 0.83$  for the southern Barents Sea and 0.89 for the Svalbard area). Spatial variations in cod cannibalism was large. Cannibalism was at a high level from 1947-1965 and then again in the mid-1990s. The high levels of cannibalism in the mid-1990s are comparable with those observed in the 1950s. The low  $FO_{\text{cod}}$  from the late 1960s to the end of the 1980s is possibly connected with cod switching on capelin predation mainly due to long-term increase in capelin stock biomass. This assumption coincides with a tendency for cannibalism levels to be inversely related to the capelin abundance.

The relationship between predator size and maximum prey (cod) size is close to a linear one; the predator length is in general at least twice the prey length. The proportion of cod in the

cod diet increases with increasing cod length based on the quantitative stomach content data base.

For the period 1984-2005,  $FO_{\text{cod}}$  from the qualitative stomach content data was related to the natural mortality induced by cannibalism for cod age groups 1-5. The correlation was positive and significant in all cases, with  $R^2$  values between 0.4 and 0.7 (i.e. Fig.1).



**Figure 1.**  $FO_{\text{cod}}$  in the southern Barents Sea vs. natural mortality for cod at age groups 1-2 for the period 1984-2005.

There are significant relationships between the abundance of cod at age 1-3 calculated by VPA, including cannibalism, and bottom trawl indices for the same ages cod obtained in the demersal fish survey in February; these indices are especially consistent for cod at age 1 and 2 ( $R^2=0.86$  and  $0.83$  respectively).

There is also significant correlation between the recruitment at age 1 calculated by VPA, including cannibalism, and the spawning stock biomass (SSB), but not a significant correlation between the recruitment at age 3 and the SSB. This indicates that cannibalism strongly modifies the year-class strength in the period before recruitment.

Further work is needed to calculate the consumption of cod at age 1-4 by predator-cod for the period 1947-1983 in order to make the whole VPA time series consistent. This will allow us to test stock-recruitment relationships for the entire time series with cod at age 1 and 3 as the recruitment age for their comparison as well as study relationships between cod cannibalism level and population/environmental factors to understand their nature and response mechanisms.

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# Age reading from Northeast Arctic cod otoliths through 50 years of history

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## Extended abstract

(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation.)

Historical Northeast Arctic cod data on mean length or weight-at-age and the proportion of mature fish at age, presented at the Arctic Fisheries Working Group in 2001, showed significant temporal trends. For instance, a weak trend for the 5-6 years age groups, indicating an increase in weight-at-age of individuals over the studied period. The trend was stronger for older age groups. An increasing maturation rate was observed for fish of age 4 years and older. The observed temporal trends in biological characteristics required further study in order to find out possible causes.

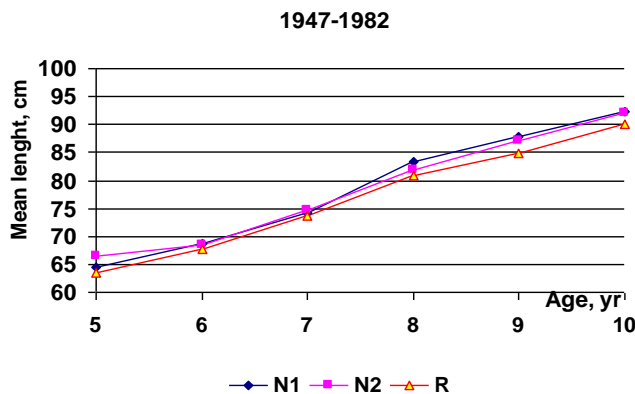
Researchers faced the question whether the observed changes of biological indices actually occurred in the populations, or were they simply artifacts caused by differences in the fish ageing now and before? In order to answer this question the authors evaluated the possible discrepancies in fish age determination as well as spawning zones numbers by contemporary age readers and the previous generation of specialists. Such discrepancies could influence the interpretation of historical series.

To determine possible variations in age reading between contemporary and historical time period, randomly chosen samples from the period 1940-1980s were re-read in 2003 by two groups of experts. The studied otoliths (N=646) were selected from seven different years spanning almost 4 decades (1947-1982). All original samples were taken in March in Lofoten during fisheries on the spawning grounds. To ensure that the otolith samples of Northeast Arctic cod are not mixed with coastal cod, only otoliths coded as 'Northeast Arctic cod' from the longline fishery samples were selected. Since the maturity ogives used in the ICES assessment change rather abruptly during 1980-1982 for some age groups, otolith samples from each of these years were selected as well. Additionally, the quality of old otoliths being stored in paper bags for more than 50 years was assessed.

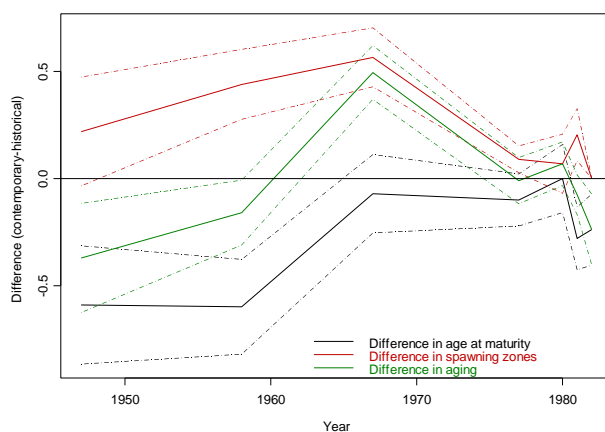
Microsoft Access and Microsoft Excel software were used for the data analysis. The values for between-reader biases and their significance levels were determined using one-sample Wilcoxon rank sum test. Coefficients of variation and other statistical indices were calculated using "Age reading comparisons" software. Information on cod weight was not available for all otolith samples, and length data were analysed instead. The significance level of the effect of different age-readers on variability in estimated mean length of fish was calculated using Student's t-criteria.

Although some year specific differences in age determination are seen between historical and contemporary readers, there was no significant effect on age readings discrepancies on length (size) at age (Fig. 1). The analysis of discrepancies in cod age readings made by different generations of specialists indicates that it cannot explain the temporal trends observed in the biological parameters. If the “errors” of historical age reading data observed by the present readers are to be corrected, this would lead to a strengthening of the observed biological tendencies, i.e. a further and more pronounced increase of the growth rates during the studied period.

A small systematical bias in the spawning zones detection was observed, demonstrating that the age at first maturation determined by the present readers is younger than that determined by the historical readers (Fig. 2). The difference was largest in the first sampled years ( $\approx -0.6$  in 1947 and 1957), and it decreased with time ( $\approx -0.28-0$  in the 1970-1980s). The presented bias in determination of age maturation by age readers could hence only explain a small part of the observed changes in mean age of 50% maturation from the 1940s to present. The study shows that the cod otoliths could be reliably used for age and growth studies even after prolonged storage.



**Figure 1.** Length-at-age relationship when pooling the data from all years 1947-1982 depending on the age determined by the historic Norwegian readers (N1) and the Norwegian (N2) and Russian (R) present readers. The discrepancies in mean length-at-age were highest in 1967, and lowest in 1980 (see also Fig. 2).



**Figure 2.** Mean differences in age at first maturity (black (lowest) line) and number of detected spawning zones (red line). The green line shows how the discrepancies in total age of the sampled otoliths varied over the years 1947-1982 (ref. Fig. 1). The broken lines are the corresponding 95% confidence intervals.

## **Russian research in oceanographic sections in the Barents Sea**

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Long experience in oceanographic research has shown data from observations in standard sections to be the most representative for the study of the spatial and temporal variability of water masses. These data can be used to monitor climate change, to develop methods to predict environmental parameters and fisheries and biological characteristics and to solve other scientific and applied problems. Scientists envisaged this possibility as far back as at the end of the 19th century at the geographical conference held in Stockholm in 1899, where measurements made at standard depths and sections were suggested.

Russian oceanographic studies on standard sections in the Barents Sea commenced with the Murmansk research and fisheries expedition in 1899-1906 under the leadership of Nikolay Knipovich. At that time, the first oceanographic observations were made in the Kola Section from the R/V “Andrey Pervozvanny” (Alekseev et al., 2005).

In 1908-1920, oceanographic observations in the Barents Sea were very rare. Since 1921 the number of observations, including those in the Kola Section, have greatly increased. At the special meeting of the Polar Commission at the Russian Academy of Sciences it was decided to carry out observations in meridian sections, including the section along 37° and 42°E. From 1928 to 1941 observations were quite regular, allowing seasonal and annual variations in the main oceanographic parameters to be estimated.

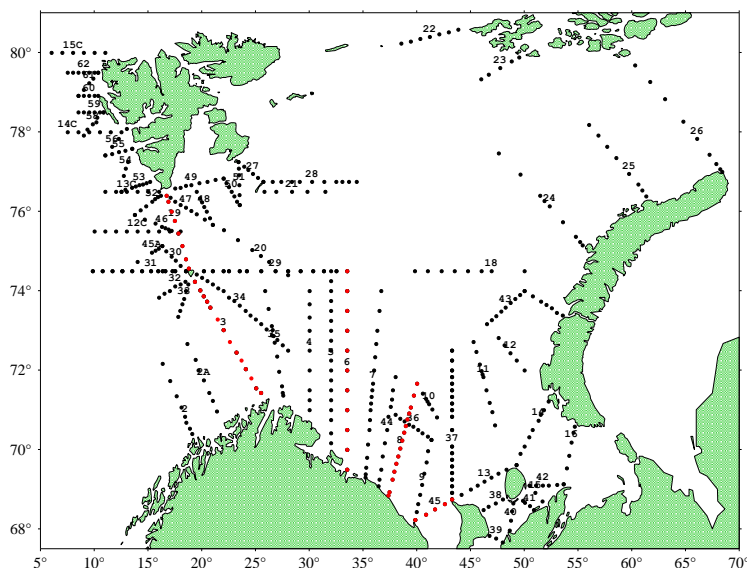
In 1934, PINRO developed a scheme of 26 sections of the Barents Sea, which was approved by the Academic Council of the Institute in 1935. This recommended monitoring oceanographic parameters in these sections using a specific method. In order to improve the quality of the studies a range of measurements and periods and tracks of seasonal oceanographic surveys were proposed, including observations on the Kola Section.

In 1954, at the meeting of Oceanographic Commission of the USSR Academy of Sciences, positions of 40 standard sections in the seas of the North European basin were officially approved, most of which already had been implemented by PINRO. Some of the sections were defined as “centennial” sections (Figure 1).

The “centennial” oceanographic sections, which were chosen from a grid of standard sections, were to meet the following requirements:

- show variability in hydrographic and hydrochemical elements of the main water masses
- cross the flows of the major currents or the main circulation systems
- cross the channels between seas or pass along the boundaries between different sea areas.

National study practice shows that observation series along the “centennial” sections are the longest and give fairly reliable estimates of the long-term and seasonal variability of oceanographic parameters.



**Figure 1.** Standard sections in the Barents Sea (positions of “centennial” sections are marked in red)

Since 1951 there has been almost monthly monitoring of water temperature, salinity and some hydrochemical elements on the standard sections of the Barents Sea: North Cape –Bear Island (No.3), to the east of Bear Island (No.29), the Kola Section (No.6), the Kharlovsky Section (No.8), Section No.10, and the Kaninsky Section (No.37). Observations in these and other sections were also made during the following surveys:

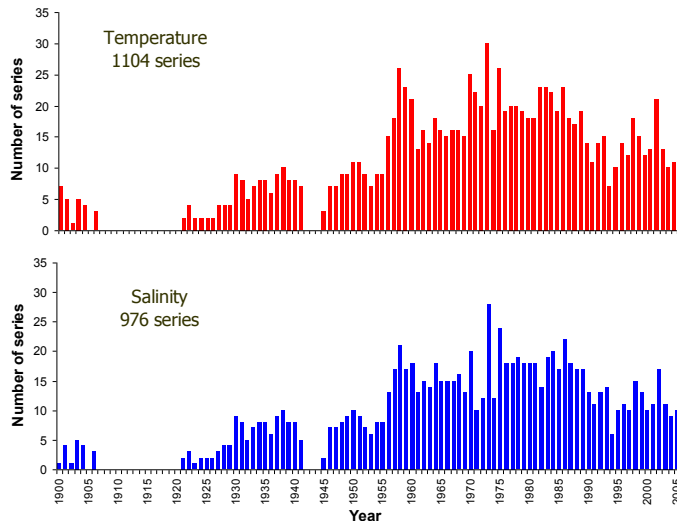
- survey of eggs and larvae in April-July from 1959 to 1993
- survey of 0-group fish in August-September since 1965 (jointly with IMR, Norway)
- survey of capelin feeding areas in August-September from 1982 to 1993
- survey of juvenile demersal fish in the Spitsbergen area in September-October since 1959
- survey of pelagic fish stocks in September-October since 1972 (jointly with IMR, Norway)
- survey of demersal fish stocks in October-December since 1950.

During the early 1990’s, the number of oceanographic researches dropped dramatically. However, PINRO continued to perform observations in the “centennial” Kola Section and some others. Since 1995 oceanographic studies have been performed not only by research vessels but also by fishing vessels. This allowed observations in a number of standard sections to be resumed and the scope of oceanographic data used to estimate hydrometeorological processes and predict their characteristics to be extended.

Thus, at present, PINRO carries out almost monthly monitoring of oceanographic conditions in the Kola Section in the Barents Sea. In the North Cape –Bear Island sections, and those to the east of Bear Island, to the west of Bear Island, the Kharlovsky Section and the Kaninsky Section observations are made two or three times a year in the period of fish stocks surveys. In the other standard sections, oceanographic data are collected at irregular intervals. The large body of oceanographic data accumulated in the standard sections is used to resolve the following basic and applied scientific problems:

- study of spatial and temporal variability of hydrometeorological and hydrochemical conditions in the Barents Sea
- development of methods to forecast oceanographic parameters and fisheries and biological characteristics
- preparation of different reference manuals
- hydrometeorological support of fisheries.

The longest time series of observations is in the Kola Section (over 100 years). This series is used to reveal the main patterns of variability in natural processes and to study climate fluctuations in the North European basin (Figure 2). Analysis of the data from this Section since 1990 resulted in the distinction of warm and cold periods in the Barents Sea (Boitsov, 2006).



**Figure 2.** Series of observations of temperature (top panel) and salinity (bottom panel) in the Kola Section in 1900-2005.

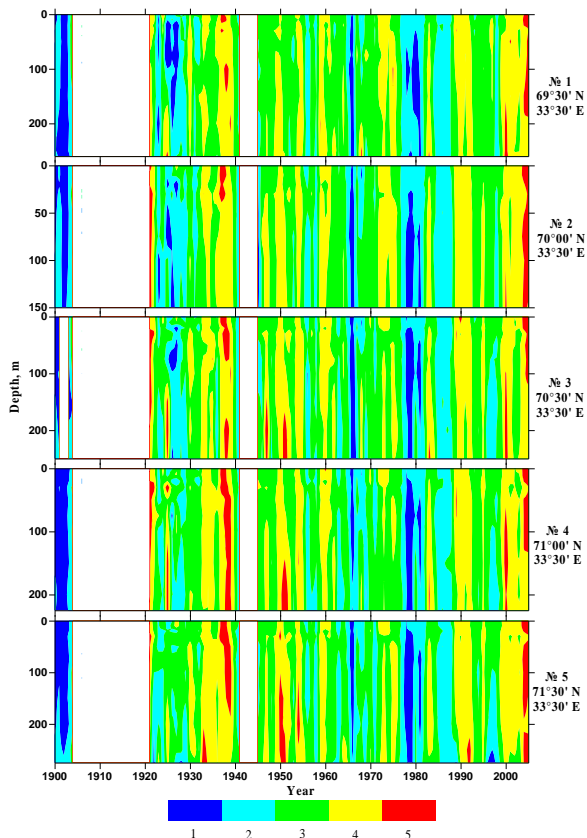
At the beginning of the last century climate conditions in the Barents Sea were severe. The sea temperature in the Kola Section did not exceed normal levels, and most years judging by the water heat content in that period could be classified as cold or abnormally cold years. In certain years at some stations on the Section absolute temperature minima were registered (Figures 3 and 4). The most severe climate conditions were recorded in 1900-1903. In the opinion of PINRO scientists this cold period lasted until 1919. The cold period was accompanied by severe ice conditions at sea. The most extreme ice coverage (92%) in the Barents Sea was registered in 1917.

The 1920s were transition years from the cold to the warm period, which lasted until the mid-1960s. In some years, sea temperatures in the Kola Section were abnormally high. The maximum temperatures were measured in 1937-1938 and in 1954.

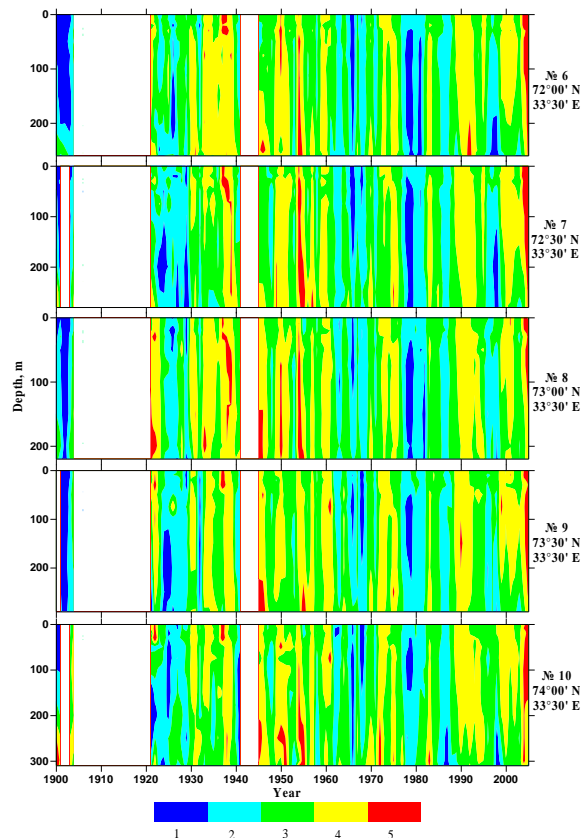
During the second half of the 1960s, the temperature of the Atlantic waters in the Barents Sea was below normal, with a minimum reached in 1966. During this period, absolute temperature minima in deep waters of the Murmansk Current were registered. From 1972 to 1976 observations in the sections showed water temperature in the Barents Sea to be above the long-term level, and on the whole these years were warm (Figures 3 and 4).

In 1977-1981, an abnormal drop in water temperatures in warm currents of the Barents Sea was observed again. The lowest values of negative anomalies in the Kola Section were registered in deep layers. The abnormal fall in sea temperature in the Kola Section compared to the cold period of 1960's was not broken by a brief rise in temperature above the long-term mean values.





**Figure 3.** Thermal conditions at stations 1-5 in the Kola Section in 1900-2005 (1-very cold; 2-cold; 3-close to normal; 4-warm; 5-very warm).



**Figure 4.** Thermal conditions at stations 6-10 in the Kola Section in 1900-2005 (1-very cold; 2-cold; 3-close to normal; 4-warm; 5-very warm).

Of particular interest is the current warm period in the Barents Sea, which has continued since 1989. In winter 1989, anomalous atmospheric processes in the North Atlantic led to an increase in heat transport by air and water masses to the Barents Sea. This initiated an intense warming of sea waters comparable in extent to the previous lengthy period of Arctic warming in 1930-1950. Reasoning from water temperature in the Kola Section, the present-day period can be characterized as warm or anomalously warm, with a slight temperature decrease in 1997-1999. Maximum water temperatures in the Kola Section were observed in 2004-2006 (Figures 3 and 4).

Data derived from oceanographic observations in the standard sections of the Barents Sea are used in the study of how its ecosystem functions and for forecasts of fisheries and biological characteristics.

The current stage of fisheries oceanography studies in the Barents Sea started in the 1960s, when the first attempts were made to demonstrate analytically the importance of abiotic parameters on standard sections in the formation of fish concentrations in the southern Barents Sea. In recent decades exploitation of the biological resources of the Barents Sea was followed by studies of environmental effects on the formation and variability in abundance and biomass of plankton and benthos, strength of fish yearclasses, dynamics of biological characteristics of fish, their distribution and migration. For instance, data from the Kola Section alone were used in more than 50 scientific publications in which results of the study of the effects of abiotic factors on marine organisms were presented (Boitsov, Nesvetova, Ozhigin and Titov, 2005).

Many scientists have noted a relatively high ( $r=0.60 - 0.90$ ) correlation between water temperature fluctuations in the Murmansk Current in the Kola Section and in sections in various areas of the southern Barents Sea. Such data may be used to fill the gaps in observations in other standard sections. Such calculations are just a partial measure. The only way to provide reliable estimates of oceanographic processes in the Barents Sea on the whole and their specific features in its local areas is to resume observations in the main standard section.

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# **Study of the spatial variability in thermohaline characteristics and water structure on the standard sections in the western Barents Sea**

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## **Introduction**

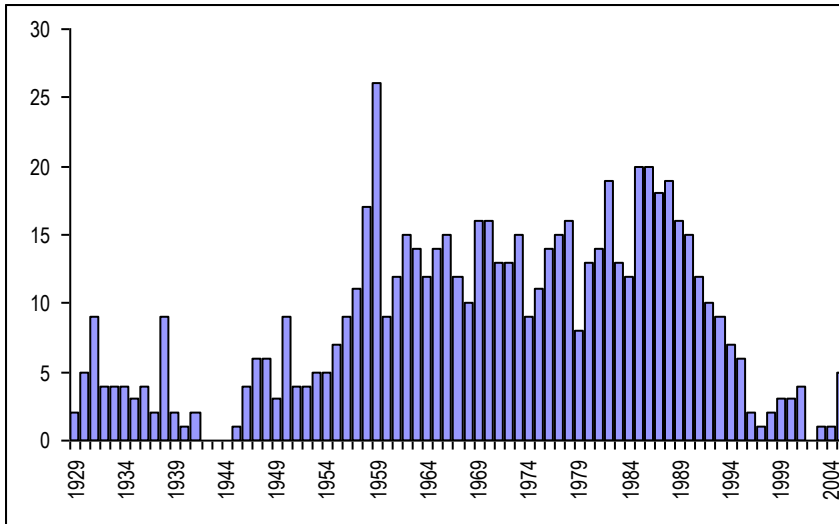
In order to ensure the comparability of observation results and to estimate seasonal and year-to-year variations in oceanographic variables, it was suggested in Stockholm as early as 1899 that measurements should be made at standard depths and on standard sections. At the beginning of the 20<sup>th</sup> century observations commenced on the Kola Section in the Barents Sea (Knipovich, 1901, 1906), and by the 1930s, a network of such sections had been developed in the area. One of them stretched from the North Cape to Bear Island.

Sections are important not only for research on hydrographic processes, but also for studies of marine ecosystem functioning (Bochkov, 1980; Tereshchenko, 1992, 1996; Adrov, 1993). Observations on the standard sections were used to study water circulation (Kislyakov, 1964, 1969; Kudlo, 1970; Loeng, 1979; Loeng H. et al., 1997, Ingvaldsen R. et al., 1999), water masses (Tsekhotskaya, 1985; Boitsov, 1995), to make hydrographic (Pennin, 1973; Fuks, 1980, Karsakov et al., 2001) and fishery (Mukhina, Dvinina, 1989; Boitsov, 2005) forecasts as well as to solve many other problems. Today, long-term data series such as the Kola Section, the section through the Faroe-Shetland Strait and others are widely used in up-to-date research (Anon, 2005).

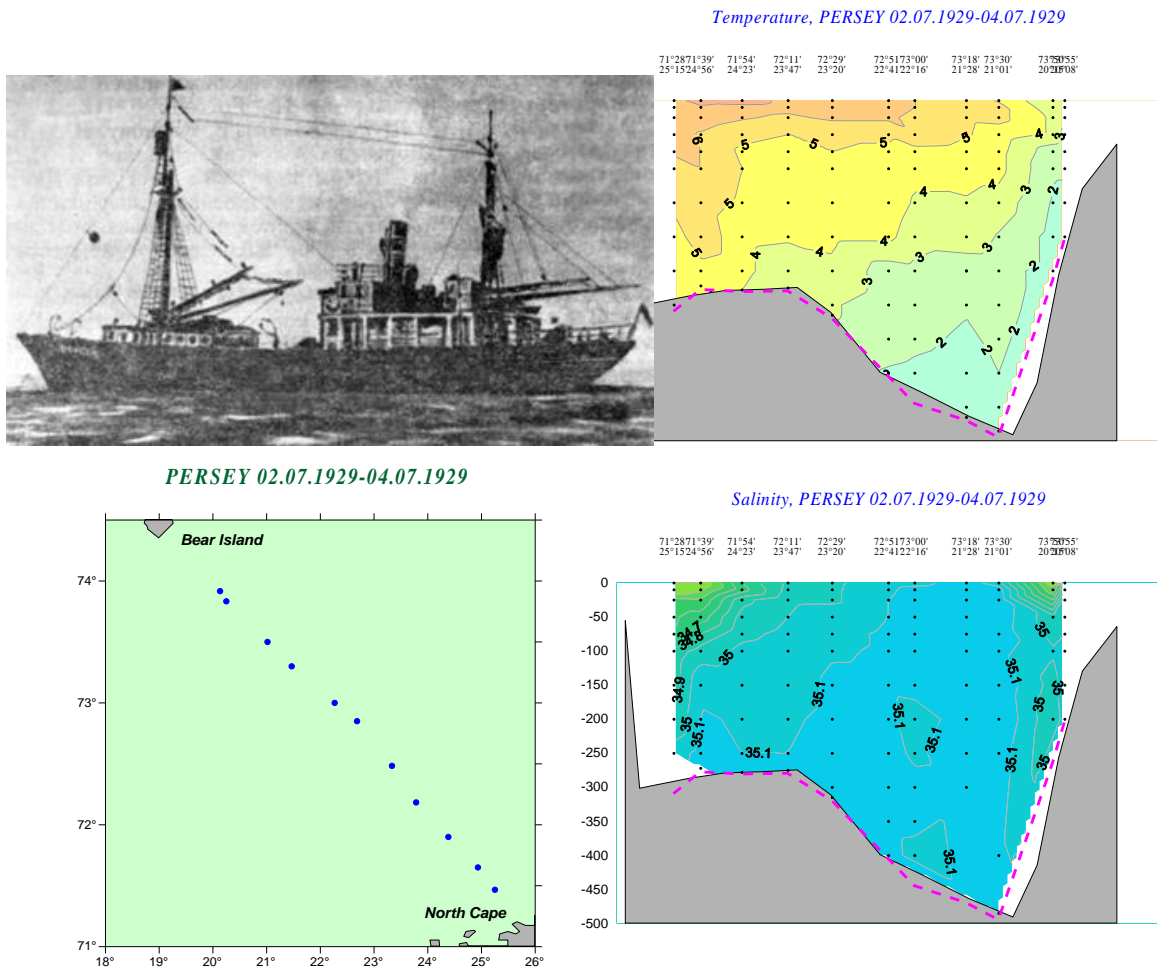
The inflow of the Atlantic water masses into the Barents Sea area is the main cause of its peculiar climate and high biological productivity. Using the Fugløy -- Bear Island (FB) and North Cape – Bear Island (NB) Sections located on the western sea border, the characteristics of the Atlantic water masses flowing into the sea can be studied.

Regular observations on FB started in 1964, but since the late 1970s they have been performed, as a rule, six times a year. The NB Section should be related to the unique ones. In total, it has been sampled more than 670 times (Figure 1) in the course of about 80 years.

The first observations on the section were made by the research vessel “Persey” in July 1929 (Figure 2).



**Figure 1.** Number of times the North Cape – Bear Island Section has been sampled between 1929 and 2004.



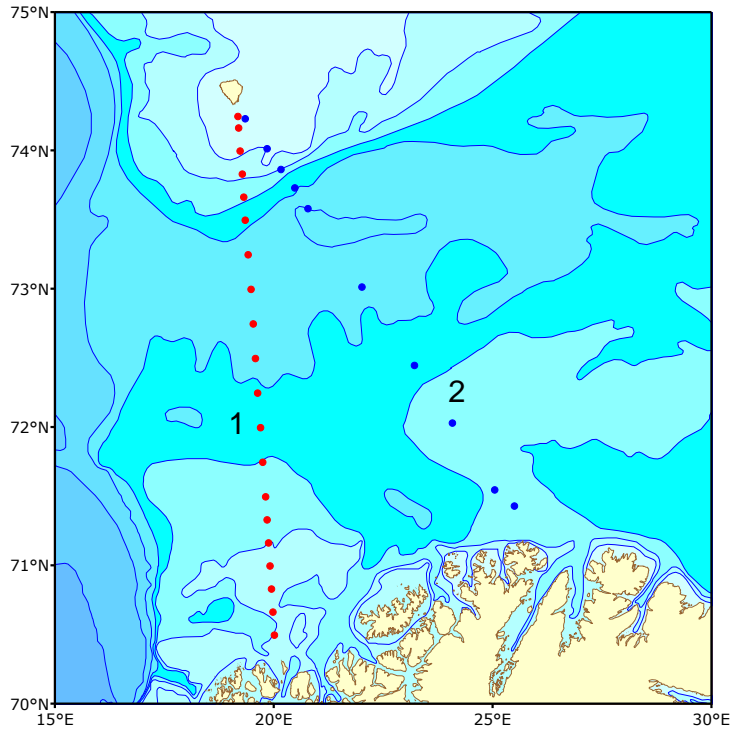
**Figure 2.** Sampling the North Cape – Bear Island Section in 1929.

Unfortunately, the number of observations on the NB Section has been severely reduced during the past 10-12 years, and at present it is sampled two or three times a year.

One possible means of filling the gaps in data series of a section is to utilise accessible information for another section. For this, it is necessary to study the thermohaline characteristics of these sections.

## Materials and methods

This study used data from hydrographic observations made on the standard FB (IMR) and NB (PINRO) Sections (Fig.3) in 1977-2005.



**Figure 3.** Position of the Norwegian Fugløy – Bear Island Section (1) and the Russian North Cape – Bear Island Section (2).

The positions of standard stations on the sections studied are shown in Table 1. Station numbering starts from the Norwegian coast.

Mean weighted values of water temperature and salinity at Stations 7-15, in the 50-200 m layer in the Fugløy – Bear Island Section were calculated by methods used in PINRO. The series were from 1977-2006 and for different months: January, March, April-May, June, August-September and October. The same was done with the aid of the hydrographic database at PINRO for the North Cape – Bear Island Section.

First, the part of the NB Section whose thermohaline characteristics were most similar to those of the FB Section was found. In general, a correlation field ( $r_{P_1P_2}$ ) in the NB Section plane was formed on the basis of the statistical relationship between the two time series:  $P_1$  – time series of temperature/salinity in the FB Section in the month studied;  $P_2$  - time series of temperature/salinity at the standard station (1-10), in the standard layer (0, 10...400 m), in the NB Section in the same month.

Some 1200 sets of correlation coefficients were calculated (T, S \* months \* standard stations on NB about 80 year Section \* standard layers). Using the correlation coefficients calculated,

vertical fields were plotted for each month in the NB Section plain, with a net horizontal pitch of 10 miles and 20 miles vertical. In order to sum the correlation fields, the mean field (for the months studied) was plotted by averaging the same named nodes in the network.

**Table 1.** Positions of standard stations on the Fugløy – Bear Island and North Cape – Bear Island Sections.

Stations	Fugløy – Bear Island			North Cape – Bear Island		
	Latitude	Longitude	Bottom Depth (m)	Latitude	Longitude	Bottom Depth (m)
1	70°30' N	20°00' E	129	71°26' N	25°29' E	298
2	70°40' N	19°58' E	158	71°33' N	25°02' E	288
3	70°50' N	19°56' E	186	72°02' N	24°04' E	278
4	71°00' N	19°54' E	188	72°27' N	23°12' E	311
5	71°10' N	19°52' E	215	73°01' N	22°00' E	429
6	71°20' N	19°50' E	207	73°35' N	20°46' E	491
7	71°30' N	19°48' E	231	73°44' N	20°28' E	419
8	71°45' N	19°44' E	265	73°52' N	20°09' E	260
9	72°00' N	19°41' E	307	74°01' N	19°50' E	129
10	72°15' N	19°37' E	322	74°14' N	19°20' E	65
11	72°30' N	19°34' E	385			
12	72°45' N	19°31' E	398			
13	73°00' N	19°28' E	410			
14	73°15' N	19°24' E	445			
15	73°30' N	19°20' E	476			
16	73°40' N	19°18' E	344			
17	73°50' N	19°16' E	232			
18	74°00' N	19°13' E	139			
19	74°10' N	19°11' E	80			
20	74°15' N	19°10' E	55			

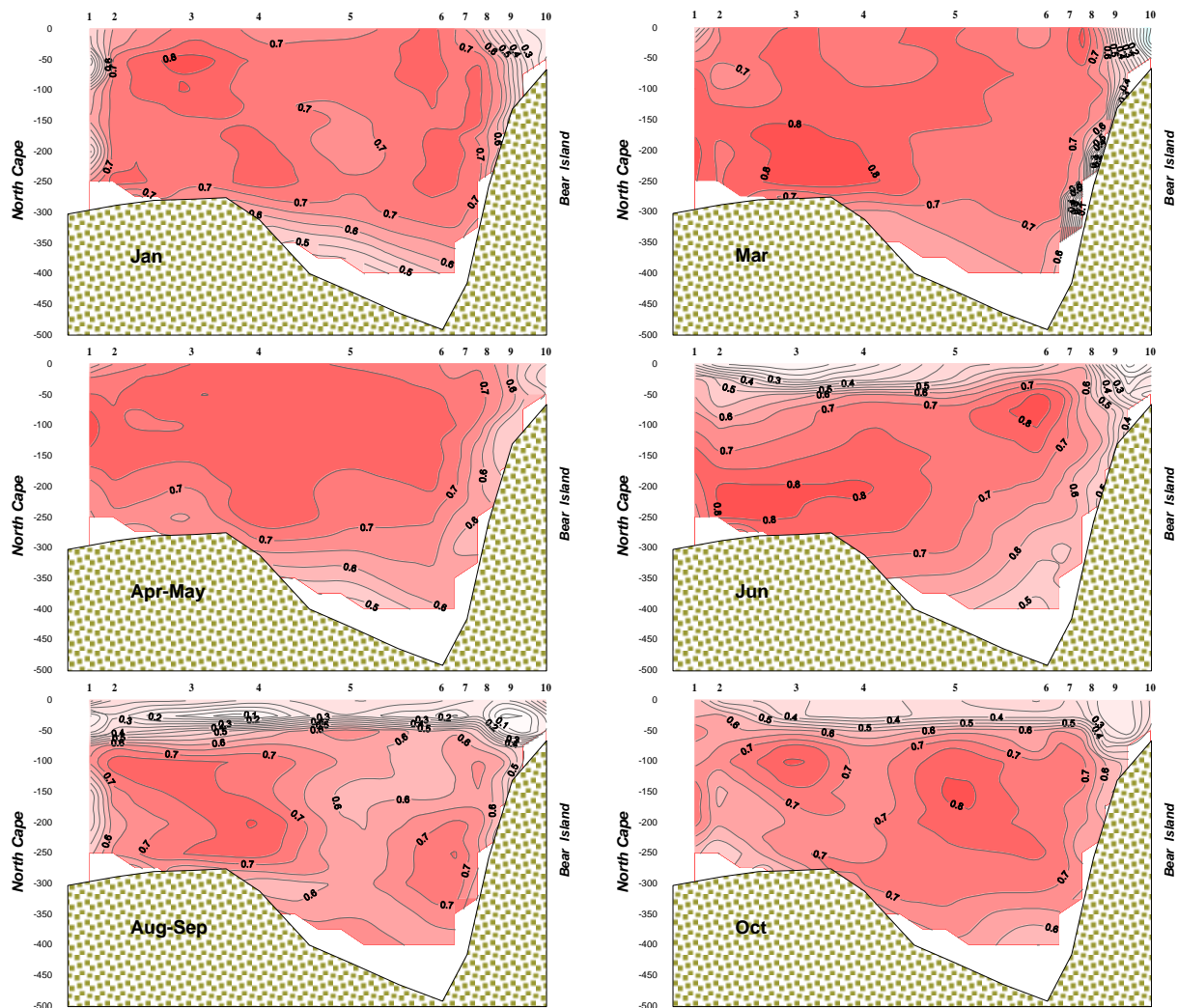
In order to analyze similarities in thermohaline characteristics, the fields of temperature/salinity standard deviations (analogous to the correlation measures) on the NB Section were calculated and mapped.

Mean weighted values of temperature and salinity in the 50-200 m layer were calculated from the NB Section stations that showed the closest similarity with the thermohaline characteristics of the FB Section. The relationship between the hydrographic characteristics in the sections was quantified by regression analysis performed on the series of averages for the NB Section and the series for the FB Section.

## Results

The existing concept of water circulation system at the entrance to the Barents Sea allows us to determine that the thermohaline characteristics of waters in the FB Section line are a “signal”, the reaction to which may be observed on the NB Section. The extent of this

“scheme” coherence in the temperature field is demonstrated quite well on the fields plotted (Figure 4).



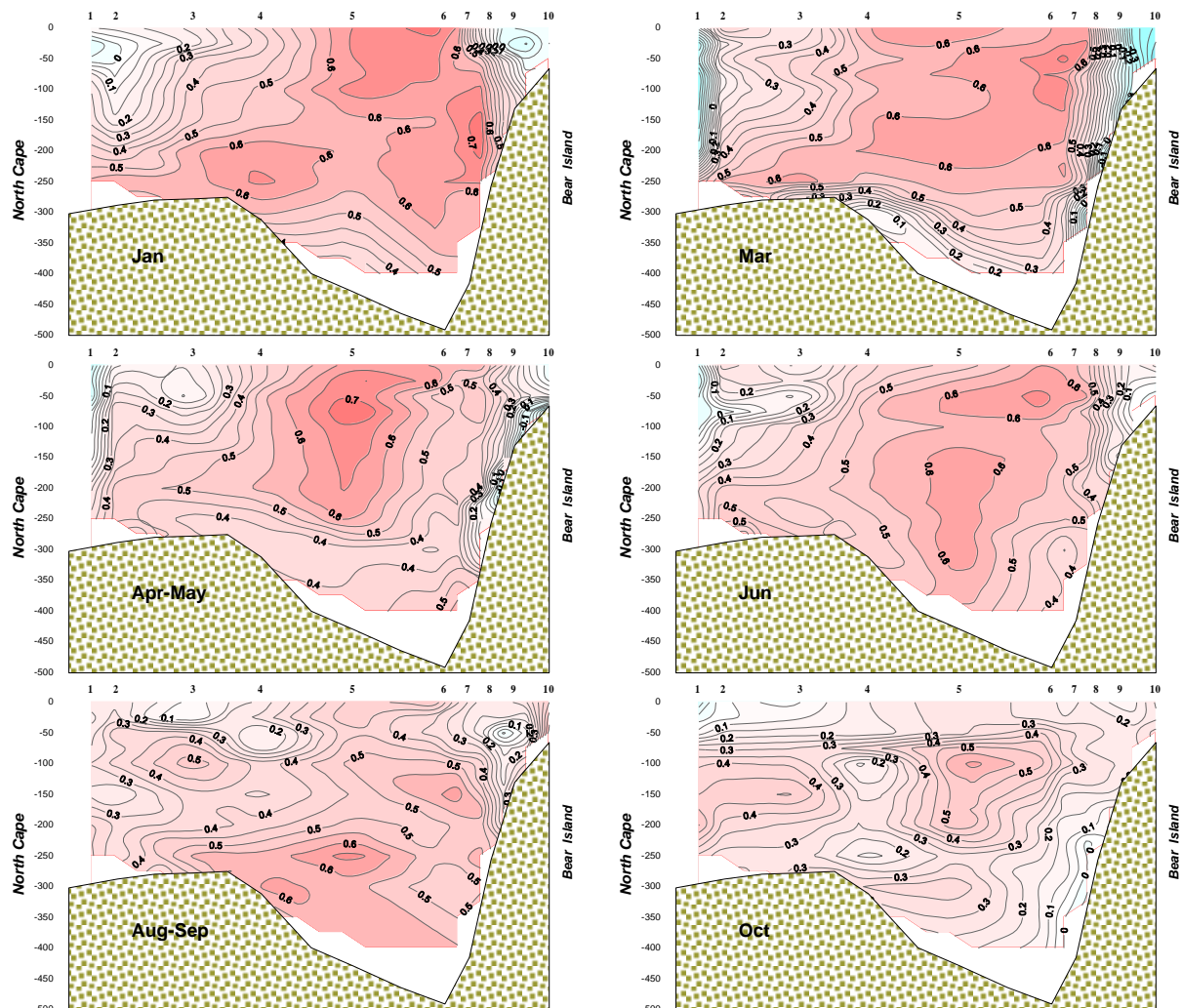
**Figure 4.** Correlation of water temperature mean weighted values in 50-200 m layer between FB and NB sections in January, March, April-May, June, August-September, October.

The correlation field for January shows the existence of a significant relationship in the wide plane of the NB Section. The highest correlation coefficients ( $r > 0.75$ ) were registered in the area of Station 3, at 50-150 m depths, and, as single local patches, at Stations 4, 6 and 7. In March, the identical area of high correlation coefficients ( $r > 0.75$ ) widens and occupies a large area from Station 1 to Station 5, from the surface down to 250 m. The closest relationship between water temperature on FB (Fugløy-Bear Island) and NB (North Cape-Bear Island) Sections is observed in April-May. Before this period, the only area with insignificant correlation coefficients is Station 10.

When the warm period of a year begins, the structure of the correlation field in the plane of the NB Section varies. A general weakening of the relationship is recorded. Primarily, this concerns the surface layers. In June, two localized areas of higher correlation values ( $r > 0.75$ ) are observed: the first one between Stations 1 and 4, at depths of 150-250 m, the second in the area of Station 6, in 50-150 m layer. However, in the core of these areas correlation coefficients may exceed 0.8. According to our calculations, August and September are the

months of least similarity in temperature on the sections studied; nevertheless, the areas of significant correlation coefficients are quite extensive. In October a rise in correlation values as compared to August-September is noticed. Maximum correlations are at Stations 3 and 5, within the depth range of 75-200 m.

In general, the similarities in variations in salinity in the two sections are less than the relationship in temperature (Figure 5).



**Figure 5.** Correlation of salinity mean weighted values in 50-200 m layer between FB and NB Sections in January, March, April-May, June, August-September, October.

Where temperature is concerned, the similarity in salinity variations is higher in the cold period of the year. In January the maximal correlation coefficients (0.6 and higher) are observed at Stations 5 and 6 from the surface to 250 m depth, and at Station 7 at a depth of 200 m (0.7 and higher). At the outermost stations of the section the relationship may be even opposite. In March, the area of higher correlation coefficients is practically the same as in January.

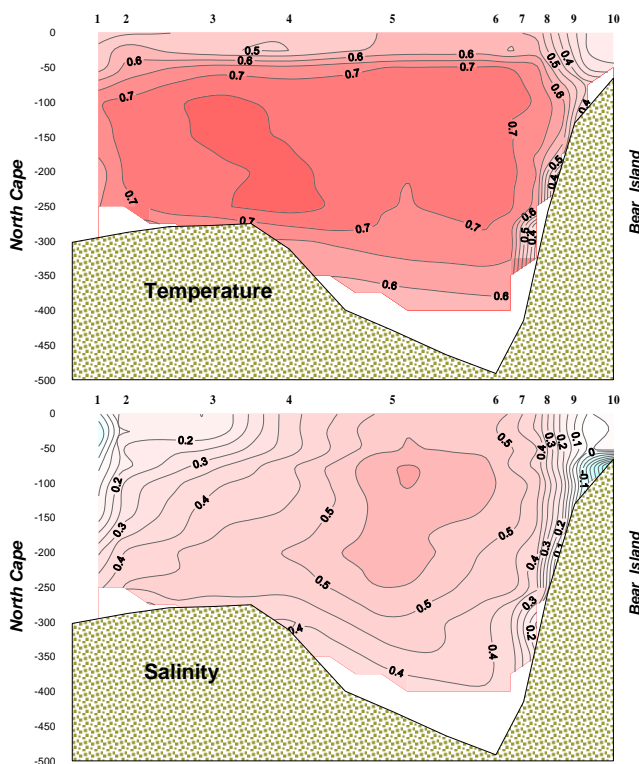
In April-May, there is a general decrease in the closeness of the relationship in comparison with the previous months. The closest relationship between the salinity series is found in the area of Station 5 on the NB Section. In June, the closest relationship is recorded at Stations 5



and 6 on this section. It should be noticed that some embedding occurs in the domain of higher correlation coefficients. If that domain was located in the upper 200 m layer in April-May, it may therefore descend to below 300 m in June. Further embedding of this domain is observed in August-September when its upper border is 200 m deep. On the whole, August may be characterized as a month with a chaotic distribution of correlation coefficients. October is the month with the least agreement in the salinity distribution. That month showed practically no steady domains of significant relationship anywhere on the section plane.

In order to determine the optimal range of averaging data on the NB Section, the average fields of correlation coefficients in studied months were plotted (Figure 6).

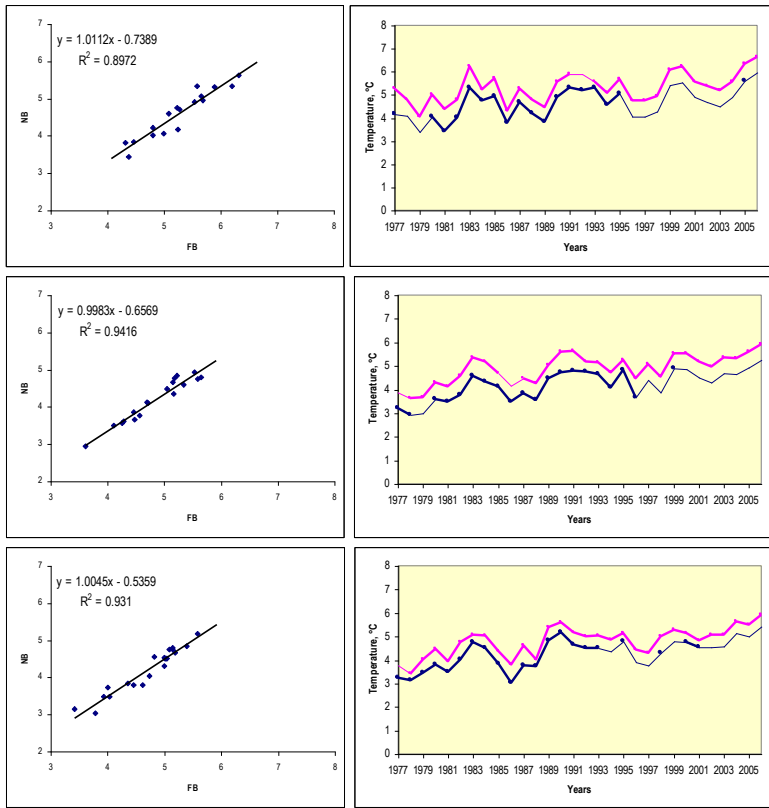
As the figures show, the field of higher correlation ( $r > 0.7$ ) in temperature occupies quite a wide area from Station 2 to Station 6, with a core ( $r > 0.75$ ) in the region of Stations 3 - 4, within the 100-250 m depth range. Based on the general plot (Figure 6) and monthly correlation fields (Figure 4), it was decided that averaging at Stations 3 - 6 of the section would be optimal. The involvement of Station 2 may weaken the relationship between the thermal water characteristics, since the correlation coefficients in the summer months (June, August-September, Figure 4) in the surface layer are low.



**Figure 6.** Average distribution of temperature and salinity correlation coefficients on the NB Section.

The average salinity field shows the relationship between the sections quite distinctly. The haline characteristics are most consistent around Station 5, while further from this station the relationship gradually decreases. Stations 4 - 7 were averaged in order to allow for monthly correlation fields (Figure 5) between the haline characteristics of waters at the sections under study. On the basis of the assigned averaging ranges at NB, we performed a regression analysis with characteristics of waters at FB Section (Station 7-15, 50-200 m layer).

The regression analysis (Figure 7) showed that the thermal characteristics of the waters in the sections were highly correlated during the cold period of the year.



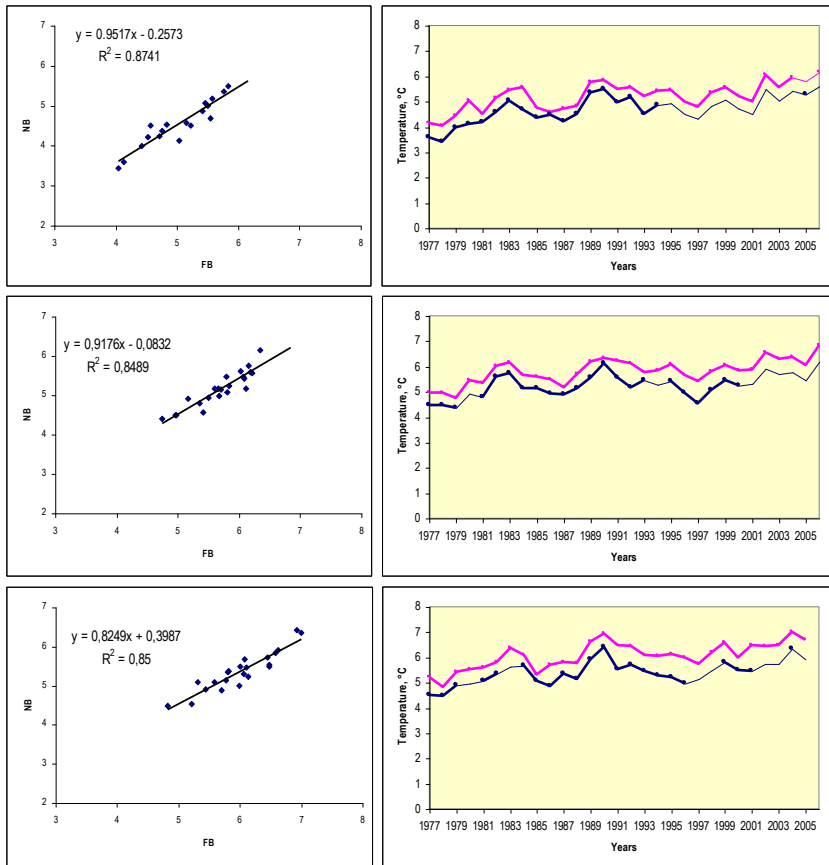
**Figure 7.** Regression between the average temperature on FB (red line) and NB (dark blue line) sections in January, March, and May, respectively. The thick line shows observed values; the thin line, restored values.

In January, the coefficient of determination between the average values of water temperature was about 0.9. According to the observation data, the water temperature in the FB section in that month was an average of  $0.7^{\circ}\text{C}$  higher than in the NB section, with a standard deviation of  $0.2^{\circ}\text{C}$ . The maximum consistency ( $R^2 > 0.94$ ) of the temperature series was obtained in March. The temperature difference between the two sections remained at the same level ( $0.67^{\circ}\text{C}$ ), with a fall in standard deviation of  $0.14^{\circ}\text{C}$ . A high association of the series ( $R^2 > 0.93$ ) was also observed in April - May. The difference in water temperature between the sections fell somewhat, and came to  $0.5^{\circ}\text{C}$ , with a standard deviation of  $0.16^{\circ}\text{C}$ .

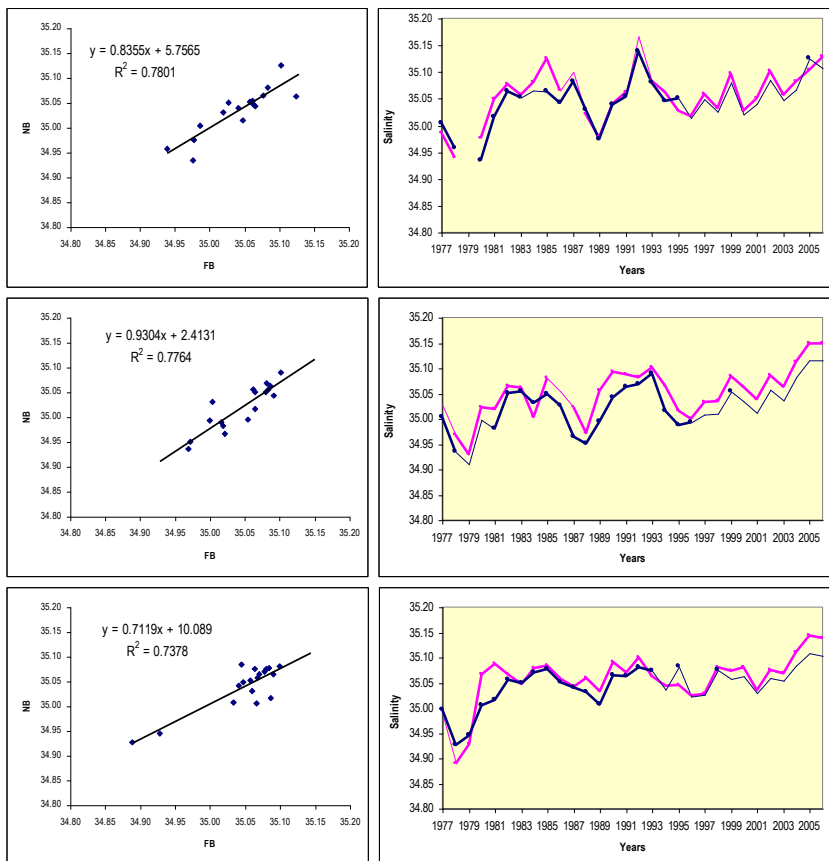
The relationship between the thermal characteristics of the different waters decreased in the sections during the warm period of the year (Figure 8).

The multiple correlation coefficient for June was 0.87. Waters in the FB Section were  $0.5^{\circ}\text{C}$  warmer than in the NB Section, with a standard deviation of  $0.2^{\circ}\text{C}$ . Regression equations with a similar determination coefficient ( $R^2 > 0.85$ ) were derived for August - September and October. In August - September, the difference between the average water temperature values was  $0.55^{\circ}\text{C}$  (standard deviation  $-0.18^{\circ}\text{C}$ ), while in October it was  $0.66^{\circ}\text{C}$  (standard deviation  $-0.22^{\circ}\text{C}$ ).

The regression analysis of haline characteristics at the sections showed less conjugation of averages (Figure 9).



**Figure 8.** Temperature regressions in June, August, October, respectively. The legend is as in Figure 7.

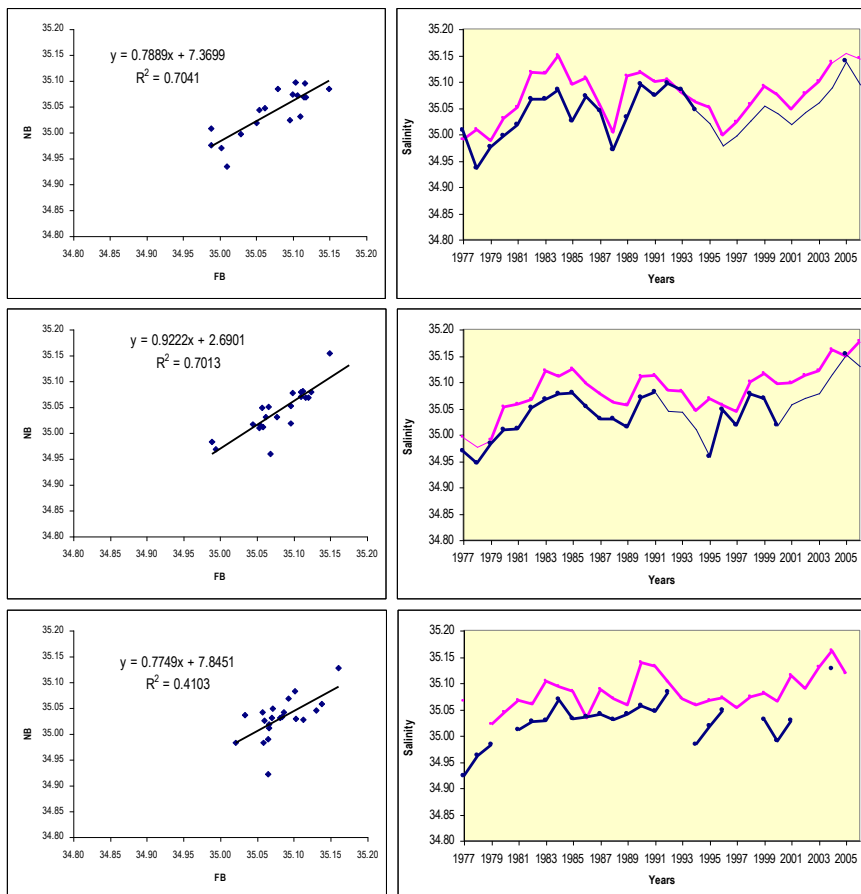


**Figure 9.** Salinity regression in January, March, May, respectively. Legend is as for Figure 7.

Where temperature was concerned, the consistency of the salinity means was higher during the cold period of the year than during the warm season. The maximum level of the relationship between haline characteristics of waters was found to be in January and May, when the coefficient of determination reached 0.78. In January, the mean salinity values at the sections were practically the same (the difference was 0.007, with a standard deviation of 0.023), and in March, the salinity on the FB Section was 0.026 times higher (standard deviation – 0.022) than on the NB Section. In April - May, the consistency of the salinity series had a coefficient of determination of 0.74. In that month, the salinity of the FB Section was 0.01 higher than on the NB Section and the standard deviation was 0.028.

In June and August-September, multiple correlation coefficients between haline characteristics came to about 0.7 (Figure 10).

During those months, the waters on the FB Section had a higher salinity than on the NB Section. In June the difference between salinity means was 0.033 (standard deviation 0.028), and in August - September it was 0.038 (standard deviation 0.025). There were no significant relationships between haline characteristics at the sections studied in October (Figure 10).



**Figure 10.** Salinity regression in June, August, October, respectively. Legend is as for Figure 7.

## Discussion

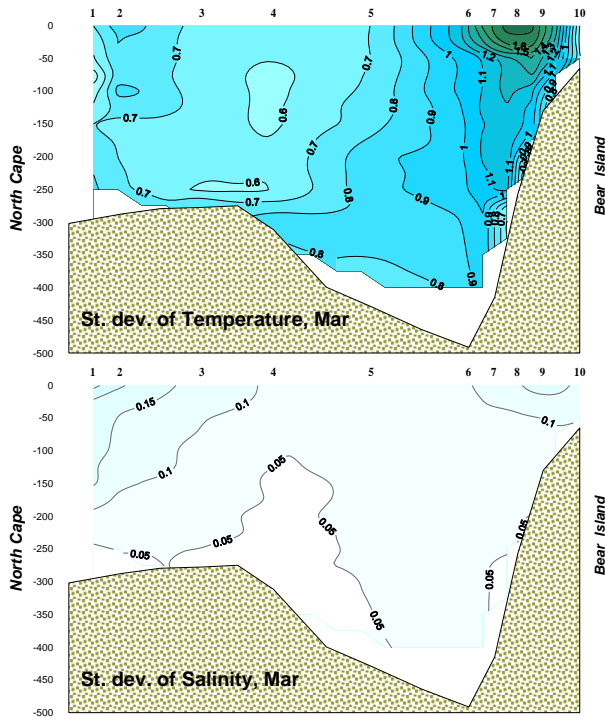
This paper considers questions related to the coherence of thermohaline water parameters on the FB and NB Sections in detail.

The close correlation of T, S variables on the sections involves makes it easy to determine the consistency of variations in water temperature and salinity over time. The length and depth range in the area between Stations 7 and 15 of the FB Section used to determine the mean weighted characteristics correspond approximately to those between Stations 3 and 7 on the NB Section (Table 1). Nevertheless, some differences in seasonal differences in hydrographic parameters on the sections (the inflow of Atlantic waters to the continental shelf; the existence of the cold Bear Island Current in the northern part of the section and the warm and freshened coastal Norwegian Current on the boundaries of which the developed frontal zones are formed; freshwater continental flow and formation processes, etc.) suggest that there are a number of peculiar conditions which need to be taken into consideration.

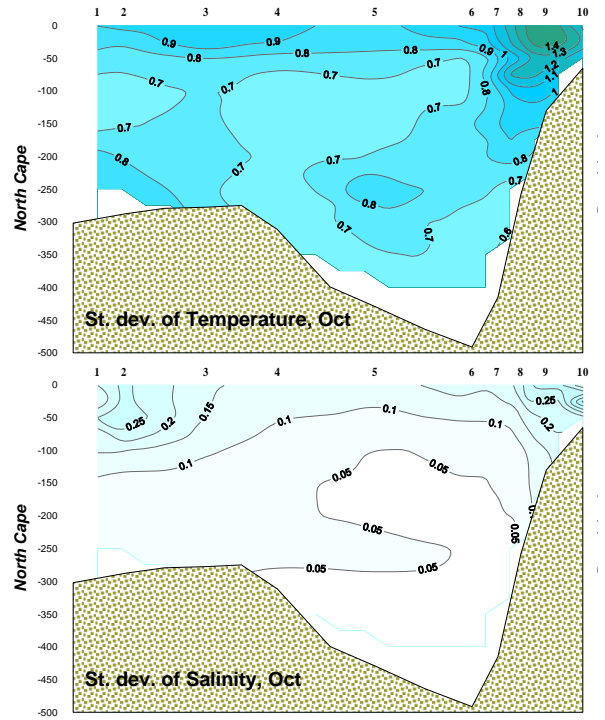
The vertical fields of temperature correlations (Figures 4 and 6) represent the total transportation of waters between the two sections quite distinctly. During the cold season January – April the correlation coefficients are relatively high in most of the water column. This is probably the result of well-developed mixing processes and, thus of great temperature homogeneity in the vertical dimension. In the warm period (June, August-September, October), during the seasonal thermocline occurrence, the temperature in the upper 30-50 m layer on the NB Section absolutely mismatches the one in the 50-200 m layer on the FB Section. The significant decrease in the correlation fields on the NB Section to the north of Station 8 is the result of effect of the Arctic waters (Ozhigin, Ivshin, 1999) transported by the Bear Island Current. In the coastal southern area of the section, the decrease was weaker, although in some months a significant decrease in correlation coefficients was noticed in the area of Station 1. The local water temperature correlation coefficient maxima were obtained somewhat unexpectedly at depths of 50-350 m at Stations 3 and 4, and additional research beyond the limits of this paper is needed to explain this phenomenon.

The correlation coefficients in the salinity field (Figure 5 and 6) were not as high as for temperature, as expected. Both any inaccuracies in determining salinity differences in the periods of observations had a negative effect on the relationship between the data series. The largest correlation coefficients for salinity were obtained between Stations 7 and 15 on the FB Section, and at Station 5 on the NB Section. The field of significant correlations was located between Stations 4 and 7 on the NB Section in January and March. In April-May and June this narrowed to Station 4-6 of the NB Section, and in August-September and October it was only significant in the area of Station 5. Haline fronts crossing the section in the south near Station 1, and at Station 8-9 in the northern part, can easily be seen in the salinity field correlation plots. One possible reason for the reduction in salinity correlation coefficients in August-September and October may be a weakening of the advection of the Atlantic waters.

The structure of temperature and salinity correlation fields may be found, in particular, through the values of standard deviations of these water parameters (Figure 11 and 12).



**Figure 11.** Standard deviations of temperature and salinity in March.



**Figure 12.** Standard deviations of temperature and salinity in October.

The figures showing the distribution of the standard deviations of temperature and salinity on the NB Section in the period of the best (March) and weakest (October) relationships distinctly reflect the main peculiarities of water structure. The standard deviations display maxima in the areas of frontal zones and minimum values in the areas of the best contingency of thermohaline characteristics. The positions of the isolines of the temperature and salinity standard deviation values are particularly interesting. In the period with the best parameter contingency (March), the standard deviations show a practically vertical homogeneity. Thus, all the data that are averaged over a station have a similar error. This means that the weightings of each value in the total average are approximately identical. During the period of weak correlations (October), the isolines of standard deviations are characterized by a somewhat horizontal position. In this case, the temperature and salinity values have different weightings in different layers, and the contribution of a separate observation may influence their total average. This in turn will influence the level of relationship (the instability condition appears). When selecting the spatial interval for averaging by section it is therefore necessary to consider not only the extent of the relationship, but the value of the standard deviation.

Allowing for the above-mentioned considerations, averaging the NB Section involved Station 3-6 to analyse the adjustment of thermal characteristics and Station 4-7 to adjust salinity means. Choosing those stations was based on both the correlation coefficient and the analysis of standard deviations. The averaging is mainly intended to provide smoothing, excluding high-frequency constituents that consist of some limiting or erroneous data. The relationship might be improved by diminishing the interval of spatial averaging by the section, but in such a case, any high-frequency constituents might remain and the regression equations obtained would be unstable. One possible approach might be dynamic determination of averaging interval boundaries. But with the aim of filling gaps in time series this approach would be quite difficult to interpret.

Statistically reliable regression equations (Figure 7 and 8) with determination coefficients of 0.85-0.94 were obtained for average water temperature between the two sections for each month. These equations enable us to fill gaps in the time series if there are data from one of the sections are available. Some wider deviations between the averages of the sections at the turn of the 1990s are probably caused by the development of new measuring methods and instruments.

Regression equations characterizing conjugation of salinity values appeared to be less highly correlated (determination coefficients of 0.70-0.78) and completely nonsignificant for October (Figures 9 and 10). As mentioned above, the lack of significant relationships is probably a result of weakening of the Atlantic water flow. The mosaic distribution of salinity correlation coefficients on the NB Section in October (Figure 5) permits us to assume that haline structure of waters on the FB Section in October is different. In this connection, to compare the data for October further, more detailed studies are required.

According to methods used by PINRO, the thermohaline characteristics on the NB Section are estimated on the basis of the data from Stations 2 – 6.

Therefore, in order to check the proposed method and fill the gaps for recent years in the time-series for the NB Section, it would be reasonable to make an attempt to adjust the averages for the NB Section and the initial data from the FB Section.

## **Conclusions**

This study analysed the consistency of water thermohaline parameters on the FB and NB Sections.

Correlation fields of temperature and salinity, as well as of standard deviations of water parameters along the NB Section were calculated and plotted. The optimal ranges of spatial averaging were determined by the distribution of higher correlation coefficients, allowing for standard deviation. The optimal range of averaging for water temperature was the part of the NB Section between Station 3 and Station 6, and for salinity between Station 4 and Station 7.

The regression analysis permitted us to obtain quite reliable statistical relationships (coefficients of determination – 0.85 - 0.94) between the mean water temperatures on the sections for all months studied.

The relationship between the water salinity of the two sections was somewhat weaker (determination coefficients – 0.70 - 0.78), and was insignificant in October. The regression equations obtained allow us to fill the gaps in the time series except for October.

The results suggest the possibility of future studies aimed at filling in the gaps in time series and extending the series of observations on the standard sections.

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# Long-term survey series on 0-group in the Barents Sea

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## Extended abstract

(Full article included in special issue of *Marine Biology Research* (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)

## Background

Since 1965, annual 0-group surveys have been performed in the Barents Sea by IMR, Norway, PINRO, Russia, and the United Kingdom (up until 1976). Prior to 2003 the 0-group survey was conducted between late August and early September. However, since 2003, the 0-group survey has formed part of a Joint Norwegian-Russian ecosystem survey of the Barents Sea, designed and carried out from early August to late September (Anon. 2005). A standard trawling procedure has been used since 1980 (Anon. 1983).

The aim of the paper is to establish a corrected Joint Norwegian-Russian database, and to present the historical distribution (1980-2006) of capelin, herring, cod and haddock, based on re-calculated fish density taken from the new database. Identification of long-term trends in abundance and distribution of 0-group fish in relation to biological and environmental factors is also an important goal.

## Data source

The applied Norwegian and Russian databases contain 23 years of annual survey data. To investigate fish distribution, densities per square nautical mile of 0-group capelin, herring, cod and haddock were re-calculated by stratified sample mean methods (Anon. 2005). The water temperature was included in the analyses due to its link to the feeding conditions, and because it is influenced by the Atlantic water inflow into the Barents Sea. The mean April-August temperature for the depth layer 0-200m, given from the fixed Fugløya-Bear Island sections, were used in the analyses.

## Results and discussion.

The Barents Sea is the vital nursery area for 0-group fish of several species. The capelin is the most abundant 0-group fish in the area; however, the abundance varied dramatically. Abundant capelin year-classes, such as 1980-83, 1989, 1999, 2003 and 2006, were widely distributed. Our results also showed that, with higher 0-group numbers the mean fish lengths decreased, probably due to greater competition for food. The number of 0-group individuals decreased as capelin overlap with cod increased, while overlap with herring had an irregularly negative effect on the index. Like capelin, cod are distributed over large areas and high numbers of cod will overlap totally with capelin during the summer, while herring overlap with capelin in the central and southern areas, thus affecting the total abundance of capelin to a lesser degree. Therefore, both 0-group cod and herring are potential predators on capelin, and spatial and temporal overlap with capelin during the first summer will increase predation pressure, thus reducing capelin 0-group abundance.

The most abundant year classes (1991, 1993, 1996, 1998 and 2004) of herring were more widely distributed than weaker ones; density was highest in the central area, and the calculated fish density could be as much as one million fish per square nautical mile. The 0-group index was positively associated with water temperature and distribution area. Herring usually overlap spatially with capelin, but the occurrence of capelin in herring areas does not crucially influence the abundance of herring.

Numbers of 0-group cod were lower than capelin and herring. Cod were distributed over larger areas, and wider distribution increases the probability of an adequate food supply at high levels of abundance. Cod overlapped with herring in the central and southern parts of the Barents Sea, and a higher cod index was associated with a larger overlap with herring, probably as a result of sharing habitat. Cod overlapped with capelin, and the lower concentrations of capelin in cod areas suggest that cod which overlap capelin may consume the smaller and suitable prey. Capelin will thus have a positive impact on the abundance of cod.

The abundance of 0-group haddock varied from year to year, and was lowest in 1981 and highest in 2005. During the past four years (2004-2006) haddock have been highly abundant. The 0-group index was positively associated with temperature, suggesting that feeding conditions were better and /or that there was a greater influx of Atlantic water

## **Conclusions**

The goal with this work was to establish an improved joint Norwegian-Russian 0-group database which could be used with larger confidence in different studies (stock assessment, recruitment, temporal and spatial). The historical distribution (1980-2006) of the most important commercial fish species: Barents Sea capelin, Norwegian spring spawning herring, Northeast Arctic cod and Northeast Arctic haddock was presented. This study shows that temperature is an important predictor of fish abundance for all the species analysed, except cod, and that the 0-group indices are generally higher in warmer years. The results also indicate that the spatial overlap between capelin and cod lead to a depletion of the capelin and an increase in cod abundance.

## **References**

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# **20<sup>th</sup> anniversary of the PINRO-IMR cooperation in the investigations of fish feeding in the Barents Sea – results and perspectives**

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## **Abstract**

Since 1986 the Institute of Marine Research, (IMR), Norway and the Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia, have carried out a joint research program on the trophic relationships in the Barents Sea. As part of this program, the two institutions have exchanged quantitative diet data from fish in the Barents Sea, mainly cod. Diet data can give information about important trophic links in the ecosystem and the strength of those links. Therefore, diet data is important for quantifying interactions between fish stocks, e.g. by calculating how natural mortality due to predation influences their dynamics. In this paper we give an overview of diet data collected by IMR and PINRO during the last 20 years, and present some results and perspectives for future work.

## **Background**

Trophic investigations using quantitative diet data started in the Barents Sea in the 1920s-1930s (e.g. Idelson, 1929; Zenkevich and Brotskaya, 1931; Zatsepin and Petrova, 1939; Zatsepin, 1939; Brown and Cheng, 1946) and continued during the 1950-1960s (e.g. Grinkevich, 1957; Sysoeva, 1958; Ponomarenko, 1958). After this period, studies on fish feeding in the Barents Sea were not so intensive and used mainly qualitative diet analyses (e.g. Ponomarenko et al., 1978; Ponomarenko and Yaragina, 1985, 1990a,b).

In the mid-1980s a new joint project was initiated by the Institute of Marine Research (IMR, Bergen, Norway) and Knipovich Polar Institute of Marine Fisheries and Oceanography (PINRO, Murmansk, Russia) to study diet and food consumption of the Barents Sea fish. The motivation for the project was to develop multispecies models for the Barents Sea fish stocks. To be able to quantify stock interactions, detailed quantitative diet data were needed together with a model of stomach evacuation rate.

In the mid-1980s, IMR together with “Fiskeriforsking“ in Tromsø got funding by the Norwegian Research Council for an initial project, where IMR sampled and analyzed diet data (Mehl 1986a), whereas Fiskeriforskning conducted laboratory experiments on stomach evacuation for cod by keeping cod in temperatures similar to what is experienced in the Barents Sea and feeding cod prey typical of the Barents Sea. Similar investigations were conducted in Murman Marine Biological Institute (MMBI) in Russia during 1984-1990 (Orlova, 1991; Orlova et al., 1989c, Orlova and Antonov, 1991). Based on their experiments dos Santos and Jobling (1992, 1995) developed stomach evacuation models that have been fundamental for the project by allowing calculation of consumption of cod using input data from the Barents Sea (Bogstad and Mehl 1992,1997, Dolgov, 1995b).

The joint project was started in 1987 by Alexander Glukhov and Natalia Yaragina from PINRO and Sigurd Tjelmeland and Sigbjørn Mehl from IMR. They initiated and developed the project, the methods for sampling, for analyzing the stomach content in the laboratory and for storing, processing and exchange of data.

The main objectives of the project were to:

- Organize the long-term sampling and quantitative analysis of demersal fish stomachs (mainly cod)
- Calculate the consumption by cod of the commercially important prey species
- Create the basis for the development of multispecies models for the Barents Sea

## **Methods used**

### **Target species**

Cod is the main fish predator in the Barents Sea (Zatsepin and Petrova 1939; Bogstad et al. 2000), and the main focus in the joint project has been on cod. From the start of the project until 1991, both IMR and PINRO collected and exchanged stomach content data on cod and haddock, but because haddock consume only small amounts of commercially important prey species (Burgos and Mehl 1987), IMR stopped sampling stomach content of haddock in 1991, while PINRO continued such sampling. Haddock stomach sampling and analysis of stomach content has followed the same procedures as for cod. Scattered information on stomach content of pelagic fish species (capelin, herring, polar cod, blue whiting) from 1980s was also included in the joint data base.

Since the mid-1990s PINRO started to regularly collect data on diet of other abundant fish species including non-target fishes in the Barents Sea – Greenland halibut, saithe, long rough dab, skates, blue whiting and some others. IMR has since the mid-1990s had some collection of data for saithe, Greenland halibut and blue whiting. These data have not been exchanged so far. At present, both institutes collect diet data from capelin and polar cod, and the exchange of such data is in process.

Data on the diet of marine mammals and seabirds have also been collected, and consumption estimates have been made also for these predators (e.g. Nilssen et al. 2000; Folkow et al. 2000; Bogstad et al. 2000; Barrett et al. 2002, and references therein). We will not go into detail on the work done on these species, as it has not been carried out within the framework of the PINRO-IMR cooperation on investigation on fish feeding. It should be noted, however, that harp seals and minke whales are very important predators on Barents Sea fish – only cod is more important as a fish consumer than these two marine mammal species.

### **Sampling**

Cod stomachs have been sampled on Russian and Norwegian surveys as part of the regular sampling procedures (Mehl and Yaragina 1992). Cod stomachs have also been sampled on Russian commercial vessels with PINRO observers onboard. The sampling procedures have changed over time, including the number of stations sampled, spatial coverage of the sampled stations and the number of stomachs per station. In general, the spatial coverage of the cruises has increased, the number of stations for which stomachs samples have been taken has increased, whereas the number of stomach per stations has decreased (Jakobsen et al. 1997). This change have been motivated by work by Bogstad et al. (1995c) who found that the

variation in diet between stations was much larger than the variation in diet within stations, and that there is strong correlation between stomach samples from the same station. Thus, the effective sample size increases when few stomachs are taken from many stations compared with many stomachs from few stations, even though the total number of stomachs is the same. Currently, 1 stomach per 5 cm length group of cod is taken per station for both Norwegian and joint Russian-Norwegian surveys. The sampling procedures on Russian commercial vessels and Russian national research surveys is different, usually 25 stomachs are analysed from each trawl station using random sampling. Spatial coverage of stations with stomach samples by year and quarter is shown in Appendix 1. Samples taken outside the Barents Sea itself have been included (cod in the Lofoten area, saithe along the Norwegian coast).

### **Laboratory analysis**

The methods used for the quantitative laboratory analysis of stomach content in this project is mainly the same as standard methods used in Russia (Anon., 1974) and for the North Sea stomach sampling project developed in the early 1980s where stomach data was collected and applied in multispecies VPA models (Anon. 1981).

Stomachs are analyzed individually. The total content of sampled stomachs is weighed and the content of the stomachs are divided according to prey species when identifiable. The total weight and the degree of digestion (from 1: newly eaten to 5: digested not identifiable) of the different prey items are recorded. Length measures are taken of prey species that can be identified and when the length is unaltered because of digestion. Finally, the number of identifiable prey individuals per stomach is recorded. From 1984-1992 the resolution of the length measurement in the Norwegian and Russian data varied by the size of the prey (Mehl and Yaragina 1992), but from 1993 on, all the prey items were measured to the nearest cm (or to a finer scale for very small prey).

In the 1990s IMR also did some of the stomach content analysis on board the cruises, but this approach was abandoned because it reduced the quality of the data. Since 1995, PINRO has in addition to the standard methods used a simplified version of the quantitative method, which is conducted onboard at the sea conditions. Total weight of stomach content, visually estimated proportion of prey species and in some cases length and number of commercially important species are determined onboard (Dolgov, 1996).

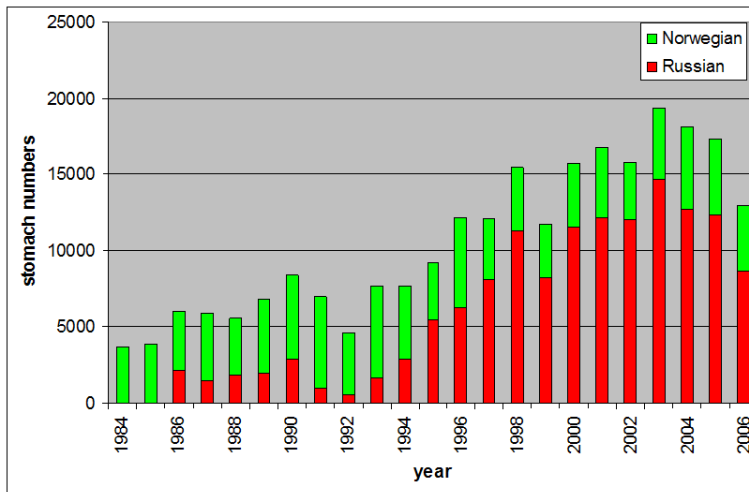
### **Software**

The program 'MAGE' ('stomach' in Norwegian) was developed in the beginning of the project for storage and exchange of data and for simple diet calculations (Westgård 1982, Mehl 1986b). When the project was initiated, stomach content data could not be included in the data bases of the two institutions, and thus a 'stand-alone' stomach content data base was created. MAGE is still used for converting data into a joint format, and for doing diet analysis, but both institutions now have their own data base systems (IMR: STUVW (Mjanger et al. 2006), PINRO: BIOFOX (Anon., 2001)) where stomach data are stored together with the relevant data on the predator (age, length, weight etc.) and station (time, date, position, catch etc.).

### **Data gathered**

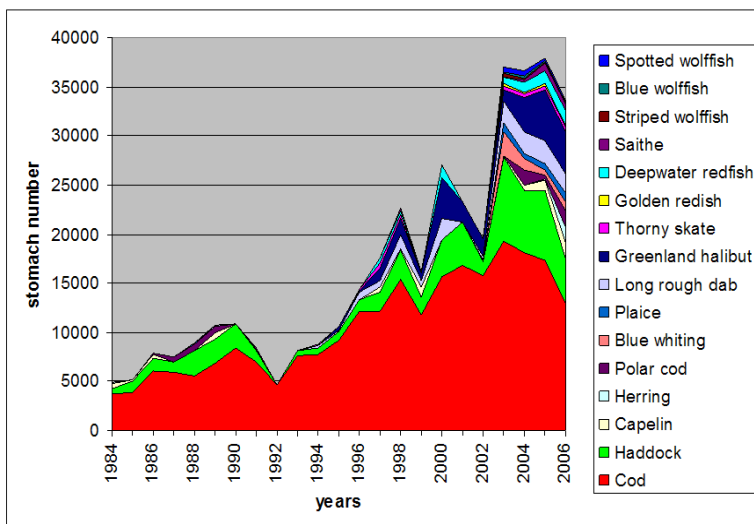
The number of cod stomachs analyzed in the joint project by nation and year is shown in Figure 1. Exchange of haddock data was discontinued in 1991 after approximately 12 000

haddock stomachs had been analyzed. The number of cod stomachs analyzed is now (on the 1<sup>st</sup> January of 2007) approximately 244000.



**Figure 1.** Total number of cod stomachs collected by Norway and Russia during 1984-2006.

From 1984-1995 between 5-10 thousand stomachs were analyzed per year (Figure 2). Since 1996 when new methods of stomach content analysis were applied in PINRO, stomach numbers increased up to 15-20 thousand and then to 35 thousand stomachs per year. This was mainly because PINRO increased the number of species for which stomach were sampled. Total stomach numbers analyzed by PINRO and IMR was approximately 380 thousand by the end of 2006. It should be noted that the joint IMR-PINRO data includes mainly cod after 1991.



**Figure 2.** The number of fish stomachs (all species) analyzed by IMR and PINRO by species and year. The joint data consists mainly of cod after 1991.

Since 1999 PINRO started to collect data on energy content of the most important prey species of cod (capelin, euphausiids, shrimp etc.). This allowed for calculation of food rations of cod in energy units (kcal). Bogstad and Mehl (1997) also carried out such calculations, based on energy content data from the literature

## Results and applications

There have been extensive publications from the joint feeding investigations, both refereed papers, institutes publications, ICES papers and working documents, popular science publications, master theses, posters and presentations on symposia and conferences. The publications can be grouped into two main categories; publications on diet, feeding and biology and publications on models.

### Results: feeding, diet and biology

The large body of studies in this category can be grouped in the following way:

- Papers describing the diet of a given species (including consumption calculations)
- Papers on the effect of predation on a given prey species
- Papers on the effect of prey abundance on predator population dynamics

### Papers describing the diet of a given species (including consumption calculations)

A summary of some key references for the diet of each predator is given in Table 1. Data on total diet composition of the most abundant demersal fishes of the Barents Sea is shown in Figure 3.

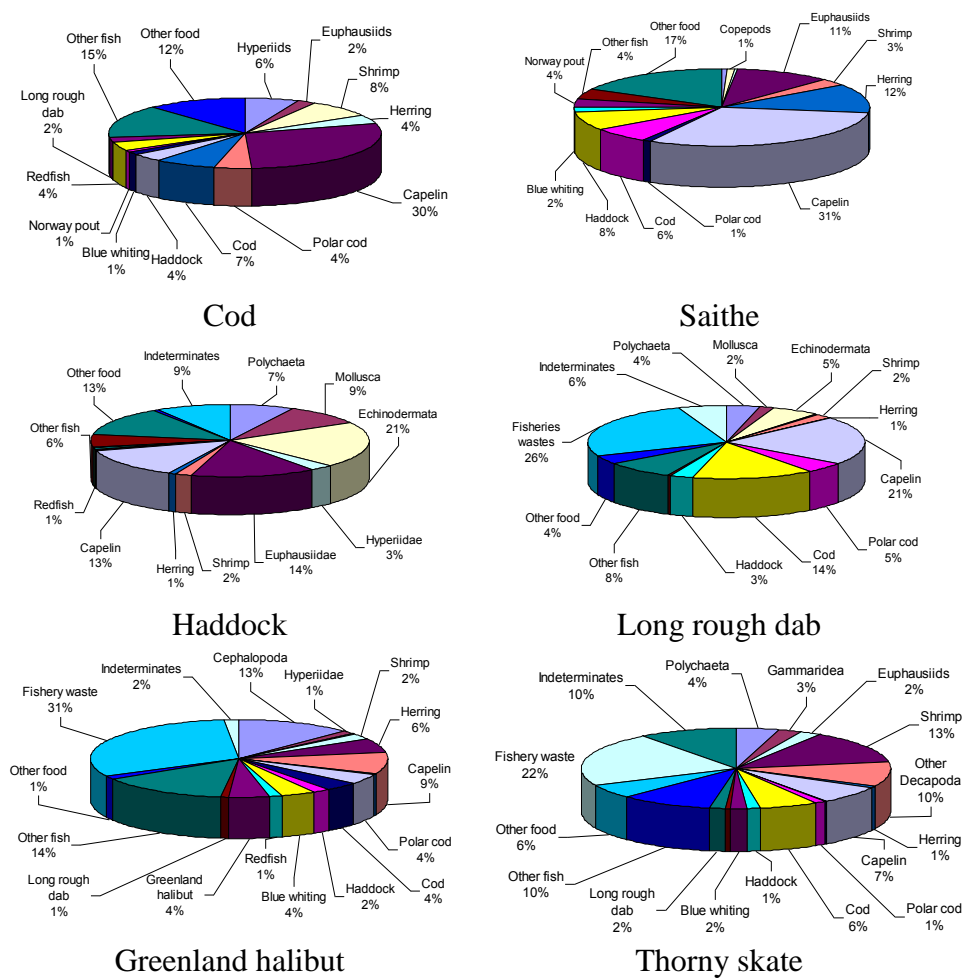
**Table 1.** Papers on the diet of each predator

Predator	Reference
Cod	Zatsepin and Petrova 1939, Mehl 1986a, 1989, Orlova and Matishov 1993; Ponomarenko and Yaragina 1996; Bogstad and Mehl 1997, Dolgov 1999, Dalpadado and Bogstad 2004
Haddock	Zatsepin 1939, Tseeb 1964; Sonina 1969; Antipova et al. 1990; Burgos and Mehl 1987; Jiang and Jørgensen 1991, Dolgov 1989b
Redfish	Boldovsky 1944; Dolgov and Drevetnyak 1990, 1993a, 1995
Greenland halibut	Shvagzhdis 1990, Michalsen and Nedreaas 1998; Dolgov 2000, Hovde et al. 2002; Vollen et al. 2004
Skates	Berestovsky 1989; Dolgov 2005a
Blue whiting	Zilanov 1984; Belikov et al. 2004; Beck et al. 2006
Long rough dab	Komarova 1939; Simacheva and Glukhov 1990; Berestovsky 1995; Dolgova and Dolgov 1997
Capelin	Prokhorov 1965; Panasenko 1989; Ajiad and Pushaeva 1991, Orlova et al. 2004
Herring	Boldovsky 1941; Manteifel 1941; Orlova et al. 2000c, 2006f
Polar cod	Belova and Tarverdieva 1964; Pechenik et al. 1973; Tarverdieva et al. 1996; Ajiad and Gjørseter 1990; Orlova et al., 2005f
Saithe	Dolgov 2000, 2002a, Mehl 2005

Some trophic groups of the Barents Sea fishes have been identified (Dolgov, 1992). Planktivorous fishes include herring, capelin, polar cod and blue whiting. Haddock, wolffishes, plaice and dab are benthivorous species. Cod, Greenland halibut, larger thorny skate and long rough dab could be considered as piscivorous fishes. Many species have a mixed diet and can relatively easy switch to feed on other more available prey organisms. Regular sampling of fish feeding allowed for new information on species where abundance

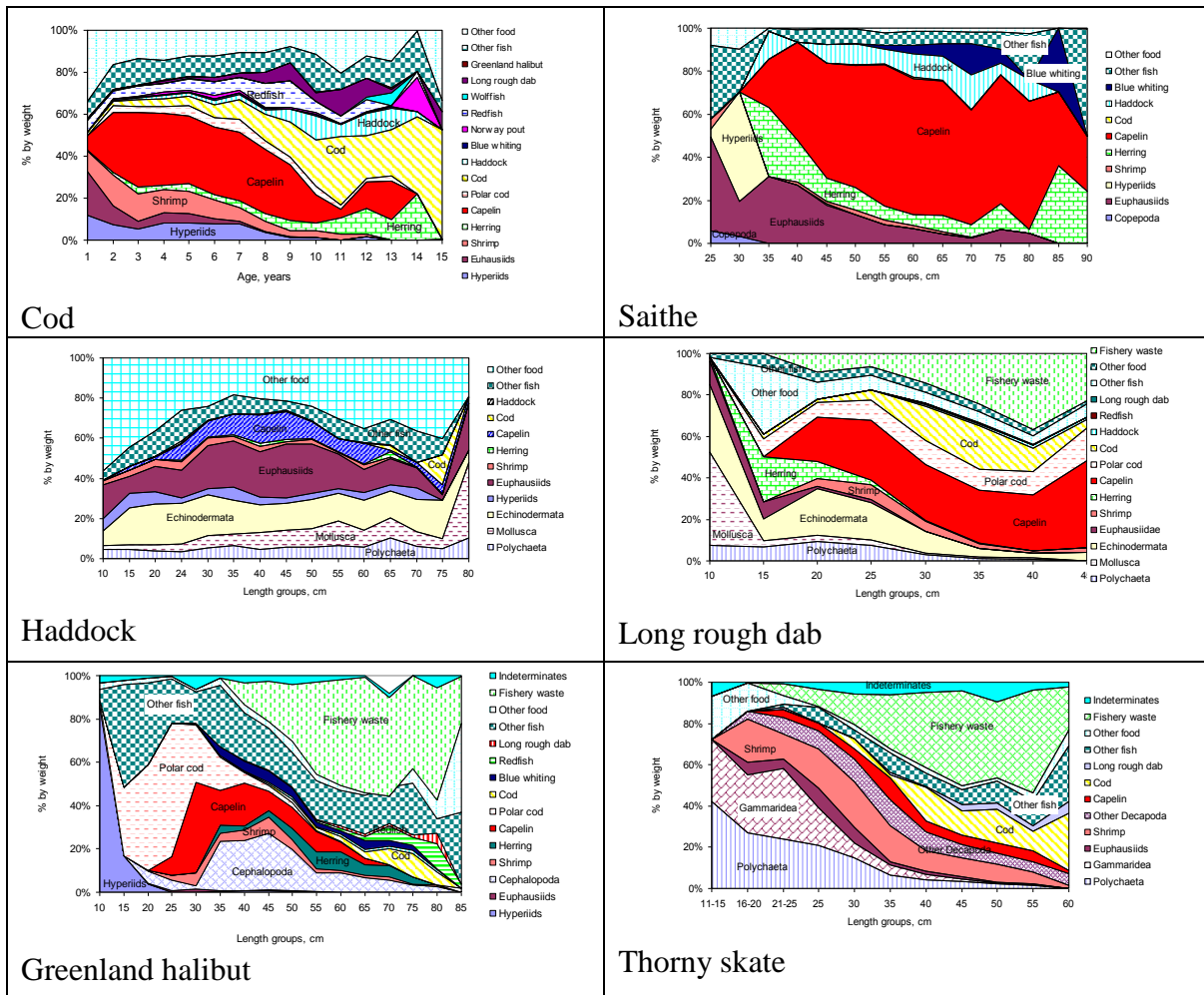


sharply increased in the Barents Sea – blue whiting (Belikov et al., 2004) and saithe (Dolgov, 2000) and to evaluate the possible effect on trophic relationships in the ecosystem.



**Figure 3.** Diet composition of the most abundant fishes in the Barents Sea (combined data for all periods), % by weight.

Juveniles and adult fishes of some species usually belong to different trophic groups. Cod juveniles feed mainly on plankton organisms while fishes with lengths above 25-30 cm prey on larger crustaceans (shrimps) and fish. For some fish where rather high numbers of stomachs was sampled length/age changes in its diet were recognized (Figure 4). Such changes were most clearly observed in cod (e.g.; Orlova et al., 1994; 1995a; Dalpadado and Bogstad, 2004). The main tendency was a dominance of small plankton organisms or benthos in the diet of juveniles, appearance of larger crustaceans and small fishes in the diet of medium sized fishes and prevalence of larger fish species in the diet of the largest individuals.

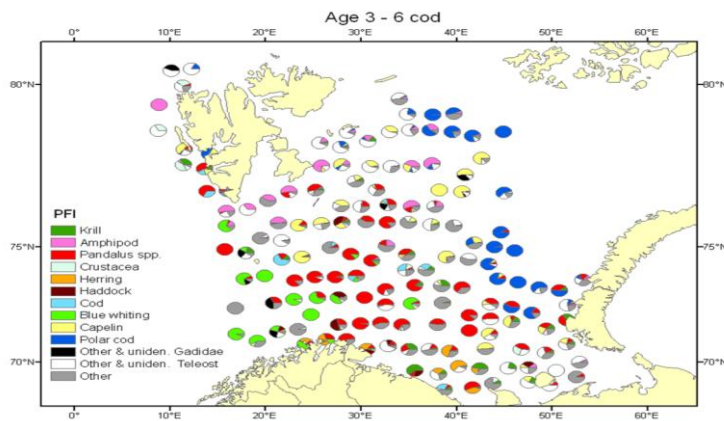


**Figure 4.** Diet composition of different age/length groups of the most abundant fishes in the Barents Sea (combined data for all periods), % by weight.

The diet of 0-group cod in the Barents Sea in the 1970s was studied by Ponomarenko (1958, 1973, 1983, 1984). Survival rates of bottom-dwelling cod until recruitment at age 3 years were found to be connected, in particular, with abundance of euphausiids - the primary food of 0-group cod. The University of Tromsø has recently completed a research program titled ‘Capelin and Herring in the Barents Sea - coexistence or exclusion (Basecoex)’. Within this program, stomach samples were taken, mainly from herring (0-group and older) and 0-group cod. A few stomachs of young haddock, sandeel and saithe were also sampled. The results from this research program are under publication, many of them were presented at the ECONORTH symposium in Tromsø in March 2007.

Large differences were revealed in the diets of some species in the different areas of the Barents Sea, an example of geographic variation in cod diet is shown in Figure 5. Cod diet reflects the geographical distribution of main prey species which again is determined by their seasonal migrations and water masses distribution

Some studies on diurnal variations in diet and variation in diet between fishes distributed at different depths have also been carried out (e.g. Dolgov and Yaragina 1990, Yaragina 1988, Tarverdieva and Yaragina 1989, Ajiad 1990, Michalsen 1993).



**Figure 5.** Geographical variation of diet composition of age 3-6 cod during the ecosystem survey August-September 2005.

Tjelmeland and Alvarez (1994) compared real stomach content data with simulated distributions of stomach content based on a feeding model, and estimated some parameters in the feeding model. This approach was developed further by Magnússon and Aspelund (1997). Comparison of food energetic rations of cod in different areas of the Barents Sea has also been conducted. The important role of capelin and herring in the energetic rations was revealed, as well as higher energetic rations in the Northern Barents Sea (Yaragina et al., 2003; Orlova et al., 2003).

### **Papers on the effect of predation on a prey species**

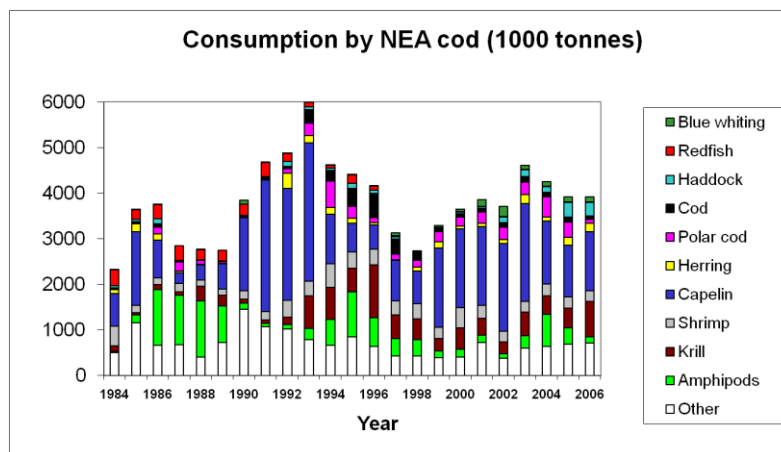
Cod is a generalist predator so changes in cod diet and consumption reflects changes at lower trophic levels in the ecosystem. For instance, we can see how the fluctuations in capelin abundance influence yearly consumption (Figure 6). We also can see how the increase in blue whiting abundance and the decline in redfish abundance are reflected in cod consumption. The fluctuations of the Barents Sea capelin stock have had strong effects on the population dynamics of its main predators, such as cod and harp seal. For cod, effects were observed on growth, maturation, fecundity and cannibalism, while for harp seal, effects on condition, reproduction, mortality and migration have been seen. The overall picture is that the first capelin collapse in the late 1980s affected the predators to a much larger extent than the second and third collapse (Gjøsæter et al. 2007). One important reason for this is probably that more alternative fish prey was available to the predators during the second and third capelin collapses.

Diet data allowed the calculation of food consumption by some fishes of the Barents Sea. The highest food consumption was observed in cod and can reach 6 million tons (Mehl 1989, Bogstad and Mehl 1992, 1997). Other predators consume less biomass. Biomass consumed by haddock did not exceed 1 mill. tonnes, other predators (Greenland halibut, long rough dab and thorny skate) – 200-250 thousand tons. Biomass of prey consumed by cod is rather variable (Figure 6) and reflect both changes in prey abundance and distribution and cod abundance and distribution as well as oceanographic conditions.

Unfortunately, there is still some discrepancy between the results from Norwegian and Russian consumption calculations (see e.g. ICES 2007a). This is due to use of different spatial and temporal aggregation when the consumption is calculated. Data on diets was used to estimate importance of the most commercially important prey species of cod (shrimp, capelin, herring etc).

**Table 2.** Papers on predation by prey species

Prey	Reference
Cod	Korzhev and Tretyak 1992, Bogstad et al. 1994, Dolgov et al. 1995, Dolgov 1999, Bogstad 2002, Yaragina et al. 2007
Haddock	No papers
Redfish	Dolgaya and Tretyak 1992; Øvstetun 2006
Shrimp	Berenboim et al. 1987, 1992, 2001, Ponomarenko and Yaragina 1990ab, Korsbrekke et al. 1991, Aschan 2000, Johannesen and Aschan 2005, Aschan et al. 2006, Johannesen et al. 2007
Zooplankton	Hassel et al. 1991, Dalpadado et al. 2001, 2002; Orlova et al. 2001b
Long rough dab	Dolgova and Dolgov 1997
Capelin	Ponomarenko and Yaragina 1990b, Ushakov et al. 1992, Huse and Toresen 2000, Dolgov 2002b, Bogstad and Gjørseter 1994, 2001; Johannesen et al. 2006
Herring	Johansen 2002, 2003, Johansen et al. 2004, Orlova et al. 1995, 1996, 2001d, 2006c, Mehl et al. 2006a
Polar cod	Orlova et al. 2001c

**Figure 6.** Annual consumption of major prey species by cod 1984-2006.

### Use of feeding data for some investigations of other aspects of biology of fishes of the Barents Sea

Data obtained during the project were used for the investigations of the cod growth (Ozhigin et al., 1994, 1995, 1996, Mehl and Sunnanå 1991), as well as reproductive potential of cod (Marshall et al., 2000, 2002; Yaragina and Marshall, 2000; Yaragina et al., 2003). Influence of feeding conditions on biological parameters and fatness dynamics of capelin was studied by Orlova et al., (2006a, 2006b), and bioenergetics models for cod have also been developed (Ajiad 1996).

### Results: Models

The joint stomach content data base has been the basis for a variety of multispecies and ecosystem models developed for the Barents Sea. Unfortunately, no 'truly' joint Russian-Norwegian models have so far developed, although there are models which have got some input from both parties.

In the first years of the project, model development was done at IMR, while model development at PINRO started in the mid-1990s. The model development at IMR and their Norwegian cooperation partners until 1997 is summarized by Tjelmeland and Bogstad (1998). We have adapted slightly the model classification given by Plagányi (2007), to group the models applied for the Barents Sea. Most of the models applied have been ‘minimum realistic’ multispecies models, while also some whole ecosystem models (Ecopath with Ecosim) have been applied.

### **Multispecies models**

All the models in this category can be considered as minimum realistic models, they are restricted to represent a limited number of species most likely to have interactions with the target species. The actual implementation of results has been done through extended single-species assessment models; these are described in Section 4.3

### **Age-length-area-structured models (MULTSPEC, Gadget, others)**

Several models with age-length and area structure have been set up for the Barents Sea. The first one was MULTSPEC (Bogstad et al. 1997a), which contained the species cod, capelin, herring, harp seal and minke whale. MULTSPEC was a predecessor of the Gadget modelling framework ([www.hafro.is/gadget](http://www.hafro.is/gadget), Begley and Howell 2004), for which model development is continuing (Lindstrøm et al. 2008, Howell and Bogstad 2007). The present Gadget model for the Barents Sea includes cod, capelin, herring and minke whale, with plans for also including harp seal. Krill abundance is included as an exogenous prey for whales. The model is age-length structured, with a monthly time step and four spatial areas (the Barents Sea and three subsidiary regions), with hindcast and forecast components. Currently, cod and capelin are modeled as having a fully closed life-cycle, while whales and herring have simpler recruitment functions. Predation by whales on cod, capelin and herring, and by cod on cod and capelin is included within the model, although the effects of prey availability on predator condition/growth are not currently modeled. Prey selection for each fish species is according to the length of the predator and prey, and conditioned to the stomach content data. Work is underway to include uncertainty in the forecast part of the model.

Models of this kind for which model development has been discontinued are, in addition to MULTSPEC, the ‘Scenario’ models (Schweder et al. 1998; 2000) and Systmod (Hamre 2003). Also, Bormicon, a predecessor of Gadget, was applied by PINRO in the late 1990s to study cod-capelin interactions.

### **MSVPA**

MSVPA models have been adapted for the Barents Sea (Bulgakova et al., 1995d; Korzhev et al., 1995; Tretyak et al., 1999; Korzhev and Dolgov, 1999) but this approach has now been abandoned. Up to 7 prey species were included (cod, haddock, capelin, shrimp, polar cod, herring, redfish), with cod the only predator. Harp seal and minke whale were considered as external predators. A major problem when using MSVPA for the Barents Sea is that capelin, which is a key species, has almost total spawning mortality and thus is not suitable for use of VPA-type approaches.

### **Other age-structured models**

The Bifrost model (Tjelmeland 2005, [www.assessment.imr.no](http://www.assessment.imr.no)) include the species cod, capelin, harp seals and herring, and is a forward simulation model which is fitted to the observations (survey data, catch data, stomach content data) and which accounts for the

uncertainty in the observations. It is an age-structured model, and for capelin length structure is also included, although in a non-dynamic way.

Stocobar (Filin 2005b) is an age-structured forward simulation model with growth depending on consumption. Feeding, growth, fishery, migration distance and maturity are included. Stocobar has cod as the only predator, and cod, haddock, capelin, shrimp, polar cod, herring, redfish and krill as prey species. STOCOBAR is a further development of the model CONCOD, which was developed to estimation of feeding intensity and yearly rations as well as growth rate of cod (Filin and Gavrilik, 2001). Cod was considered as predator and 6 species (shrimp, capelin, polar cod, herring, juvenile cod and haddock) as prey. The model STRAFICOD was based on CONCOD and developed for analysis of effectiveness of different strategies of cod fisheries management taking into account its trophic relations with capelin. Only two species (cod as predator and capelin as prey) were included in this model.

The Norwegian models AGGMULT and ECONMULT, described by Tjelmeland and Bogstad (1998), but no longer in use, also belong to this category.

### **Ecosystem models**

As part of the collaboration between the Sea Around Us project at the University of British Columbia and the 'Ecosystem Norwegian Sea' program of the Institute of Marine Research, Dommasnes et al. (2001) constructed an Ecopath with Ecosim (EwE) model for the Norwegian Sea and Barents Sea. The model covers 3,116,000 km<sup>2</sup> of Atlantic, Arctic and shelf waters. Thirty functional groups were included, ranging from marine mammals to phytoplankton and detritus. Partly based on the model from 2001, Skaret and Pitcher (2007) constructed a model for the Barents Sea and Norwegian Sea mass balanced for the years 1950 and 2000. They included 58 functional groups including 12 juvenile fish groups. They used Ecosim to simulate the period 1950 to 2000 based on the 1950-model. Catch data on all targeted functional groups were used as forcing functions and the simulated abundance was fitted to 15 abundance time series from VPA, acoustic abundance estimates or CPUE-estimates. A primary production forcing function was added to investigate bottom-up effects in the ecosystem and significantly improved the fit, in particular for the variable capelin abundance. This suggests that bottom-up effects are important in this ecosystem. The model was partly validated using 15 independent time series and time series on stomach data from cod and haddock.

Blanchard et al. (2002) also developed an EwE model of the Barents Sea. The model has been used to investigate the consequences of alternative functional response formulations on the predictions of responses by marine mammals (Mackinson et al. 2003) and to examine effects of model structure on the robustness of outputs (Pinnegar et al. 2005). A model for the Barents Sea by Falk-Petersen et al. (in prep.) to investigate effects of different management regimes on benthos is under construction.

### **Application in assessment and management**

- Important milestones:
- 1987- first calculation of total prey consumption by cod (IMR)
- 1990- stomach data used in joint capelin assessment
- 1991- 5th joint symposium: Interrelationships between fish populations in the Barents Sea (Murmansk, Russia)

- 1995- stomach data used in cod and haddock assessment (ICES Arctic Fisheries Working Group)
- 2000 – calculations of energetic food rations of cod (PINRO)
- 2003- calculation of food consumption by other predators (PINRO)

Interrelations between cod, haddock and capelin were considered by the ICES North-East Arctic Fisheries Working Group as early as 1975 (ICES 1975), but such interrelations were then not taken into account in the assessment.

Since the start of the project application of results to the assessment of commercially important fish stocks and fisheries management was a goal. Consumption estimations of various prey species by different predators is needed to achieve these goals. The most direct application of results from the feeding investigations for management has been the inclusion of cod consumption into fish stock assessment, of commercially important prey species. This has been done using extended single-species assessment models.

Cod consumption was used in capelin assessment for the first time in 1990, to account for natural mortality due to cod predation (Bogstad and Gjørseter 1994). This methodology has been developed further using the Bifrost and CapTool models (Gjørseter et al. 2002, Tjelmeland 2005). These models include predation by cod in a single-species, age-length structured capelin model.

Predation by cod on cod and haddock has since 1995 been included in the assessment of these two species in a MSVPA-like way by assuming that  $M=M_1+M_2$ , where  $M_2$  is the predation mortality induced by cod. The amount of cod and haddock eaten is taken from calculations of the cod stock's total consumption by predator age groups and prey species and length/age groups (Bogstad and Mehl 1997, updated calculations given in ICES 2007a). For cod, an iterative procedure is needed to carry out the calculations.

An extended single-species cod Gadget-type model (Frøysa et al. 2002) is used as an additional assessment model for assessing Northeast Arctic cod. The model includes cod cannibalism, and uses capelin abundance as an exogenous alternate prey for cod.

SeaStar (Tjelmeland and Lindstrøm 2005) should also be mentioned, although it at present utilises data from a predator species not considered here (minke whale). It allows for including predation by minke whale on herring in the herring assessment, although SeaStar is at present used only as single-species model in assessment of Norwegian Spring-spawning herring. Cod and harp seals could be included in addition to minke whale as predators on herring.

Shrimp is also a commercially important prey species of cod, and natural mortality of shrimp due to cod predations is probably large. Some attempts were made to estimate shrimp mortality due to cod predation (Berenboim et al., 1992, 2001). However, there is no agreed upon assessment of shrimp, and including cod predation into shrimp assessment have proved to be problematic (Hvingel 2006).

Dolgov (2005b) calculated the amount of commercially important prey consumed by other fish predators (haddock, Greenland halibut, long rough dab and thorny skate), but these consumption estimates are not used in assessment yet.

The Joint Norwegian-Russian Fisheries Commission (JRNC) has initiated a project to make a scientific assessment of optimal harvest (maximum sustainable yield) for the most important species in the Barents Sea, taking into account existing knowledge. This work should be based on an analysis of the population dynamics of Northeast Arctic cod and take into account this species' interaction with other species than cod. The project started in 2005, and will last until 2014. The first phase of the project ends in 2007. Data on fish feeding will be crucial for this project. More information about the project can be found at: <http://www.assessment.imr.no/Request/index.html>.

## **Work by ICES and in EU projects**

Species interactions in the Barents Sea have also been addressed by other parties than Russia and Norway. The ICES Multispecies Assessment Working Group considered multispecies modeling of the Barents Sea at several of its meetings, in particular the 1990 and 1995 meetings (ICES 1990, 1996). The new ICES Working Group on Multispecies Assessment Methods summarized multispecies modeling work in all areas, including the Barents Sea, at its 2007 meeting (ICES, 2007b).

Also, the EU projects *dst*<sup>2</sup> (2000-2003) and BECAUSE (2004-2007) helped advance multispecies modeling of the Barents Sea at IMR, particularly with the development of the Gadget modeling framework. Multispecies modeling, with focus on recruitment processes and stock recovery, will continue further during the new EU project UNCOVER (2006-2010), in which both IMR and PINRO take part.

## **Perspectives and conclusions**

The cooperation of IMR and PINRO has been productive and fruitful. The most important result is a creation of extensive data base on long term time series (more than 20 years) of cod stomach content. It is one of the most extensive and long time series of this kind in the North Atlantic. Joint efforts of both institutes allowed reducing the cost of trophic investigations and simultaneously improving temporal and spatial coverage of sampled data. Stomach data analysis is relatively labour intensive, so careful thinking is needed before stomach sampling effort in the Barents Sea is increased or altered.

The ecosystem approach to management avowed by the ICES requires use of compound multispecies models. Extensive stomach content data such as those available in the Joint stomach data base are necessary for model verification. Further studies are needed to investigate North Atlantic marine ecosystems taking into account climatic changes and impacts of intensive fisheries as well as species interactions.

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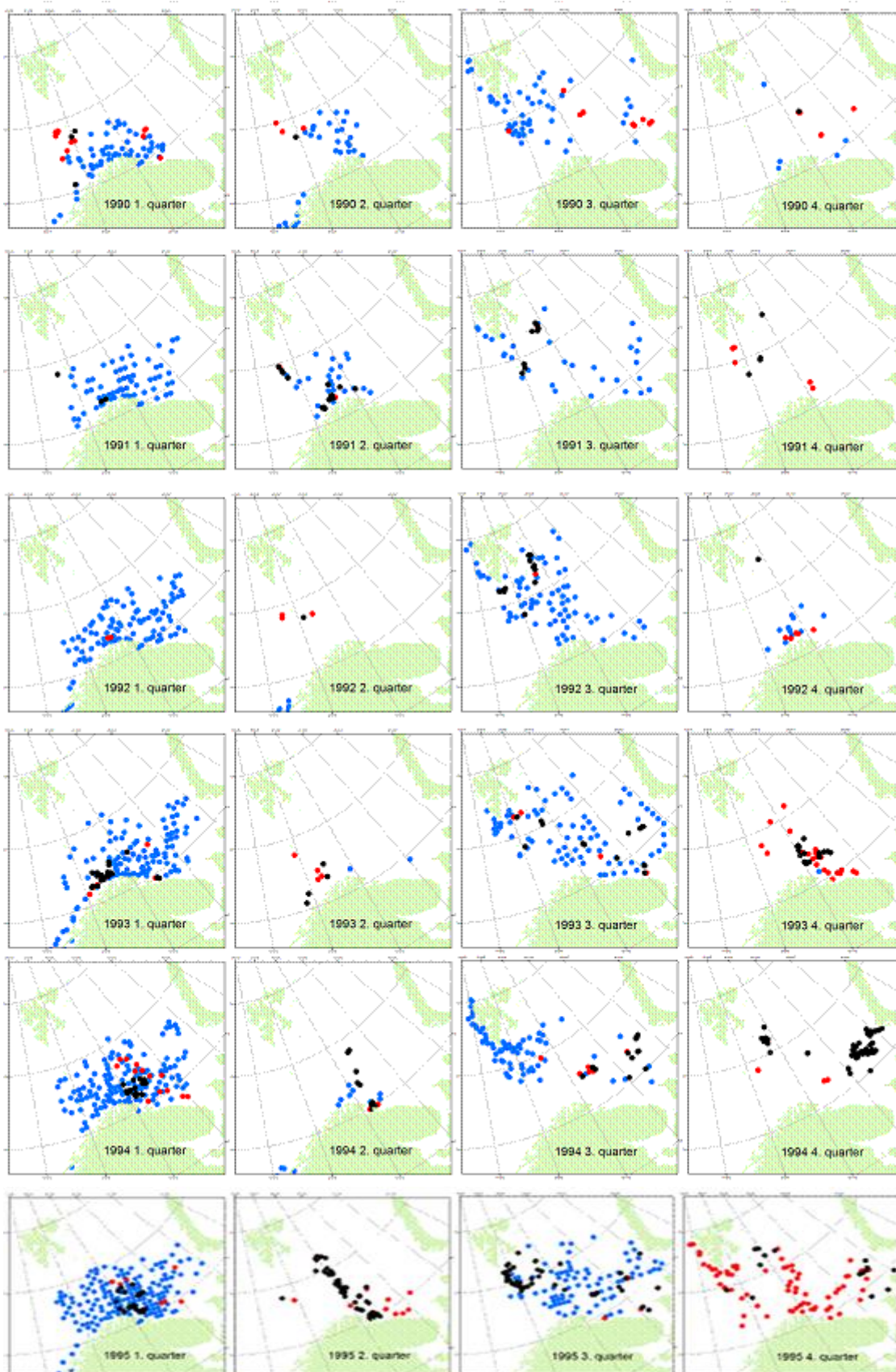
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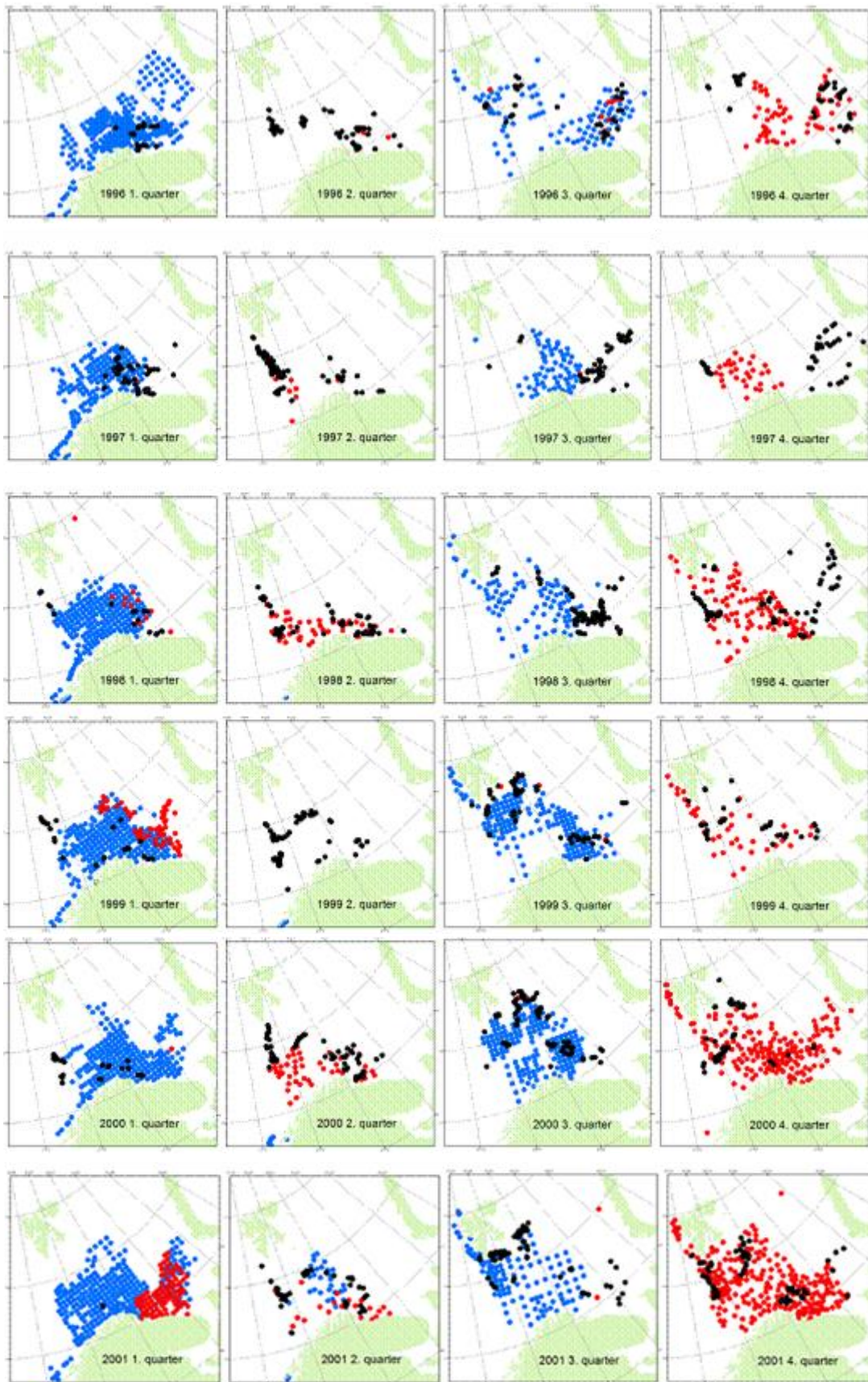
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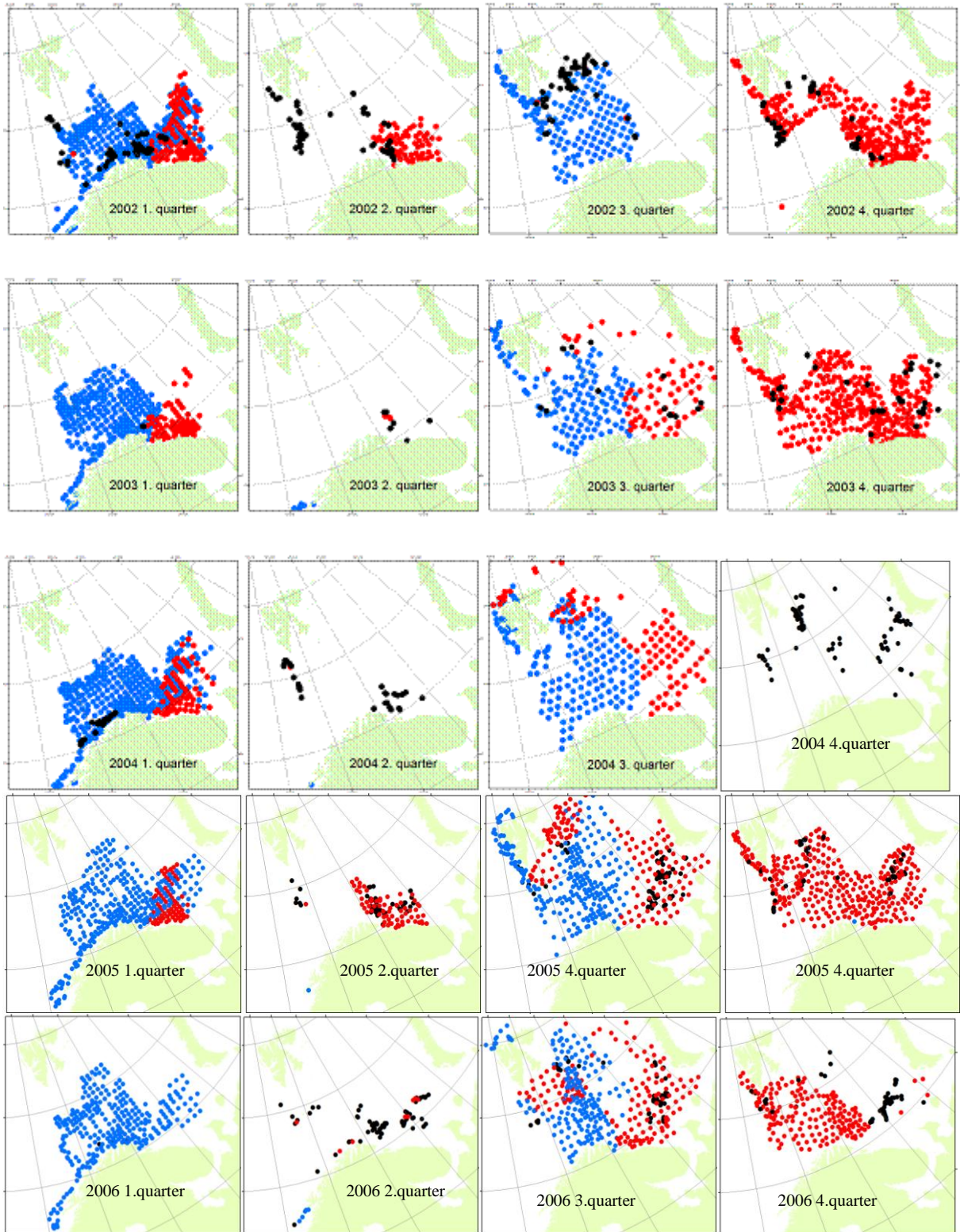
## Appendix 1.

Stations with stomach samples by year and quarter 1984-2006. Blue represent Norwegian stations, red Russian stations with trawling time less than 1.5 h, and black Russian stations with trawling time more than 1.5 h.









# Seabird monitoring and the Barents Sea ecosystem

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Like most high-latitude marine shelf ecosystems, the Barents Sea supports a numerous and diverse group of seabirds (Anker-Nilssen et al., 2000). About 2.7 million pairs of seabirds are estimated to breed in the area. Including non-breeding individuals, the area holds more than 20 million individuals during summer. Large breeding populations of Brünnich's guillemot (*Uria lomvia*), little auk (*Alle alle*) and kittiwake (*Rissa tridactyla*) are found in the Arctic part of the ecosystem. Important food items in this area are associated with the marginal ice zone and include polar cod (*Boreogadus saida*), capelin (*Mallotus villosus*), krill, amphipods and copepods (Mehlum et al., 1996; 1998; Weslawski et al., 1999). The seabird colonies in the Atlantic part of the Barents Sea are dominated by Atlantic puffin (*Fratercula arctica*) in west and Kittiwake (*Rissa tridactyla*) and Common guillemots (*Uria aalge*) in east. Fish larvae of *Gadoids* and herring (*Clupea harengus*) drift along the Norwegian coast into the Barents Sea and supports the large breeding colonies of puffin along the coast of northern Norway (Anker-Nilssen 1992; Durant et al., 2003). Small pelagic schooling fish including, capelin, juvenile herring and sandeels (*Ammodytes* spp.) are important food items for the colonies of eastern Finnmark and Murman (Barrett & Krasnov 1996; Barrett 2002).

Seabird population dynamics, demography and diet are effectively monitored in several colonies on the Russian and Norwegian side (Anker-Nilssen et al. 2005; Krasnov et al., 2007). The establishment of the seabird monitoring program SEAPOP ([www.seapop.no](http://www.seapop.no)) has recently increased the monitoring activity considerably on Svalbard and Northern Norway.

## Monitoring seabirds at sea

Seabirds at sea is commonly monitored from ship based surveys and aircrafts. However, the spatial distribution of seabirds is highly dynamic and variable in time and space (Fauchald et al. 2000, Fauchald & Erikstad 2002) and extensive datasets are needed to give reliable estimates on the abundance and the general spatial pattern of the different species (Fauchald et al. 2002). The Norwegian seabird at sea database ([www.seapop.no](http://www.seapop.no)), contains data from ship based surveys conducted in Norwegian and adjacent waters from 1983 to present. A total of 101 000 km transects are included in the database. Most of the data have been collected as a part of combined research cruises conducted by the Institute of Marine Research. Since 2003, observation of seabirds has been a regular task on the Ecosystem Surveys in the Barents Sea and the Norwegian Sea.

This study reports the average spatial distribution of the eight most common seabird species in the Barents Sea. Analyses were done on 66 500 km of transects from the Norwegian seabird at sea database. The eight species analyzed accounted for 94% of all birds observed on the surveys and included northern fulmar (*Fulmarus glacialis*), herring gull (*Larus argentatus*), glaucous gull (*Larus hyperboreus*), kittiwake (*Rissa tridactyla*), common guillemot (*Uria aalge*), Brünnich's guillemot (*Uria lomvia*), little auk (*Alle alle*) and Atlantic puffin (*Fratercula arctica*). Due to different migratory pattern, the different species varies in seasonal abundance and spatial pattern. Analyses were therefore done on three distinct seasons separately. The data included 11 years of winter (01 Nov. – 31 March) data, 8 years of summer (01 April – 31 July) data and 8 years of autumn (01 Aug. – 31 Oct.) data.

Data were collected by standard strip transect sampling (Tasker et al. 1984). All birds seen within an arc with a radius of 300 m extending directly ahead of the ship to 90° to one side of the ship were counted. Registrations were done when the ship was cruising at speed of approximately 19 km/h. To remove small-scale heterogeneity and to reduce the effect of zero-inflation (see Fauchald et al. 2000, Ciannelli et al. in press), data were aggregated within a radius of 20 km along the transect line. To approach the normal distribution, the density of each species were  $\log(\text{density}+0.01)$  transformed.

Data were analyzed by non-linear regressions using generalized additive models (GAM) (Wood 2006) controlling for yearly variation in abundance. Density was modeled by a tensor product of the positions of the data points (transect segments) in the X and Y –direction (see e.g. Wood 2006, pp.254-262). The model used is given by:  $\text{Log}(\text{Density}+0.01) \sim \text{te}(\text{X},\text{Y}) + \text{factor}(\text{Year}) + \text{Error}$ . Predicted values from the models were used to interpolate the average distributional pattern for each species and season on a 10x10 km<sup>2</sup> geographical grid.

## **Spatial and seasonal distribution of seabirds in the Barents Sea**

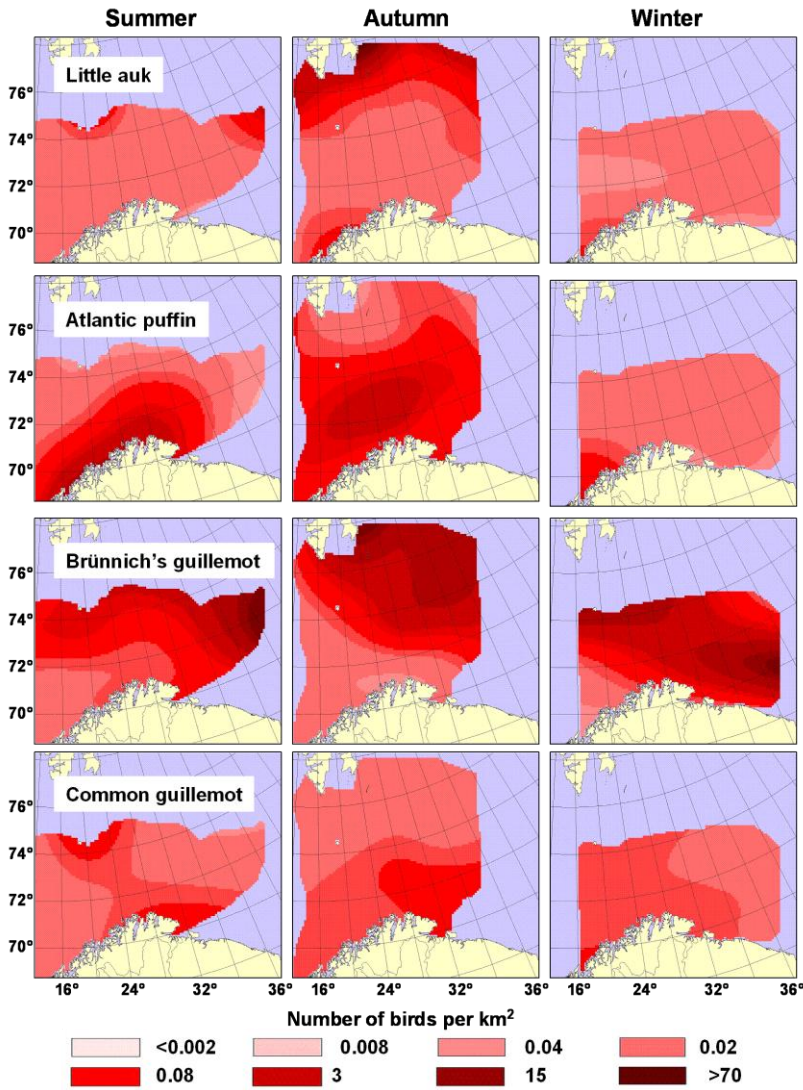
The average distribution of auks in the Barents Sea is shown in Fig. 1 for three seasons. In summer, the distribution of auks reflects their major breeding areas. Puffins are found in high numbers along the Norwegian coast, little auks and Brünnich's guillemots are found in the high Arctic and common guillemots are found around the Bear Island and close to the south-eastern coast. Juvenile fish that drifts with the Norwegian coastal current into the Barents Sea during summer is an important prey for Atlantic puffin at the large breeding colonies along the coast (Anker-Nilssen 1992).

After breeding, puffins seem to migrate after the juvenile fish into the Barents Sea and in autumn puffins are found in a large concentration in the southern and central Barents Sea. In the same period, little auks are found in the northern part of the Barents Sea, close to the ice where they forage on the bloom of zooplankton (Weslawski et al. 1999). Brünnich's guillemots are found in the northern part of the Barents Sea where they possibly track the feeding migration of capelin. Common guillemots are mainly found in the south-eastern part of the Barents Sea.

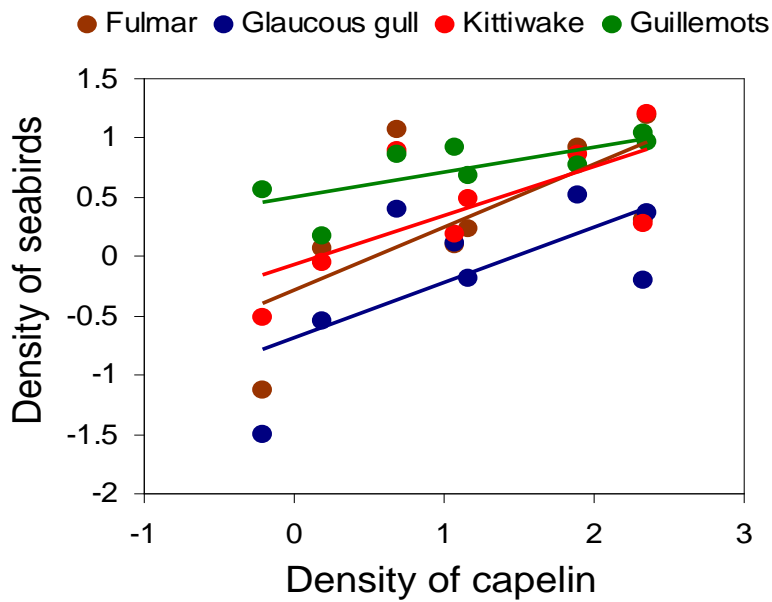
As juvenile fish and crustaceans become unavailable, puffins, little auks and common guillemots migrate southward out of the Barents Sea during winter and only low densities of these species can be found along the Norwegian coast. Data on ring-recovery suggest that Brünnich's guillemots also migrate out of the Barents Sea during winter (Bakken & Mehlum 2005). However, Brünnich's guillemots are in this period found in high densities in the ice-free part of the Barents Sea where they feed on maturing capelin (Fauchald & Erikstad 2002, Figure. 1).

In early spring, the spawning of capelin is a key factor to seabirds in the area (Vader et al., 1990; Fauchald & Erikstad 2002). During years of high capelin abundance, a number of seabird species are attracted to the southern Barents Sea to forage on spawning products and spawning and spent capelin. There is accordingly a positive relationship between the abundance of different seabird species and the abundance of maturing capelin (Figure 2).





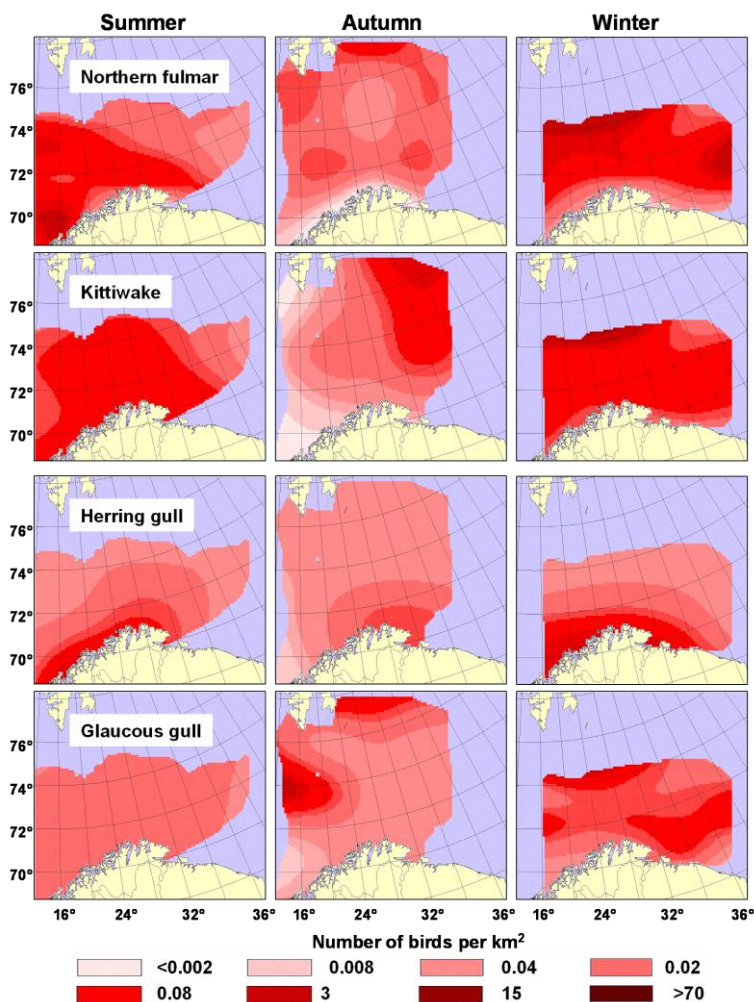
**Figure 1.** Average spatial distribution of auks in the Barents Sea. Colours represent predicted values from a GAM model relating data on densities of birds to position in X and Y direction. Data from the Norwegian seabird at sea database from 1983-2006 were used in the analyses.



**Figure 2.** Relationships between estimated density of different seabird species during late winter and the abundance of capelin in the Barents Sea. Data for capelin are average echo integral values. Values are log transformed. Estimates are from surveys conducted in the period February – March, 1987 – 94.

Figure 3 shows the average distribution of surface feeding seabirds for each season. Kittiwakes and northern fulmars are pelagic surface feeders and are found in relatively high numbers throughout the Barents Sea in all seasons. These species can only utilize the upper half meter of the water column but they are excellent flyers and roam over large areas in the search for sparsely distributed patches of food. They often follow ships and forage on discards from the fishing fleet. For that reason the abundance of these species is probably over estimated.

During summer, fulmars are found in high numbers in the Norwegian Sea and the density decreases eastward into the Barents Sea. In autumn and winter fulmars are abundant in the Barents Sea but they seem to avoid the coastal areas of Northern Norway. Kittiwakes are found throughout the Barents Sea but have a distinct eastward distribution during autumn. The herring gull is a coastal surface feeder. It is opportunistic with a wide diet and is mainly found along the Norwegian coast all year round. The glaucous gull is a large Arctic gull. This species is more pelagic than herring gull, with high concentrations in the central and Arctic part of the area.



**Figure 3.** Average spatial distribution of surface feeding seabirds in the Barents Sea. Colours represent predicted values from a GAM model relating data on densities of birds to position in X and Y direction. Data from the Norwegian seabird at sea database from 1983-2006 were used in the analyses.

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# **Establishment and monitoring of permanently marked habitats on rocky bottom in North Norway and Spitzbergen**

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## **Abstract**

Characteristics of many macrozoobenthic organisms such as sessility or little motility as adults and long life span make them suitable as indicators of environmental influences over long periods of time. Therefore, selected benthic taxa are commonly considered as good indicators of biological changes on long-term scales in marine ecosystems.

Monitoring stations on rocky bottom consisting of either ten or twelve adjacent squares, within depths from 5 to 30 meters, (0.5m\*0.5m) were established in 1976/1980. To ensure the accuracy when revisiting the stations, they are marked by expansion bolts drilled into the rocky bottom. The stations are localised at the coast of North-Troms and Finnmark county (4 stations) and at Spitzbergen (3 stations). Photographs are taken annually. An experimental design was implemented at some of the stations. Here all organisms from half of the monitored area were removed and the rest were left untouched. This allows us to study colonisation and succession of fauna. Relevant variables studied were species composition, abundance, individual growth, and fluctuation in cover of colonial species etc. Such data were used to calculate diversity indexes. Variation over time in diversity indexes has been related to oscillations in climate indexes. Knowledge and understanding about the natural variation in biodiversity is necessary in order to quantify possible effects of human impact on the environment.

Challenges related to methods were especially treatment and analysis of the underwater photographs using up-to-date scanning techniques (making it better and less time-consuming by automatisation), introduction of digital photography (implemented from 2004), and development of statistical multivariate techniques.

## **Introduction**

Indications and evidences of the climate being in a transitory state and becoming warmer, is almost daily being presented in news headlines. Scientists all around the world, and especially in colder regions, are dealing with this important issue, though with somewhat different angles of view according to profession. Oceanographers have registered an increase in average temperature in the seas and this seems to be most pronounced for seas located at high latitudes. Marine ecologists put much effort into investigations concerning alteration in biodiversity related to this variation in temperature.

In general, marine ecosystems display large natural fluctuations in species composition, species numbers and abundance of individuals. It is both important and essential to have knowledge of natural variability in such factors when questioning effects of e.g. pollution, in order to find relationship between the pollutant and changes in ecosystem.

Benthic animals are organisms which spend their lives in close association with the seafloor, in contrast to plankton and nekton which live in the free water masses. Benthic organisms are often used in studies aiming at verifying biological effects of pollution due to their sessile life strategy and reduced ability to escape and avoid possible pollution. Furthermore, temporal studies of distribution in benthic organisms may release information of changes/ alterations in sea climate. During the last decades there are several examples where benthic organisms have established new and usually a more northerly boundary in their distribution pattern along the coast of Norway, e.g. the edible crab (*Cancer pagurus*) and common lobster (*Homarus gammarus*).

The soft bottom communities have traditionally been used when monitoring biological effects of pollution. The petroleum industry on the continental shelf is required to make environmental studies of soft bottom fauna in the areas where oil exploitation is taking place. The frequent use of soft bottom organisms has close relation to the general trend in developing techniques and methods to collect data from marine environments. Using surface-operated tools such as various types of grabs, box-corers and sledges, has made it more convenient to collect data from soft sediment environments than from rockier bottom substrate. However, such sampling is done in a destructive manner, meaning that the fauna investigated is physically removed and thus not suitable in following the organisms through their whole life cycle.

During the last 20 years the development of increasingly better sampling techniques using SCUBA diving has made it more and more relevant to use rocky bottom benthos to study variations in ecosystems (and also effects of e.g. pollution). We want to show here that a good example of non-destructive sampling is underwater photography using SCUBA diving.

It might even be more appropriate to use rocky bottom benthos in preference to soft bottom, when monitoring effects of pollution. This is especially evident in areas with high sedimentation rates because sedimentation has a tendency to mask effects in soft bottom communities. In rocky bottom benthos, the effects of sedimentation are usually less important.

## **Regular photographic monitoring**

Questions can be raised as to whether rocky bottom substrate are suitable for monitoring in general. To approach this matter the following summary of characteristics in macrozoobenthic organisms may partly answer the question:

- Many organisms have long life spans (from years to decades, especially in the abundant colonial organisms).
- Many organisms are sessile/semi-sessile and have reduced motility as adults.

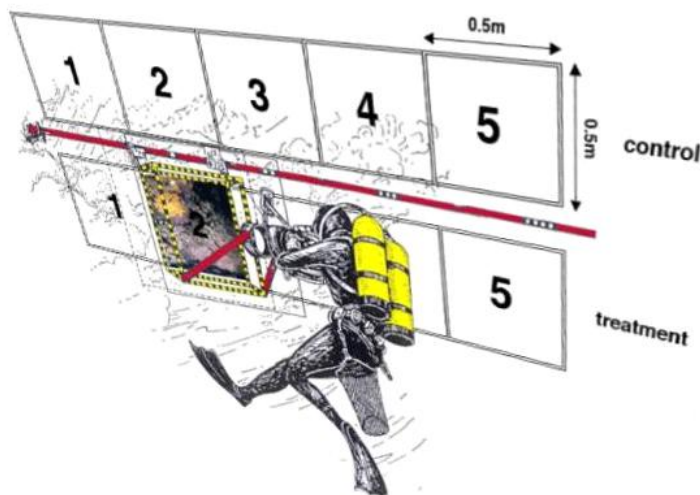
Many organisms on rocky bottom have therefore a potential for accumulating environmental influences over long periods of time, and such organisms can therefore be considered as excellent indicators of alterations (natural, human made etc) in marine ecosystems.

Further, when using underwater photography as sampling tool, why select a rocky bottom substrate? In addition to the biological aspects mentioned above, there is also a practical reason for this, as there are less infaunal organisms on rocky bottom and a predomination of filter feeding organisms. In the end this will increase the observational success when analyzing the photographs (i.e. doing the image analysis - see later).

## Methodology in fieldwork and practical solutions

In our long time monitoring of marine rocky bottom communities we have used a modified technique based upon stereo photography of permanently marked bottom areas. This technique was first described by Lundälv (1971) and later by Torlegård and Lundälv (1974). Stereo photography is a technique to make two photographs of the same subject, from slightly different positions. For normal close, small objects, the two positions should differ approximately by the human eye distance (about 10cm or 4"). This option makes it possible to observe pictures in a 3-dimensional way, which might open for new and relevant study aspects (e.g. more exact measurements of surface area of colonial organisms etc.). We have in our analysis not yet utilized the full potential in stereo photography and hence we make use of only one of the two photographs from each square.

In the following we will shortly explain the major elements in the monitoring setup (Figure 1). On the seafloor the area of interest is marked with two expansion bolts drilled into the ground/ bottom. The distance between these two bolts is typically 2.5 meter and a steel bar is fitted and mounted onto the bolts. Further, a metal rig secures that the area of each picture is 0.25 m<sup>2</sup> and a digital SLR camera and flashes in underwater housings are mounted onto the rig.



**Figure 1.** Schematic outline of monitoring setup (Lundälv 1971, modified by Frank Beuchel, NCFS, University of Tromsø).

As indicated in Figure 1, the monitoring can be extended to include an experimental design, aiming at studying faunal succession/ recolonization after removal of all fauna from the seafloor. We have implemented this at our stations in Spitzbergen waters, where ice scouring is not unlikely to happen and hence the topic is highly relevant.

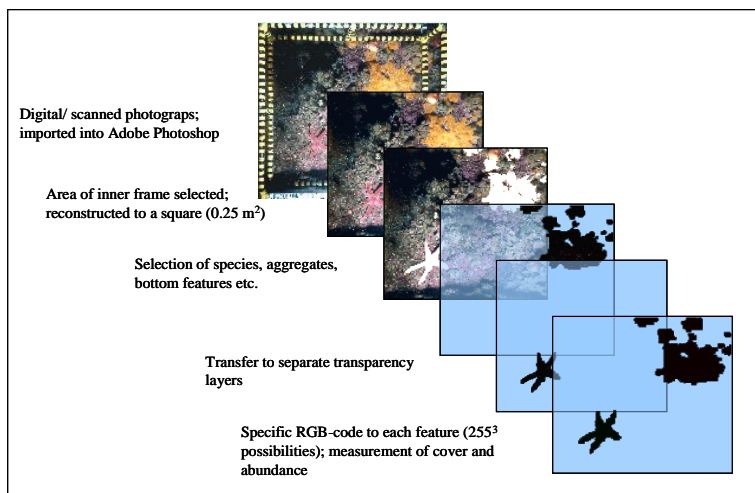
Following the outlines above we are secured that every time a station is revisited the exact same areas are photographed and thus the fauna can be followed over long periods of time. The stations were mounted in the period 1976 – 1980, and photographed at least once per year since then. The monitoring technique can be summed up as in Table 1.

**Table 1.** Advantages and disadvantages using photography in monitoring.

Advantages	Disadvantages
Non-destructive sampling on the localities/ stations allows repetitive investigations of the exact same areas	Limitation in lower size of organisms that can be identified from pictures
Large amount of raw-data collected with limited time expenditures	Must disregard infaunal (where sediments are accumulated) and cryptic organisms
Quantitative and qualitative sampling	The use of SCUBA diving in sampling limits maximum depth of sampling
The method follows up guidelines given in <i>Norsk Standard</i>	

## Image processing and data analysis

Doing picture analysis is a rather time- and resource consuming activity, due to the, very often, high complexity in biodiversity found on rocky bottom substrate. PhD candidate Frank Beuchel (Norwegian College of Fishery Science, University of Tromsø) has developed a semi-automated analysis procedure, based on the software Adobe Photoshop, to reduce the time required to analysis large amounts of pictures/ images. The following schematic outline is here redrawn and presented with permission from Beuchel and must be read as a synopsis of his analysis procedure (Figure 2). During this procedure, numbers and measurements of species abundance and colonial organisms/ aggregates are produced in ordinary spreadsheets, for further statistic treatment.



**Figure 2.** Schematic outline of the analysis procedure (after Frank Beuchel, NCFs, University of Tromsø).

## Scope of results from the long time monitoring

The monitoring here described was initiated in 1976/1980 by Prof. Bjørn Gulliksen (NCFs, University of Tromsø) and is still continued. It consists of four stations at the coast of Northern Troms and Finnmark County and three stations on Spitzbergen (including Bear Island).

From the long time monitoring as described herein, an array of interesting and relevant topics can be approached. Relevant findings can be temporal variations in biodiversity and faunal



composition (i.e. species numbers, abundance of solitary organisms, cover of colonial organisms) and thereafter one can search for solutions why this has happened. The reasons for any temporal changes in biological parameters might be multiple, but it is of utmost importance to have, through the datasets, a feeling of what can be subscribed to an external factor and not displayed from natural variation in the fauna. This is the strength of long time monitoring in general, meaning it can provide you with data of the “prior” situation of the fauna in an area.

When having access to data from earlier years it is possible to make more reliable studies of any variation in the fauna as well as interannual changes in benthic communities. As mentioned, faunal succession and recolonisation can be described and used in later studies where i.e. pollution may create a similar situation. Doing sampling by taking photographs the organisms’ life cycle can be followed, which releases several interesting aspects both in ecology and autecology of species. Information on the community level, as species diversity, density or lack of species in an area, can be supported by parameters as growth rates and morphological alterations in selected species.

Another topic is faunal variation related to climate changes. This has been a theme for Frank Beuchel (NCFS, University of Tromsø) in his PhD studies and an excellent example can be seen in Beuchel et al. (2006). Here he used a long time monitored station in Kongsfjord (Spitzbergen) and treated data from the period 1980-2003. He found strong correlations between changes in the benthic community structure and major shifts in the NAOI regime.

## **Litterature**

Beuchel, F., Gulliksen, B., Carroll, M.L. 2006 Long-term patterns of rocky bottom macrobenthic community structure in an Arctic fjord (Kongsfjorden, Svalbard) in relation to climate variability (1980 – 2003). *Journal of Marine Systems* 63:35-48.

Lundälv, T. 1971. Quantitative studies on rocky bottom biocoenoses by underwater photogrammetry. *Thalassia Jugoslavica* 7(1): 201-208.

Torlegård, K., Lundälv, T. 1974. Under-water analytical system. *Photogrammetric Engineering and Remote Sensing* 40: 287-293.

## ***Theme Session II: Development and improvement of new methods and models***

### **Fifteen years of annual Norwegian-Russian cod comparative age readings**

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#### **Extended abstract**

*(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation.)*

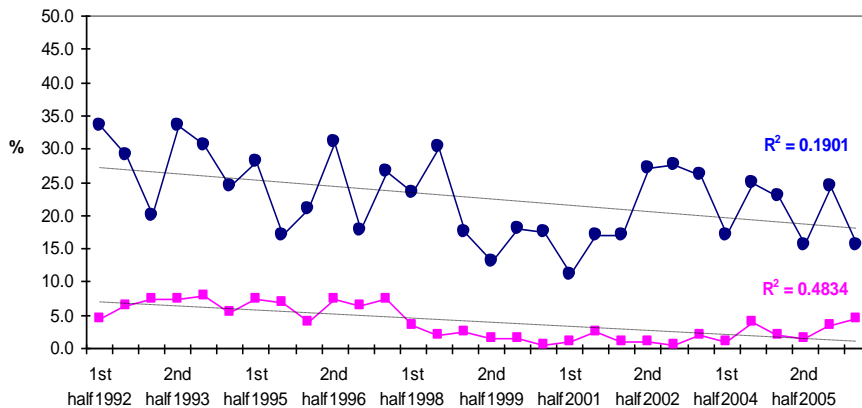
Fish age readings with great accuracy and precision are fundamental to any age-based fish stock assessments. Age estimation errors may result in incorrect estimation of age structure of the population, misinterpretation of age composition of fish caught, and incorrect estimation of year-class strengths. At the end, current abundance and “stock-recruitment” relationship could be distorted. Besides, age estimation errors may affect estimates of fish biological parameters, such as mean length/weight-at-age, proportion mature, and fecundity at age used in the estimation of fishable and spawning stock biomass. All the above said may entail wrong advices of the fisheries management. Moreover, it may lead to overestimation or underestimation of growth and maturity rates, condition factor and index of stomach fullness by age, which may blur the observation of any relationship with environmental parameters (sea temperature, abundance of food objects, and other environmental and ecological factors).

Annual exchange of material for age determination and of specialists between the laboratories of PINRO (Murmansk, Russia) and IMR (Bergen, Norway) was initiated in 1992. At first, it was necessary to check up paradoxical discrepancies between PINRO and IMR data obtained in trawl acoustic surveys in the Barents Sea using approximately similar fishing gear. The discrepancies were particularly high for the 1990-1991 cod data. This became a reason to advert to the problem of cod age determination with the aim of clearing up possible reasons for age discrepancies. It turned out that this cooperation was of great benefit for specialists of both institutes; and meetings of specialists and exchange of samples became regular.

In all, 6386 pairs of otoliths were exchanged during 1992-2006, and 1331 of these were repeatedly read at the annual joint age readers’ meetings. The otoliths exchanged were selected at random (though with some area constraints) from the IMR and PINRO otolith archives. Results of initial age readings were not presented to the other institute upon delivery in order to get blind age reading. At the annual meetings, the specialists re-examined only those otoliths which were read differently, using a discussion binocular. The specialists discussed the otolith structure and, finally, came to an agreement and changed their initial results or continued to disagree. In most cases an agreement was reached. Microsoft Access and Microsoft Excel software was used for the analysis of results. The values of between

reader biases and their significance were determined using STATISTICA and the nonparametrical statistical module Wilcoxon Matched Pairs Test and Sign Test.

The largest initial differences were observed in the first half of the year of 1992 and in the second half of 1993, whereas the smallest ones in the second half of 1999 and in the first half of 2001 (Fig. 1). In total a significant trend of decrease of discrepancies of the initial age determination by specialists of the two laboratories can be seen ( $R^2 = 0.19$ ). The discrepancy after discussing and re-reading the initial disagreed otoliths has in recent years been less than 5%.



**Figure 1.** Percentage of discrepancies in the annual (twice per year) comparative cod age readings. Initial discrepancy before joint reading and discussion are shown by the dark curve, and the discrepancy after re-reading and discussion by the pink curve.

Insignificant differences were obtained in 1997-2000, while in the rest of the years differences were significant with the most pronounced ones in 1993-1994. Although a clear systematic bias between age determinations was not always observed, Russian estimates usually showed older age compared to corresponding Norwegian estimates.

Otoliths from the Bear Island-Spitsbergen area should be admitted as the easiest to read (the determined age by the two laboratories coincided in 83.2% of the cases) and otoliths from the southern Barents Sea as the most difficult for age reading (coincided in 75.7%). The intermediate position is occupied by otoliths of cod caught at the north-eastern coast of Norway (coincided in 76.3%).

Discrepancies in age estimates increased with cod age. Based on pooled data for all the years investigated, differences on one-year-olds occurred in only 10.1% of the cases, while in twelve-year-olds differences occurred in 85.7% of the cases. A significant linear trend was observed indicating a decrease in percentage of agreed age estimates by cod age.

Significant between reader biases were noted in fish at age 1-5 years, while no significant biases were observed in fish at age 6-9 and 11 years. For fish older than 11 years very little material was collected to get an indisputable answer. It should be noticed, that the trend in differences in age reading has an S-shaped curve, i.e. in young age groups Norwegian experts are inclined to underestimate the age compared to Russian experts, but from age 7 onwards the trend is opposite.

Important lessons have been learned from these fifteen years of regular and systematic age reading cooperation. Standardization of equipment is an initial and essential step. It is

necessary to evaluate the readers' abilities and to standardize the methods. Specialists should be trained for several years to promote continued consistency among readers. Understanding of mechanisms used for assigning the fish age permits avoidance of serious errors in our routine work and enables us to discover and correct errors immediately and, therefore, to avoid the accumulation of errors over time. Clearly, the differences in cod age reading between two laboratories have apparently decreased over the cooperation period, although we could wish that the "learning-curve" had been steeper.

There is an indisputable necessity in regular meetings and tunings of age readers. The scientific biological, and hence also the economic effect, of this work is obvious.

# Building time series of female reproductive parameters for Northeast Atlantic harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*)

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## Introduction

Collaboration between Norwegian and Russian Scientists in seal research dates back at least a hundred years to the joint publication of “Bericht über die Lebensverhältnisse und den Fang der nordischen Seehunden“ by Johan Hjort and Nikolai Knipovich in 1907.

The history of joint Norwegian-Russian exploitation of seals dates back even longer, but already in the early days of the Soviet Union, joint research plans were set up to provide guidance on the regulation of sealing effort in the White Sea area (Sivertsen, 1941). Joint research on seal biology was in fact one of the premises in the Soviet concessions to Norwegian sealers in the White Sea in the 1920s (Sivertsen, 1941).

In the mid 1950s, Soviet sealing vessels joined the Norwegian vessels on the sealing grounds in the Greenland Sea pack ice. Since then Norway and Russia have jointly exploited, monitored and managed the Greenland Sea populations of harp and hooded seals as well as the Barents Sea/White Sea harp seal population.

High postwar exploitation rates called for improvements in the understanding of harp and hooded seal population dynamics (Sergeant, 1991). Thus, driven by need and inspired by a new method for age determination of mammals based on teeth (Scheffer, 1950; Laws, 1952), both Russian and Norwegian scientists initiated sampling of age specific reproductive data in the late 1950s. In the following years, Russian and Norwegian scientists made many contributions to the scientific literature on the reproductive biology of seals (e.g. Popov, 1960; Øritsland, 1964; Jakovenko and Nazarenko, 1967; Khuzin, 1972). Regular sampling of teeth and ovaries has continued until recently resulting in accumulation of long-term data series on female reproductive traits such as mean age at maturity (MAM). This type of data is needed for models converting pup censuses into total population sizes (e.g. ICES, 2004) and the dynamics of MAM itself may be used as an indicator of per capita resource levels (Eberhardt and Siniff, 1977).

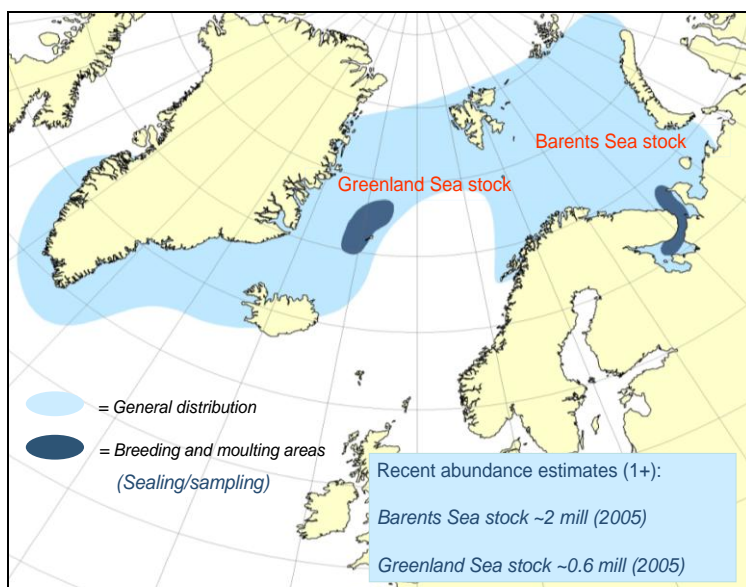
Obtaining representative samples from the wide-ranging Northeast Atlantic stocks of harp and hooded seals requires a considerable sampling effort. It is therefore desirable to combine data sets, which in turn requires a common understanding of procedures for sampling, laboratory analyses and statistical analyses. This common understanding has developed over the years through cooperation in various fora such as the scientific committee of the Norwegian-Soviet Sealing Committee operating from 1959 to 1984 (Bjordal et al, 2004).

From 1991 onwards, the Joint ICES-NAFO working group on harp and hooded seals (WGHARP) has been the principal scientific advisory body for management. WGHARP comprises scientists from Russia, Norway, Canada, Greenland, the USA and the EU and thus represents a multilateralisation of seal management advice reflecting the transatlantic distribution of both harp and hooded seals.

Political changes in Russia in the late 1980s facilitated direct scientific collaboration and led to an increase in joint publications on various aspects of seal biology including distribution (e.g. Haug et al, 1994), diet (Nilssen et al, 1995; Potelov et al, 2000) and reproductive biology (Frie et al, 2003). This paper reviews results from recent years Russian-Norwegian cooperation on harp and hooded seal reproductive biology and also provides some transatlantic and future perspectives on this research.

## Harp seals

Due to their high abundances, the Barents Sea/White Sea harp seal stock (~2 million animals) and the Greenland Sea harp seal stock (~600000 animals) are important components of their respective ecosystems (ICES, 2004). They are significant predators on krill, amphipods and smaller forage fish such as capelin (*Mallotus Villosus*), polar cod (*Boreogadus saida*) and herring (*Clupeus harengus*) and are themselves preyed upon by polar bears and hunted by humans (Nilssen et al, 2000; Derocher et al, 2002; ACIA, 2005).



**Figure 1.** Distribution of Northeast Atlantic harp seals.

The so-called harp seal invasions during the Barents Sea capelin crash in 1986-1988 increased the public and scientific focus on harp seal ecology and population dynamics and a number of studies were initiated, many of them funded by the Norwegian Fisheries Research Council under the Marine Mammal Research Programme running from 1988-1994 (See Blix et al, 1995). During this period, there was also a renewed interest in harp seal reproductive studies. Based on different data sets and analytical approaches, researchers from Norway and Russia found a considerable reduction in reproductive rates of female Barents Sea/White Sea harp seals from the 1960s to the late 1980s (Kjellqwist et al, 1995; Timoshenko, 1995). Both studies related their findings to the decrease in abundance of winter forage fish such as

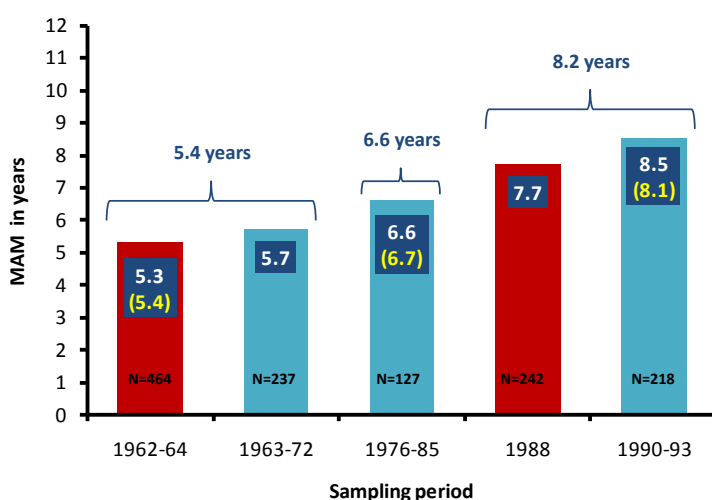
capelin, herring and polar cod in the southern Barents Sea. Yuriy Timoshenko titled his paper “Harp seals as indicators of the Barents Sea ecosystem, and was thus an early advocate of the ecosystem approach.

Kjellqwist et al (1995) estimated mean age at maturity of Barents Sea/White Sea harp seals based on age specific accumulations of ovarian corpora and found an increase in MAM from 5.5 years in 1963-1972 to 8.1 years in 1988-1993. The term ovarian corpora refers to various stages of the *Corpus luteum* - a hormone producing structure formed annually at ovulation. Regressing stages of *Corpora luteae* usually remain visible in the ovaries for several years after formation.

The estimated values of MAM in the late 1980s are considerably higher than the previous record for the species of 6.1 years estimated for Northwest Atlantic harp seal stock (Bowen et al, 1981) and the results caused some discussion in WGHARP. Were the observed inter-stock differences real biological differences or results of methodological differences? Had a similar increase in MAM occurred in the Greenland Sea stock?

These questions were later addressed in a joint Norwegian-Russian-Greenlandic publication analysing combined Norwegian and Russian reproductive data from the Barents Sea/White Sea harp seal stock and Russian data from the Greenland Sea harp seal stock (Frie et al, 2003). This time MAM was estimated from age specific proportions mature by a method similar to the one previously used in the Northwest Atlantic, thus allowing direct comparisons of estimates.

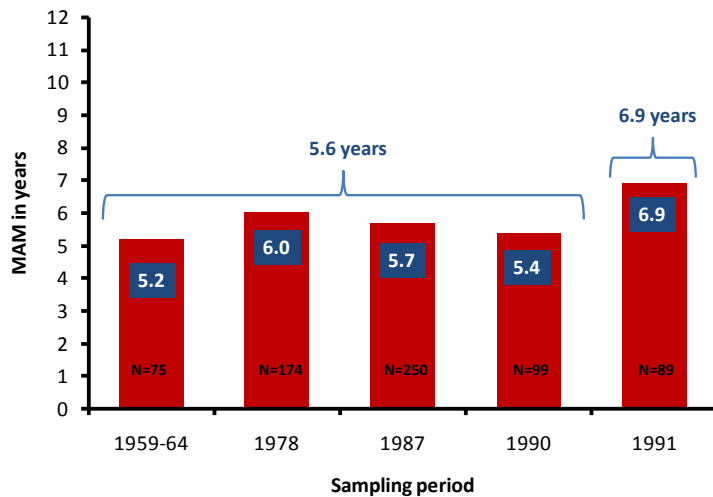
For the Barents Sea/White Sea stock, the analysis of MAM (Figure 2) showed very similar results for Norwegian and Russian data sets indicating inter-laboratory consistency of routines on age determination and ovary analysis. The values of MAM derived by the new method were also very similar to the values previously found by Kjellqwist et al (1995).



**Figure 2.** Estimates of MAM for moult patch samples of White Sea/Barents Sea harp seals. White numbers in blue squares indicate MAM estimated from age specific proportion mature according to Frie et al (2003). Yellow numbers in blue squares indicate MAM as estimated by Kjellqwist et al (1995) based on quantification of ovarian scars. Parentheses show groupings of samples based on maximum likelihood tests and numbers above parentheses indicate MAM estimated from the most parsimonious model as described in Frie et al, 2003. Black numbers on the bars indicate sample sizes.

The Greenland Sea material differed from the White Sea/Barents Sea material in that there was no clear long term trend in MAM, and the values of MAM were significantly lower than for the Barents Sea/White Sea harp seal stock in the late 1980s (Figure 3). The data show a rather clear ecological differentiation between the two Northeast Atlantic harp seal stocks,

indicating that young seals from the two stocks are likely to rely on different prey bases. This, together with observed differences in the seasonal timing of breeding, supports the current delineation of management units even though population genetic studies so far have not found evidence for population subdivision between the two areas (Perry et al, 2000).



**Figure 3.** Estimates of MAM for Russian moult patch samples of Greenland Sea harp seals. White numbers in blue squares indicate MAM estimated from sigmoid maturity curves fitted to age specific proportion mature according to Frie et al (2003). Parentheses show groupings of samples based on maximum likelihood tests and numbers above parentheses indicate MAM estimated from the most parsimonious model as described in Frie et al, 2003. Black numbers on the bars indicate sample sizes.

Using MAM as an indicator of per capita resource levels, it is noteworthy that the Barents Sea/White Sea harp seal stock with a maximum observed abundance of around 2 million animals has displayed a significantly higher MAM than the Northwest Atlantic stock with a maximum observed abundance of around 5.5 million animals (DFO, 2005). This probably indicates significant differences in carrying capacity between the Barents Sea and the Northwest Atlantic but the results could also be at least partly due to potential differences in sampling probabilities of mature and immature seals between areas or systematic differences in age determinations between Canadian and Russian/Norwegian labs.

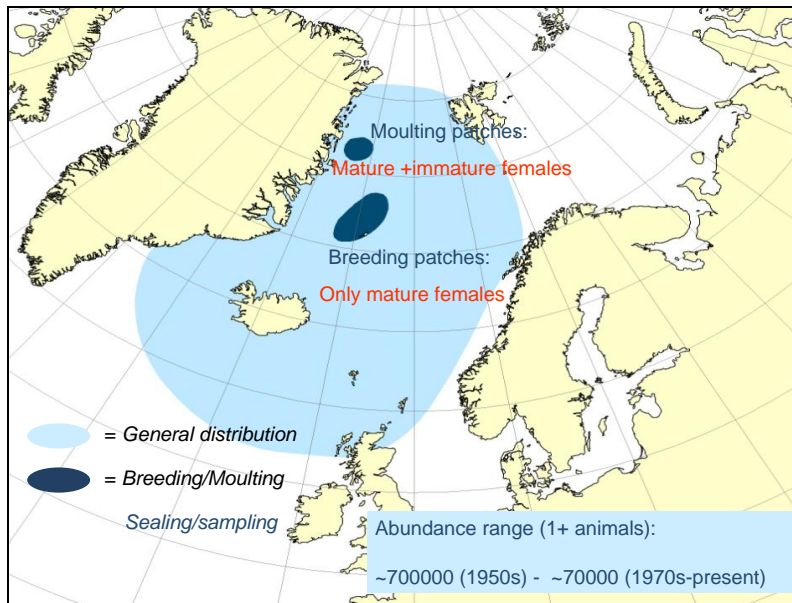
Ongoing and planned harp seal satellite tagging programs on both sides of the Atlantic are likely to shed more light on questions regarding spatial and/or temporal differences in distribution patterns of mature and immature harp seals and which (if any) effect this has on the estimation of reproductive rates. So far, satellite tagging in the Northeast Atlantic has primarily focused on mature animals (Folkow et al, 2004), but for the understanding of population dynamic factors, the distribution of immature animals, particularly females, is equally important. Hopefully a joint IMR/PINRO satellite tagging project planned to start in 2008 will provide this type of information.

The role of age determination biases is currently being evaluated based on results from an Internordic/Russian/Canadian age determination workshop held at the Institute of Marine Research in Bergen in 2006. The workshop included a blind-reading experiment based on images of more than 100 tooth sections from known age harp seals, which have been tagged as pups during joint Norwegian –Russian tagging operations in the period 1977-1991. Age readers from all laboratories regularly engaging in age determination of harp seals participated in the experiment and considerable inter-reader variability was found. Simulation studies are underway to assess the possible effect of age reading errors on age related parameters. This workshop reflects a general trend towards closer integration of monitoring methodology between institutes participating in WGHARP. Continued collaboration aimed at identification and reduction of methodological biases, will facilitate future ecosystem level comparisons of seal population dynamics across all of the North Atlantic.



## Hooded seals

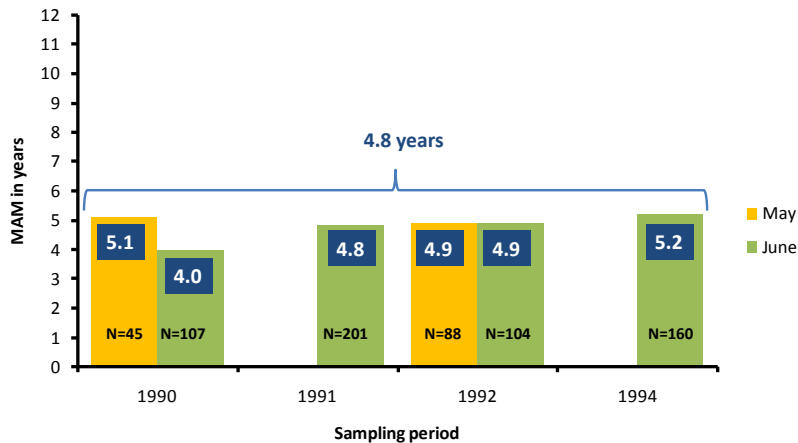
Like harp seals, hooded seals are ice-breeding seals distributed on both sides of the North Atlantic (Coltman et al, 2006) (Figure 4). The Greenland Sea hooded seal stock breeds and moults in the Greenland Sea pack ice, while the Northwest Atlantic hooded sea stock primarily breeds in the Labrador Sea and moults in the Denmark Strait (Sergeant, 1991). Almost all published data on reproductive rates of hooded seals are from the Northwest Atlantic Stock and have indicated a remarkably early age at maturity in females (2-4 years) and pregnancy rates close to 100% (Øritsland, 1964; Born, 1982).



Despite a relatively large sampling effort, no stock specific estimates of reproductive rates have actually been available for the Greenland Sea hooded seal stock in the past and modeling has therefore relied on data for the Northwest Atlantic stock. In 2005, the total pup production of Greenland Sea hooded seals was estimated at 15000 pups (CV=24%), which is only about half of the amount caught annually by sealers in the 1950s and 1960s (ICES, 2007). Modeling suggests that the reduction in pup production may represent a 10-fold decrease in total abundance from the 1950s to 2005 (ICES, 2007).

While high exploitation levels are likely to have driven most of the decline, the apparent lack of recovery, following a significant decrease in hunting pressure in the 1980s, is somewhat surprising and unlike the development in the Northwest Atlantic stock (ICES, 2007). This situation has highlighted the need for stock specific population parameters (ICES, 2007) both for historical population models and current management models. In order to maximise data quantity and quality, joint Norwegian -Russian analyses of all available historical material are currently being conducted and some preliminary results can be presented.

A common MAM of 4.8 years (see Figure 5) could be fitted to Russian moult patch samples from the period 1990-94 regardless of month of sampling. This is the highest MAM on record for hooded seals. Using the same methods to fit MAM to two Northwest Atlantic data sets from 1956-60 (Øritsland, 1964) and 1970-71 (Born, 1982) a common value of 3.1 years is found (ICES, 2007).



**Figure 5.** Estimates of MAM for Russian moult patch samples of Greenland Sea hooded seals. White numbers in blue squares indicate MAM estimated from age specific proportions mature according to Frie et al (2003). Parentheses show grouping of samples based on maximum likelihood tests and numbers above parentheses indicate MAM estimated from the most parsimonious model following principles described in Frie et al (2003). Black numbers on the bars indicate sample sizes.

The difference in MAM between Greenland Sea samples and Northwest Atlantic samples is both statistically and biologically significant, but as the sampling periods are 20-30 years apart, it is impossible to determine, if the split represents a spatial or a temporal difference. Nevertheless, the high MAM found for Greenland Sea hooded seals seems to suggest, that the stock experienced suboptimal resource availability during a period of historically low abundance in the late 1980s and early 1990s and that a reduction in food availability may be playing a role in preventing recovery of the stock.

The hooded seal is a deep diving species thought to forage to a large extent on meso- and bathypelagic prey species such as redfish (*Sebastes spp.*), Greenland halibut (*Rheinhardtius hippoglossoides*), blue whiting (*Micromesistius poutassou*), herring and the squid *Gonatus fabricii* (Folkow et al, 1996, Haug et al, 2007). In drift ice areas, polar cod, capelin and sand eel (*Ammodytes spp.*) are the most important prey species in addition to *Gonatus fabricii* (Haug et al, 2007).

Several of these prey species have shown very dynamic abundance and distribution patterns over the past 50 years, but our understanding of the relative importance of prey species for hooded seals is still too limited to establish any likely relationships between prey dynamics and hooded seal reproductive rates.

Unfortunately this Russian data set is the only moult patch data available for Greenland Sea hooded seals and therefore no long-term trends in MAM can be extracted. However, long-term ovary data from breeding patches exist and are currently being analysed by us. Breeding patch material only comprises data from mature females, and analyses therefore rely on quantification of age specific accumulation of ovarian corpora. This type of analysis is more prone to reader biases than simple classifications of females as either mature or immature and to ensure comparability of data in time and space, calibrations of ovary readings between readers are to be conducted before the analyses can be completed.

## Future Perspectives

There is currently an urgent need for updates on female reproductive rates for both harp and hooded seals in the Northeast Atlantic. In recent years, high quality pup production surveys have been carried out for all three stocks but the conversion to absolute population abundances unfortunately have to rely on outdated reproductive data from the early 1990s (ICES, 2004; ICES, 2007). Sensitivity analyses of the currently used population models

(ICES, 2005), suggest this may have a significant impact on the total abundance estimates, which are the basis for catch quota calculations and estimation of seal prey consumption.

Harp seals are the most abundant mammals in the Barents Sea and they are resident year round (Haug et al, 1998). Understanding the dynamics of harp seal prey consumption is therefore a key element in ecosystem research and management in the Barents Sea. This is acknowledged in a recent advisory report to the Norwegian government on ecosystem management of the Barents Sea listing total abundance of harp seals as well as MAM as relevant ecosystem indicators in the Barents Sea (Quillfeldt et al, 2005).

In the past, harp and hooded seals have sustained high catch levels and hunting mortality has widely been regarded as the primary driving factor for population growth rates (Stortingsmelding 27, 2004). In the past 2-3 decades, hunting pressures have been historically low for the Northeast Atlantic stocks of harp and hooded seals, but the population trajectory seen in Greenland Sea hooded seals suggests that other factors than the catches may significantly affect population growth rates. The importance of environmental conditions is also highlighted by the scenarios for global warming, which is expected to have a negative impact on the population dynamics of arctic seal species through loss of breeding habitat (ACIA, 2005). Climate change is also likely to affect resource availability for harp and hooded seals but the population dynamic effect of this is harder to predict. Implementing the precautionary approach to management, WGHARP recommends updates of pup production estimates and reproductive parameters every 5 years. Otherwise a given stock is characterised as data poor and recommended catch options will be restricted (ICES, 2004).

Some new reproductive material has been collected from Northeast Atlantic harp and hooded seals in recent years, but based on previous experience, sample sizes are not yet sufficient to derive reliable estimates of MAM. For harp seals, sampling of reproductive data can be carried out at relatively low cost from Norwegian sealing vessels operating in the moulting period (April-May). For hooded seals, on the other hand, dedicated cruises are necessary to obtain samples from moulting patches as all regular hunting takes place in the breeding season.

In addition to the classical monitoring of age at maturity, extraction of actual age specific late term pregnancy rates, would greatly enhance population dynamic models. However, this would either require expensive dedicated sampling efforts in the period immediately prior to the breeding season or development of reliable methods for indirect estimation of pregnancy rates based on sampling at other times of the year. Together with Canadian and Greenlandic colleagues, Norwegian and Russian researchers are currently seeking funding for research projects aimed at increasing our understanding of reproductive processes in female seals and identification of morphological and/or biochemical characteristics, which will allow us to record the most important reproductive events from a variety of sample types.

Continuation of the existing time series on MAM and age specific corpora accumulation is valuable in its own right, because they represent long term indicators of habitat quality for harp and hooded seals in different ecosystems and under changing environmental conditions. The level of sophistication of such analyses of course depends on the amount of synoptic information on seal abundance, distribution and prey availability. The abundance of these types of information has increased over time and will hopefully continue to do so in the future. By continuing long-term data series along with this larger suite of ecosystem data, we're likely to learn a lot more about the parameter dynamics, which will also be of use to

retrospective analyses. To make full use of MAM and corpora accumulation rates in this context, the comparability of results in space and time must be tested by regular calibration of methods between laboratories.

## Acknowledgements

We thank Torger Øritsland and Tore Haug for inputs on the history of WGHARP and the Norwegian-Soviet Sealing Commission.

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# A model of Norwegian spring spawning herring dynamics as a tool for testing for harvest control rule variants

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## Abstract

A simulation model of Norwegian spring spawning herring (NSSH) dynamics was developed in order to evaluate various harvest control rules (HCR). The model simulated herring dynamics between 1980 and 2004 and for a forecast period (2005- 2012). The following HCRs (rules for determination the fishing mortality coefficient  $F(5-14)$ ) were examined:

1.  $F(5-14)$  values by year are constant and equal to 0.125, 0.15, 0.2, 0.3 or 0.5;

2. a single-step rule:  $F(5-14) = 0$ , if  $SSB < 2500\ 000\ t$ , else  $F(5-14) = 0.15$

3. a double-step rule: if  $SSB < 2500\ 000\ t$ ,  $F(5-14) = 0$ , else:

if  $SSB > 5000\ 000\ t$ ,  $F(5-14) = F2$ , else  $F(5-14) = F1$  ( $F2 \geq F1$ ).

The work was carried out using determinate and stochastic model versions. The determinate version showed that increasing  $F(5-14)$  up to  $0.15 \div 0.2$  did not endanger the herring stock, at the same time as catch = TAC was increasing.

In the stochastic version of the model, stochastic noise was incorporated into stock numbers by age in the start year (1980) and in the annual recruitment values, and implementation error was taken into account. This allowed a risk analysis to be carried out. The risk depends on  $F(5-14)$  or on  $F1$  and  $F2$  values chosen. Using a step function for fishery management not only decreases the risk of SSB declining below the Blim level but supports higher catches in prognostic years.

*Keywords: simulation, Norwegian spring spawning herring stock, harvest control rule*

## Methods and material

A simulation model of Norwegian spring spawning herring (NSSH) dynamics was developed in order to evaluate various harvest control rules. The model simulated NSSH dynamics between 1980 and 2004. A forecast period of 2005 to 2012 was also studied. The advantage of the proposed approach over conventional ones is that the majority of stock-fishery system parameters are already known from the Report of the Northern Pelagic and Blue Whiting Fisheries Working Group (ICES 2005): weight-at age data, maturity rates, natural mortality rates, which increases the reliability of the model's conclusions regarding the practicability of one or another of the HCR versions.

Parts of the input parameters was taken from the separable model ISVPA results: abundance by age group in the start year (1980) and the matrix of fishing mortality rates  $F(a,y)$ . For each year, fishing mortality rates averaged by age groups from 5 to 14 ( $Fbar$ ) were calculated with the help of the  $F(a,y)$  matrix as weighted by population size of the same ages. The relationship

$F(a,y)/Fbar(y)$  was also calculated for each age and each year, in order to make a selectivity function by age, which varied from year to year.

For the prognosis period (2005 – 2012) some population parameters were assumed to be averaged through the last five years of the 1980-2004 period (weights-at-age, maturity rates by age and fishery selectivity). A number of recruits were assumed to be equal to the mean annual value or were estimated by one or other of the stock recruitment models described below. Abundance was simulated ahead in time for each HCR variant.

A number of management rules were considered:

1. Fishing mortality rate is constant throughout the year in question. The calculations were carried out for  $Fbar = F(5-14) = 0.125, 0.15, 0.20, 0.3$  and  $0.5$ .
2. Fishing mortality for each year is estimated by the "single-step" rule:  
if  $SSB < 2500\ 000\ t$  then  $Fbar = 0$ , else  $Fbar = 0.15$ .
3. Fishing mortality for each year is estimated by the "double-step" rule:  
if  $SSB < 2\ 500\ 000\ t$ , then  $Fbar = 0$ , else  
if  $SSB > 5\ 000\ 000\ t$ , then  $Fbar = F2$ , else  $Fbar = F1$ .

In the double-step rule,  $F1$  was set at  $0.125$  and  $F2=0.15$  or at  $F1=0.15$  and  $F2 =0.20$ .

Any management rule which can be theoretically set to start from any year within the retrospective period has an effect on population dynamics. Although, in this connection, the new  $SSB$  values are being obtained, as a first approximation of the model it is possible to accept the same recruitment series  $R(2,y)$  obtained from ISVPA. It is possible to justify this admission when modelling because there is only a weak dependence between herring recruitment and spawning biomass, which is not visible in comparison with environment effects. It was assumed that the influence of environmental factors did not vary during the retrospective period with  $SSB$  variations.

Two versions, determinate and stochastic, of the simulation model were investigated. The model was realized as an EXCEL spreadsheet using Visual Basic macros.

## Results

### The determinate version

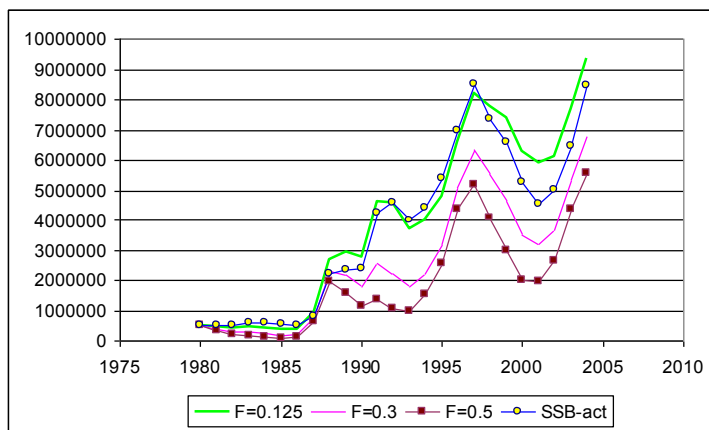
The results of modelling carried out with different HCR variants are summarized in the Table 1 and Figure 1.

The "actual" population attributes corresponding to the ISVPA results are shown on the upper line. Herring biomass in the start year ( $492\ 000\ t$ ) was much lower than accepted for this stock  $Blim = 2500\ 000\ t$ , and for several years after the start year the population reconstruction took place for runs with all HCRs considered. In variants 1b, 1c and 1d in Table 1, increasing  $Fbar$  up to  $0.15-0.3$  did not endanger herring stock status, at the same time as catch = TAC was increasing; the step rules (variants 2 and 3) are also permitted. In the case of  $Fbar = 0.5$ , catch increased to  $1933\ t$  in 2004, while  $SSB$  fell to  $5\ 590\ 000\ t$ . This  $SSB$  level was sufficiently high, but within the retrospective period, even after the stock reconstruction (after 1989) the  $SSB$  estimates were less than  $Blim$  in some years (see Figure 2), and taking into account the fact that the model version considered was determinate and that the stochastic version should display a more dangerous situation, this HCR regime should be rejected.



**Table 1.** The spawning stock biomass SSB, total stock biomass TSB=B(2+) and catch C=TAC in the final year (2004) and average catch in all years C(aver), obtained with the help of the determinate model, for various HCRs used on retrospective years

HCR variant	F(4-10)	C(2004), 1000 t	SSB(2004) 1000 t	TSB(2004) 1000 t	C(aver) 1000 t	Min SSB 1000 t
	Actual F(y)	1116	8458	10736	531	492
1a	F=0.125	1274	9380	11660	521	372
1b	F=0.15	1347	8802	11080	564	337
1c	F=0.20	1457	7928	10195	627	278
1d	F=0.30	1630	6816	9065	700	191
1e	F=0.5	1933	5590	7805	766	94
2	single-step rule (F1=0.15)	1349	8807	11083	562	492
3	double-step rule (F1=0.125 F2=0.15)	1356	8826	11102	556	492

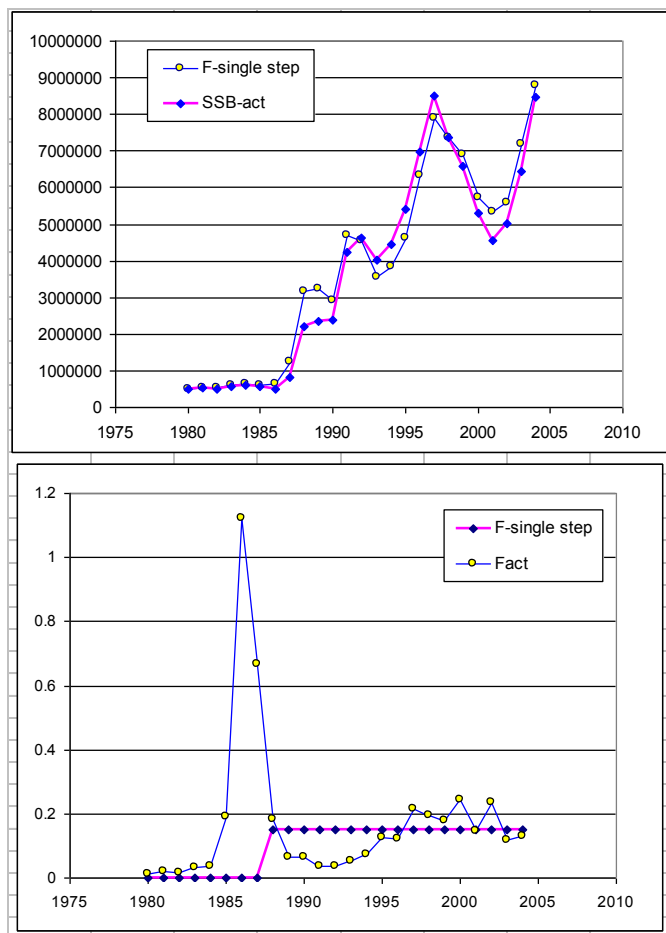


**Figure 1.** The determinate version of the simulation model results. Comparison of actual SSB dynamics (obtained by ISVPA, in tonnes) with the model results if Fbar was constant for all years and equal to 0.125, 0.3 or 0.5.

In cases 2 and 3 of the HCR, the herring fishery in the model was stopped in 1980-1987 as  $SSB < 2\,500\,000$  t (Figure 2). It was shown that HCRs in its single-step and double-step forms (F1=0.125 and F2=0.15) led to similar stock dynamics. The stock biomass dynamics in variants 2 and 3 was also very close to the case when we used  $F_{bar} = const = 0.15$ .

As the recruitment series was the same for all the model runs, the low SSB level did not lead to reproduction variations and thus to severe losses of stocks. The SSB curves at Figure 1 are similar and even when the exploitation rate was high (F=0.5) the spawning biomass was increasing until 2004 but to a less high level.

In the runs with  $F_{bar} = const$  the model fishery was carried out in beginning years too when SSB was less than  $2.5 \cdot 10^6$  tons.



**Figure 2.** Results of the determinate version of the simulation model. The upper figure compares actual SSB dynamics (obtained from ISVPA model) with the results of the simulation model for the second variant of HCR (single-step). The lower figure shows annual variations in  $F_{bar}$  for the same runs.

### Stochastic version

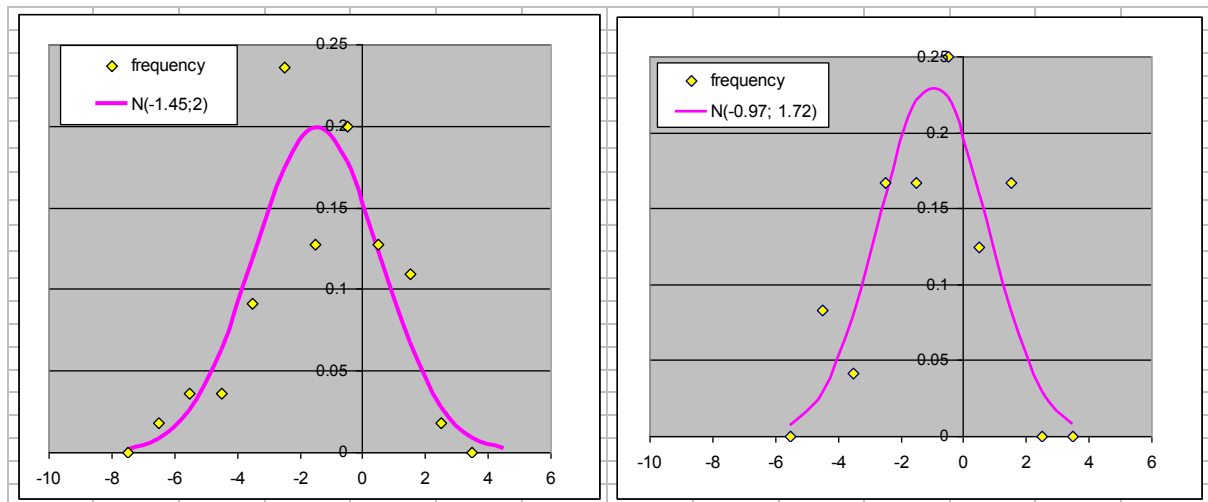
In the stochastic version of the model, stochastic noise was incorporated in several parameters, enabling us to perform risk analysis procedures too. This version incorporated the noise in the stock number by age in the start year (1980) and in the recruitment values by year. The implementation error was taken into account too. This approach has been described in our previous papers (Bulgakova 2004, 2005).

The noise in the stock number was taken as lognormal values with a standard deviation of 0.2. The recruitment values for retrospective years were taken from an ISVPA run (ICES 2005) as “actual” values of recruitment and lognormal noise with standard deviation 0.2 added. The problem arose in connection with the estimation of recruitment for prognostic years. Two variants of recruitment modelling were developed for the forecast. In the first variant the annual average for 1980-2004 ( $R(aver)$ ) was taken as a mathematical expectation of recruitment and lognormal noise was added, using the parameter estimates shown in Table 2. Obtained frequency and theoretical probability distributions were built (see Figure 3).

The negative value of the mathematical expectation of logarithmic deviations from mean recruitment implies that below-average year-classes occur more often than numerous ones. As a result, median abundance is always less than mean recruitment (Table 1). The distribution function of logarithmic deviations from mean recruitment (Figure 3) is not highly symmetrical, and this distribution can be considered as only approximately normal.

**Table 2.** Herring recruitment statistical parameters for two year-class intervals.

	1950-2003	1980-2003
<b>Recruitment parameter</b>		
Mean number in 10 <sup>6</sup> ind.	13244	17199
Median in 10 <sup>6</sup> ind.	2101	10156
<b>Parameters of log-deviation from mean recruitment</b>		
St. deviation	2.0	1.72
Mathematical expectation	-1.45	-0.97



**Figure 3.** Frequency distributions of LN(R/R(aver)) for two year-class intervals, 1950-2003 – left, and 1980-2003 – right, and corresponding theoretical normal distributions

In the second variant of recruitment modelling, the stock-recruitment relationships were built. It is clear that the linear relation  $R(SSB)$  has to work when the SSB level is very low. If the spawning biomass is high, egg mortality may increase as herring spawn on marine vegetation and sometimes in several layers. Egg mortality in the lower layers may rise. This phenomenon can be described by Ricker's model. On the other hand, competition for food during the first year of life means that the mortality of young fish is a function of their abundance, which decides in favour of employing the Beverton and Holt model.

The model chosen is useful only when it allows us to reduce the uncertainty of recruitment estimates vis-à-vis their mean value.

Ricker's model was used in the simplest form:

$$R(2,y) = \alpha * SSB(y-2) * EXP(-\beta * SSB(y-2)).$$

The Beverton and Holt model was used as follows:

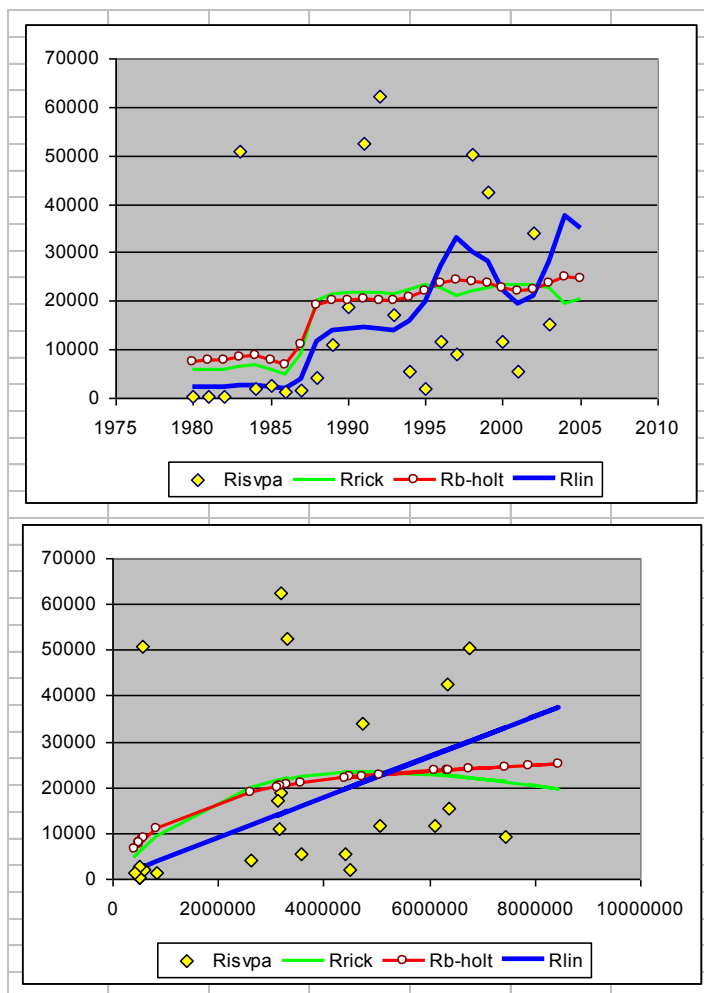
$$R(2,y) = \frac{aSSB(y-2)}{1 + bSSB(y-2)}$$

Linear function  $R(2,y) = k SSB(y-2)$ .

Parameters  $\alpha$ ,  $\beta$ ,  $a$ ,  $b$ ,  $k$  are constant values estimated by the series  $R(2,y)$  and  $SSB(y-2)$  for year-classes from 1980 to 2003 and shown in Table 3. The results of fitting these models to data are shown in Figure 4.

**Table 3.** The stock-recruitment model parameters are estimated for year-classes 1980-2003 on the stipulation that SSB is measured in tonnes, and recruitment per  $10^6$  individuals.

Parameters	Ricker' model	Beverton-Holt' model	Linear relation
$\alpha, a, k$	0.0129	0.0209	0.00444
$\beta, b$	$2.035 \cdot 10^{-7}$	$7.197 \cdot 10^{-7}$	-
SSB giving maxR	4915000 t	-	-
Asymptote a/b	-	$29040 \cdot 10^6$ ind.	-
Residual variance	$361 \cdot 10^6$	$360 \cdot 10^6$	$378 \cdot 10^6$
Mean value of lognormal noise	-0.80	-0.88	-0.39
Standard deviation from the model	1.38	1.43	1.28
Correlation coefficient $r^2$	0.085	0.088	0.042

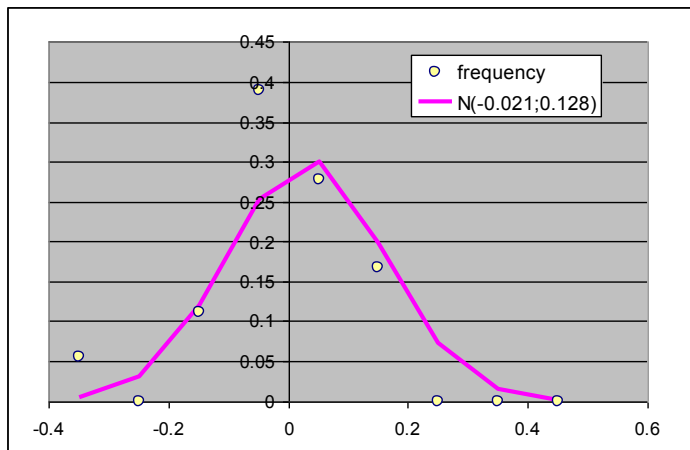


**Figure 4.** Approximation of  $R(y)$  and  $SSB(y-2)$  data by Ricker's model, the Beverton & Holt model and by linear function for year-classes 1980-2003 (below). The recruitment number at age 2 (in  $10^6$  ind.) calculated by the same models is shown on the x-axis. The y-axis shows year-class in the upper figure and SSB in tonnes in the lower one.

The total variance in recruitment abundance equals  $394 \cdot 10^6$  for 1980-2003. Correlation ratios for the three models are very low (Table 2), in that only 4-8% of recruitment variability is explained by the recruitment relationship on SSB. However, we attempted to include two of the three functions of  $R(SSB)$  for the recruitment calculations for prognostic years, slightly

reducing the noise level. The noise parameters estimated for recruitment models are shown in Table 3.

Implementation error was estimated by comparing two series, actual catch and TAC values estimated by the ICES Working Group (ICES, 2005) for 1988-2006. The following estimates were obtained for log-deviations of LN(C/TAC): Mean= -0.021, median= -0.0125,  $\sigma = 0.128$ . That means that within the year interval the average catch was a little lower than the corresponding TAC.



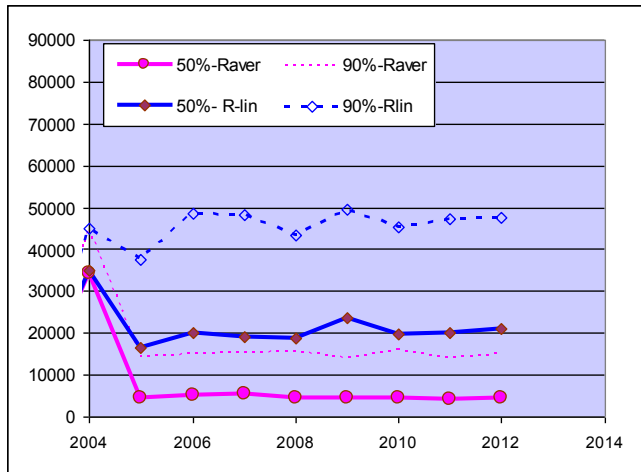
**Figure 5.** Frequency distribution of LN(C/TAC) based on actual catch data and TAC series for 1988-2006 and predicted density function as normal distribution

The risk probability was calculated as the probability that SSB fell below  $Blim=2\ 500\ 000$  tons. As biomass in the start year 1980 was very low, the risk during the first years was close to unity in all model runs. For this reason, we compared the risk probability obtained in different runs only for the years after reconstruction of the stock; i.e. after 1988.

The stochastic model runs were carried out using the same HCR variants as the determinate runs. As recruitment levels for 1980-2004, "actual" values were used and log-normal noise with a standard deviation of 0.2 was incorporated. For prognostic years in different runs recruitment level was calculated by one of the following three methods:

- 1) recruitment is equal to the annual mean for 1980-2003 with stochastic component:  
 $R(2,y)=R_{aver}*\exp(\epsilon_1)$ , where  $\epsilon_1=N(-0.97;1.72)$   
 (see the last column of Table 3 and Figure 3 right);
- 2) recruitment is a linear function of SSB (see Table 3):  
 $R(2,y)=0.003*SSB(y-2)*\exp(\epsilon)$ , where  $\epsilon=N(-0.39; 1.28)$ ,
- 3) recruitment is a Ricker function of SSB (see Table 3):  
 $R=R_{rick}(SSB(y-2))*\exp(\epsilon_2)$ , where  $\epsilon_2=N(-0.80; 1.375)$ .

It is evident from Figure 6 that when recruitment *for prognostic years* was estimated using its mean, not only the median but also the 90th percentile of  $R(2,y)$  were much less than  $R(2,y)$  as obtained by the linear relationship  $R_{lin}(SSB)$ . As a result, stock biomass decreased on forecast interval. For example, in the model run with  $F=const=0.15$  and using the first method of recruitment estimation, spawning biomass decreased sharply from  $9.1 * 10^6$  t in 2004 to  $3.9 * 10^6$  t in 2012.



**Figure 6.** Differences in herring recruitment in prognostic years in the form of median and 90th percentiles obtained by two stochastic runs. In the first run recruitment was estimated by way of annual mean (Raver), in the second run through the linear function of SSB (Rlin(SSB)). Lognormal noise was included in both runs. Fishery mortality in these runs was constant and equal to 0.15 in all years.

If in forecast years,  $R(a,y)$  was estimated by Richer' model, recruitment also decreased in that year and on average was equal  $7642 \cdot 10^6$  ind. As a result SSB also sharply decreased (Table 4).

In all model runs, the recruitment median and stock median were less than the corresponding average values. As a rule these two values were very close in the retrospective year interval (difference is less 1.5%) but the median recruitment level is remarkably lower than average Raver for the prognostic years.

**Table 4.** Results of stochastic model runs obtained for various HCRs and for three recruitment models used for prognosis.

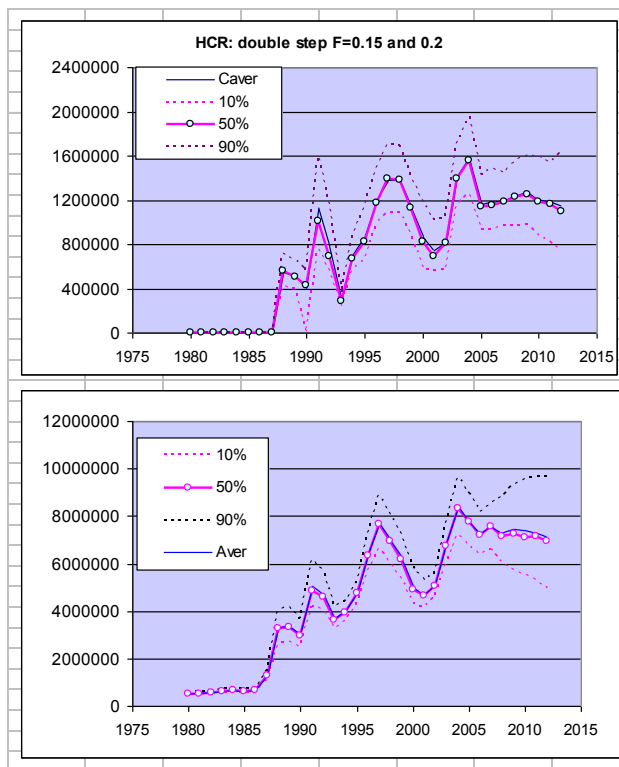
HCR variant	Recruitment model for prognosis	Averaged for prognostic interval, 1000' t			Risk prob. in 1990
		C/TAC	SSB	TSB(2+)	
F=const = 0.15	Raver	910/920	6460	7530	0.44
Double step F1=0.125, F2=0.15	Rrick	890/900	6505	7640	0.07
F=const = 0.125	Rlin	1050/1065	9310	12230	0.26
F=const = 0.15	Rlin	1115/1125	8535	11310	0.34
F=const = 0.20	Rlin	1185/1065	7290	9775	0.71
F=const = 0.30	Rlin	1240/1256	5665	7740	0.95
Single step, F1=F2=0.15	Rlin	1120/1130	8590	11405	0.11
Double step F1=0.125, F2=0.15	Rlin	1110/1125	8545	11300	0.06
Double step F1=0.15, F2=0.20	Rlin	1200/1210	7394	9885	0.12

In subsequent runs the linear recruitment model  $Rlin(y)=kSSB(y-2)$  was used. The comparison of runs using the constant  $Fbar$  showed that if  $Fbar = 0.125$  or  $0.15$  the spawning biomass increased slightly during the prognostic years (Figure 7), if  $Fbar = 0.20$  SSB was stabilized on

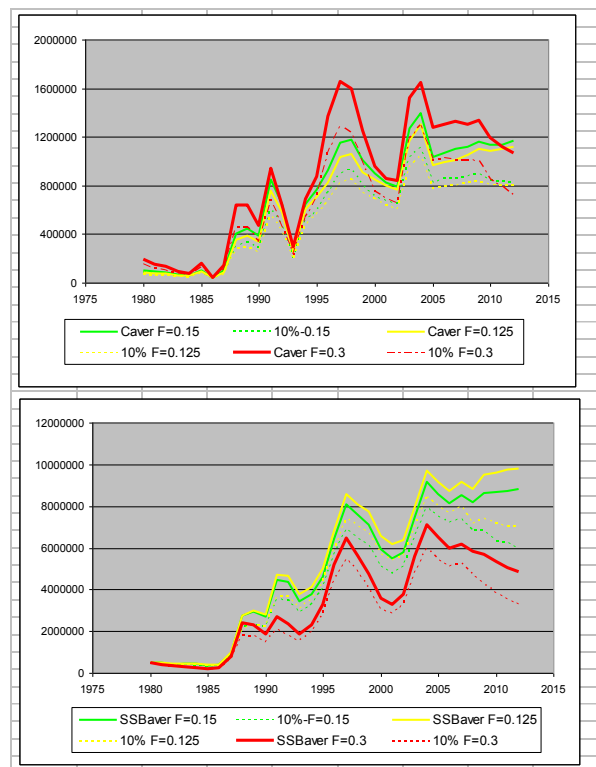
the same year interval at a sufficiently high level, but if  $F_{bar}=0.30$  SSB fell up to  $4.5 \cdot 10^6$  t in 2012 (the lower Figure 7). In the last case the average catch by realizations = actual catch was at its highest level of 1300000 t at the beginning of the prognostic interval, and which it also decreased (upper panel, Figure 7).

The probability of SSB declining below Blim is another important result of using different HCRs. The highest value of the risk probability fell in 1990 for all model runs presented in Table 4. These risk values for 1990 appear in the final column of the table. During the prognostic period of eight years, the risk function was equal to zero (see Figure 9).

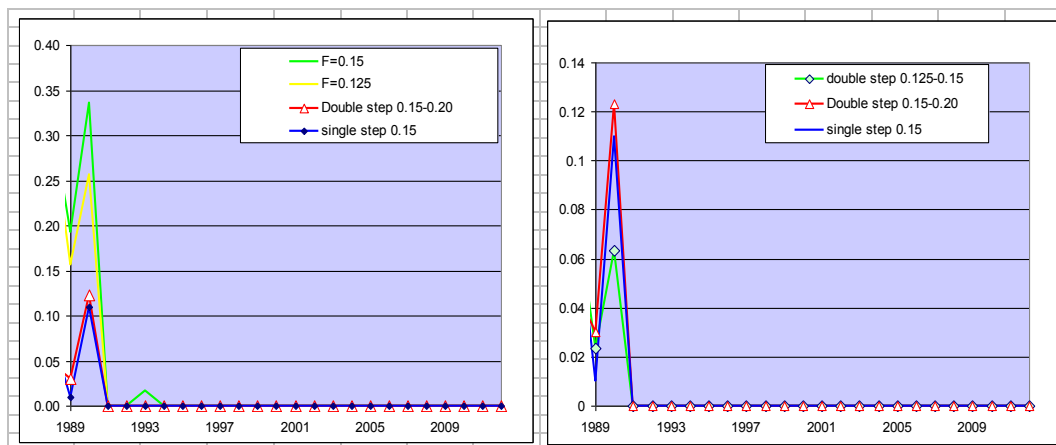
In terms of risk probability, the most suitable variants of HCR are single and double steps. Double step ( $F_1=0.125$  and  $F_2=0.15$ ) showed the lowest risk (6% in 1990) but averaged over the prognostic years, catches were 100 000 tons lower than those obtained if double step with slightly higher fishery mortality values ( $F_1=0.15$  and  $F_2=0.20$ ) were used. In the latter case, risk was equal to 12% (Figure 9) and modeling results are shown in Figure 8.



**Figure 7.** Comparison of three runs with HCR=const =0.125, 0.15 and 0.30. The upper Figure is catch dynamics, the lower one is SSB dynamics; the average values and 10-percentiles are shown.  $R(2,y)$  for prognostic years was estimated by linear function on SSB.



**Figure 8.** The upper panel illustrates catch dynamics, and the lower one SSB dynamics, with mean values, median and percentiles.  $R(2,y)$  for the prognostic years was estimated by linear function on SSB. HCR was set in the form of double step ( $F_1=0.15$  and  $F_2=0.20$ ).



**Figure 9.** The risk probability for different HCRs (the probability of SSB decreasing below 2500 000 tonnes) for two values of  $F=const=0.125$  and  $0.15$  – left figure, for single step and for two double step variants– right figure. A different ordinate scale was used in the two figures.

## Conclusions

The following conclusions apply to the modeling situation if some HCR were incorporated since 1980.

On the basis of determinate runs of the simulation model it is possible to draw the conclusion that increasing  $F_{bar}$  to  $0.15-0.20$  is not dangerous for stock status, while  $catch=TAC$  is increasing.

With the help of stochastic model runs it was shown that given the above stipulations regarding the uncertainty levels of the model parameters, the risk depended on the HCR set (Figure 9 and Table 4). During the year considered after the stock reconstruction the maximum risk values fell in 1990 for all model runs. For example, if  $F_{bar}=const=0.30$ , the risk in 1990 rose to 0.95. If  $F_{bar}=0.15$ , the risk for the same year was 0.34. Using HCR in the form of double step ( $F_1=0.15$ ,  $F_2=0.20$ ) allows us to lower the risk to 0.12.

Using the step function for fishery management not only decreases the risk of SSB declining below  $B_{lim}$  level but also supports catches in prognostic years at a level of 1 200 000 tonnes.

The value  $B_{lim}=2\ 500\ 000\ t$  was chosen by Working Group (ICES 2005) as a limiting reference point, and the risk was estimated in this paper relative to this value. There is no certainty regarding the correctness of the chosen value of  $B_{lim}$  for herring spawning stocks. This level is not a historical minimum for herring: in 21 out of 56 years (from 1950 up to 2004), i.e. 37% of cases, the spawning biomass was lower than this value!

The functions of  $R(SSB)$  studied here described only a small proportion of recruitment variability, insufficient for modeling the actual population dynamics required for forecasts. For the further development of the simulation model, it would be desirable to identify the most important environmental factors that affect the recruitment process. Norwegian scientists (Stiansen et al. 2002) have developed a regression model to describe the relationship of herring recruitment at age 3 to two climate variables: average sea-surface temperature in January-March on a station in the Norwegian Sea and the NAO index (both factors were measured in the birth year of each year-class), and on the 0-group index calculated from



autumn surveys data. The last factor is the dominant one ( $R^2=0.79$ ). This model allows recruitment to be forecast for three years ahead after the last autumn survey. It would be interesting to identify the factors that determine herring survival rates during the first year of life.

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# Estimating the Barents Sea cod stock by the "GIS method"

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## Abstract

The traditional approach to estimating cod stocks includes both data from trawling surveys and models of fish biomass based on fishery theory. The method proposed here is a synthesis of the traditional area method and current information technologies that enable the results of the Russian fishery to be obtained on-line. The daily vessel reports on which estimates of fish stocks have been based include the following information: coordinates of trawling operations, catch weight, type of vessel and trawl and duration of trawls. The area of the effective catches was less than the area of cod distribution, producing underestimations of the stocks. During the period under study (2000-2006), 181,000 reports were dealt with, of which 89,000 were used for the biomass estimate. The results showed that the interannual variability of biomass ranged from 1.9 million tonnes to 2.8 million tonnes (at an average of 2.3 million tonnes for the period). In recent years, the stock has increased, from 2.0 to 2.6 million tonnes from 2005 to 2006, i.e. a growth of 30%.

## Introduction

The North-east Arctic cod stock is one of the most valuable target fisheries in the Barents Sea. VNIRO receives update information on Russian trawling for cod in the Barents Sea on a daily basis. Until recently, large amounts of information submitted through the Fishery Monitoring System remained unused. The first use of such information on the north-east Atlantic with the help of advanced GIS technology dealt with the cod fishery in 2005 (Borisov et al., 2006). Fishery data and GIS technology were also successfully used to assess cod biomass in 2000, 2002, 2004 and 2006 (Bulatov et al., 2007).

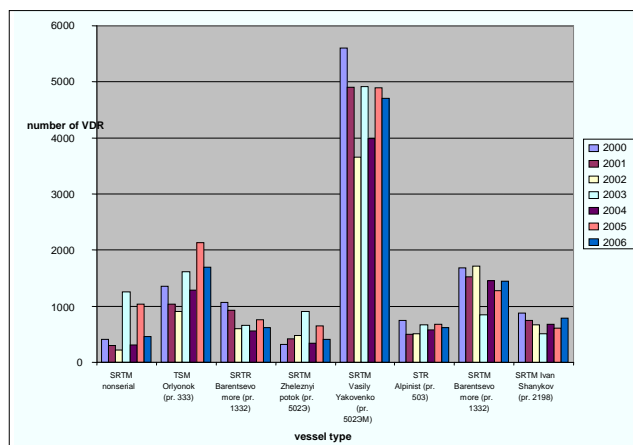
This report is an attempt to determine the total allowable catch (TAC) of cod in 2000-2006 by using the stock assessment based on GIS technology.

## Materials and Methods

The fishable biomass of cod in the survey area was assessed on the basis of vessels' daily reports (VDRs). The following VDR data concerning fishing operations of a vessel were of particular importance:

- date of report
- latitude
- longitude
- target species
- type of fishing vessel
- catch by species
- type of fishing gear
- duration of fishing operations.

The area was divided into a number of quadrangles ( $0,5^{\circ} \times 2^{\circ}$ ). Analysis of the dataset showed that the cod fishery occupied 17 types of fishing vessels. We decided to choose eight types of mid-sized vessels which took the largest part of the annual catch: from 37% (in 2000) to 46% (in 2006). The largest part of the VDRs came from medium refrigeration trawlers of the SRTM Vasilyi Yakovenko class (Figure1). The share of this type vessel varied from 27 to 40% of total catch (Table 1).



**Figure 1.** Number of vessel daily reports by vessel type.

**Table 1.** The total catch distribution between vessel types in 2000-2006.

Type of Vessel	2000	2001	2002	2003	2004	2005	2006
Vasiliy Yakovenko	40.3	40.1	35.8	28.9	28.6	27.1	33.0
Orlyonok	15.7	14.4	12.7	17.4	15.2	18.6	18.4
Barentsevo more	14.2	16.4	22.0	9.9	18.3	15.3	16.6
Others	29.8	29.1	29.5	43.8	37.9	39.0	32.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

During the survey period, various types of trawl were used to catch cod. Analysis of their operations revealed that out of 35 types of fishing gear, sixtypes of bottom trawl were mentioned in 39.3% - 62.1% of the total number of VDRs. Overall, between 2000 and 2006 we analysed 181,068 VDRs; i.e. half of the total number of VDRs were used to make biomass calculations (Table 2).

**Table 2.** Number of VDRs submitted for the surveyed area, 2000-2006.

Year \ Number of VDRs	Total number of VDRs	Number of VDRs with known trawl type	Percentage of VDRs with known trawl type (%)
2000	36,797	14,458	39.3
2001	31,118	13,220	42.5
2002	23,716	11,236	47.4
2003	20,095	11,052	55.0
2004	22,111	13,712	62.1
2005	21,746	10,969	50.5
2006	25,485	14,381	56.5
Total	181,068	89,028	49.2

The selected types of trawls were thus used in only certain parts of the survey area. This led to the underestimation of stocks because the area covered was less than the total area of distribution of the cod. The VDR data on trawling duration and the weight of cod catches enabled us to compute the value of catch per hour of trawling. Knowing the characteristics of the trawls and the catchability coefficient we could compute the stock density (t/km<sup>2</sup>). Catches which exceeded 2 t/h of trawling were regarded as erroneous and were rejected. Analysis of the catch distribution frequency allowed us to employ the assumption of log-normal distribution.

The cod biomass in each square was computed using the method of Aksyutina (1968).

$$P = \sum_{i=1}^n \left( \frac{Q_i \times x_i}{q \times k} \right);$$

where  $P$  is the biomass, tonnes;  
 $Q_i$  is the area of each square (i), km<sup>2</sup>;  
 $x_i$  is the mean actual catch in square (i), t/h of trawling;  
 $q$  is the area of trawling (determined by multiplying the trawl horizontal opening by the distance covered), km<sup>2</sup>;  
 $k$  is the catchability coefficient, which totaled 0.3 (estimated by Serebrov, 1988 for 4-6 year-old fish).

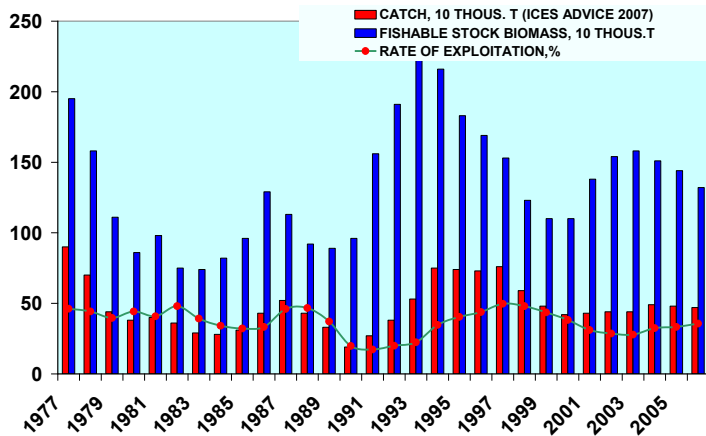
In each selected square (0.5 degree of latitude x 2 degrees of longitude), the mean catch per one hour of trawling was computed for a period of 15 days. Then, knowing the area of the square, the area of trawling, and the catchability coefficient for the trawl, we were able to find the density (t/sq. km) and cod biomass within these squares, i.e. the sum of the biomass assessments in the squares.

The mean monthly biomass of cod was found as the arithmetic mean biomass for two 15-days periods. Mean annual biomass was the arithmetic mean for mean monthly values for the period of April-December. Areas of squares (polygons) were determined using the GIS software package ArcView 3.2 (ESRI). We did not need to apply extrapolation techniques, but used only actual catches.

As mentioned above, we regard the resulting fishable biomass values as being obviously lower than the true values, for the following reasons: incorrect fishery statistical data which led to underestimation of actual catches and incomplete coverage of the surveyed area. However, the dataset which we used was considerably larger than those obtained through traditional biomass surveys.

## Results and discussion

The cod fishery has a rather long history. ICES data show that during the past 30 years, the fishable stock dynamics have been marked by three maxima, which occurred in the mid-1970s, early 1990s and in 2002-2004. Maximum catches exceeding 700,000 tonnes were registered in the 1970s and 1990s (Figure 2). It is noteworthy that in general catch dynamics moved almost simultaneously with the stock dynamics.



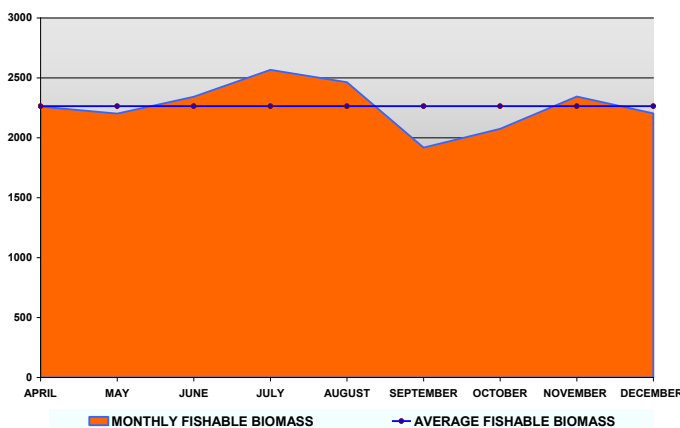
**Figure 2.** Fishable biomass and catch of Arctic cod in 1977-2006, thousand tonnes.

The stock biomass within the survey area was assessed several times: overall, we obtained more than 125 values for the biomass. The results showed that every year, with the exception of 2000 and 2001, two seasonal maxima were observed (Table 3). The seasonal dynamics of cod biomass within the surveyed area are probably related to cod migrations, which were associated with seasonal changes in water temperature and availability of food.

Mean monthly values of the fishable biomass for April-December varied within a rather narrow range: from 1.9-2.1 million tonnes in autumn to 2.3-2.6 million tonnes in summer (Figure 3). The seasonal maximum was observed in July.

**Table 3.** The cod fishable biomass dynamics in April-December, thousands tonnes.

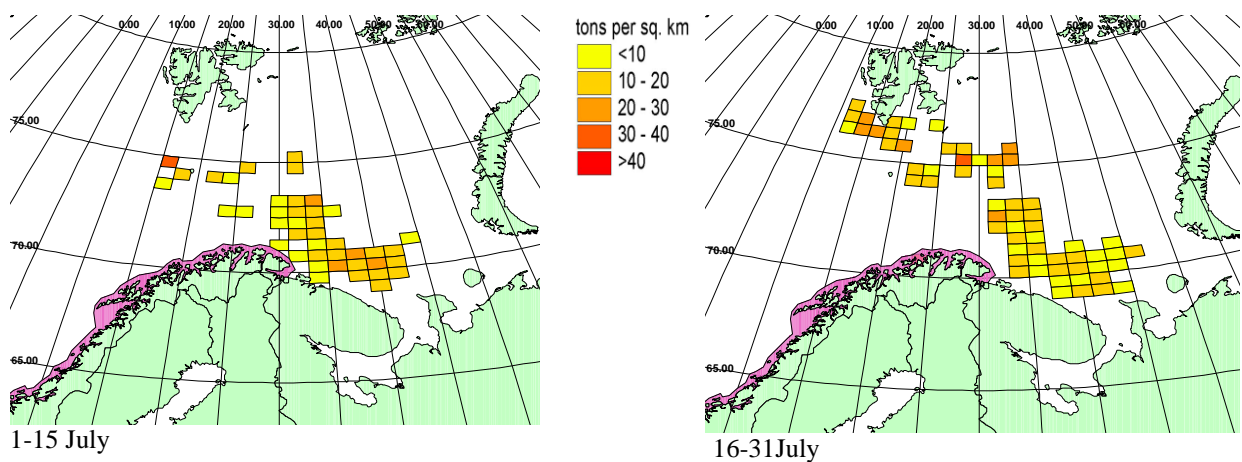
Month/year	2000	2001	2002	2003	2004	2005	2006	Mean	%
April	2323	2045	<b>2878</b>	<b>2273</b>	2404	2056	1845	2260	88.0
May	2358	2302	2248	1286	2167	2271	2785	2202	85.8
June	2136	<b>2799</b>	2702	1922	2298	2276	2262	2342	91.2
July	2439	2640	2502	1322	<b>3369</b>	<b>2432</b>	3264	<b>2567</b>	<b>100.0</b>
August	<b>2902</b>	2180	2323	1493	2899	1713	<b>3738</b>	2464	96.0
September	1485	1558	2206	1499	2242	1734	2705	1918	74.7
October	1585	1840	1674	2178	2972	1881	2394	2075	80.8
November	1748	1384	<b>2991</b>	<b>2427</b>	2954	<b>2020</b>	<b>2883</b>	<b>2344</b>	<b>91.3</b>
December	1736	1466	2342	2360	<b>3596</b>	1950	1976	2204	85.8



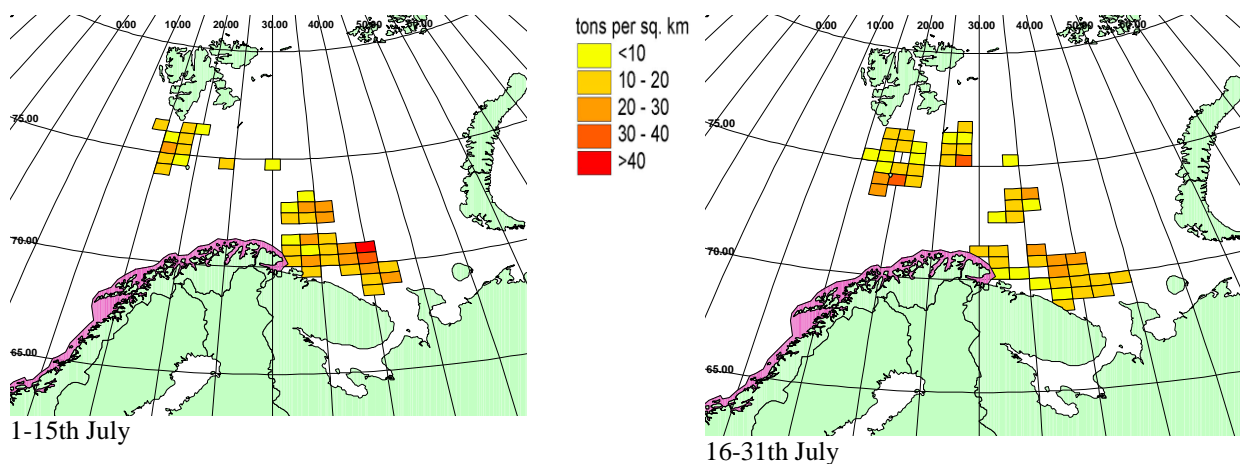
**Figure 3.** Monthly mean and average fishable biomass of Arctic cod in april-December 2000-2006; thousand tonnes.

The spatial density distribution of the cod stock during the feeding period obtained through trawl catch data showed that in July the largest concentrations ( $\geq 40 \text{ t/km}^2$ ) could be found as far north as as  $75\text{-}76^\circ \text{ N}$ . As a rule, the fishing fleet was concentrated in two areas. The largest area of dense aggregations was observed in the eastern part of the surveyarea (Figure 4 - 8). In July the northern and eastern aggregations were widely separated.

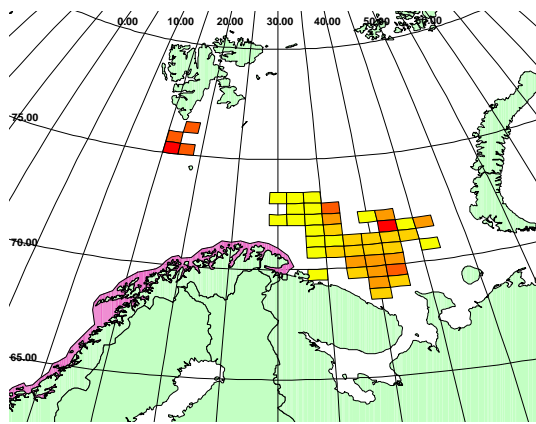
According to the VNIRO data, the interannual variability of fishable biomass ranges from 1.9 million tonnes in 2003 to 2.8 million tonnes in 2004 (Figure 9). Thus, in adjacent years an increase of 47% in the stock biomass was noted. The similar situation was observed in 2005-2006 also, when the biomass increased from 2.0 to 2.6 million tonnes (+30%). Thus, in some years the essential changes in biomass were registered. On the average, according to the VNIRO data the cod biomass was 2.3 million tonnes.



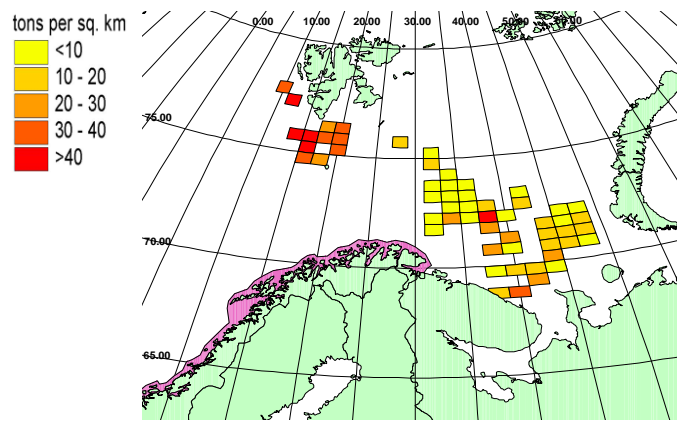
**Figure 4.** Density distribution of arctic cod in July 2000 .



**Figure 5.** Density distribution of arctic cod in July 2002.

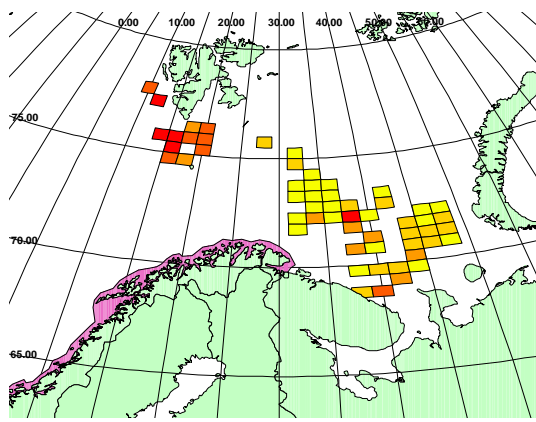


1-15th July

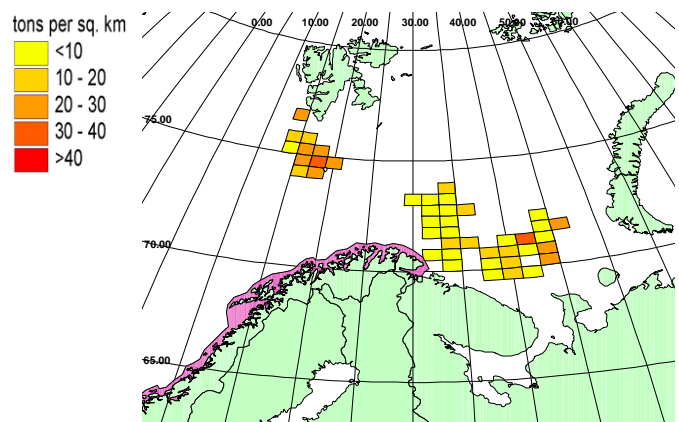


16-31th July

**Figure 6.** Density distribution of arctic cod in July 2004.

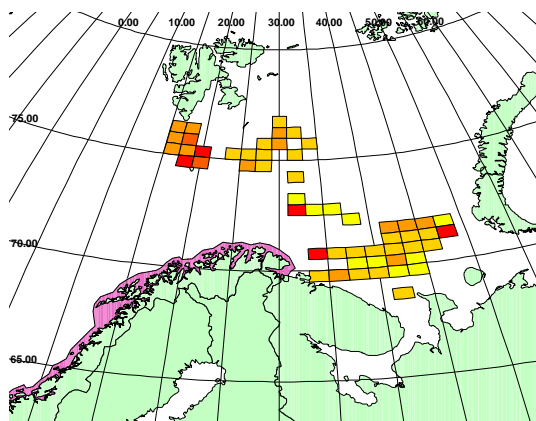


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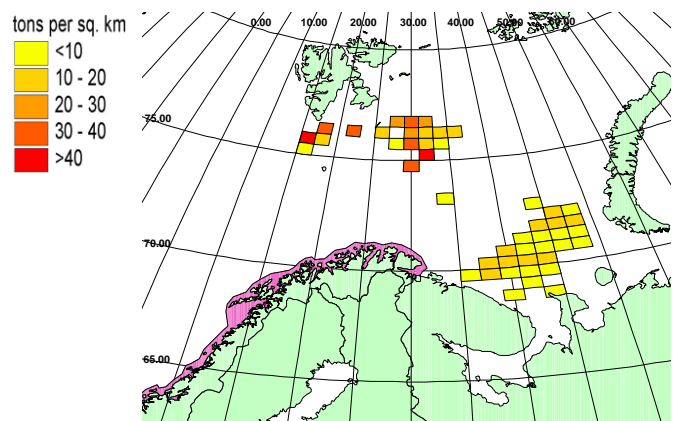


16-31th July

**Figure 7.** Density distribution of arctic cod in July 2005.

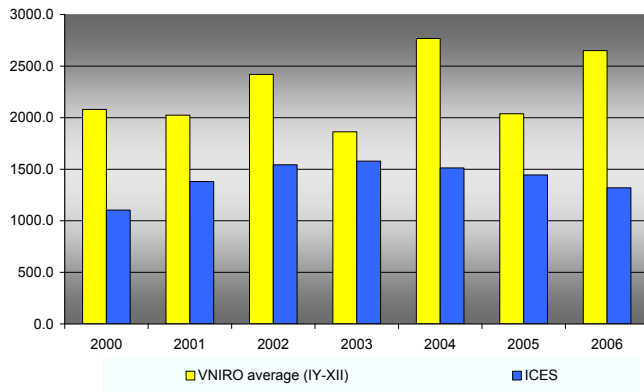


1-15th July



16-31th July

**Figure 8.** Density distribution of arctic cod in July 2006



**Figure 9.** Assessment of the fishable stock based on XSA (ICES) and GIS (VNIRO) methods; thousand tonnes.

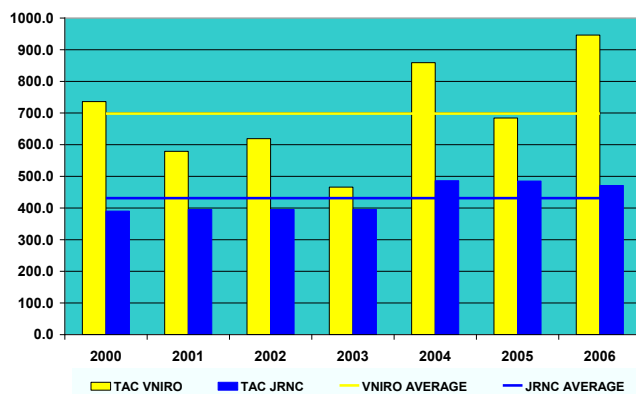
According to ICES data (ICES AFWG Report, 2006) the fishable biomass varied within a narrow range. During the years concerned, its minimum was registered in 2000 (1.1 million tonnes), and its maximum in 2003 (1.6 million tonnes), whereafter a stable falling tendency in the stock biomass was observed, with a predicted minimum of 1.3 million tonnes in 2006.

Comparison of the mean values of biomass obtained by the different methods showed that according to the VNIRO data (GIS method) the average biomass in 2000-2006 was 2.3 million tonnes, while the ICES data (XSA) produced a figure of 1.4 million tonnes; i.e. their ratio was 1.6:1.

However, by 2006 the situation had changed, and the trends in stock dynamics were in the other direction (the VNIRO data found an increase in biomass, while the ICES forecast indicated a decrease). The ratio of the GIS and XSA estimates was 2:1.

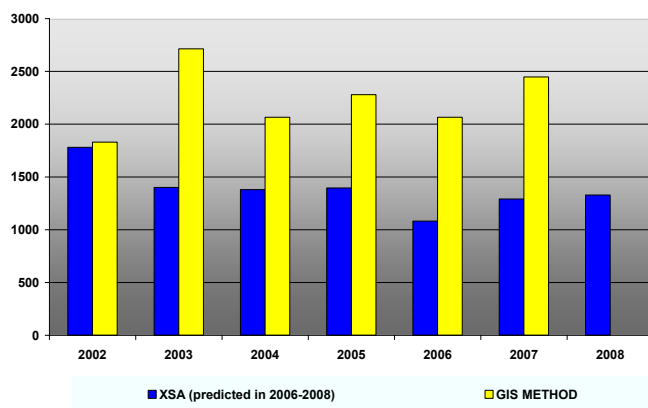
Based on the "new values" of the fishable biomass obtained by the GIS method (VNIRO), and rates of exploitation adopted by the JRNC we retrospectively estimated the TAC for 2000-2006. The estimates showed that in these years the TAC could exceed 700,000 tonnes (Figure 10).

It should be noted that the same pattern was observed in assessments of walleye pollock stocks in the Okhotsk Sea when we compared the biomass values obtained by the different methods. Data showed that biomass obtained by the GIS method in 2002-2007 ranged from 1.8 to 2.7 million tonnes, the average fishable biomass was 2.2 million tonnes, while the XSA method (Magadan TINRO data) ranged from 1.1 to 1.8 million tonnes (Figure 11), on average being equal to 1.4 million tonnes, i.e. their ratio was 1.6:1.



**Figure 10.** Assessment of Total Allowable Catch (TAC) of Arctic cod by different methods; thousand tonnes.





**Figure 11.** Assessment of fishable biomass of walleye pollock in the North Okhotsk Sea obtained by XSA and GIS-method; thousand tonnes.

## Conclusions

The biomass of cod stocks in the Barents Sea in 2000-2006 was at a good level and according to the GIS method, estimates exceeded 2.3 million tonnes. Based on the “new” cod biomass estimated according to the GIS method and at the current rate of exploitation, TAC values in 2000-2006 can reach an average of 700,000 tonnes.

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# Methodological bases of fishing - ecological monitoring and new approaches to marine bioresources estimation

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## Abstract

Studies performed in the framework of the Program of comprehensive resources exploration in open waters of the North-East Atlantic ocean (NEA), 2002-2007, have enabled us to articulate and develop a methodological basis for synoptic fishery-ecosystem monitoring aimed at studying the following: the effects of hydrophysical processes and natural synoptic periods (cycles), on biological phases of the fish stock status; the peculiarities of hydrometeorological processes and the identification of essential phases of their development (studies of the ocean weather); the development of peculiarities of hydrophysical, biological, and fishery processes that affect both the evolution of hydrophysical structures and their intermittent changes leading to formation and shifts of zones with high biological and fish productivity; innovative system approaches to the study of oceanological and biological importance of the ocean synoptic variability which sometimes exceeds seasonal variability (i.e. development of ecosystem oceanography). The materials described in this paper are based on a new approach to fishery exploration studies, namely the complex synoptic monitoring of the natural-industrial system of marine living resources, the environment and fisheries.

Environmental data were collected using ships, satellite and air surveillance of changes in SST and sea level. For purposes of analysis we also used long-period weather databases in the Northern Hemisphere .

A new approach to estimating biomass, for example cod (*Gadus morhua* L), is based on satellite positioning of the fishing fleet including individual trawl hauls, commercial fleet statistics, sea surface temperature (SST) and altitude measuring which describes the hydrodynamic status of the Barents Sea. According to our method, the biomass estimates of cod in June – August 2003-2007 changes from 2.1 to 2.6 million tonnes. Improvements in the technologies discussed here will include the use of the weight and sizes of cod catches and acoustic data on density and biomass of cod stocks.

**Keywords:** *Gadus morhua*; cod; SST satellite monitoring; cod stock biomass.

## Introduction

Setting an annual total allowable catch (TAC) is a widely used fisheries management tool which seems to be useful for many exploited stocks. Establishing an appropriate TAC naturally requires the availability of unbiased data on both the status of the total population and that of the fishing stock.

Preventing overfishing on the one hand and providing maximal sustainable yields on the other necessitate a revision of traditional techniques of fishing stock assessment, studies of ways of improving it, and testing new assessment techniques which could present situations most realistically.

Besides fisheries, annual or larger-scale temporal variability in any exploited stock obviously involves a set of natural factors which may have a significant impact on the abundance of the generation that is entering the fishing stock. Taking environmental conditions and other ecosystem components that influence the distribution and biomass dynamics of the stock is an essential aspect of any scientifically sound ecosystem approach to fisheries management.

Meanwhile, the ideology of current practice in the management of aquatic living resources continues to be the 'precautionary approach' to resource exploitation. Focus is primarily on studying the impact of fisheries on stocks as well as on the necessity for TAC cuts to maintain the biomass of spawning stocks, in order to ensure the production of abundant new generations. This ideology generates ambitious statements about our capability to manage stocks (while, actually, we can only manage fisheries) and unintentionally belittles the role of natural factors in population dynamics, diminishing interest in studying their impact on the production of strong year-classes and the characteristics of changes in fish biomass.

Implementation of the principle of sustainable fisheries through precautionary TACs and the maintenance of a surplus 'precautionary' biomass of spawning stocks will only be possible if catches are brought to levels below the present annual average.

Such fisheries, however, cannot be called rational at least for two reasons. First, concerning northern traditional target fish species whose biomass is generally highly fluctuating (e.g. cod, haddock, saithe, herring, blue whiting, and mackerel), biologically based exploitation need to take their considerable natural interannual variations into account. Secondly, the non-exploitation of periodic natural increases in stocks contradicts one of the main principles of rational fishery, i.e. to provide the maximal possible long-term profitability of the exploitation of a stock.

The northeast Atlantic includes traditional Russian fishery grounds. For the past decade the resources of this area have annually provided up to 1,000,000 tonnes of national catches, including commercially valuable cod and haddock (at present Russian landings of these two species total 250,000-270,000 tonnes, with a total TAC of 500,000-600,000 tonnes). We believe that the current state of the gadoid stocks could allow us to significantly increase TACs and thus Russian quotas.

## **Materials and methods**

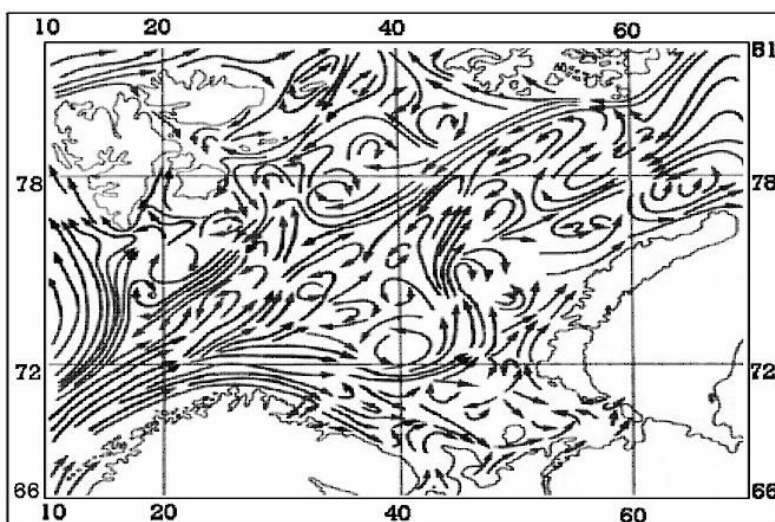
This paper presents the results of our first experience of the Barents Sea cod stock assessment based on the synoptic method for estimating the pelagic fish biomass, described by Shatokhin et al. (2002).

The principal environmental factors that determine the reproduction, abundance and biomass dynamics and distribution patterns of the Arctic-Norwegian cod undoubtedly comprise the system of large-scale quasi-stationary currents in the Barents Sea, including their seasonal and interannual dynamics, the synoptic variability in eddy-induced currents, and the productive

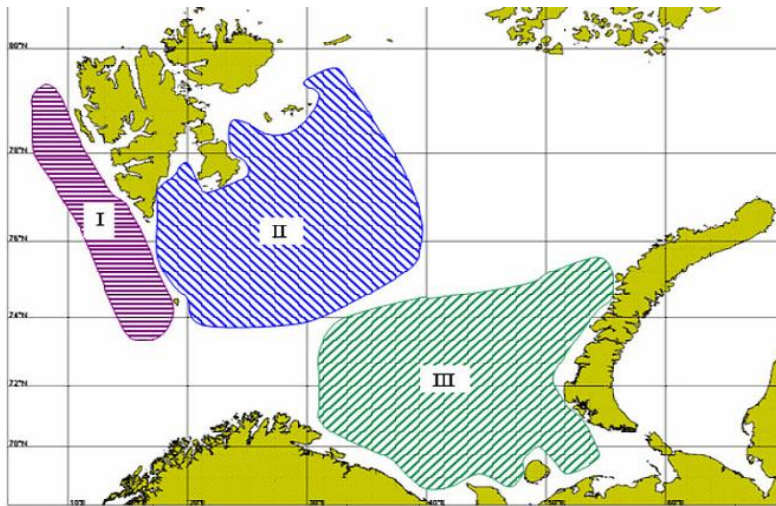
potential of the lower levels of the trophic chain. Each of these factors determines peculiarities not only of the entire life cycle of the cod stock, but also its individual stages (e.g. feeding, wintering, spawning, migration patterns depending on the system of "cold" and "warm" currents. A modern understanding of the role of synoptic variability is most vividly illustrated by the scheme of water mass circulation and quasi-stationary currents in the Barents Sea suggested by Novitskiy (1961) (Figure 1).

From the viewpoint of our objective, the important fact is that surveys undertaken by PINRO and Norwegian scientists have demonstrated a strong correlation between season and direction of cod feeding migrations and hydrological situation . (Anon., 2003). Meanwhile, in order to take into account spatial and temporal irregularities in the cod migrations revealed on the synoptic scale, we require continuous monitoring of these processes. It is noteworthy that in the course of the last decade revolutionary changes have taken place in at least two important spheres of fisheries studies: (1) the development of remote sensing of the sea surface, which provides us with a qualitatively new tool to assess processes associated with thermal dynamics and biological productivity; and (2) satellite positioning of fishing fleets which gives us an important ability to precisely determine the location of individual fishing operations (tows).

Assessment of the biomass of cod stocks are based on actual results of fishing activities in three relatively isolated areas of the cod feeding grounds where adult fishes migrate after spawning to mix with the immature fish that have not participated in spawning. Each of the three selected areas has its own current structure, namely: (1) the north-west area formed by the westerly and southerly Spitsbergen currents, (2) the north-central area influenced by the Northern and Central branches of the Nord current and (3) the coastal area, whose productivity depends on the intensity of the central and coastal branches of the Murmansk current. The relative independence of these currents leads to the relative autonomy of the selected feeding areas and relative isolation of stocks which initially migrate to *their* individual area. Altogether, these three areas cover most of the cod feeding grounds, and total estimates of fish concentrations in these areas based on fisheries data may be regarded as a reasonable estimate of the biomass of the fishing stock (Figure 2).



**Figure 1.** General scheme of water circulation in the Barents Sea, according to Novitskiy (1961).



**Figure 2.** Selected areas of cod distribution in the Barents Sea, March-November, 2003-2007.

Selection of these three autonomous feeding areas that prevents repeated counts of cod stocks which migrate from one area to another is based on the results of numerous studies (Maslov, 1944; Trout, 1957; Konstantinov, 1957; Ponomarenko, 1966; Ponomarenko et al., 1985). These studies highlighted: first, that summer migrations were associated with horizontal shifts of water masses; secondly, that stronger currents could influence the choice of migration direction; and thirdly, and particularly important, that migration from one major feeding area to another is extremely rare on an annual scale, although it could occur on a multiyear scale.

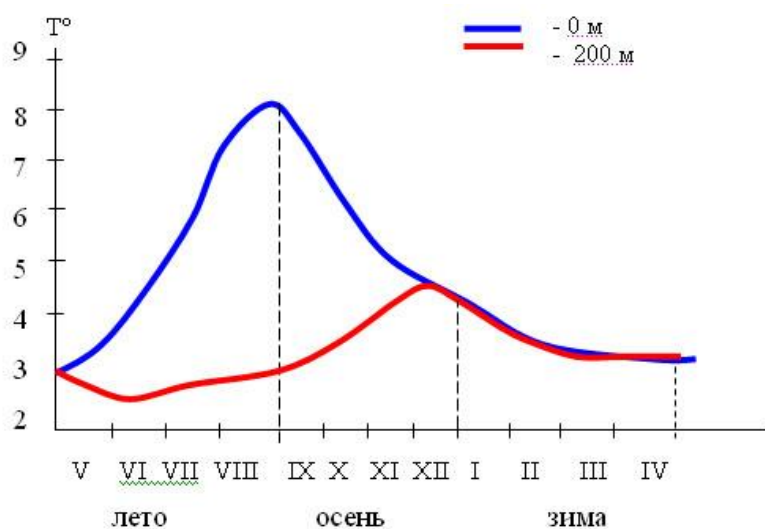
Another conceptual peculiarity of the total stock assessment is the irregular distribution of the fish biomass both on the temporal and spatial scales. This means that assessment of the total biomass of the cod stock could be derived as a sum of maximum biomass values which are recorded in the selected areas at different times, depending on the rate at which the fish form maximum concentrations in their individual feeding area. Synoptic monitoring of the cod biomass in these three selected feeding areas reveals both the time and the absolute values of maximum biomass.

In the fisheries scientific community there is a well-known and at present indisputable concept that natural changes in the hydrological situation on the annual scale affect a number of stages in the life cycle of marine living resources (e.g. spawning, wintering, feeding migrations, etc.). These life stages are related to natural hydrological periods, i.e. spring, summer, autumn, and winter. In the Barents Sea, the mean duration of these climatic seasons totals two or three months. The main seasons (summer and winter), however, may last for four months or be as short as two to two and a half months in some years. Studies of seasonal cycles require an understanding of their main phases. There are year-to-year variations in the time of the ice-melt and the onset and end of spawning, in phases of the most intensive heating of waters with development of feeding stock and in the time of feeding migrations, in winter cooling of waters and return migration patterns, and in the formation of the ice cover and wintering conditions. Every year, the climatic seasons and phases in the life cycle of fish vary temporally and spatially and one of the most obvious hydrophysical characteristics of these variations is the sea surface temperature (SST).

Here we should note a peculiarity of the Barents Sea. The fact is that in the World Ocean, annual variations in hydrophysical features of water masses on the synoptic scale reach to depths of 200-300 m. Studying seasonal cycles, it is essential to determine the beginning, end and duration of hydrophysical seasons, the phases in their progress as well as the amplitude and nature of variations within these phases. Since the Barents Sea is a shallow basin with

mean depths of 200-300 m, in our studies of the temporal and spatial progress of hydrophysical seasons and phases we were able to use data about the hydrophysical features of the entire water column.

Temperature fields are the most representative and well-studied of these features. Annual differences in the SST of the Barents Sea can be very large. Thus, in the western fishing grounds, the difference between maximum summer and minimum winter temperatures in the surface layer may be  $4.6^{\circ}$ , while in the eastern fishing grounds the difference can be as much as  $6.5^{\circ}$ . Figure 3 illustrates the temperature distribution along the Kola Section (Sarygina, 1980).



**Figure 3.** Annual variations (by month) in the SST along the Kola Section.

This temperature distribution pattern is a regular feature in every area of the Barents Sea in which Atlantic water masses are present. It is particularly important to consider the peculiarities of the temperature regime in the bottom layer when the causes and patterns of the cod migrations are being analysed. Thus, a longer period of deep layer heating and a delayed seasonal temperature maximum allow the cod aggregations to remain in their feeding grounds even until the onset of rapid cooling of the upper water layers, etc. This discussion suggests the following conclusions:

- Irregularities in the seasonal progress of temperature regimes in the surface and bottom layers as well as their dynamic relationship lead to temporal and spatial irregularities in cod migrations along the main currents.
- In turn, this factor determines the phase duration and areas of maximum concentrations of both feeding and pre-spawning cod along the respective currents. During the summer migration to the east and north-east, the cod leave waters with a relatively high temperature ( $3.2^{\circ}$ ) for relatively low-temperature waters ( $1.1^{\circ}$ ).
- Evolutionary adaptation to a hydrological regime of this type partly explains the impossibility (or a low probability) of cod concentrations migrating between the selected "autonomous" feeding grounds.

Basing on the results of the VNIRO and AtlantNIRO studies of potential fishing stocks of principal pelagic fish species (Kadil'nikov, 2001), and addressing issues of cod biomass assessment on the synoptic scale of variability, we have developed a technique that comprises the following major components:

1) filtered data from fishing vessels' daily reports (FVDR) on each operation (tow) and respective satellite positioning data are used to calculate average catches per unit effort (t/hr of towing) in each 10-mile square of the fishing grounds with the aim to obtaining data on the density distribution of cod concentrations (t/hr) in the area of the fishing fleet operations, for example in 2005 (Table 1);

2) to convert the cod density into biomass (t/mile<sup>2</sup>) we used averaged characteristics of a fishing vessel/fishing gear (e.g. the towing velocity, vertical and horizontal opening of the trawl), differentiating among nine classes of fishing vessels (Table 2) with their respective mean catchability coefficients (Lapshin, 2005); this allowed us to calculate the cod biomass (t/mile<sup>2</sup>) in each square; and

3) the total biomass of cod in the area of the fishing fleet operations was calculated as the sum of the biomass values in individual squares (Serebrov et al., 1994) which were part of the "autonomous" fishing grounds/ Cod density distribution fields were plotted with specially designed software based on a weighted-moving-average algorithm.

**Table 2.** Width of trawls for various types of fishing vessels.

Type of vessel	Width of trawl, m
MRTK	10
SRTM-K	19
STR	20
PST	30
PSTM	30
STM	30
BMRT other	30
KRTM	60
SRTM-I	90

After comparative analysis of the towing coordinates reported by fishing vessels and towing trajectories plotted on satellite data (INMARSAT and Argos systems); discrepancies were rejected (Figure 4 and 5). The software utilized to plot cod concentration fields has a special feature: the program allows the algorithm to be adjusted to the structure of the initial data, i.e. coordinates of the towing trajectories and respective values of the biomass density in the optimal sections along the towing route. The biomass density along the towing route was calculated using data on each catch, towing velocity, trawl type, and towing trajectory. Mean densities per mile were calculated for each tow. The data for each period of a uniform phase in the season were subsequently averaged in terms of 1-mile squares.

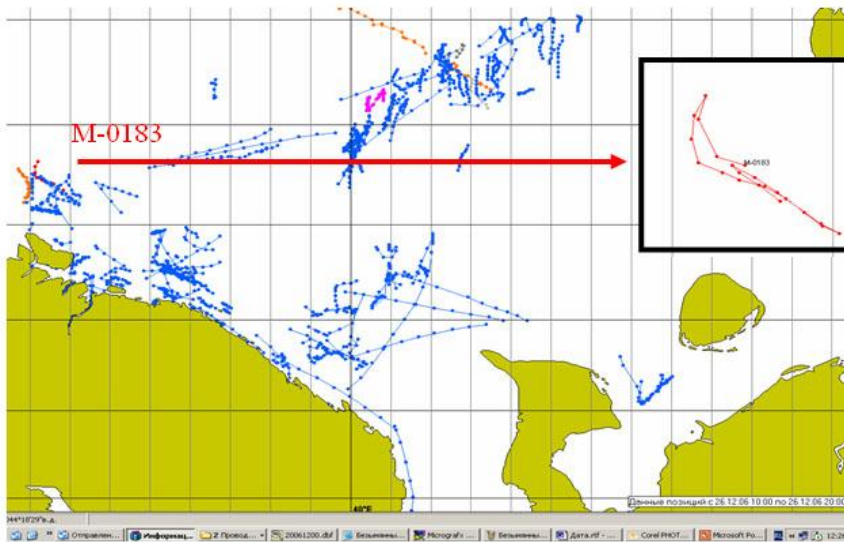
The resultant discrete field of the biomass density distribution averaged by 1-mile squares was used to plot the biomass distribution over the entire area of respective fishing grounds, and thus, to estimate the total biomass.

**Table 1.** Quantitative characteristics of the Barents cod fisheries by selected feeding areas, used for biomass estimations; March - November, 2005.

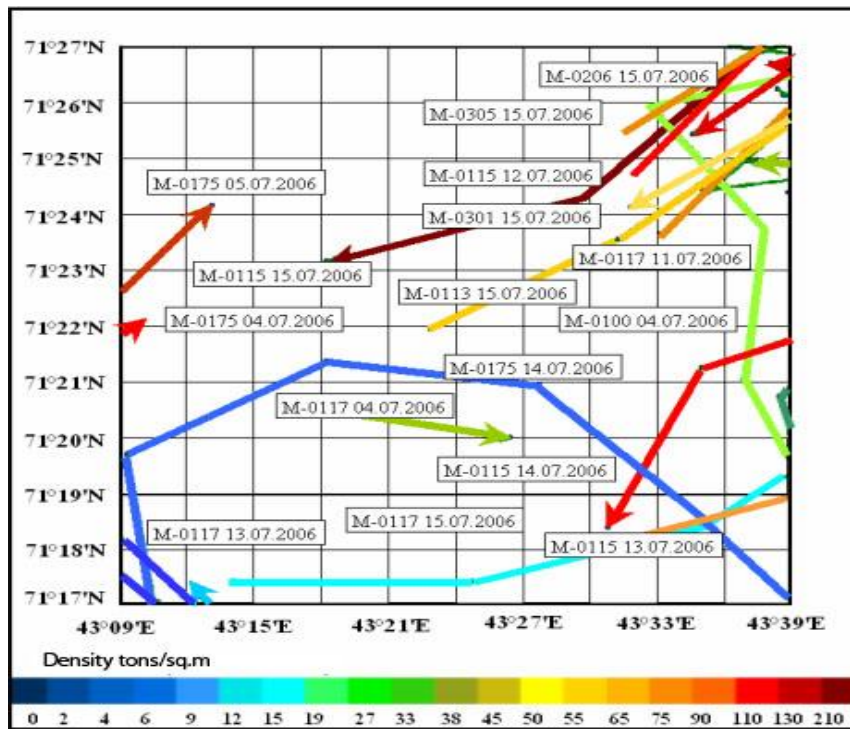
Month/ period	Feeding areas											
	I				II				III			
	No. of squares	No. of hauls	Total hours of hauling	Mean catch per hour of hauling, t	No. of squares	No. of hauls	Total hours of hauling	Mean catch per an hour of hauling, t	No. of squares	No. of hauls	Total hours of hauling	Mean catch per an hour of hauling, t
<b>March</b>												
<b>1*</b>	44	303	2110.90	0.30	-	-	-	-	160	997	4383.30	0.23
<b>2*</b>	83	483	3325.30	0.35	1	1	6.50	-	198	1764	7509.90	0.25
<b>April</b>												
<b>1</b>	101	653	4655.60	0.35	3	3	32.00	0.07	159	1248	5611.80	0.27
<b>2</b>	140	2505	12059.20	0.55	15	19	48.60	0.11	223	1132	4882.50	0.15
<b>May</b>												
<b>1</b>	110	1895	8484.20	0.57	46	146	1270.80	0.19	211	2078	9221.50	0.28
<b>2</b>	35	166	826.10	1.13	9	25	238.00	0.32	200	4717	23036.70	0.50
<b>June</b>												
<b>1</b>	31	285	1312.60	2.71	3	4	24.70	0.10	286	4070	19995.10	0.34
<b>2</b>	50	809	3408.90	1.34	3	6	56.20	0.08	239	2552	12775.90	0.43
<b>July</b>												
<b>1</b>	83	943	4037.70	0.95	21	71	927.00	0.10	200	1984	9974.10	0.60
<b>2</b>	67	178	1373.30	0.43	68	524	2374.60	1.34	207	2479	12022.70	0.31
<b>August</b>												
<b>1</b>	24	139	2025.20	0.07	74	450	1733.30	1.51	218	2546	12129.40	0.21
<b>2</b>	39	123	1696.10	0.06	131	1084	4569.80	0.90	329	2002	9292.50	0.21
<b>September</b>												
<b>1</b>	36	111	557.90	0.11	129	1009	4628.00	0.54	302	1839	9448.20	0.24
<b>2</b>	67	189	1395.70	0.15	128	1178	5251.00	0.31	185	1133	5775.60	0.14
<b>October</b>												
<b>1</b>	12	42	540.10	0.03	102	442	2319.40	0.40	177	1007	4676.90	0.20
<b>2</b>	20	51	337.90	0.24	119	1506	8910.00	0.65	227	1178	6453.10	0.19
<b>November</b>												
<b>1</b>	128	680	3451.10	0.23	126	1546	12025.70	0.49	200	1115	6079.00	0.21
<b>2</b>	90	929	5121.20	0.60	74	1053	5776.10	0.29	160	1405	7956.40	0.46

1\* - first half of the month, 2\* - second half of the month.





**Figure 4.** Position of vessels according to satellite data, June 2006.



**Figure.5.** Trajectories and results of trawls in individual fishing squares.

Here, we present the algorithm used to reconstruct the biomass distribution field from the values averaged in terms of 1-mile squares. The mean value for the density field equals:

$$\xi_0 = \sum_{i=1}^n p_i \xi_i, \text{ where}$$

$\xi_i$  is the element value in each of  $n$  points,

$p_i$  is the weight of the element,  $\sum_{i=1}^n p_i = 1$ .

The weight of each of  $n$  points surrounding the knot is considered to be inversely proportional to the distance between the point and the knot. The target value could thus be derived using the following formula:

$$\xi_o = \frac{\sum_{i=1}^n \xi_i}{l_i \sum_{i=1}^n 1 / l_i^K} = \frac{1}{\sum_{i=1}^n 1 / l_i^K} \sum_{i=1}^n \frac{\xi_i}{l_i} \quad (1)$$

where  $l_i$  is the distance between the knot and the measurement points;

$\kappa$  is the exponent of a power from 1 to 3.

The distance between points on the Earth's surface is found using the following formula:

$$l_i = R_3 \arccos (\sin \lambda_i \sin \lambda_j + \cos \lambda_i \cos \lambda_j \cos (\varphi_j - \varphi_i)),$$

where  $R_3 = 6371$  км is the radius of the Earth;

$(\varphi_i, \lambda_i)$  и  $(\varphi_j, \lambda_j)$  are the geographical coordinates of the points (in radians); west longitude and south latitude should be entered with a minus (-) sign.

Equation (1) allows for an indefinite number of points surrounding the knot.

We used the above algorithm to determine the biomass density distribution in order to perform a set of numerical experiments. These numerical experiments were principally aimed at resolving the following problems:

1. To assess the robustness of algorithms for determination of the biomass density distribution at various degrees of availability of initial data on the marine area in which the fish biomass is being estimated.
2. To estimate relative and absolute errors for various degrees of availability of initial data.
3. To study the influence of variations in free parameters of the algorithm on the resulting biomass value.
4. To study the influence of the structure of discrete initial data and free parameters of the algorithm on characteristics of the resulting field of cod density distribution.

It is important to note that our method of assessing commercial cod stocks in the Barents Sea involves certain assumptions and weaknesses :

- Estimation of biomass were made only in areas of commercial fleet activity.
- Distribution of cod in layers (pelagic component) was not taken into account.
- The coefficient of catchability was taken as 0.27.
- Radius of field restoration is minimum and was equal to only three miles.
- Catch data are sometimes underestimated in daily vessel reports. Therefore our biomass estimates based on official statistics are lower than they should be.
- Catches of the Norwegian fishing fleet and vessels of other countries in the Barents Sea were not taken into account.

## Results

The results obtained suggest the following:

- The 15-day period used for averaging allows us to define major regularities in the cod distribution in the Barents Sea against the annual cycle of this species; at the same time, the length of this period reveals the necessity of introducing variable time discreteness into further calculations which will depend on the duration of individual synoptic periods.
- The temporal dynamics of the biomass reveals at least two peaks in each of the three areas: the summer peak is reached when after spawning adult fish mix with immature stock that have not spawned, together forming the densest concentrations; the autumnal one is associated with the concentration of the stocks in their individual areas before mass return migration.
- The variability in the success of fisheries in the course of a uniform synoptic period in all areas of the Barents Sea tends to be low, which justifies use of FVDRs and satellite positioning data.
- The total summer biomass of between 2,119,073 – 2, 689,158 tonnes in 2003-2007 (Table 3) differs considerably from the ICES assessment, which states that the fishing cod stock currently does not exceed 1,200,000 tonnes.

## Conclusions

The authors regard the resulting assessment of the fishing cod stock as having been underestimated, because the calculations were only based on three areas of major fisheries importance during March-November, although cod also occur outside of these areas. We believe that further studies using satellite data for discrete assessment of the haul distribution within the squares of fishing grounds, mass acoustic data from fishing vessels carrying scientists and observers, as well as other means, could lead to greater objectivity in assessments of stock abundance. The technique discussed here is our first experience of applying advanced approaches to the study of living resources in the Barents Sea. Our results make us more cautious about data obtained with widely used methods based on the 'precautionary approach', which continue to underestimate the ecological component of stock dynamics.

The authors hope that this study will interest the international research community dealing with similar fishing stock assessment problems, who can help us to identify any drawbacks of this technique and to improve it.

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**Table 3.** Calculation of the biomass of cod stocks on the restored fields of one-mile fishing squares, with radius of 3 miles, thousand tonnes; coefficient of catchability 0.27.

Summer, 2003						
Area	June		July		August	
	01-15	16-30	01-15	16-31	01-15	16-31
1	342 398,8	187 318,0	81 369,3	48 562,3	17 254,1	30 973,8
2	10 201,1	5 849,3	0,0	0,0	16 114,1	107 316,8
3	1 123 833,3	1 669 357,6	917 635,8	761 967,2	802 091,6	685 404,6
<b>Total</b>	<b>2 119 073,2</b>					
Summer, 2004						
Area	June		July		August	
	01-15	16-30	01-15	16-31	01-15	16-31
1	160 772,9	108 154,6	126 420,3	391 745,6	220 308,7	217 941,5
2	1 311,6	14 470,5	63 978,5	125 141,6	301 679,2	526 492,3
3	1 047 259,6	1 294 386,9	1 271 085,4	850 096,1	572 385,2	510 812,4
<b>Total</b>	<b>2 212 624,8</b>					
Summer, 2005						
Area	June		July		August	
	01-15	16-30	01-15	16-31	01-15	16-31
1	521 764,8	476 021,3	526 098,6	148 900,8	34 517,0	73 177,1
2	2 710,5	4 972,7	64 815,9	573 629,6	542 575,9	803 191,1
3	1 028 810,3	934 774,6	812 607,8	492 709,8	498 199,1	581 041,3
<b>Total</b>	<b>2 353 766,2</b>					
Summer, 2006						
Area	June		July		August	
	01-15	16-30	01-15	16-31	01-15	16-31
1	568 857,4	438 917,4	315 633,7	177 336,9	132 872,1	211 011,8
2	45 227,0	131 322,3	417 052,1	639 366,4	670 302,8	772 863,3
3	1 286 334,3	1 010 730,6	758 145,9	658 814,9	830 673,3	593 414,4
<b>Total</b>	<b>2 628 055,0</b>					
Summer 2007						
Area	June		July		August	
	01-15	16-30	01-15	16-31	01-15	16-31
1	355 647,0	545 674,1	384 038,8	647 079,6	75 934,3	111 256,3
2	65 915,9	208 018,1	350 662,0	178 983,2	534 731,4	602 787,1
3	1 439 291,4	1 404 219,9	1 098 898,5	1 430 069,0	665 888,1	527 774,2
<b>Total</b>	<b>2 689 158,1</b>					

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# Cyclic changes in climate and major commercial stocks in the Barents Sea

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## Extended abstract

(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)

The term “climate” is defined as long-term statistically averaged weather indices. Climatic variability is usually described by 10-30-year averaging for aquatic areas covering several million square kilometres.

The dynamics of the average surface air Global temperature anomaly (Global dT) for a 140-year observation period shows an rising secular linear trend (about 0.06° C per decade). On the background of the secular linear trend, Global dT displays roughly 50-70 year long fluctuations. An approximately 60-year repeating pattern can also be clearly inferred from temperature anomaly dynamics in the circumpolar Arctic zone (Arctic dT) between 60° and 85° N. A specific feature of the long-period temperature dynamics in Arctic zone is the absence of a secular, linearly increasing temperature trend in Global dT. A “global climatic signal”, i.e. the simultaneous development of climatic processes with approximately 60-year periodicity can be observed, at least, over the whole northern hemisphere. These results are based on the analysis of relatively short observation periods, generally about 100- 140 years. Reliable detection of climatic processes requires the analysis of much longer climate data series, as long as several hundreds or even thousands of years.

Spectral analysis of palaeotemperature time series using O<sup>18</sup> content in Greenland ice cores, Arctic pine and Northern California pine growth-rings for the past 1500 years shows predominantly 50-70-year fluctuations.

The dynamics of Arctic climatic indices: Arctic dT, detrended Global dT and average temperature for 200 m water column along the Kola meridian for the last 100 years display approximately 60-year fluctuations and largely coincide in time with the recruitment dynamics of Atlantic spring-spawning herring populations.

The recruitment dynamics of North-East Arctic cod stocks correspond to Arctic dT and Global dT dynamics, with a delay of approximately eight years. The recruitment dynamics of cod and herring populations are similar, but with almost a delay of almost a decade for cod.

Barents Sea ice-free area dynamics display an approximately 60-year periodicity and virtually reproduce Global dT shape delayed by almost a decade. This indicates inertia of the ice cover fluctuation. This process reflects the multiyear dynamics of heat accumulation and reduction by the water masses.

Comparison of the ice-free water area dynamics and the North -East Arctic cod stock recruitment shows that the two curves correlate fairly well, but that the recruitment curve is delayed by five to six years.

Long-term climatic indices such as Global dT, Arctic dT, the mean temperature in the 200 m water layer within the Kola meridian, Atlantic water delivery to the Arctic basin and ice cover area dynamics in the Barents Sea (with respect to time shifts) intercorrelate well and can be used to characterize climatic changes in the Arctic region. Based on the analysis of the predominant periodicities of climate and biota, we have proposed a stochastic model for prospective forecasting of some commercial fish stocks fluctuation dynamics (Klyashtorin and Lyubushin 2005).

According to our projected trend, the total biomass of the Atlantic spring spawning herring commercial stock will increase until the early 2010s, and then will start to decrease again. Commercial stocks of the North -East Arctic cod will increase until the late 2010s–early 2020s and will thereafter start to gradually fall.

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# **The Bayesian approach to assessments of red king crab (*Paralithodes camtschaticus*) and northern shrimp (*Pandalus borealis*) stocks in the Barents Sea**

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## **Abstract**

This paper presents the first attempt to employ a Bayesian framework for making quantitative assessments, predictions, and risk analysis of shrimp and red king crab stock dynamics in the Barents Sea. The first type is based on Shaffer's production model and the second on cohort analysis of catches from surveys (CSA and LBA). The Bayesian approach was taken in order to construct the distribution of posterior probability of the possible values of model parameters. Biomass indices from research surveys and standardized commercial catch-per-unit-effort series, catch and "priors" of model parameters provided input to the models. A Bayesian approach was used to construct a "posterior" model parameter distribution and derived variables that would be relevant for the development of management advice. The stock biomass estimated by the model correlates well with survey indices and catches per unit effort data. Calculated relative shrimp indices of biomass and the rate of stock exploitation show that in 1982-2005, stock status was not critical and, in the majority of cases, it was in the precautionary approach safe zone. Assessment of the red king crab stock showed that the dynamics of population parameters were extremely unstable. The analysis demonstrates the possibility of using Bayesian approach to estimate population dynamics and determine TAC of the northern shrimp and red king crab in the Barents Sea.

**Key words:** northern shrimp , red king crab, the Barents Sea, models, stock dynamic

## **Introduction**

Bayes' theorem and mathematical approaches that utilise it began to be employed in fishery biology at the beginning of the 1990s. At present, such models are widely used to describe the status of stocks, to forecast their dynamics and estimate reference points for marine mammals, fish and invertebrates. The models have been successfully adapted to estimate stocks of northern shrimp, Canadian salmon, South African anchovy, whales, Pacific halibut, Pacific herring and others. Estimates of the stock status and forecasts made by this method have been used in different scientific organizations including ANTCOM, FAO, NAFO, NEAFC and ICES.

The aim of this paper is to estimate the possibility of using this method to describe the population dynamics and determine TAC for northern shrimp and red king crab in the Barents Sea.

## **Method**

The models were based on system analysis, which used the state-space method. This method allows us to link the time-series of the observed indices with non-observed absolute abundance and biomass, assuming errors in methods and observations. The approach is quite



flexible as a way of creating models of stock dynamics and data-stock relationship. The Bayesian approach production model for the northern shrimp stocks was described for the first time by Hvingel and Kingsley (2006).

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

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

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

The two types of red king crab cohort analysis LBA (length-based analysis) and CSA (catch-survey analysis) were described by Kruse and Collie (1991). A three-stage catch survey analysis is principally similar to other length-based analyses. CSA considers only three age-size groups of male crabs: prerecruits, recruits and post recruits. The model links the crab abundances in three seasons of the year  $t+1$  to the abundances and catch in the previous year through natural mortality, molting probabilities and growth matrix:

$$R_{t+1} = PR_t * molt * G_{PR,R} * e^{-M} * e^a,$$

$$P_{t+1} = ((P_t + R_t + PR_t * molt * G_{PR,P}) * e^{-M} - C_t * e^{(y-1)*M}) * e^b,$$

where  $molt$  is the molting probabilities for prerecruits,  $G_{i,j}$  is a growth matrix containing the proportions of molting crabs growing from group  $i$  to group  $j$ ,  $M$  is natural mortality in year  $t$ ,  $C_t$  - is commercial catch in year  $t$  and  $y_t$  is time lag from the survey to the mid-point of the fishery in year  $t$ .

The LBA model is as follows:

$$N_{l+1,t+1} = \sum_{l'=l+1}^{l=t+1} \left\{ P_{l',l+1} (N_{l',t} + O_{l',t}) e^{-M_t} - C_{l',t} e^{(y-1)M_t} \right\} molt_{l',t} \Bigg\} R_{l+1,t+1}, \text{ and}$$

$$O_{l+1,t+1} = [(N_{l+1,t} + O_{l+1,t}) e^{-M_t} - C_{l+1,t} e^{(y-1)M_t}] (1 - molt_{l+1,t}),$$

where  $N_{l,t}$  is new-shell crab abundances in length class  $l$  and year  $t$ ,  $O_{l,t}$  is old-shell crab abundances in length class  $l$  and year  $t$ ,  $M_t$  is instantaneous natural mortality in year  $t$ ,  $molt_{l,t}$  is molting probability for length class  $l$  in year  $t$ ,  $R_{l,t}$  is recruitment into length class  $l$  in year  $t$ ,  $y$  - lag in years between assessment survey and the fishery,  $P_{l',l}$  is the proportion of molting crabs growing from length  $l'$  to length  $l$  after 1 molt, and  $C_{l,t}$  the catch of length class  $l$  in year  $t$ .

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

The models use the series of biomass indices: the standardized index of catch per unit effort ( $CPUE_t$ ) in the shrimp fishery in 1982-2005 and the index of biomass ( $surv_t$ ) obtained from the results of the Russian and Norwegian surveys in 1982-2006 for northern shrimp and the index of abundance obtained from the results of the Russian survey in 1994-2006 for red king

crab. Indices of absolute biomass are expressed through catchability coefficients. Errors of observations are assumed to be lognormally distributed.

The data on shrimp catch and mortality associated with cod predation were taken from the reports of the NAFO/ICES Pandalus Assessment and Arctic Fisheries Working Groups (Aschan, Bakanev, 2005; Anon., 2005). The catch data are regarded as reliable and were included into the model as being error-free. The discards of shrimp are assumed to be negligible. The observation errors for mortality associated with cod predation are taken to be lognormally distributed.

## Results

### Shrimp

The model biomass estimates correlate well with the indices of abundance for survey and catches per unit effort (Figure 1). Maximal stable catch, making allowances for cod predation, amounted to 370 000 tonnes with biomass  $B_{MSY}$  equaled to 2 200 000 tonnes and  $K$  equal to 4 500 000 tonnes. The calculated relative indices of biomass and the rate of stock exploitation show that, in 1982-2005, stock status was not critical and, in the majority of cases, was within the zone of stability for this stock (Figure 2). The risk analysis showed that with the cumulative probability of exceeding MSY being equal to 30%, the catch of shrimp, even with an allowance for cod predation, might reach 300 000 tonnes (Figure 3).

### Crab

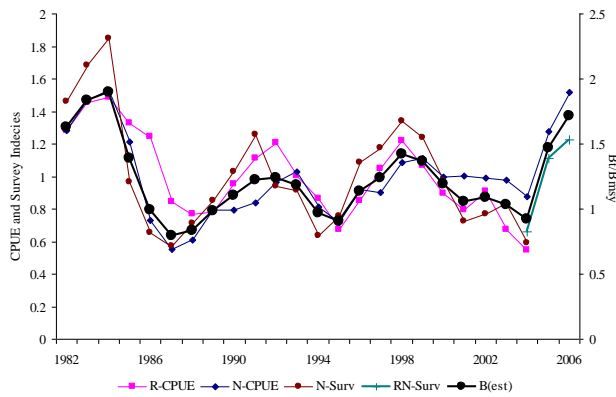
The estimation algorithms of production models CSA and LBA provided satisfactory similarity of the model data to the input data. The results turned out to be insensitive to the initial values of the evaluation parameters.

When similar scaling coefficients were utilised, the calculation indices using different versions of stochastic models satisfactorily describe actual indices as produced by surveys (Figure 4). The greater flexibility of the production model describes the data better than cohort models. Nevertheless, *a posteriori* probabilities of parameter distribution obtained by using the production model have less expressed modes and wider confidence interval limits than in calculations using a cohort method.

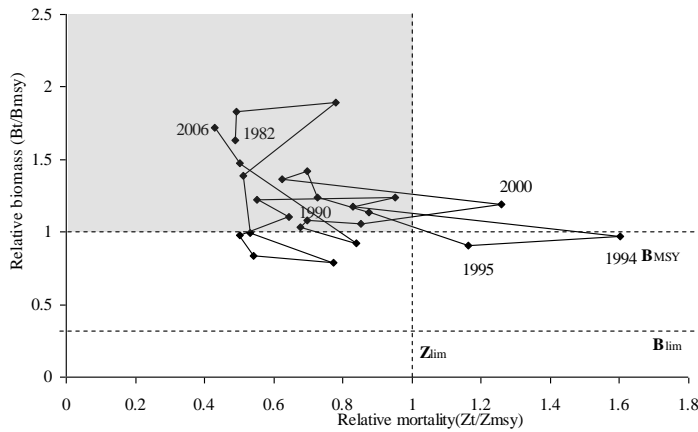
In the course of the study, the abundance of all the groups significantly increased (Figure 4). In 1994-2001, stock abundance remained at a stable low level and all the models describe this period in a similar manner. The sharp rise in abundance in 2003-2004 is described less well by the cohort models, but, by 2005-2006, the trends in abundance variation are described similarly by all of the models. Maximum stock abundance was registered in 2003 and, according to the cohort models, in 2004-2005. By 2006, abundance had fallen again and was equal to about 10 million individuals. Taking into account that the initial data and our choice of the *a priori* probability of catchability coefficients was the same, the results of estimation by models were also similar.

In 2007, the commercial stock was estimated at 8-10 million individuals. The forecast of the stock status in 2008-2009 at different levels of exploitation shows that with catches of 2 million individuals, the commercial stock increases according to the calculations of the three models and, when the catch is equal to three million individuals, the stock abundance remains

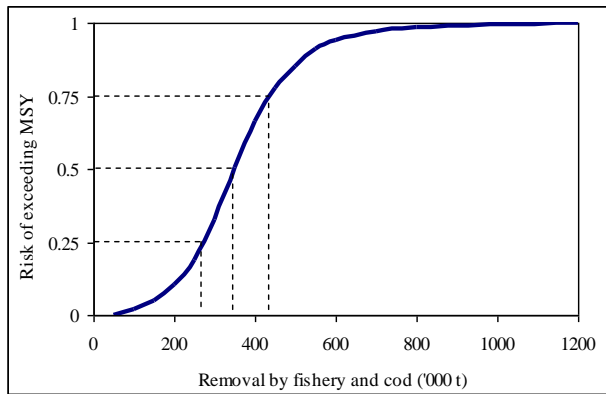
unchanged (Figure 5). According to the production, CSA and LBA models, a catch of four million individuals would lead to a fall in stock levels. The forecast estimates for catches of four million individuals two year ahead are pessimistic, according to the calculations of all three models.



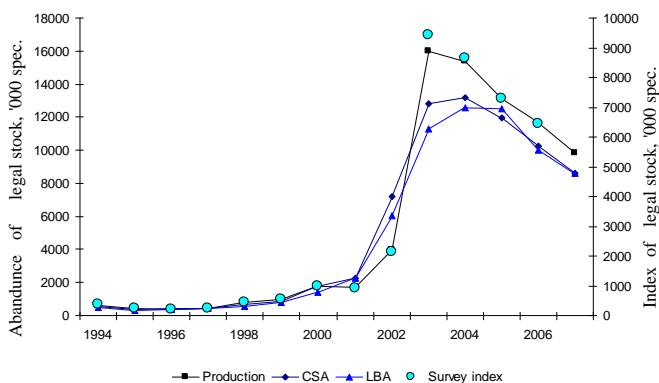
**Figure 1.** Comparison of model estimated ( $B_{(est)}$ ) and observed values: Russian and Norwegian CPUE (R-CPUE and N-CPUE) and Norwegian and Ecosystem survey stock biomass indices (N-Surv, Eco-Surv).



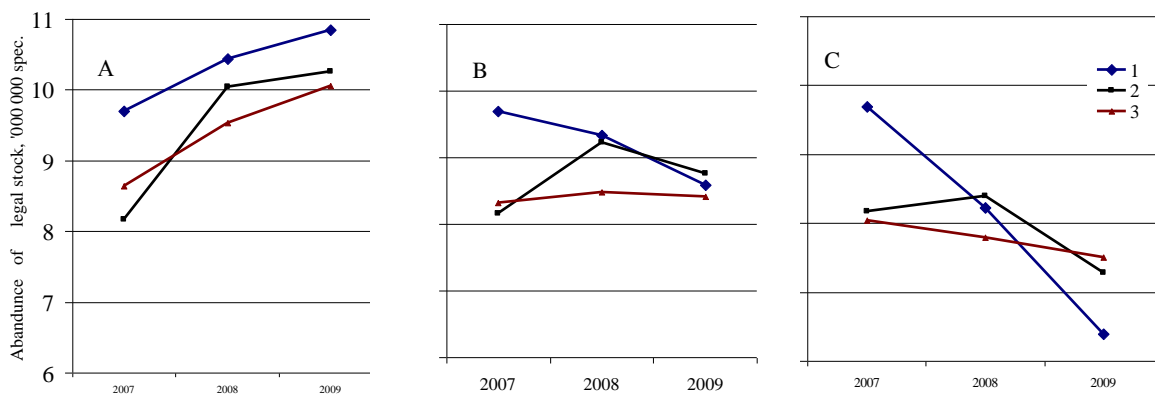
**Figure 2.** Dynamics of the Northern shrimp stock from the Barents Sea in 1982-2005 by zones of the regulation area, according to the precautionary approach (dark area – safe zone).



**Figure 3.** The cumulative probability of exceeding MSY.



**Figure 4.** Fitted (lines) and observed survey index (dots) of commercial abundance using production, CSA and LBA models in REZ.



**Figure 5.** Projections of commercial stocks of red king crab by maintaining annual catch levels of two (A), three (B) and four millions (C) individuals during 2007-2009, according to production (1), CSA (2) and LBA (3) models.

## Conclusions

The Bayesian approach can be used to estimate the population dynamics of northern shrimp and red king crab in the Barents Sea and Spitsbergen region.

The dynamics of the Barents Sea red king crab population parameters are extremely unstable. However, the presence of strong year-classes permits us to forecast stock dynamics and to develop appropriate management strategies.

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# A Probabilistic Approach to Estimating Marine Biological Objects Using Aerial Survey Data

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## Extended abstract

*(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)*

This method consist in the use of extrapolation and interpolation throughout the entire area of assessment of probabilistic fits in particular interval classes of density data rather than absolute benchmark density values. The selection of these classes is determined by the Monte Carlo method.

The benchmark data for calculations are the densities of marine mammals counted at a site with coordinates  $X, Y$ . We designate these  $\rho_i(X, Y)$ . For all aerial survey benchmark data, we draw up a table for the density distribution of the animals recorded, including zero values.

The range of measurements of the density is divided into  $L$  suitable class intervals  $G_j$  with certain limits

$$G1_j \leq \rho_i(X, Y) \leq G2_j \quad (1)$$

where  $G1_j$  – the lower limit of the density values,

$G2_j$  – the upper limit of the density values.

The values of the 0-class ( $\rho_i(X, Y)=0, G1_j=0, G2_j=0$ ) are determined separately.

The benchmark data and  $\rho_i(X, Y)$  permit us to calculate the group density of  $n_j$ , i.e. those values that fit within the class interval  $G_j$ , and consequently, the relative frequency (probability) of the implementation of a particular distribution class, using the equation:

$$P(j) = \frac{n_j}{N} \quad (2),$$

where  $N$  – the number of density benchmark data.

The survey area is divided into  $T$  cells, corresponding to the individual density area. Equation (2) is used to determine the internal class and the probability of their realization in  $j$ -cells.

In the estimated  $k$  cell of the area they determine the sum total of the probabilities of class interval  $G_j$ , taking into account all benchmark data from the equation:

$$S_k(j) = W * \sum_{i=1}^N P_i(j) \quad (3),$$

where  $S_k(j)$  – is the sum of the probabilities of realization of the class interval  $G_j$  in the initial two  $j$  cells,  $W$  – weight coefficient, which is a function of the  $R_{ik}$  between the calculated  $k$  cells and  $i$  cell with benchmark data and which also has a different form for different suggested patterns of distribution of marine mammals:

for evenly random distribution  $W = \frac{1}{R_{ik}}$  (4),

for group distribution  $W = \frac{1}{R^2_{ik}}$  (5),

for aggregated distribution  $W = \frac{1}{R^3_{ik}}$  (6).

In accordance with equation (3), we calculate each class interval  $G_j$  to obtain in cell  $k$  a set of values of the sums total of all class density intervals  $S(j)$ . Normalization of the values obtained:

$$P(j) = \frac{S(j)}{\sum_{j=1}^L S(j)} \quad (7)$$

This gives in the estimated cell  $k$  the distribution of the probabilities of each interval  $G_j$ . Having applied the Monte Carlo method to the distribution of the probabilities, we determine the class interval of the values of the area cell to be estimated. By repeating the Monte Carlo estimation, the random values of the numbers within the class  $G_j$  are determined.

The number of marine mammals ( $M$ ) throughout the entire area is estimated by summing the values of all the cells of the area:

$$M = \sum_{i=1}^T P_i(X, Y) \quad (3),$$

The above calculation is repeatedly checked and the mean value of the estimated numbers of marine mammals and the standard deviation are determined.

In order to implement the above method for calculating the numbers of marine mammals, I developed an original computer program to be used for number calculations of harp seal in the White Sea.

Comparisons were made between the probabilistic approach and traditional methods of calculation of a number with the aid of a mathematical model of the distribution of biological objects. On average, the results of calculations using the probabilistic approach exceeds the values calculated by traditional methods by 15-20%.

The advantages of the proposed method of assessment are the following:

- an absence of restraints associated with collection of primary data (parallel transects, regularity of the distribution of survey sites, etc)
- the possibility of taking into account the biological properties of the distribution of marine mammals via weighting coefficient
- the selection of arbitrary limits of number assessments in the area under study.

# Transports and propagation of anomalies in the Norwegian and Barents Seas

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## Extended abstract

(Full article: Skagseth, Ø., Furevik, T., Ingvaldsen, R., Loeng, H., Mork, K.A., Orvik, K.A., Ozhigin, V. (2008) Volume and heat transports to the Arctic via the Norwegian and Barents Seas. In Arctic-Subarctic Ocean Fluxes: Defining the role of the Northern Seas in Climate. Eds. R. Dickson, J. Meincke and P. Rhines, Springer Verlag.)

The main aim of this paper has been to present a holistic view of the Atlantic water flow along the Norwegian Coast and into the Barents Sea. It has focused on the period starting in the mid-1990s, with simultaneous arrays of moored current meters in the Svinøy section and the Barents Sea Opening. These detailed measurements have provided the bases for improved estimates of means and variations in fluxes, and their forcing mechanisms (Skagseth, 2008). Mean volume and heat fluxes associated with the Atlantic water are 4.3 Sv and 126 TW respectively for the Svinøy section, showing no significant trends, and 1.8 Sv and 48 TW for the Barents Sea Opening, where positive trends have been found in both measures. The transport series show a prominent, but irregular, seasonal cycle at both sites, mainly determined by variations in the volume flux. The inter-annual changes are both substantial, but are relatively larger in the Barents Sea Opening.

In terms of prediction the data confirm the approximately two-year lag in anomalies from the Svinøy section to the Barents Sea Opening. This strongly suggests that the recent relative cooling of the Svinøy section will be seen in the Barents Sea Opening in the next few years. However, as the volume flux becomes relatively more important in determining the climate in the eastern part of the Barents Sea, this region is probably less predictable, since atmospheric forcing is basically unpredictable beyond time-scales of one week.

Hydrographic data along the Norwegian Coast show that the periods of direct current measurements, after 1995 for the Svinøy section and 1997 for the Barents Sea Opening, are the prolongations of a period that started in the late 1970s, since when Atlantic water has become warmer and saltier. This means that, given the assumption of constant volume fluxes, the estimated heat fluxes are higher than the long-term mean.

The close resemblance, throughout the record, between temperature variations in the Kola section and the AMO-index back to the early 20<sup>th</sup> century illustrates the importance of large-scale long-term variations in the Barents Sea system. Although the magnitudes of these variations are relatively small in comparison with inter-annual variations, other studies have shown them to be of major importance for ecosystem changes (ACIA, 2005).

Forcing mechanisms, relating primarily to the wind, of the NwASC and the Atlantic water flow into the Barents Sea, were reviewed. The different forcing effects of the NwASC and the Atlantic inflow to the Barents Sea to similar atmospheric systems are noted. The results strongly suggest that the relative distribution of the NwAC entering the Barents Sea and passing through the Fram Strait is very sensitive to storm tracks. Thus, in a climate change perspective, changes in the predominant storm tracks may trigger major changes, including feedback mechanisms, for the Barents Sea climate and the heat budget of the Arctic Ocean.



# Climate variations and the state of zooplankton in the Barents sea

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## Abstract

We present data on zooplankton biomass distribution in August-September 2005-2006 obtained in the integrated ecosystem system survey for the Barents Sea performed by Russian and Norwegian vessels. In order to establish the general regularities of plankton biomass, data collected in the central latitudinal zone of the Barents Sea in individual years (cold 1987, moderate warm 1989, anomalous warm 2002, 2004, 2005) were analysed. Considerable annual differences in the species and age structure of plankton community in water masses of different origin depending on dynamics of the ice cover in that part of the sea were found.

In 2002, owing to the northerly position of the ice edge in summer, the plankton community was characterized by its mixed composition (Atlantic and Arctic species) and high abundance. In 2005 when the advective processes were weak and the eastern areas became free from ice later, a considerable reduction in the abundance of warm-water species was observed. When the position of the ice edge was most southerly in 2004, the bulk of the plankton community was made up of Arctic species and a lack of warm-water species was recorded. In 1987 and 1989, high horizontal gradients of water temperature in the areas of Atlantic and interactions of Arctic water masses were, together with anomalous ice distribution, the main factors influencing the state of zooplankton.

**Key-words:** ice edge, plankton, *C. finmarchicus*, *C. glacialis*, distribution, biomass

## Introduction

The central Barents Sea is an important feeding area for many commercial fish species and zooplankton form the basis food during most of their life cycle. The state of the food supply of commercial fishes is of great importance for the ability to attain peak physiological condition and form strong year-classes.

Most plankton investigations in the north of the Barents Sea are restricted to the central part of the sea and to the spring/summer season, when copepod reproduction and development occur (Skjoldal, Hassel, Ray et al., 1987; Melle, Skjoldal, 1998; Arashkevich et al., 2002). These studies paid most attention to the life cycles of two dominant copepods, *Calanus finmarchicus* and *Calanus glacialis*. The latter species is most dominant in the Arctic water masses in the north (Jaschnov, 1970; Hassel et al.; 1991; Tande, 1991), and may comprise up to 80-90% of the total mass of copepods in some areas. A number of papers written between 1980 and 2000 cover the data on biomass, age composition and reproduction of dominant copepods (Koptev, Nesterova, 1983; Degtereva, Nesterova, Panasenko, 1990; Skjoldal, Gjørseter, Loeng, 1992; Orlova, Boitsov, Ushakov, 2004). Other studies provide information on copepod seasonal reproduction and growth features and on the impact of climate

variations on biological processes in the central and north-eastern part of the sea (Orlova et al., 2002, 2005, 2007).

In this paper we discuss the inter-annual variability in the structure of plankton community and biomass in different water masses. The influence of heat-related sea-ice dynamics on zooplankton during summer in different years was also investigated.

## Materials and Methods

Regular plankton investigations by PINRO in the north of the Barents Sea have been carried out in 1982-1993 and 2002 to the present, and by IMR since 1990 to the present (Table 1). The catches are taken using several plankton gears, including Juday (PINRO), WP2 and MOCNESS (IMR). The materials for cold (1987), moderate (1989) and warm (2002, 2004, 2005) years were analysed. A total of 437 zooplankton samples were processed by PINRO during this period. Most attention was paid to two biomass-forming species, the North Atlantic *C. finmarchicus* and the Arctic *C. glacialis*. The maps of the ice edge position in July were made using the data from the Norwegian Meteorological Institute in Tromsø.

**Table 1.** Plankton studies in the North Barents Sea were carried out by PINRO and IMR.

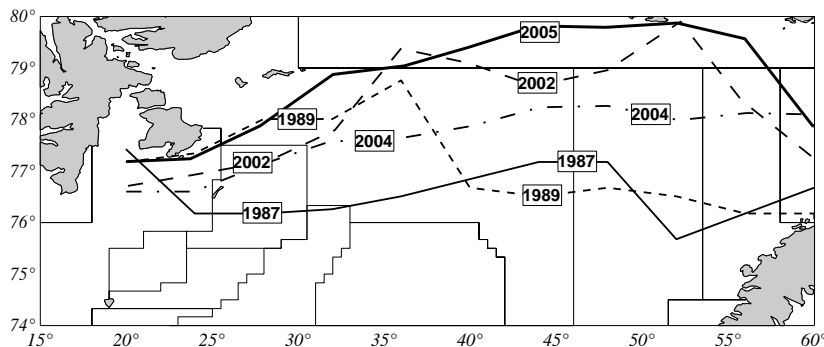
year	IMR		PINRO	
	WP2	MOCNESS	WP2	JUDAY
	N stations			
1982				52
1983				78
1984				79
1985				260
1986				88
1987				91
1988				169
1989				42
1990	107	27		143
1991	129	25		
1992	123	28		138
1993	112	30		156
1994	141	33		
1995	117	42		
1996	113	54		
1997	129	44		
1998	201	44		
1999	169	39		
2000	139	56		
2001	142	50		
2002	129	43		62
2003	88	37	86	
2004	157	34	35	37
2005	134	48	51	41
2006	150	43		133

## Results

### Oceanographic conditions

The central Barents Sea is occupied by waters of three basic types: Atlantic, Arctic and waters of the Barents Sea (Loeng, 1991; Ozhigin, Ivshin, 1999). Since the central latitudinal zone is very extended, the regime of its individual parts is formed under the influence of both general and local hydrographical and meteorological factors (Boitsov, Tereshchenko, 1998; Tereshchenko, 1999).

In 1987, a weakened seasonal heating in the surface layer in the spring-summer period caused a warmth deficit. Even in July the ice edge was located along parallel 76° N in the west, between 76-77 °N in the centre, and 60-100 miles southward of the mean annual condition in the east (Fig. 1). In September, the pack ice was between 79 and 80° N, and was close to normal. In 1989, in June-August, waters in the branches of warm currents in the Barents Sea in the upper 200-metre layer had an abnormally high temperature. The ice coverage in the sea in June corresponded to the norm, although in July-August, in the central part of the sea, the ice edge was 60-80 miles south of its usual position, owing to the intensive ice transport from the north east.



**Figure 1.** Location of ice edge in July 1987, 1989, 2002, 2004, 2005.

On the whole, the hydrological regime in August 1989 was formed under the influence of the intensified inflow of both Arctic and Atlantic waters.

A warm period in 2000, after a series of cold years, was characterized by inter-annual differences in oceanographic conditions, including the ice coverage of the sea. Although the mean annual values of this parameter in 2002, 2004 and 2005 were below the mean annual level, it was observed that in the summer the sea became free of ice at different rates (Borovkov et al., 2004; Pedchenko et al., 2005).

A specific feature of the oceanographic regime in the Barents Sea in 2002 was the intensification of the warm advection by a system of the North Cape and Murmansk Currents in the spring-summer period. At that time, the total ice coverage of the sea was 8-15% less than normal. In July, in the north-east of the Sea, the ice edge was located to the north of its mean annual position, while on the meridian 50° E, it was close to Franz Josef Land (FJL), which was approximately 100 miles north of the normal position.

In the spring-summer period 2004, intensive heating of the surface layers was observed, reaching a peak in July. The ice edge in July 2004 was at the mean annual level. In September, the edge was at 82° N, and the pack ice was represented by a small “tongue” along the eastern coast of FJL.

In summer 2005 there was intensive ice melting and pack ice destruction in the Barents Sea. Ice coverage in July was only 13%, which was almost half of its normal extent. In the north-east of the sea the ice edge was observed to the north of the mean annual position and of the position in July 2002 and 2004. In August – September, the Barents Sea water area was ice-free. The pack ice was located generally to the north of 81° N.

In 1987 and 2004, the ice edge dynamics were maximal compared to 2002 and 2005. This was caused by extreme positive anomalies in the air temperature and stable southerly winds, which greatly influenced the processes of ice melting and disintegration. The character of the ice edge dynamics in the different parts of the sea was heterogeneous, so it was provisionally divided into western (30-32° E), centre (32-45° E) and eastern (46-60° E) sectors.

### Zooplankton

The data for recent years shows that plankton biomass has grown from 7.3 to 9.2 g/m<sup>2</sup> (Fig. 2.) One of the major factors behind this growth was a decrease in the stock of the basic plankton consumer; capelin (Fig. 3). However, the plankton biomass is also influenced by other predators such as young cod, haddock and herring in particular, as their abundance has increased in the recent years. Besides these, during the past few years, an increase in abundance and expansion to the western part of the Barents Sea of blue whiting and polar cod in the east have been observed. These may increase the total pressure on zooplankton. The intensification of advective plankton drift with the Atlantic waters is also an important factor.

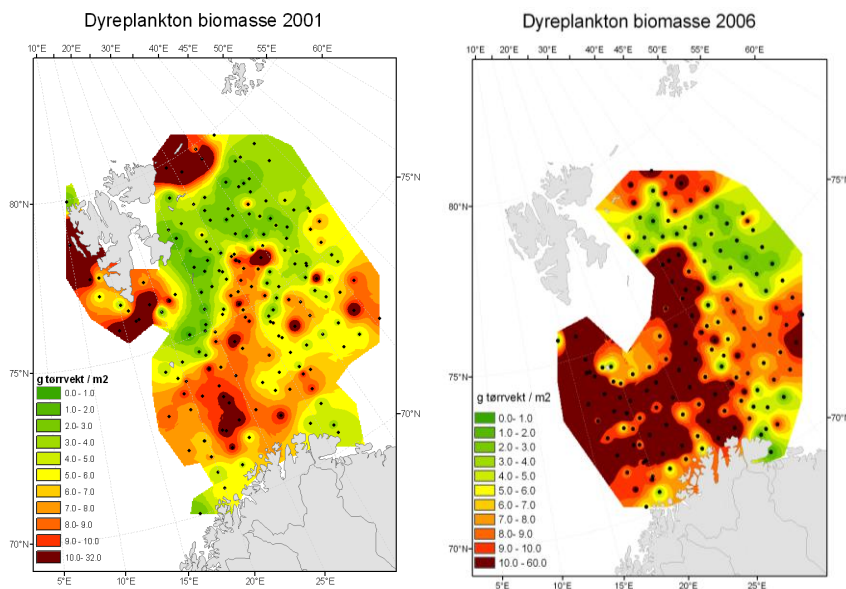


Figure 2. Distribution of zooplankton biomass in 2001 and 2006.

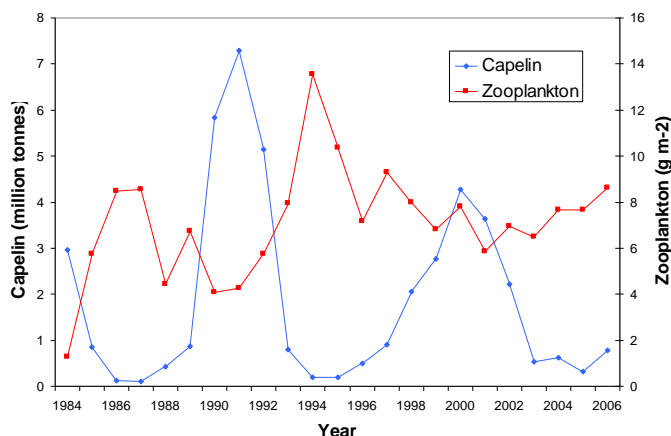
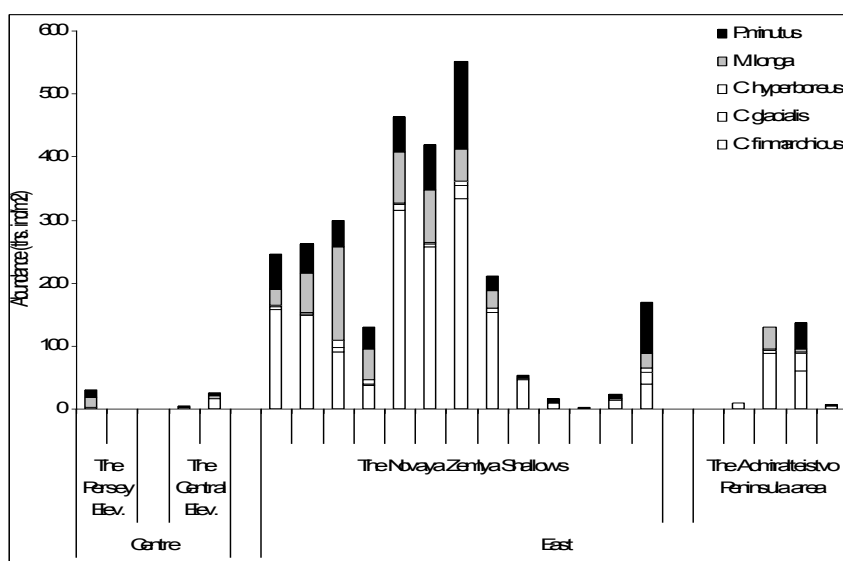


Figure 3. Annual fluctuations in zooplankton biomass (WP2) and size of capelin stock in the Barents Sea.

In 1987, the Arctic water masses occupied practically all of the central and eastern parts of the latitudinal zone from the surface to the bottom. Meanwhile, in northern waters, there were some areas where the water temperature was below  $-1^{\circ}\text{C}$ . In the west a thermal front zone was formed. A characteristic of that year was a relative low abundance of plankton in August, which was related to the greater ice cover of the Barents Sea in July, which prevented copepod transportation. The abundance of the North Atlantic species *C. finmarchicus* was characterized by the greatest variability. In the beginning of August, in the east ( $50-56^{\circ}\text{E}$ ), and in the second part of the month, in the centre ( $36-42^{\circ}\text{E}$ ), its abundance in the Arctic water masses was very low (Fig. 4). Although on the Novaya Zemlya Bank ( $46-48^{\circ}\text{E}$ ), where the rates of destruction of the ice edge and the shift of the edge northwards were at their greatest, a sudden increase in abundance of this species was observed. In the mixed waters, the concentrations of *C. finmarchicus* in the centre were also low, and only uncertain areas in the west (the South Cape Deep) did they increase with an abrupt retreat of the ice edge.

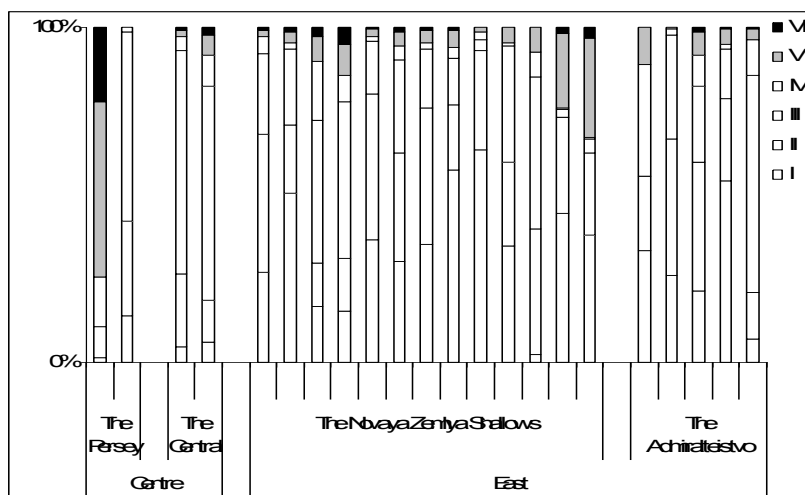


**Figure 4.** Abundance of zooplankton in Arctic waters in August 1987.

Arctic species were mostly found in the central and eastern areas. *C. glacialis* was unevenly distributed, mostly in the north of the eastern areas. We should note that a specific feature of 1987 was a correspondence between dominant concentrations and areas with increased horizontal water temperature gradients.

More complete information on the ways of forming aggregations and copepod biomass is provided by their age structure. At the beginning of August, in Arctic waters, in the north of the eastern areas, the reproduction of the local *C. finmarchicus* stock was observed. The spawning progress was judged by the presence of females (in some cases together with males), by the number of nauplii at IV-V stages, and rarely by the presence of Calanoid eggs.

In the east and in the centre, we observed areas where all these features appeared almost simultaneously, which indicated mass reproduction. The population was recruited also from young fry (CI-II), brought from the other areas; the number of crustaceans CIII was smaller (Fig. 5). In the second part of the month, in the western areas, the relative number of *C. finmarchicus* CIII-IV was high. The *C. glacialis* population in most cases was made up of hibernates CIII-V. At the same time, during the first ten-day period of August, in the north of the Novaya Zemlya Bank area ( $76-77^{\circ}\text{N}$ ), a large number of females was observed, (sometimes together with males) while large eggs of those species were also found.

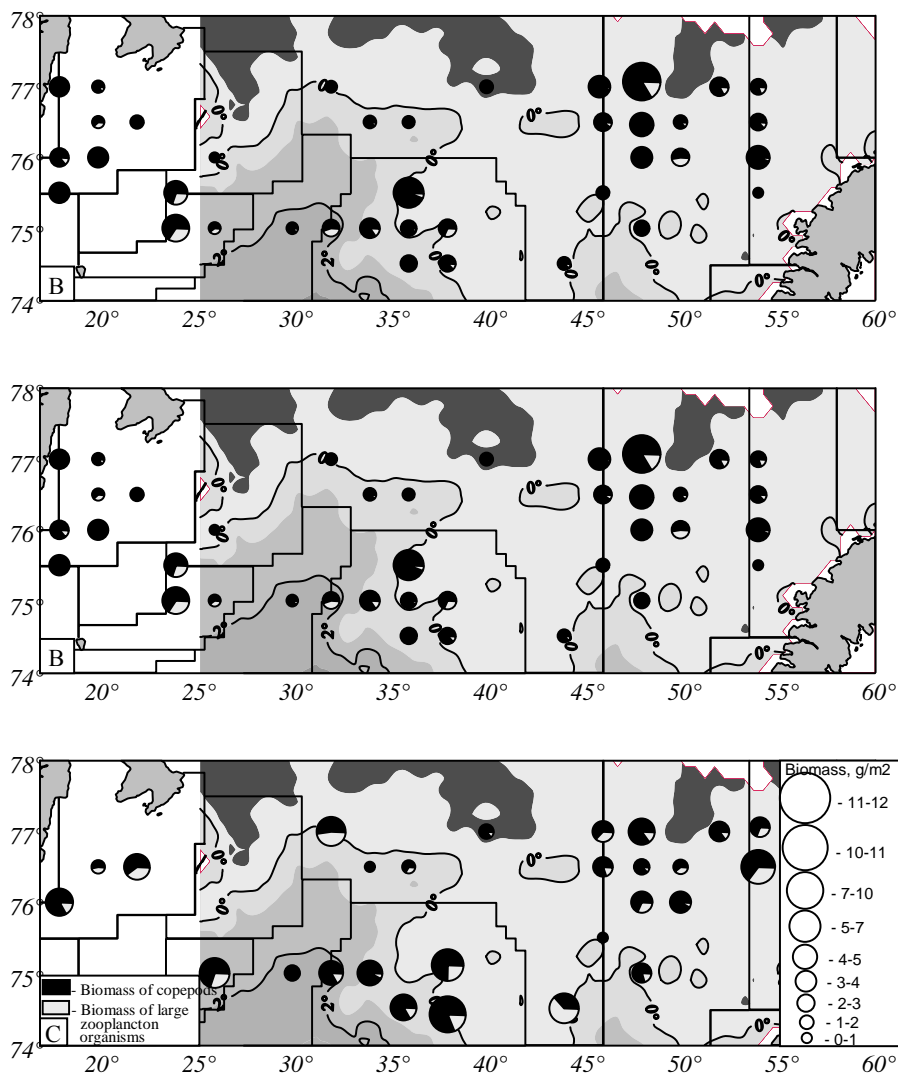


**Figure 5.** Stage composition of *Calanus finmarchicus* in Arctic waters in August 1987.

The formation of aggregations and the reproduction of the most dominant copepods, observed in August in the northern water areas, corresponded to heavy (3-4 points) blooms of diatoms and golden-brown algae. This was most evident in the first ten-day period of the month, on the Novaya Zemlya Bank, and, in the area of Admiralty Peninsula, where *C. glacialis* was observed in great quantities. In the centre, the bloom finished earlier, due to a more rapid ice retreat, and the number of copepods was thus lower than usual. The exception was the north-west of the Persey Elevation, where in mid-August, in Arctic and mixed waters, intense blooms of diatoms remained, and larger numbers of *C. finmarchicus* concentrations were found. In the west, at the end of August, in the northern waters (mixed waters) the uneven blooming of diatoms and golden-brown algae (*Chaetoceros*, *Phaeocystis*) remained, the spawning of *C. finmarchicus* was also observed, but, in most cases, the bulk of its population was made up by copepodite stages (CI-III). The percentage of older *C. finmarchicus* copepodite stages increased in the southern direction, a relative part of *C. glacialis* decreased simultaneously.

As well as the distribution of copepods, there were some differences in their vertical distribution, which influenced biomass values. In the upper layer (0-50 m), they were estimated by a correlation between copepodite stages, maturing and mature individuals. Similarly, in the Arctic and mixed waters of the Novaya Zemlya Bank and the Admiralty Peninsula, where *C. finmarchicus* and *C. glacialis* young were predominant, biomasses were low (2-5 g/m<sup>2</sup>). In the center, where high abundance of *C. finmarchicus* CI-IV and *C. glacialis* CIII-V only remained in the north-west of the Persey Elevation, the biomass reached 11-12 g/m<sup>2</sup>; in the west, biomasses varied considerably (Fig. 6). In 50-100 m layer, the plankton species composition was close to that one in 0-50 m layer. The areas with relatively close aggregations of *C. glacialis* CV in the north-west and *C. hyperboreus* CIV in the centre and in the east and their joint aggregations were found.

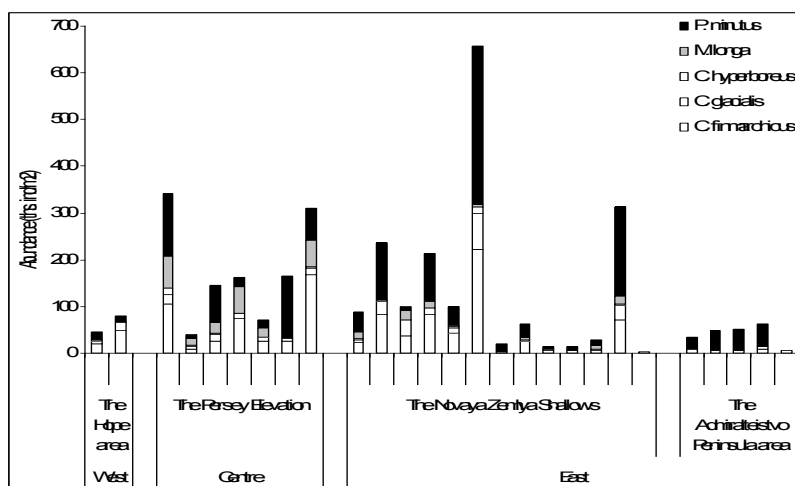
Thus, it should be noticed that copepods had basic migrations within the feeding ground within the depth range of 0-100 m. Meanwhile in some cases our data allow us to support their quite flexible food strategy, which consisted in the shift of food migration time depending on food supply. This peculiarity appeared locally and differentially in different species and age of crustaceans, which conditioned great variations in biomass rates in different layers. On the whole, in the cold 1987, a distinctive feature is low copepod abundance of adults and younger stages, in early August. The total biomass, mainly consisting of two copepod species, *C. finmarchicus* and *C. glacialis* was low, 1-4 g/m<sup>2</sup>. The percentage of *C. glacialis* in Arctic waters was 42-68%, in the mixed waters - 21-75%.



**Figure 6.** Zooplankton biomass distribution in the 0-50 m layer (A), 50-100 m layer (B) and 100 m-bottom layer (C) in August 1987.

In 1989, the ice conditions in July influenced configuration of boundaries of the Arctic water mass distribution in August-September.

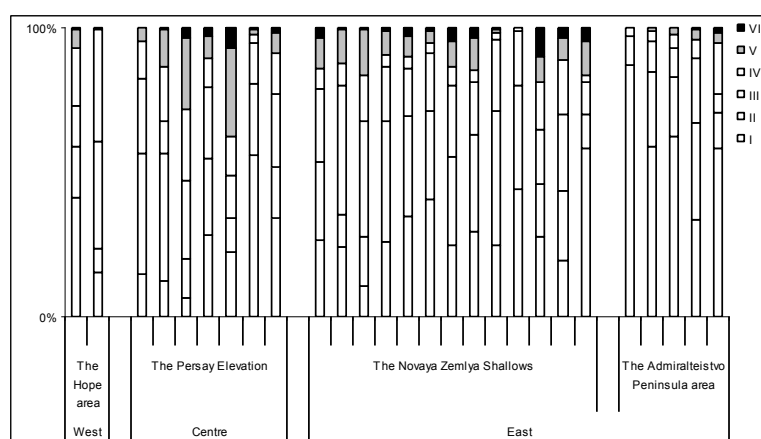
In the east (54-56° E), where the ice edge occupied the most southern area in July, an intensive bloom of diatoms was observed. However, there were few copepods (*C. finmarchicus*, in particular) in that period (Fig. 7). The copepods in minimal numbers were found at the ice edge correspondingly (76°06' N 52°00' E). A stable increase in copepod concentrations, including *C. finmarchicus*, was observed on early August in the northern water areas, in the centre and in the east, along 44-48° E, where the rates of the ice edge retreat rose, followed by an intensive bloom of diatoms. Besides *C. finmarchicus*, the density of *C. glacialis* aggregations also increased there. During the second ten-day period of August, in the centre along 40° E, where the ice edge suddenly retreated to the north, the situation was almost the same, but with the diatom bloom fading. There, in a small territory occupied by Arctic water, at the end of the second ten-day period in August, the bloom was weak and there were few copepods.



**Figure 7.** Abundance of zooplankton in Arctic waters in August 1989..

In the areas with mixed waters, the copepods formed denser aggregations, although their numbers were higher in the west. The distribution of *C. finmarchicus* was uneven, with its greatest aggregations mostly in areas with temperatures of 0-1° C. Besides that species, *C. glacialis* was characterized by a wide distribution with a higher density of aggregations mostly in the west and in the centre.

The rates of the ice retreat also influenced the age composition of copepod populations. Along with hibernates overwintering adrift, young fry CI-II and, to a less degree, CIII appeared in the Arctic water masses, at the beginning of August, in areas that had recently become free of ice, where *C. finmarchicus* aggregations were very low (Fig. 8). Although *C. finmarchicus* started their process of reproduction, number of Calanoid nauplii were still low. In the northern water areas, where the temperature was 0-1° C and the intense phytoplankton bloom was observed, the wintered females started the reproduction process, which had a mass character in the east and the centre, after which they accumulated and probably matured. This year, a peculiarity of the *C. glacialis* population structure in the Arctic waters was the abundance of crustaceans CI-III, brought there by the Arctic water masses after the ice-melt in some areas (alongside with wintered individuals CIV-V). The percentage of fry was highest in the east.



**Figure 8.** Stage composition of *Calanus finmarchicus* in Arctic waters in August 1989.

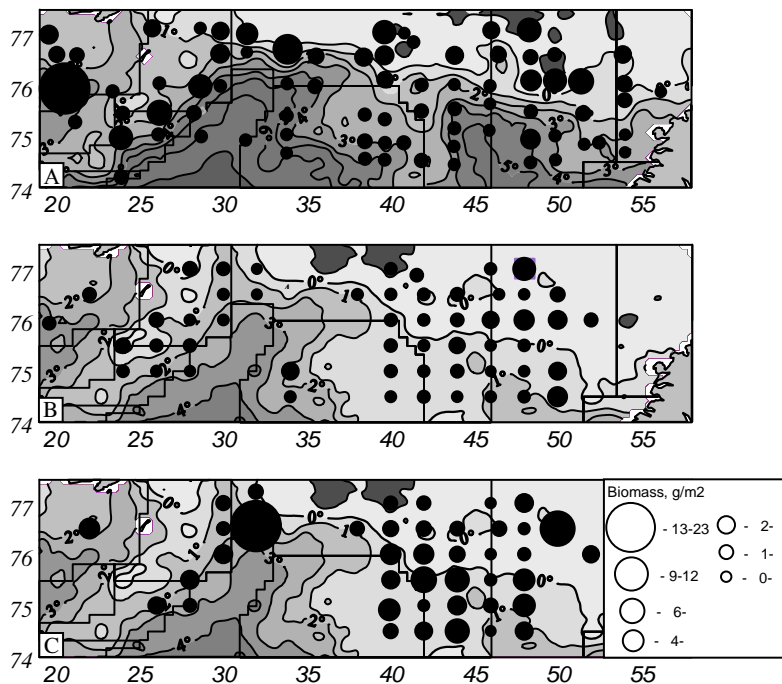
In the mixed waters, with their wide spread in the centre and east, the structure of *C. finmarchicus* population was close to that in the Arctic waters. The age composition of populations of *C. glacialis* was generally influenced by the isotherm position at 0° C, which in the west (40° N) passed mostly through northern waters, while in the east, through southern



waters. As a result, in the west, where the ice melting was faster, the percentage of drifting fry (mostly CII-III) was higher (on average 65%, as against 40% in the east). There was an inverse correlation between numbers of individuals in the prespawning stock (CIV-V) and mature females.

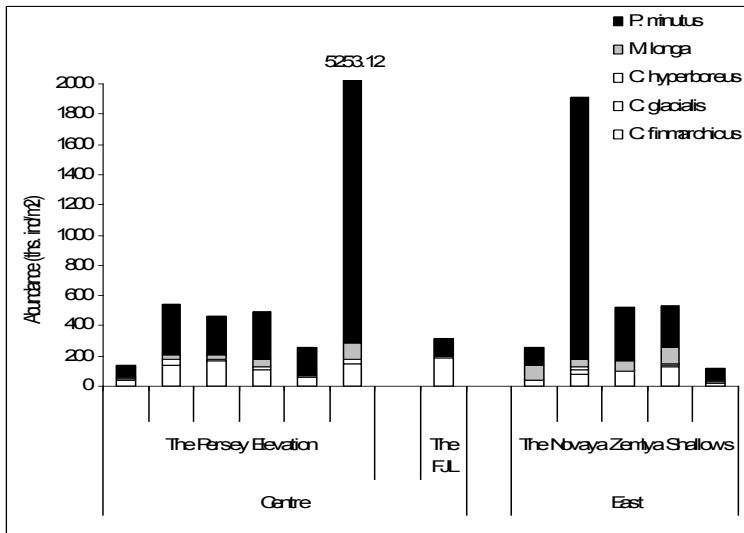
On the whole, in 1989, when a increased inflow of Atlantic water occurred simultaneously with wider distribution of Arctic water, plankton biomass was greater than in 1987, especially in the mixed waters, where older stages of *C. glacialis* were prevalent. Biomasses were thus also higher., at 3-8 g/m<sup>2</sup> (Fig. 9). In the Arctic water masses, biomasses did not exceed 3-4 g/m<sup>2</sup>, with a range of of *C. glacialis* of bewteen 44-85%.

In early September 2002, copepod abundance was high, particularly in waters north of 78° N and 40 – 44° E (Fig. 10). *C. glacialis* abundance varied somewhat less. In the toal area, in the centre, occupied by mixed waters, the number of *C. finmarchicus* increased. The exception was the area of the Admiralty Peninsula, where, just as in Arctic waters, the abundance of *C. glacialis* was high. The densest aggregations of that species were in the north-east (77°50' N 57°50' E), where ice remained for a long time, and, in mid-September, a bloom of Ceratium (1-3 points) was recorded.

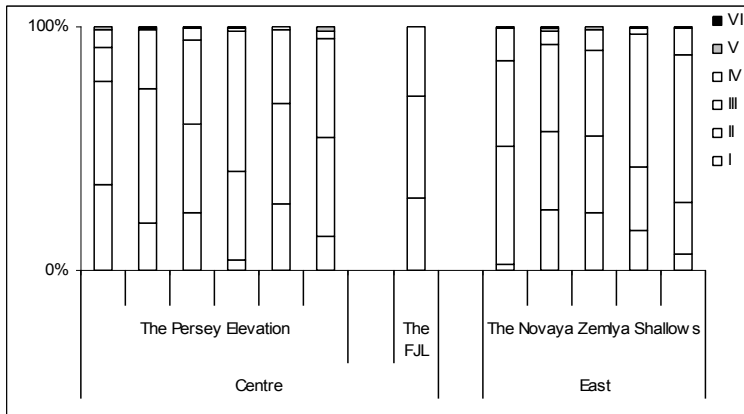


**Figure 9.** Zooplankton biomass distribution in the 0-50 m layer (A), 50-100 m layer (B) and 100 m-bottom layer (C) in August 1989.

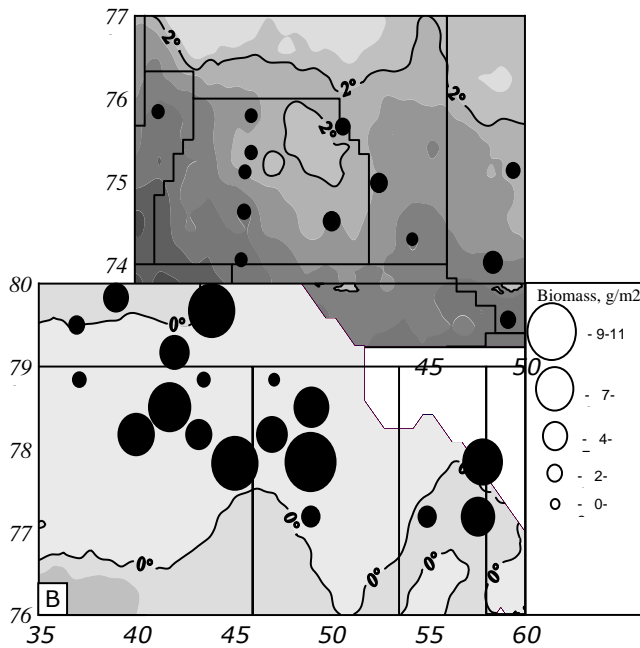
In the areas dominated by *C. finmarchicus*, in the Arctic water masses, its population was mainly represented by fry, but the abundance of young fry (CI-II) was higher in the most northern water areas (FJL), which became free from ice later (Fig. 11). The structure of *C. glacialis* population was also characterized by the fry predominance, but in the area of FJL, the percentage of young fry was low, while the percentage of CIV-V (VI) notably increased. The predominance of *C. finmarchicus* in the population structure in the north (78-81° N) of the recruitment area, in particular, caused biomass variations. In the mixed waters, their biomass rates reached a maximum level (4.4-12.5 g/m<sup>2</sup>) in the north of FJL area and in the east with *C. glacialis*, a value of 75-90% (Fig. 12).



**Figure 10.** Abundance of zooplankton in Arctic waters in August-September 2002.



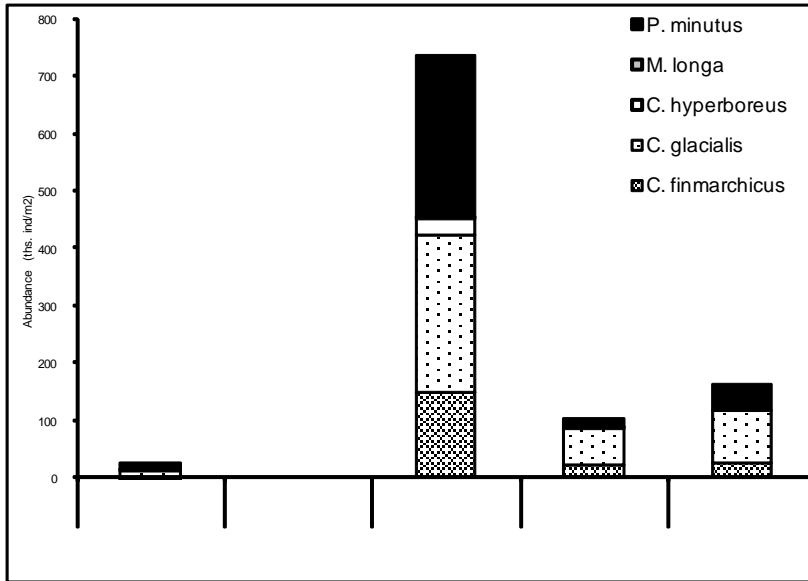
**Figure 11.** Stage composition of *Calanus finmarchicus* in Arctic waters in August 2002.



**Figure 12.** Zooplankton biomass distribution in the 0-50 m layer (A) and 100 m-bottom layer (B) in August-September 2002.

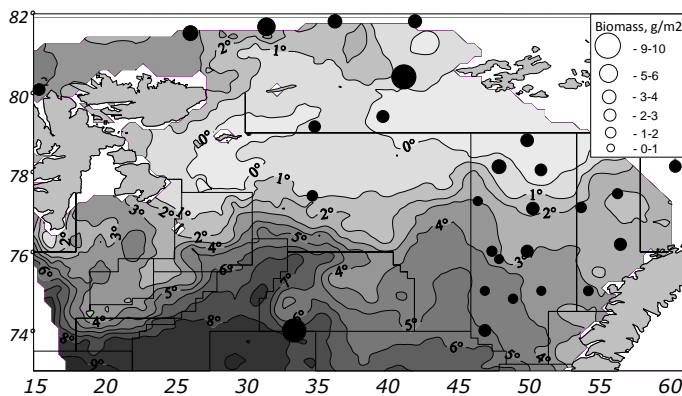
In 2004 the Arctic waters were widespread only in the north-east (FJL, the Novaya Zemlya Bank), while the mixed waters occupied a large area from eastern to north-western areas, with a southern boundary around 76-77° N.

In Arctic waters between September 4 and 19, a bloom of Peridinea algae was observed, reaching its greatest intensity (3 points) in the east. Among the plankton, Arctic species were observed in equal ratios (Fig. 13). On the Novaya Zemlya Bank, the percentage of *C. finmarchicus* was also high. Both species of Calanus were generally represented by fry. In areas with mixed waters (between 76-77° and 81° N), the basic differences in plankton were a result of the abundance and age composition of *C. finmarchicus* and *C. glacialis*, which predominated in different sea areas. A predominance of *C. finmarchicus* was clearly observed to the west of FJL (81°25' N 31°33' E), but its abundance decreased eastwards, while the abundance of *C. glacialis* rose in the eastern area. In the areas of *C. glacialis* predominance, that species was obviously reproducing, as its large eggs were regularly found here.



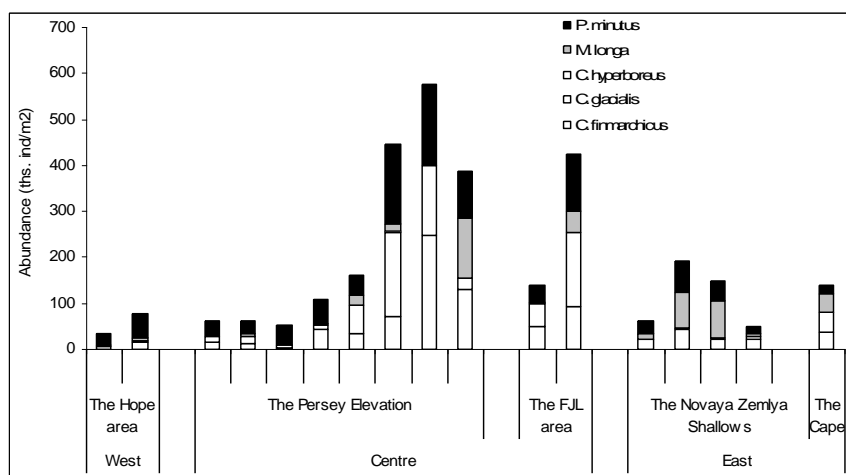
**Figure 13.** Abundance of zooplankton in Arctic waters in August-September 2004.

In 2004, the tendency to high biomass formation in the areas of *C. glacialis* mass distribution remained (Fig. 14). This year, with its maximal percentage both in the Arctic and mixed waters, biomasses rose to 2.8-12.6 and 4.6-8.6 g/m<sup>2</sup> correspondingly.



**Figure 14.** Zooplankton biomass distribution in the 0-50 m layer in August-September 2004.

In 2005 the distribution of the Arctic water masses in September was delimited by the north-western and north-eastern areas. *C. finmarchicus* and *C. glacialis* were predominant in the plankton. Total copepod concentrations were low. In the large area occupied by mixed waters, plankton aggregations reached high values in the western areas of FJL and the Persey Elevation. Their species composition was close to that of the Arctic waters (Fig. 15).



**Figure 15.** Abundance of zooplankton in the mixed waters in August-September 2005.

In September, individuals of all stages were observed in the Arctic waters, and their relationships were characterized by a large variability. In the north-west between 13 and 24 September, a weak bloom of peridinea algae was observed.

In the *C. finmarchicus* population CI-II fry predominated, and nauplii Calanoida were observed in large quantities, though eggs were rarely found. At the same time, in the centre and east (77°50'-80°45' N 32-59°30' E), phytoplankton development was not homogeneous, presenting a series of isolated patches, where intensive blooms of peridinea and diatom algae were observed along with an absence of algae. The dominating groups of *C. finmarchicus* were CI-III, while CIV individuals were in abundance.

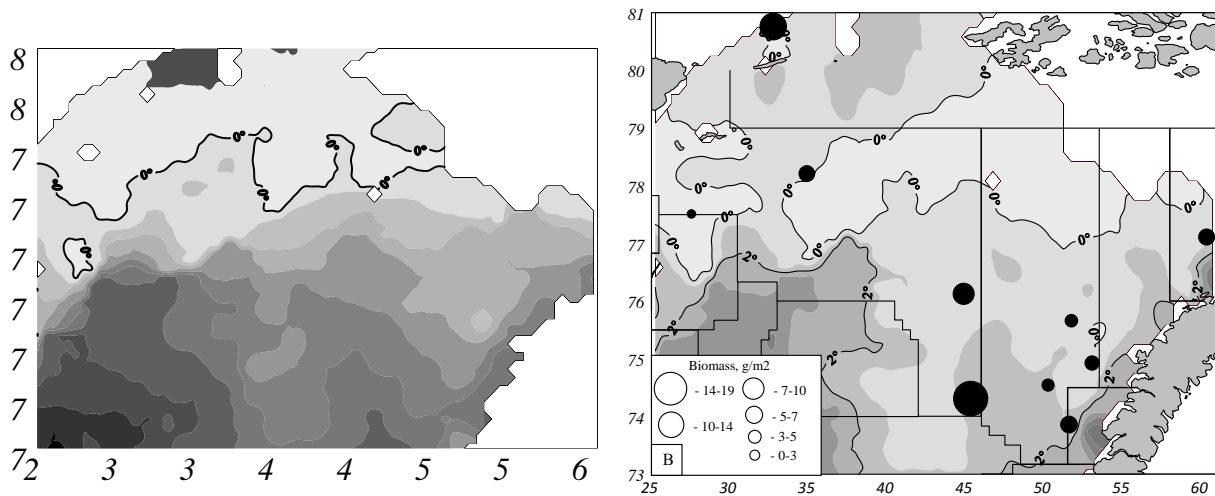
At the same time, in this area, intensive reproduction of *C. glacialis* and *C. hyperboreus* was observed in the east. A similar situation was noticed in the mixed waters, with the difference that in the west (76-78° N 25-30° E), in the second half of September, an intense diatom bloom (1-3 points), and a weak bloom of Peridinea algae were recorded.

The early stage of plankton development took place in the east (78-80° N 33-35° E) as was indicated by a high abundance of *C. finmarchicus* fry (CI-II), the regular occurrence of Calanoid eggs, and large quantities of nauplii and females. Moreover, as the abundance of *C. glacialis* was high, mass reproduction of that species was observed there along with one of *C. hyperboreus*. Meanwhile, a sudden replacement of diatoms by Peridinea algae occurred with a high-intensity bloom (2-3 points).

More significant variations in plankton development were observed in the centre and east, where the ice edge reached 80° N in July. The most characteristic features in *C. finmarchicus* population were CIII predominance in the first ten-day period of September. The only exception was the most northerly and easterly areas, where the essential part was occupied by young fry of *C. finmarchicus* and CIII-IV groups and large quantities of nauplii, while in the east, large eggs, probably of *C. glacialis*, were observed. That species reproduced at that time in the vicinity of FJL, where it was characterized by a high abundance. The ratio of males and females was almost equal (3:2; 4:4; 9:8); in the other areas females prevailed.

In 2005, the most significant differences in biomass values were found at the expense of copepods (0.7-6 g/m<sup>2</sup> in the Arctic waters and 0.4-27 g/m<sup>2</sup> in the mixed waters) (Fig. 16). As in 2002-2004, in most cases, the maximal biomasses appeared in northern water thanks to *C. glacialis*, which came to 60-100% in the Arctic water masses (biomasses 4.7-7.7 g/m<sup>2</sup>) and to

30-95% in the mixed ones (biomasses 5.6-27 g/m<sup>2</sup>). Sometimes, mostly in the mixed waters, the leading role in biomass formation was played by *C. finmarchicus* (biomass 1.8-12 g/m<sup>2</sup>).



**Figure 16.** Zooplankton biomass distribution in the 0-50 m layer (A) and 100 m-bottom layer (B) in August-September 2005.

## DISCUSSION

The data available from the Barents Sea allowed the major pattern of plankton community structure formation in different parts of the Barents Sea to be traced. The sea ice dynamics is the main factor for this process, which influences the distribution of water masses of different origin. This factor was thus crucial in forming the populations of the dominant copepod species, *C. finmarchicus* and *C. glacialis*. The link between plankton and hydrological factors along with the specific character of different climatic periods, had common features in a number of cases.

In August 1987 and 1989, in spite of the differences in the areas occupied by Arctic water (large in 1987 and limited in 1989), the character of the biological processes that took place there was quite similar. In both years, in the Arctic water with its northern boundary along 77° N, intensive reproduction of *C. finmarchicus* was taking place. At the same time its population recruited young fry transported from southern spawning sites. However, due to the late retreat of the ice, the density of *C. finmarchicus* aggregations, as well as those of other species, was not high. At the same time, one can assume that there was an accumulation of transported plankton along the ice edge and during its sudden retreat .

In some places with higher horizontal gradient of water temperature (in 1987 along 44-50° E, in 1989 along 44-48° E) “outbreaks” of *C. finmarchicus* population’s growth were observed. They were also found in other locations but with lower intensities. On that background in the mixed waters occupying small areas (in 1987), aggregations of *C. finmarchicus* were small. Its reproduction here in the second half of August was in its final stages, except for northern areas in the west and centre; the distribution of nauplii was wider. In 1989, in the mixed waters, the aggregations of *C. finmarchicus* were larger; its intensive reproduction was only observed in the first ten days of August in the southern areas in the centre and east.

The differences in *C. glacialis* in those years were more prominent. In 1987, in the Arctic water mostly stage V hibernates were found in small numbers, some of which began

reproduction throughout the whole area after the ice retreat. In the mixed waters a similar situation was observed. At the same time sparse aggregations of its fry were found, mostly in Arctic waters in the east. In 1989, large numbers of *C. glacialis* were typical, due to large amounts of ice arriving and melting. In the Arctic water (east and centre) large aggregations of hibernating stages IV-V were found, but reproduction of *C. glacialis* was extremely rare. Distribution of the fry was widespread but patchy. In the mixed waters (centre and west) the number of fry was greatest.

The data for 2002, 2004 and 2005 reflected not only the specific character of the warm period but also the specific features of year-to-year dynamics of copepod distribution in September in relation to rates of ice retreat. In 2002, when the ice edge lay to the north of its multi-year average position and Arctic water masses occupied a vast area from 78 to 81° N, the population of *C. finmarchicus* was larger than in other years. This species was also numerous in the northern areas of mixed waters, with a distribution that was significantly greater than that of *C. glacialis*. In 2004, when the ice edge in July was more dynamic the area of distribution of *C. finmarchicus* in Arctic waters was small, as was its population. At the same time dramatic increases in the population of the Arctic *C. glacialis* and in its large habitat were observed, especially in the east. In 2005, in spite of the most northerly position of the ice edge occurring in July, the population of *C. finmarchicus* in Arctic waters was lower than in 2002 and 2004, due to weaker heat advection and the later ice retreat in the east. Its major component was found in the mixed waters; in the centre the aggregations were denser than in the east and sometimes even exceeded those in 2002.

In spite of these differences large numbers of transported fry were characteristic of the populations of both species in both Arctic and mixed waters. In some years (2002, 2005) in northerly areas, *C. finmarchicus* were still reproducing at the same time. In the mixed waters this happened mostly in the north and east (2002), and in 2005 the reproduction period was extended due to the large area occupied by these waters. Reproduction of *C. glacialis* was also more active and prolonged in 2005 in the mixed waters in the centre and east. Along with fry and mature individuals in the populations of *C. finmarchicus* and *C. glacialis*, stage IV-V hibernates were also found locally (2002, 2005).

Development rates also varied. By mid-August in 1987 and 1989, in Arctic waters around the Persey Elevation, a large proportion of *C. finmarchicus* and *C. glacialis* fry had reached stage III; in the west the development was even more rapid. Obviously, particular features of the hydrological regime in those years played the main role: the intensive retreat of the ice to the north due to its faster erosion caused by steady southern winds and thus abnormally higher air temperatures. We may therefore assume that the copepods transported in August were developing in warmer waters further to the south. In September 2002 and 2005 in Arctic waters which were expanding far northwards, *C. finmarchicus* was mostly represented by CI-II with a transition into CIII, while *C. glacialis* was represented by CII-III. In the mixed waters their reproduction took place more rapidly, and in consequence, stages II-III and III were dominant. In 2005, due to the extended reproduction period of *C. finmarchicus*, a larger proportion of young fry was observed in the north than in the south, where CIII prevailed. In general the crustaceans' development directly depended on their latitude, and at the southern stations they often reached stages IV-V, while in the north, in contrast, in a number of cases their reproduction was still being observed.

The research data illustrate the time difference in seasonal changes in copepod development in different parts of the latitude zone of the Barents Sea, as confirmed by the condition of

the plant community. Thus, intensive blooms of diatomic algae (often simultaneously with yellow-green algae and peridineans) were usually observed in Arctic waters in the first half of August in the east and centre after the ice edge retreat and in the Arctic and mixed waters in the west; by the end of the month this had slackened (1987, 1989). In September in abnormally warm years the ice edge retreat reached 78-80° N and was accompanied by intensive bloom, though diatomaceous algae were replaced by peridineans (2002, 2004) and only in individual cases in the centre and east (80° N) were blooms simultaneous of diatom and peridinean algae observed (2005).

Thus, while in cold years spring processes in the pelagic zone were already taking place in August, in warmer years the northern ice edge position in July effectively caused these processes to shift to September. This becomes quite obvious when we compare our data for August-September and early July (Arashkevich et al., 2002). The stage structures in the populations of *C. finmarchicus* and *C. glacialis* (August 1987 and 1989) in the ice-free area close to the Persey Elevation thus match quite well those of July (considering the time-related changes in the crustaceans' development). Large numbers of both species' stage CI-III fry were a common feature in these years in the area 76-77° N. The cold year of 1987 was an exception, when *C. glacialis* was represented only by older copepodites (CIII-V). However, further north our data showed an obvious discrepancy with those of the above-mentioned authors, especially with respect to *C. finmarchicus*. In July 1999 at the northern stations (77-78° N) the latter species was only represented by older, mature individuals (CIV-VI) while in the *C. glacialis* population fry just began to appear. In September of the abnormally warm years (2004-2005) the areas around 78-79° N were free of ice. As a result, in both species, fry were the dominant stage, just as in August 1987 and 1989.

The biomass depended on the numbers of the dominant species; *C. finmarchicus* and *C. glacialis*, their reproduction scale, ratio between younger and older copepodites and growth rates. In this study the maximum biomasses were found in the northern areas in Arctic and mixed waters, where there was a large proportion of older copepodites and mature individuals of both species; the role of *C. glacialis* was becoming more important. This species alone helped the biomasses reach 10-25 g/m<sup>2</sup>. In most other cases they varied considerably.

These data closely match the data of the maximal efficient feeding of capelin at high latitudes in 2002 (Orlova et al., 2006), permitting us to draw a comparison with the cold 1970s, when capelin were abundant and distributed in the north and east (Røttingen and Dommasnes, 1985) and reached high fatness (15-18%) in September because their diet included a high proportion of large copepods (*C. finmarchicus*, *C. glacialis*, *C. hyperboreus*) with a higher fat content. Their caloric value in Arctic waters in autumn reaches 2-2.8 Kkal/g (Kosobokova, 1980). Crustaceans, in their turn, have such a high proportion of fat due to their feeding on high-latitude phytoplankton which is characterized by a high lipid content under unstable dietary conditions (Clarke, 1983). This can be explained by the fact that the northern area (78°30' N) is the richest in the quantitative development of the phytoplankton (Zernova, Shevchenko, Politova, 2002), and because in September large amounts flora typical of the ice zone can still be found south of Franz Josef Land.

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# Climate swings and ecosystem effects

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## Extended abstract

(Full article included in special issue of *Marine Biology Research* (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation.)

The seasonal transmission of incoming solar radiation to primary producers in Arctic seas varies on all time scales, from days to decades and longer due to the variability in sea ice conditions. Carbon fixed photosynthetically in algal blooms is converted into high-energy lipid (oil) reserves by the major Arctic herbivores, the calanoid copepods *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus*. The lipid - based energy flux is the primary reason for the large stocks of fish and mammals in Polar waters. The increase in lipid level from 10-20% of dry mass in phytoplankton to 50 to 70% in herbivorous zooplankton and ice-associated fauna is probably one of the most fundamental specialisations in Arctic bioproduction. The lipid-rich zooplankton tends to aggregate in shoals and these serve as energy-loaded food items for fish, marine mammals and sea birds migrating to the north during the Arctic summer.

The three Arctic *Calanus* species, *C. finmarchicus*, *C. glacialis* and *C. hyperboreus*, are the most important herbivores in Arctic Seas in terms of species biomass. *C. finmarchicus* tends to dominate the zooplankton community where Atlantic water masses are present in the Barents Sea, while in the Arctic water masses *Calanus glacialis* dominate over the Arctic shelf seas while *C. hyperboreus* is normally predominant in the Arctic Ocean and Greenland Sea.

The size spectrum and energy content of the zooplankton species that are potential prey for zooplankton-eating fish and sea birds are, therefore, keys in structuring the biodiversity of Arctic ecosystems. Both the population size spectrum and individual energy content differ substantially between the three *Calanus* species. For example, the large stage V of *C. hyperboreus* has approx. 25 times more energy per individual than the smaller *C. finmarchicus*. We postulate that a warmer climate with reduced ice cover will shift zooplankton community structure towards a smaller size spectrum and with lower energy contents per individual in the Barents Sea, while in the Arctic Seas the higher levels of primary production during periods with little ice will increase biomass of the large and energy rich high arctic *C. hyperboreus* and *C. glacialis*, and that the increased energy flux to higher trophic levels may result in a higher production of fish, mammals and sea birds. The ARCTOS network which includes the Norwegian College of Fishery Science / University of Tromsø, the Norwegian Polar Institute, Akvaplan-niva, the University Centre in Svalbard, the Institute of Marine Research (Tromsø branch) and the Bodø University Collage, together with international partners, maintain a large set of monitoring stations and marine observatories to study ecosystem effects of climate swings.

# Why did three capelin stock collapses in the Barents Sea affect the ecosystem differently?

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## Extended abstract

(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)

The Barents Sea capelin stock underwent drastic changes in stock size during the last three decades. There is circumstantial evidence that the capelin stock has been at very low levels during periods also earlier, and substantial fluctuations of capelin stock size may be an inherent trait of this ecosystem. The three stock collapses, which are well described, occurred in 1985-1989, 1993-1997, and from 2003-2006. The collapses had effects both downwards and upwards in the food web. The release in predation pressure from the capelin stock led to increased amount of zooplankton during the collapse periods. When capelin biomass was drastically reduced, its predators were affected in various ways. The cod experienced increased natural mortality because of increased cannibalism, the growth was reduced and the maturation delayed. Seabirds experienced increased death rates and total recruitment failures, and breeding colonies were abandoned for several years. Harp seals experienced food shortage, increased mortality because they invaded the coastal areas and were caught in fishing gears, and recruitment failures.

The three capelin collapses affected the predators differently. The effects were most serious during the 1985-1989 collapse and some effects can hardly be traced during the two last collapses. Various explanations why the first stock collapse affected the ecosystem more seriously than the last two are possible, but we explored the following two hypotheses:

1. A better supply of capelin for the predators during the two last collapse periods
2. A better supply of other food for the predators during the two last collapse periods

It was found that the stock size of capelin was, at average, somewhat higher during the second and third collapse compared to the first. Further, the biomass production from the capelin stock (calculated as the natural mortality coefficient multiplied by the average body weight) was about two times higher during the two last collapse periods. This quantity is an estimate for the amount of capelin available for its predators. These facts support the first hypothesis. We also found that the amount of capelin consumed by cod was smaller during the first collapse compared to the others. However, the cod stock was increasing during this period, and the capelin consumed per individual cod was only slightly larger during the two last collapse periods. Therefore, the first hypothesis can only partly explain why cod and other predators were less affected by the lack of capelin during the two last periods.

The second hypothesis is not so easy to test, because knowledge about the amount of alternative food is partly lacking. Analysis of cod stomachs shows that the total food intake was in fact higher during the second and third collapse period compared to the first one. But again, the food intake per capita was not. Food intake by weight may be partly misleading when comparing different prey species, since the energetic content may vary both with prey

species and time of the year. While alternative food mostly consisted of various crustaceans during the first collapse, fish prey like blue whiting, polar cod and haddock made up a substantial part of the alternative prey during recent years. No time series of consumption estimates of sea mammals or seabirds exists for this area, and consequently it is impossible to explore in detail how their food intake was affected by the lack of capelin in periods. It is known that harp seals are opportunistic feeders that partly shifted to other fish when the capelin disappeared. As a whole, it seems reasonable to conclude that the reason why the capelin predators did better was probably a better availability of alternative food during the two last capelin collapse periods.

# **Long-term variation and adaptive relationship of the life-cycle parameters of the North-east Atlantic cod *Gadus morhua***

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## **Abstract**

We studied the long-term dynamics of main biological parameters of the North-east Atlantic cod which represent its life cycle strategy and determines its abundance dynamics, rates of growth and individual maturation rates in individual year classes and maximum possible life span. It was found that, after the mid-1970s, in the cod population, the numerical values of those parameters changed. Mathematical expectations of growth and maturation rates increased, while life-span was reduced. Variances in growth rate and life span rose, while that of maturation rate decreased. The change in the main element of population reproductive strategy, maturation rate, which is caused by the cumulative intensity of stock exploitation in the historical period, and is close to the real life-span of a year-class and precedes its appearance, adapts the population to the historically intensive stock exploitation and variable hydrographic conditions of the Barents Sea. We have demonstrated the adaptive relationship of certain biological parameters of the life cycle and maturation rate and developed a hypothesis of a population mechanism of abundance regulation under conditions of intensive exploitation.

Key words: NEA cod, year-classes, biological parameters.

## **Introduction**

Due to the NEA stock management measures taken by Russia and Norway during the past decade, the rate of exploitation of cod has stabilized but remains at a very high level. The commercial stock increased, but, as before, has been lower than the level of the 1970s, which were unfavourable in that respect. However, the spawning stock biomass currently significantly exceeds the level of the 1950s and its abundance is approaching the level of the 1940s. The increase in spawning stock abundance has not led to the expected rapid growth in recruitment. Despite the favourable climatic conditions for successful survival of juveniles in the 1990s and recent years, and the reduction in cannibalism which was indirectly indicated by the decrease in juveniles in cod stomachs, the cod population could not produce a single superabundant year-class. In that period, the abundance of commercial stock recruitment was relatively stable, but not high. Obviously, to restore the stock we need to know the population mechanism of its abundance regulation under conditions of intensive fishery. This paper offers a hypothesis about such a mechanism and considers the long-term variation and the adaptive relationship of some parameters of the cod life cycle.

## **Material and methods**

The paper is based on historical time-series of the lengths of cod aged, mainly, 3-9, from the population and of the portion of mature fish as old as 3-15. Between 1985 and 2006, length time-series were obtained from age samples taken during the Russian and Norwegian monitoring of bottom species abundance, and in 1949-1984 – by the results of the

extrapolation of fish lengths at that age. The extrapolation was used data on cod length from Russian trawl catches in the southern part of the Barents Sea and on their relationship to fish length in the population. The time-series characterizing variations in proportions of mature fish were taken from the materials of the ICES Arctic Fisheries Working Group (AFWG) (Anon., 2000).

It was assumed that the length of a cod individual from the population at age  $t$  equaled the length of fish of the same age caught by the research trawl, whose inner mesh size was very small. On Russian vessels, fishing gear is a commercial bottom trawl (Drawing 2283) into the codend of which kapron netting with a 16 mm inner mesh is inserted. The trawl has an approximately 80 m horizontal opening between the boards; the vertical opening in the mouth is 7.5-8.0 m (Shevelev et al., 1996). Norwegian vessels use the shrimp trawl (Campelen 1800), in which the groundrope with bobbins is replaced by rockhopper gear. The mesh size in the codend is 22 mm (Jakobsen et al., 1997).

The metabolism parameter  $k$  from Bertalanffy's equation (Bertalanffy, 1938, 1951) was taken as a parameter characterizing the growth rate of cod from different year-classes. It was calculated for 1946-1997 year-classes by method of conjugate gradients from the condition:

$$\sum_{t=3}^9 (\ell_t - \ell_{\infty} \cdot (1 - \exp(-k \cdot (t - t_0))))^2 \Rightarrow \min \quad (1)$$

where  $\ell_t$  - cod length at age  $t$  in the year-class under study;

$\ell_{\infty}$  and  $t_0$  - parameters of equation – physiologically possible limiting (asymptotic) length of

fish from the year-class and the age at which fish length would be equal to 0 if it grew in accordance with Bertalanffy's equation at all life stages.

Taking into account the fact that asymptotic fish length is a growth indicator which is peculiar to the species, the  $\ell_{\infty}$ - parameter was taken as constant for all year-classes.

In the 1985-2006 population, the length of one cod individual at age  $t$  was calculated by the formula:

$$\ell_{t,y} = 0.5 \cdot \left( \ell_{t-1,y-1}^{\text{Rus}} + \frac{n_{t,y}^{\text{N,Bar}} \cdot \ell_{t,y}^{\text{N,Bar}} + n_{t,y}^{\text{Lof}} \cdot \ell_{t,y}^{\text{Lof}}}{n_{t,y}^{\text{N,Bar}} + n_{t,y}^{\text{Lof}}} \right) \quad (2)$$

where  $\ell_{t-1,y-1}^{\text{Rus}}$  - the length of the individual at the age of  $t-1$  years, calculated using the results from the Russian autumn-winter (November-December) acoustic and trawl survey in the Barents Sea in  $(y-1)$  year (Anon., 2006), cm;

$n_{t,y}^{\text{N,Bar}}, \ell_{t,y}^{\text{N,Bar}}$  - the index of abundance ( $10^6$  ind.) and the length of one individual (cm) at the age of  $t$  years calculated from the results of the Norwegian winter-spring (January-March) acoustic survey in the Barents Sea in year  $y$  (Anon., 2006);

$n_{t,y}^{\text{Lof}}, \ell_{t,y}^{\text{Lof}}$  - index of abundance ( $10^6$  ind.) and the length of one cod individual (cm) at

the age of  $t$  years calculated using the results of the Norwegian spring (March-April) acoustic survey in the Lofoten Islands in year  $y$  (Anon., 2006).

The length of one cod individual from each year-class  $j$  at age  $t$  ( $\ell_{t,j}$ ) in 1949-1984 population is calculated from the relationship:

$$\ell_{t,j} = \ell_{t,j}^{\text{tr.}} \frac{\bar{\ell}_t^{\text{p.}}}{\bar{\ell}_t^{\text{tr.}}}, \quad (3)$$

where  $\ell_{t,j}^{\text{tr.}}$  - the length of one cod individual from year-class  $j$ , at age  $t$ , caught in the southern Barents Sea by a Russian kapron fishing trawl with 125 mm inner mesh size;

$\bar{\ell}_t^{\text{p.}}$  - the average length of one cod individual (for 1985-2000) caught by the research trawl;

$\bar{\ell}_t^{\text{tr.}}$  - the average length of one cod individual (for that period), at age  $t$ , caught in the southern Barents Sea by a Russian kapron fishing trawl with 125 mm inner mesh size.

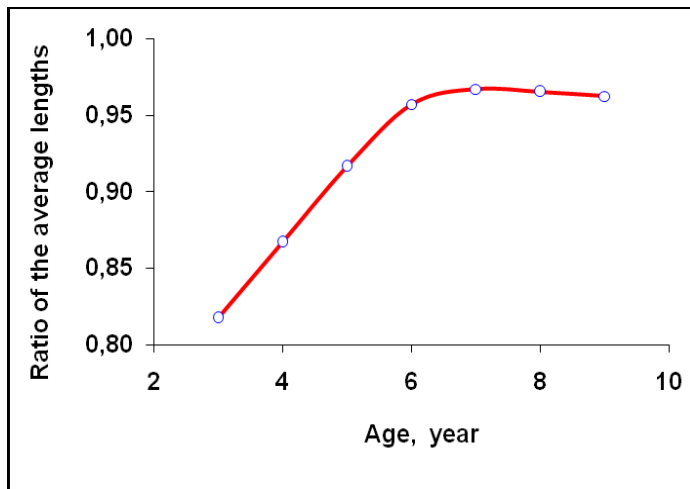
It should be noticed that, in 1949-2000, during the fishery in the southern Barents Sea, Russian fishermen used different types of trawl fishing gears made of different materials and having different mesh size in the codends. Up to and including 1966, they had only employed trawls of Manila hemp. Before 1960, the inner mesh size in the codends was 90 mm, in 1961-1962, it was 110 mm and, in 1963-1966 is was 120 mm. In 1967-1980, they used Manila hemp trawls with 130 mm meshes and kapron trawls with 120 mm meshes. After 1980 and to date, Russian fishermen having been using kapron trawls with 125 mm inner mesh size (Boitsov et al, 1996). Using trawls with different selective properties leads to nonstationary time series from Russian trawl catches in the southern Barents Sea by mathematical expectation (their inhomogeneity) and complicates using Equation 3 to calculate the length of cod at any given age in 1949-1980 population.

In order to eliminate the nonhomogeneity and allow Equation 3 to be utilized for any year-class fished in 1949-1980, the length of cod caught by trawls with 90-120 mm mesh size was adjusted to the length of one taken by kapron trawl with 125 mm inner mesh size (further we

shall use “adjusted to 125 mm mesh”). For this purpose, we studied the variation of  $\frac{\bar{\ell}_t^{\text{p.}}}{\bar{\ell}_t^{\text{tr.}}}$  with

cod age increase (Fig.1). When age rises from three to six years the ratio is characterized by linear growth, after which it is constant and close to 1. This variation of ratio shows that the mean length of the same age fish retained by the kapron trawl is more than the average length of fish at the corresponding age that are retained by the research trawl within the age range studied. However, in relation to cod aged six or more, the selective properties of the trawls concerned with such different mesh sizes are almost identical and do not change. This allows us to assume that the difference in the selective properties of the research trawl and fishing trawls with smaller differences in the mesh size previously employed is even smaller as

regards fish of this age. In that connection, it was assumed that the average length of cod aged 6 and older caught by fishing trawls with 90-120 mm inner mesh size might be regarded as having been adjusted to 125 mm mesh.



**Figure 1.** Variation of the ratio between the average (for 1985-2000) length of a cod specimen caught by research trawl and the average (in this period) length of a cod specimen in the Russian trawl catches, in the southern Barents Sea, depending on fish age.

In order to adjust the length of fish caught at age 3-5 to that mesh size the cod year-classes fished at that age by the same type trawls were united into 12 groups (4 mesh size x 3 age groups). Taking into account that at the age of 3-10 mean absolute length increments of cod vary little (Ponomarenko, Tretyak, 1973), in each group the mean length was approximated by linear regression equations and the mean length was extrapolated into the region of lower age (3-5 years). The length of fish in each year-class aged 3-5, adjusted to 125 mm mesh, in Russian trawl catches taken in the southern Barents Sea between 1949 and 1980 was determined from the relationship:

$$\ell_{t,i,j}^{tr.} = \ell_{t,i,j}^{act.} \cdot \frac{\widehat{\ell}_{t,i}}{\overline{\ell}_{t,i}}, \quad (4)$$

where  $\ell_{t,i,j}^{act.}$  - actual average length of fish from year-class j in group i, at age t, retained by used fishing trawl;

$\widehat{\ell}_{t,i}$  - extrapolated (adjusted to 125 mm mesh) mean length of fish at age t in group i;

$\overline{\ell}_{t,i}$  - average length of fish at age t in group I retained by the trawl.

The estimates of asymptotic length,  $\ell_{\infty}$ , in each separate year-class were determined from condition (1), on the assumption that all three parameters in von Bertalanffy's equation were unknown, unstable and disorderly. In our opinion, the reason for this is the lack of consistent initial data on the length of cod from older age groups. At the beginning, therefore, the  $\ell_{\infty}$  - parameter was determined first using the data on the average length of cod from 3-12 year age groups in populations from different parts of the time series: 1949-1960, 1961-1962, 1963-1966, 1967-1980 and 1981-2006. The estimates for the studied periods equal to 220.6, 218.4, 218.5, 220.8 and 220.6 cm, respectively. The results of the Russian trawl-acoustic surveys for



abundance in the Barents Sea in 1985-2000 estimated the asymptotic cod length at 222.5 cm. According to the summarized data from Russian and Norwegian surveys in 1985-2000 – the asymptotic cod length was estimated at 215.9 cm. It was calculated to be 222 cm (Ponomarenko, Tretyak, 1973) using the Tomlinson-Abramson method (Tomlinson & Abramson, 1961). Allowing for the estimates as presented, the  $l_{\infty}$  - parameter was taken as constant for all year-classes and equaled to 220 cm.

The maximum possible life span ( $t_e$ ) is the age until which some fish can live in real ecological conditions, when there is no fishery. To estimate  $t_e$ , this parameter was assumed to correspond to the length of the largest cod known at that moment (Suvorov, 1948). Unfortunately the age of that specimen had not been determined. The limiting age of cod from different year-classes was calculated in accordance with the reverse dependence of the maximum possible life span on the metabolism parameter,  $k$ , following from the von Bertalanffy equation:

$$t_e = t_0 - \frac{1}{k} \cdot \ln \left( 1 - \frac{l_{t_e}}{l_{\infty}} \right), \quad (5)$$

where  $l_{t_e}$  - the length of the largest cod individual (169 cm).

The ratio  $\frac{l_{t_e}}{l_{\infty}}$  in equation (5) is invariant in time (Romanovsky, 1989). Therefore the assumption that  $l_{t_e} = \text{const.}$  is logical under the condition that  $l_{\infty} = \text{const.}$

The average maturity rate of cod from each year-class was taken to be equal to (Tretyak, 2007):

$$v_s = \frac{0.5}{t_s - 3}, \quad (6)$$

where  $t_s$  - the age at which 50% of fish become mature;  
3 - the age, at which single mature individuals are registered for the first time in any

historical period of observations.

$t_s$  and  $v_s$  - parameters are determined for 1930-1997 year-classes (Tretyak, 2007), by the results of mature fish portion variation with age.

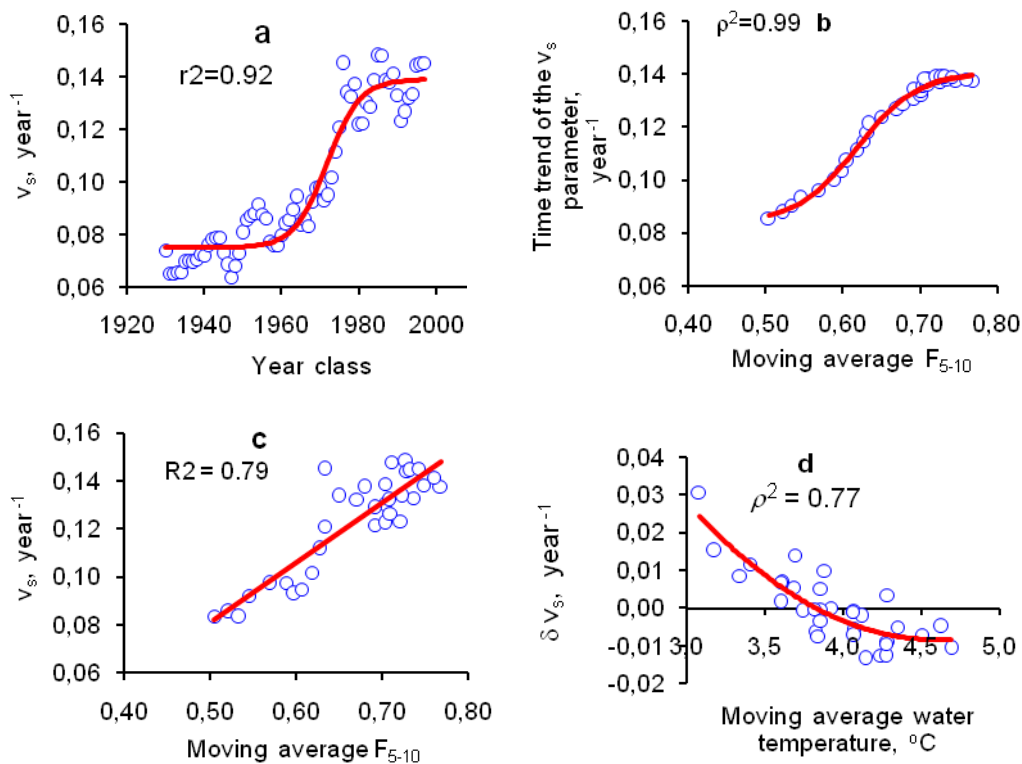
## Results and discussion

### Growth rate, maturation rate and life span of cod

The maturation rate of a contiguous series of cod year-classes has a long-term logistic tendency to increase (Figure 2a). This tendency was most pronounced in the 1931-1944, 1947-1954 and 1971-1976 year-classes. The increase in the  $v_s$ -parameter was unexpected, spontaneous and growing from one time interval to another. At the same time, the duration of the consecutive intervals fell, suggesting that there was an acceleration of the  $v_s$ -parameter

increase until 1975 inclusive. In the year-classes after 1975 the trend to an increase in  $v_s$  rate almost stopped, and the  $v_s$ -parameter began to oscillate around a value of  $0.136 \text{ year}^{-1}$ .

This acceleration in the rate of cod maturation, the main element in the structure of reproductive organization and population abundance dynamics (Lapin, 1971; Romanovsky, 1989; Malkin, 1999), has developed under the influence of intensive fishery. The long-term logistic trend is caused by the exploitation rate of cod stocks in previous years. The nonlinear dependence of  $v_s$  calculated by trend, from the moving average rate of fishing mortality of cod aged 5-10 ( $F_{5-10}$ ) calculated from 19 previous years (the period that is close to the real-life span of a year-class and preceding its appearance), with zero advance, is almost functional (Figure 2b). There is also a statistically significant linear relationship between the instant  $v_s$ -parameter and the cumulative rate of stock exploitation calculated for various historical periods between zero and 30 years. When the historical period with one-year steps increases, this relationship rises, at the beginning, and then decreases. It reaches a maximum with an average rate calculated for 19 years, which are preceding the appearance of a year-class (Fig.2c).



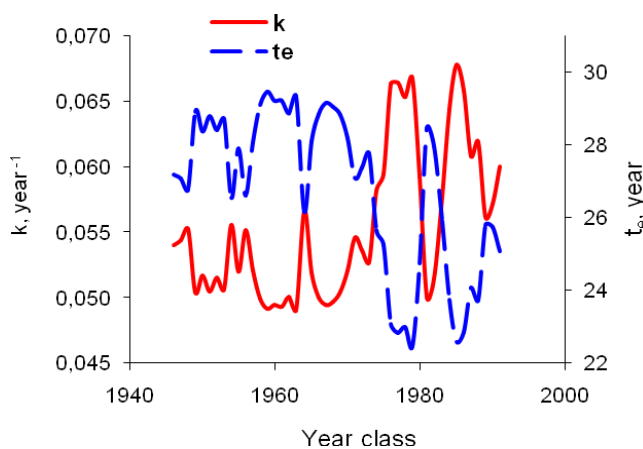
**Figure 2.** Variation of cod different year-class maturation rate.

The deviation of  $v_s$ -rate from the regression line is quasicyclic character and it correlates well ( $\rho^2=0.77$ ) with the average standardized water temperature in the 0-200 m layer of the main branch of the Murmansk Current in the second and third years of the cod life-cycle, in October, and in the third and fourth years in April (Figure 2d). October in one year and April in the following year mark the times of the beginning and end of phenological season in the Barents Sea, which is known as the “hydrological winter” (Boitsov, 2006). In this period, due to intensive convective mixing of water masses in the photic layer, the number of biogenic elements increases to the level needed for intensive phytoplankton producing in the following spring-summer hydrologic season (Nesvetova, 1997). The pattern of winter stratification of

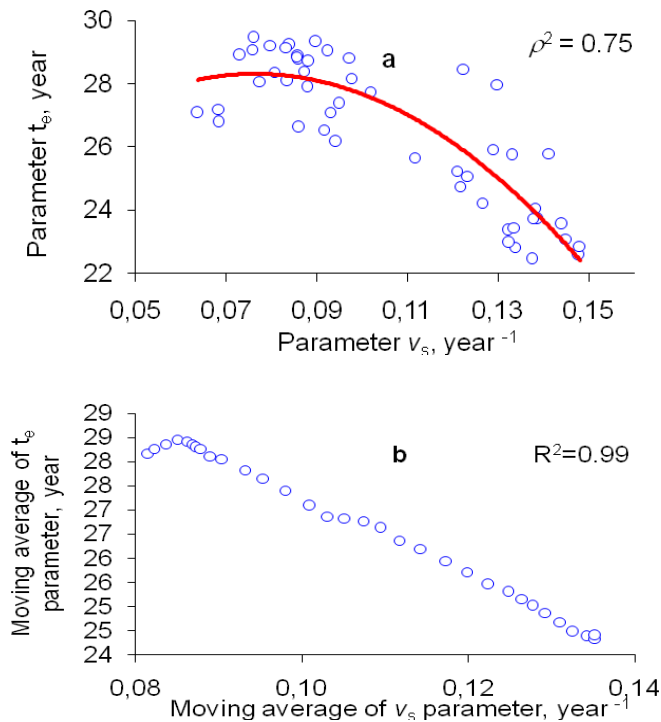
the Barents Sea water masses thus influences the formation of primary production, whose biomass has a significant impact on the productivity dynamics of the first- and second-order consumers. Water temperature indirectly, through ecosystem trophic chains, affects fluctuations in the deviations of  $v_s$ -rate from the regression line, approximately 1.5 year before the beginning of sexual maturation. It has an effect on the rate of physiological processes in 3-4 year-old fish and changing the volume of biological productive water changes the current and further food supply of cod.

Researchers studying the growth of NEA cod noticed extremely high variability and the tendency to increase the length and weight of fish of the same age since the 1930s. The lability of growth values is considered to be caused by variation of population density, food supply and temperature conditions, and the acceleration in cod is a result of the long-term intensive fishery. By reducing population density, the fishery tends to improve food supply (Ponomarenko, 1968) and changing the structure of spawning population selects for rapidly growing fish (Borisov, 1978). The study by Jorgensen (1992) as well as our own research (Ozhigin et al., 1994; 1995a,b; 1996) showed that the length and weight of cod from the same year-class at any given age greatly influenced the length and weight of fish of that year-class at the following age. This shows that the length and weight, at the certain age, give little information on the growth rate in a given year (Jorgensen, 1992).

Our study indicates that the growth rate of cod year-classes drastically changed after 1975. The time series of the k-parameter may be divided into two periods, 1946-1975 and post-1975. The average and amplitude of k-parameter fluctuations in the second period are considerably greater (Fig.3). In accordance with equation (5), the change in the maximum possible life span is asynchronous with respect to the k-parameter. Exactly in the mid-1970s, the maximum possible cod life span fell drastically (Figure 3). In the intervals with different numerical characteristics of these parameters, the rate of maturation is also different (Fig.2a). As expected, the  $v_s$ -parameter correlated well with the maximum possible life span in all the historical series of observations (Figure 4a). The relationship between these parameters becomes even closer after smoothing the fluctuations, which are peculiar to the  $v_s$ -parameter (Figure 4b). The contribution of the maturation rate to the variance of the  $t_e$ -parameter is as high as 99%.



**Figure 3.** Long-term dynamics of the cod different year class growth rate (k) and maximum possible life span ( $t_e$ ).



**Figure 4.** Relationship between cod different year class maturation rate ( $v_s$ ) and maximum possible life span ( $t_e$ ) - (a), between their moving average by 21 years - (b).

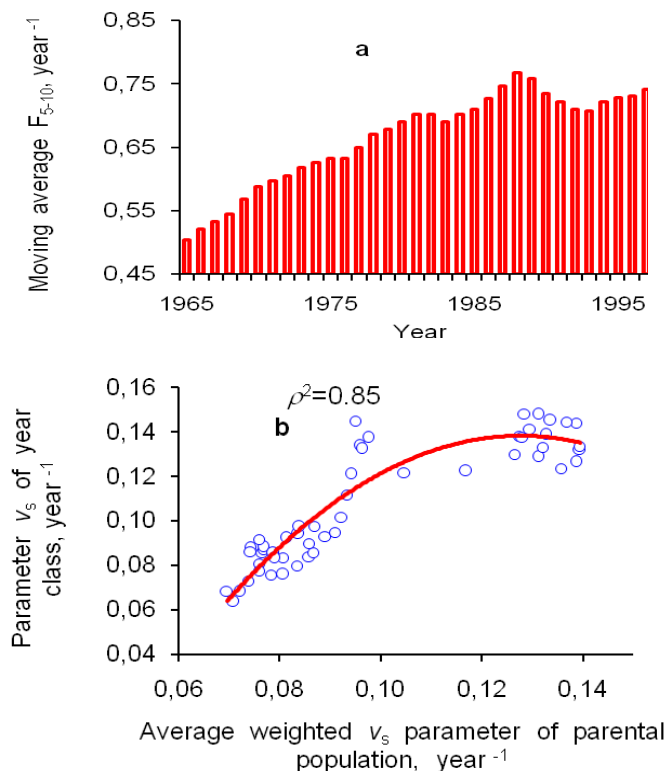
### Hypothesis regarding the population mechanism of abundance regulation

The long-term and growing effect of any factor including the fishing rate on population inevitably leads to evolutionally significant genetic changes in the population, as the genotypic composition (or the gene pool) of the population changes for a long period. The gene pool of individual year-classes, the carriers of genetic information received from parents, also changes. In 1965, the level of historical exploitation of cod commercial stock was already high (Figure 5a). The moving average rate of fishing mortality  $F_{5-10}$  calculated for 19 previous years was  $0.504 \text{ year}^{-1}$  and greater than the precautionary level of exploitation ( $F_{pa}=0.40 \text{ year}^{-1}$ ) by approximately 25%. The rising trend continued until and including 1988, after which the rate of historical exploitation was stabilized at the very high level of  $0.729 \text{ year}^{-1}$ .

There is a hypothesis about the existence of early and late maturing fish in each cod year-class, according to which each of the groups unites individuals with a particular genotype. Under conditions of intensive fishery, the individuals from the second group have less opportunity to live until the first and following spawning periods. The abundance of fish from that group falls, so that they virtually do not participate in reproduction; their reproductive contribution is close to zero. The reproductive contribution of early maturing fish with a shorter life span rises. They have the advantage in forming future year-classes and creating the gene pool of the spawning population.

Obviously, the tendency to increase the rate of year-class maturation is not a result of the direct phenotypical response of population to the change in life conditions, but rather the result of the adaptive change in the genetic structure of the population caused by the selective action of a long-term intensive fishery. The indirect corroboration of this is a statistically significant positive linear relationship between the average weighted rate of spawning population maturation and the  $v_s$ -parameter of the year-class (Figure 5b). This relationship

shows the existence of a genetic component in the variation of year-class maturation rate and its transmission from parents to progeny.



**Figure 5.** Variation of moving average rate of fishing mortality  $F_{5-10}$  calculated for 19 retrospective years (a) and of the maturation rate of different cod year classes depending on average weighted maturation rate of parental population (b).

The rise in year-class maturation rate favours an increase in the abundance of mature fish and is thus directed at a growth in recruitment and a reduction in the negative impact of increasing mortality on the total abundance of population. However, the increase in the maturation rate altered the abundance relationships and age compositions of early- and late-maturing cod, i.e. it changed the structure of reproductive organization of the population. It launched the mechanism of positive feedback, whose action leads to wider divergences in abundance relationships and age compositions of early- and late-maturing fish and prevents population from rapid recovery. After the mid-1970s, the abundance of late maturing cod was already minor, about 3%, but year-classes were very rich in early-maturing fish that were therefore less efficient in restoring the population. Besides, the year-class maturation rate has an upper limit, since it is inversely proportional to  $t_s$ -age, which, according to the definition, is limited on the left. Therefore, when the historical exploitation rate increases there is a moving average  $F_{5-10}$  with which the  $v_s$ -parameter equals the threshold value outside which the stock will collapse, i.e. the state of population threatens its significance as a fishery and is characterized by catastrophic falls in total abundance and reproductive potential.

## Conclusions

Since the mid-1970s, the quantitative characteristics of the main biological parameters of the NEA cod population have changed. Mean growth and maturation rates have increased, while average life span has decreased. Variances in growth rate and life span have increased, while variance in the maturation rate has decreased. The mentioned variation of maximum possible life span inevitably results in increases in absolute values and variability of natural mortality.

The adaptive relationship between the maturation rate and the life span of NEA cod is inverse and statistically significant ( $\rho^2=0.75$ ).

The long historical series of observations demonstrates that the main element in the structure of reproductive organization and population abundance dynamics, the year-class maturation rate, ( $v_s$ ), had a well-pronounced logistic trend to increase over time ( $\rho^2=0.92$ ). This process is caused by the historical rate of stock exploitation in the period, which is close to the life span of a year-class and precedes its appearance ( $R^2=0.79$ ). It promotes the increase in abundance of mature fish and is therefore tends to reduce the negative influence of increasing mortality on population abundance. Nevertheless the year-class maturation rate cannot grow *ad infinitum*. It has a threshold value, beyond which the stock begins to collapse.

The research was carried out within the framework of an UNCOVER project.

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# **Spatial migration pattern of deep-sea redfish (*Sebastes mentella* Travin) in the Barents Sea as inferred from long-term research survey series**

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## **Extended abstract**

(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)

Fishery for the deep-sea redfish (*Sebastes mentella* Travin) in the Barents and Norwegian seas dates back to 1952 (Zakharov *et al.*, 1977). Scientists have studied many issues of the deep-sea redfish biology. Nevertheless, one of the crucial issues for both understanding the life history and fishery management is the migration, and this has not yet been adequately explored.

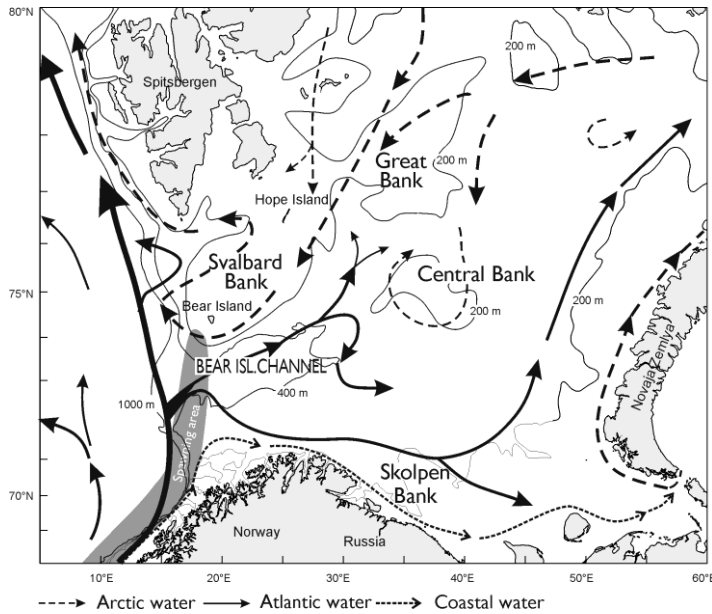
Study of redfish migration by traditional tagging-methods faces great difficulties. The redfish taken onboard a vessel usually prove to be nonviable. A sharp hydrostatic pressure differential is lethal for the redfish having a closed swim bladder.

The main purpose of the present paper is to determine migration pattern of the deep-sea redfish (*Sebastes mentella*) juveniles. To study the deep-sea redfish migration, data from Russian and Norwegian scientific trawl surveys conducted during autumn and winter of 1982-1995 were used.

The Petersen method was applied to analyse size composition of the deep-sea redfish catches taken during the above trawl surveys. The conclusion made from prior researches that the deep-sea redfish year classes of 1982 and 1988 were strong compared to their neighboring ones was confirmed.

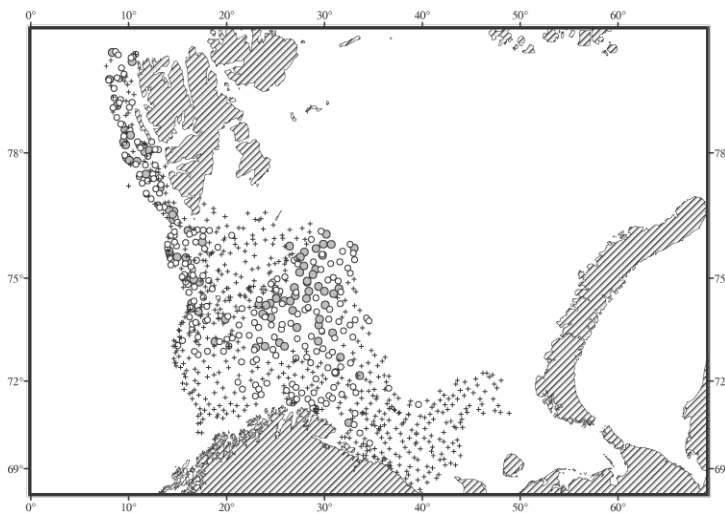
On the assumption that "peaks" in the length distributions of survey catches displayed strong yearclasses, the annual corresponding lengths were defined for the 1982 and 1988 year classes of deep-sea redfish at different ages (from 0 to 7 years). Subsequently, using the database from trawl surveys and knowing the length of the deep-sea redfish from strong yearclasses at different ages, the distribution of these yearclasses by year was mapped. Based on the analysis of these maps, migration patterns of the deep-sea redfish juveniles in the Barents and Norwegian Seas were plotted.





**Figure 1.** Dominating prevalent current systems in Norwegian Sea/ Barents Sea. Whole lines – warm Atlantic water, dotted line – warm coastal water, and stipled line - cold Arctic currents. Spawning area of *Sebastes mentella* has been emphasized (grey area).

From spawning areas along the continental slope from 62°N to the Bear Island (Mukhina *et al.*, 1992; Nedreaas, 1995), juvenile redfish drift with the warm Atlantic currents (Fig. 1) to the Barents Sea and Svalbard areas. The main nursery areas of the juvenile redfish are the Bear Island Channel and waters adjacent to the southwest of the Central Bank and continental slope along the western coast of Spitsbergen (Figure 2). During the first years of life (age 0 and 1) the redfish juveniles also drift to the Skolpen Bank, but later on, concentrations in this area are not observed.



**Figure 2.** Distribution of 13-17 cm *S.mentella* (age 3, yearclass 1982) in 1985. The circles represent the position of the tow, and the circle diameter corresponds to the percentage of the yearclass caught in a given position of its total catch during the whole survey.

This gives reasons to assume that the drift of a deep-sea redfish yearclass may last for the two first years of life. The deep-sea redfish are distributed within the nursery areas until they are 4 years old. From then on, the redfish start active migration against the current towards the mature population distribution areas.

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## **Where do the northern Atlantic salmon feed during their sea residence; in the Norwegian Sea or in the Barents sea?**

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Atlantic salmon (*Salmo salar*) exhibit a complex life history that is influenced by factors encompassing various freshwater and marine habitats, and that spans large spatial as well as temporal scales (Kocik and Ferreri 1998). Populations are characterized by annual fluctuations in survival and abundance. At times, fluctuations can be quite severe and occur commonly over wide geographic areas (Dempson et al. 1998). The number of salmon returning to rivers is dependent upon the smolt production (Jonsson et al. 1998), as well as marine exploitation rates, predation, parasite infection etc. (see Crozier and Kennedy 1994, 1999). Similarly, variability in ocean conditions (e.g. sea water temperature) can influence the survival, growth rates and sea-age at maturation of salmon, as well as the timing and location of their migrations. Survival is thought to be heavily influenced by events during the first months at sea (Friedland 1998). Factors affecting marine survival of salmon are however generally poorly understood (Reddin and Friedland 1993 and references therein) and the Atlantic salmon's life in the ocean is often referred to as a "black box".

Salmon rivers in northernmost Norway, Finland and the Kola peninsula (Russia), support important fisheries, both in coastal areas and in the rivers themselves, and contribute to more than 40 % of the world freshwater catch of wild Atlantic salmon. The River Tana, a large complex river system that forms the border between northernmost Norway and Finland, at present supports the largest wild Atlantic stock in the world, and is also of particular importance to the Sami people. Based on the potential for increased exploitation on this and other northern Atlantic salmon stocks, interactions or impacts resulting from the proposed expansion of salmonid aquaculture into these northern areas, and uncertain consequences resulting from global climate change, the project "Salmon in the north (SIN)" was initiated (2002-2010) to study the dynamics of the world's largest salmon producing rivers.

In the last decades the abundance of Atlantic salmon has declined in most rivers all over the world, except from the most north-easterly rivers, i.e. in rivers in north-eastern Norway and on the Kola peninsula. This suggests that salmon from north-eastern areas may migrate and reside in other marine areas than salmon populations elsewhere. Several preliminary results from the SIN-project seem to support this (see below).

The smolt age of salmon captured in the Norwegian Sea is less than two years, while smolt age of adult salmon captured along the mid-Norwegian and Southerly Norwegian coast is mainly three years of age (see Jacobsen & Hansen 2000). The smolt age of the Tana salmon, as well as salmon from the Kola rivers, is between 4 and 5 years. Since the Tana salmon alone contribute to more than 20 % of salmon captured in Norwegian rivers, it is obvious that both Tana and Kola salmon did not contribute significantly in the above mentioned Norwegian Sea

catches, i.e. suggesting that the Tana and Kola salmon probably feed somewhere else during their sea residence.

Adult Atlantic salmon have been captured in the inner part of Isfjorden (Adventfjorden), close to Longyearbyen, Svalbard. In September 2002, more than 20 wild Atlantic salmon (smolt age 4 and 5 years) were captured, in addition to some pink salmon and one farmed rainbow trout, all captured close to the shoreline, near Longyearbyen. Local people in Longyearbyen captured wild salmon in Isfjorden also in 2003, 2005 and 2007. During the last decades pink salmon have frequently been captured along the north-western coast of Spitsbergen, and even in rivers and lakes, both in south-western and north-western part of Spitsbergen, showing that Pacific salmon, probably from rivers on the Kola peninsula (Svenning 1995) are feeding far north in the Barents Sea, as well. Anadromous populations of Arctic charr, the only fresh water fish species reproducing on the Svalbard islands, are also feeding along the Svalbard coast in the summer period. All in all, this demonstrates that these extreme northerly fjords are housing several anadromus salmonids, at least during the icefree summer period.

Atlantic salmon smolts has also been captured in the Barents Sea. In 2000, the Institute of Marine Research (Bergen, Norway), during their survey with the research vessel “G. O. Sars”, starting the survey in the inner Tanafjord, captured Atlantic salmon smolts in July, even as far north at 72 degrees north (pers. comm. Jens C. Holst, Institute of Marine Research). In addition, Russian vessels from Polar Research Institute of Marine Fisheries and Oceanography (PINRO-Murmansk) have captured Atlantic salmon smolts as far north and east as 50 km west of the southern point of Novaya Zemlya. We have also found a positive correlation, among years, between the estimated abundance of capelin (*Mallotus villosus*) in the Barents Sea and the size of 1SW (summer-winter) returning Atlantic salmon in the Tana river system, suggesting that at least the Tana salmon are feeding in the Barents Sea.

In a review paper, Jonsson and Jonsson (2004) found positive correlations between the North Atlantic Oscillation winter index for the post-smolt year and production variables in North-Sea rivers, while Niemelä et al. (2004) found no such correlations for Atlantic salmon populations in the eastern Finnmark rivers, Tana and Neiden, thus suggesting that salmon populations from these north-eastern rivers migrate and feed somewhere else during their sea residence than populations farther south. In 2007 (November and December), we even captured several adult salmon north of the Finnmark coast, suggesting that some populations, temporally and/or partially, may also feed in north-eastern coastal areas during late autumn and early winter.

Much has been learned about the ocean migrations and marine distribution patterns of salmon in the North Atlantic over the past decade (e.g. Holst et al. 2000; Holm et al. 2003; Lacroix et al. 2004). Additional insight has been obtained from the use of data storage tags (DST) (e.g. Moore et al. 2000; Reddin et al. 2004) that can also provide information on the temperatures, salinities and depths fish have encountered. Despite the advances, much is still to be learned. Recently, ICES (2005, 2006) has recommended co-ordinated tagging and tracking studies on smolts, adult salmon as well as kelts using DST tags. Recovery of the latter tags, however, is often limited owing to high marine mortality of salmon at sea and the great expense and logistical difficulties in carrying out large-scale surveys at sea (Moore et al. 2000).

An alternative means to retrieve information is to use ‘pop-up’ archival tags, and in summer 2007, during the SIN-project, we tagged 30 kelts descending the Tana river system with satellite (pop-up) tags. As far as we know, this is the first time satellite tags have been used on Atlantic salmon. In addition to tell the position of the fish when popping up, the tags also

record water temperature, depth (pressure) and dusk/dawn every 15 minutes after tagging. We hope the results from these taggings, when tags start popping up in early winter 2008, will throw new light on the nature of sea residence of north-eastern Atlantic salmon populations.

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# **Current distribution and numbers of marine mammals in the Barents sea in connection with climatic change**

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## **Introduction**

PINRO began regular studies of the distribution and numbers of marine mammals in the Barents Sea from 2000. By now, we understand that marine mammals play a significant role in the Barents Sea ecosystem as predators. Further, the influence of human activities and climatic changes (which are very considerable in the past few years) on marine mammals from other side is also important.

However, PINRO already had a very long history of studies, beginning in 1928, of the harp seal *Phoca groenlandica* (the White Sea population); its biology, distribution and numbers in the Barents and White Seas area, as being one of the most numerous marine mammals in the Barents Sea.

Most recent estimates are that about 24 marine mammals species regularly occur in the Barents Sea, comprising 7 species of pinnipeds, 12 large cetaceans, and 5 small cetaceans species. Besides the harp seal, the most common species are white-beaked dolphin (*Lagenorhynchus albirostris*), walrus (*Odobenus rosmarus*), and minke whale (*Balaenoptera acutorostrata*). Some marine mammals species can be observed in the Barents Sea area all year around, while other occur at certain phases of their life-cycle or seasons of the year.

Recent years have seen the discovery of clear changes in the distribution and numbers of marine mammals in the Barents Sea among the species traditionally recorded (area of occupation, numbers and duration of stay are all increasing). Some marine mammal species not previously noted have also been observed. This demands a study and understanding of the role of marine mammals in the Barents Sea ecosystem in order to take them into account in rational fisheries management. Further, the development and improvement of ecosystem models must be carried out, as marine mammals are top predators and are a significant component of the Barents Sea ecosystem. The marine mammals have annual food consumption of marine fisheries organisms (mostly crustaceans, capelin, herring, polar cod, and gadoids, depending on area and time of year) is believed to be several times greater than total catches by commercial marine fisheries.

Here we consider one aspect of the situation; the current distribution and numbers of marine mammals in the Barents Sea in connection with climate change (global warming).

## **Methods and data**

The main problem facing research in this area is that of obtaining high quality representative raw data from large areas of the Barents Sea in a short time, including data on current surface and sub-surface oceanographic conditions and the distribution and species numbers of marine mammals. The first data for this purpose were collected during the annual Russian-Norwegian ecosystem surveys in August-September, in which two or three Norwegian research vessels

(R/V) and two Russian R/V (“vessel surveys”) plus Russian research aircraft An-26 “Antonov” (“aerial surveys”) participated. Both countries provided equal financial support and collect high-quality raw data. Unfortunately, during the Russian-Norwegian ecosystem survey in 2006 “Antonov” could not participate, due to financial problems at PINRO.

The aerial surveys were carried out along transects which are primarily oriented along latitudes. As far as possible, distances between transects were no more than 30 n. miles, and altitudes were between 100 and 250 m, depending on cloud height. Observations of marine mammals were visual, with the most interesting situations being photographed. Observations were made by at least two observers through blister windows on the right and left sides of the aircraft (two “blisters” on each side). The observers recorded marine mammals within the observation swath (swath wide equal to altitude) on their side. Information was sent to the onboard computer (OC) by means of a special communication link. The aircraft's remote sensing equipment simultaneously measured sea surface temperature (SST), pycnocline depth, plankton concentration in the subsurface layers and chlorophyll A concentration on the surface, and transparency. All these data were input to the OC as data concerning marine mammals. All flight information was complex and was input to the OC in real time and position using of GPS.

The vessel observations for marine mammals performed along the ecosystem survey transect routes were made from the highest point of the vessel where there was safe access (usually for Russian research vessels it is 12-15 m above sea surface). On each Russian R/V a single observer covered a 360° section. On the Norwegian R/V observations were made by three observers simultaneously (two for marine mammals and one for seabirds), with each observer covering a 90° section (total of 180° for marine mammals).

All vessel observations were subject to weather conditions. When these were not good enough for quality observations (too large waves and too much wind, foggy, high probability of fog or precipitation) observations were not made. Observations were not performed on the stations, only along transects.

For on-board observations, the observers use binoculars with reticle, dictaphone, GPS and PC notebook. These observations were performed according to standard methods recommended by the NAMMCO Scientific Committee. Data on current oceanographic conditions were collected at each oceanographic station. All raw vessel data, like the aircraft data, were uploaded to the central onboard computer in real time and with position.

The Russian observers also used data from fisheries vessels with PINRO observers, and data collected during special field expeditions in the Barents Sea coastal zone.

## **Results and discussion**

The current distribution and numbers of marine mammals in the Barents Sea is dependent on many factors, and its interrelations are very difficult and complicated. Here we only discuss the current situation for marine mammals and during the past few years in connection with the climatic situation in the Barents Sea.

As is well known, the results of the latest ecosystem surveys (for both types of survey platforms – vessels and aircraft; aircraft did not participate in 2006) showed that the temperature was generally above the long-term mean throughout the Barents Sea, including

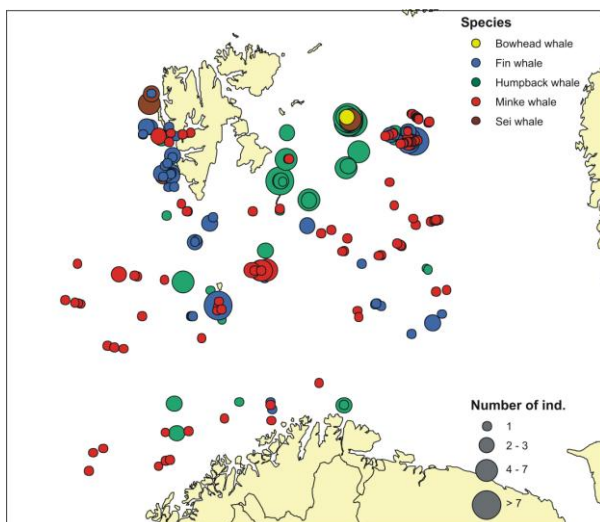


all main sections. If we consider the 2006 results in comparison with the previous few years before and with long-term means, we come to the following conclusions: SST were higher than the long-term mean by an average of 0.5-1.5° C throughout the whole study area. The maximum positive SST anomalies were observed to the south and south-east of the Spitsbergen Archipelago, to the north-west of Cape Kanin and to the east of Kolguev Island. However, in some areas in the north-eastern and southern parts of the survey area negative SST anomalies (down to -0.6° C) were found.

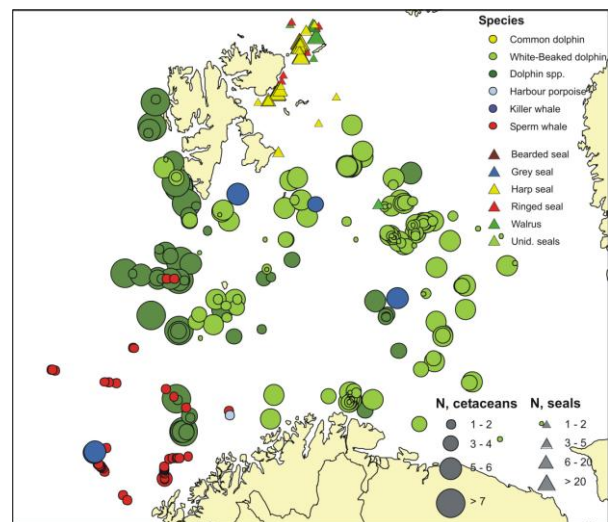
Compared with 2005 and previous years SST was lower (on average 0.8-1.8° C) in southern, eastern and central parts of the sea, with the highest deviation in the southern part (by more than 2° C lower in 2006). But SST was higher (on average 1.0-2.0° C) in the northern and northwestern parts of the Barents Sea, with the highest deviation to the south-east of the Spitsbergen Archipelago (by more than 3° C).

Temperatures in the deeper layers were between 0.3 and 1.3° C higher in 2006 than in 2005 and the previous few years in most of the Barents Sea, except in the northern and eastern parts, where waters were colder than in 2005. The water temperature at depths of 50, 100 and 200 m was generally higher in 2006 than in 2005 and last previous years in most of the Barents Sea area.

In the above climatic situation will be further considered in the marine mammal situation. Here we should note the following (see Tables 1 and 2 and Figures 1 - 3 below. Here we first consider the marine mammals species that were identified reliably as the quality of identification is in no doubt.



**Figure 1.** Distribution of baleen whales observations from the R/Vs “Johan Hjort”, “G.O. Sars”, “Smolensk”, “F. Nansen”, and the research aircraft “Arktika” during the 2005 ecosystem survey(August-September).



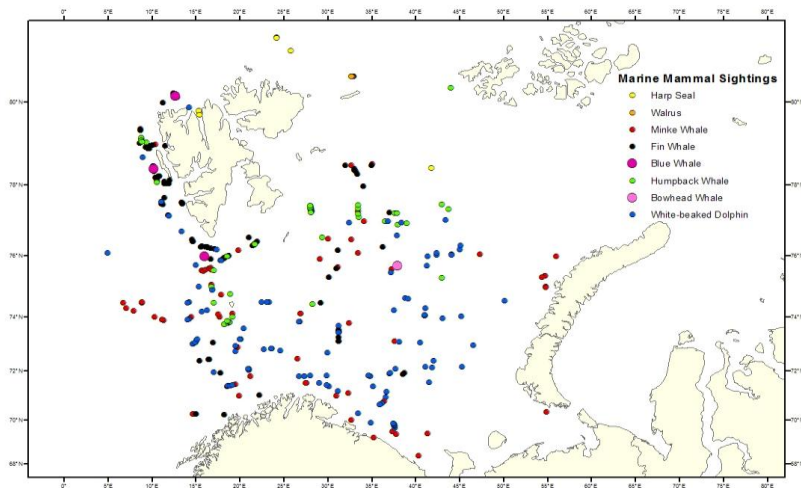
**Figure 2.** Distribution of seal and toothed whale observations from the R/Vs “Johan Hjort”, “G.O. Sars”, “Smolensk”, “F. Nansen”, and the research aircraft “Arktika” during the 2005ecosystem survey.

**Table 1.** Number of marine mammal individuals observed from R/V “Johan Hjort”, “G.O. Sars”, “Smolensk”, “F. Nansen”, and research aircraft An-26 “Arktika” during the 2005 ecosystem survey (August-September).

Class/sub-order	Species name	“Johan Hjort”	“G.O. Sars”	“Smolensk”	“F. Nansen”	An-26 “Arktika”	Total	%%
Cetacea/baleen whales	Minke whale	37	73	7	9	22	148	2.66
	Sei whale	0	0	0	14	0	14	0.25
	Fin whale	46	60	0	9	0	115	2.07
	Humpback whale	15	22	16	135	11	199	3.58
	Bowhead whale	0	0	2	0	0	2	0.04
	Unidentified whales	2	0	5	33	20	60	1.08
	Unidentified large whales	16	16	0	0	0	32	0.58
Subtotal	5 (reliably identified)	116	171	30	200	53	570	10.26
Cetacea/toothed whales	Sperm whale	35	22	0	0	0	57	1.02
	Killer whale	28	0	0	3	2	33	0.59
	White-beaked dolphin	0	526	42	987	45	1600	28.76
	Harbour porpoise	0	2	0	0	0	2	0.04
	Common dolphin	0	0	1	0	0	1	0.02
	Unidentified dolphins	252	30	0	37	0	319	5.73
Subtotal	5 (reliably identified)	315	580	43	1027	47	2012	35.16
Pinnipedia	Harp seal	0	0	0	2504	234	2738	49.21
	Ringed seal	0	0	0	0	9	9	0.16
	Bearded seal	0	0	0	0	2	2	0.04
	Walrus	0	0	0	109	112	221	3.97
	Grey seal	0	0	1	0	0	1	0.02
	Unidentified seals	0	0	0	0	5	5	0.09
Subtotal	5 (reliably identified)	0	0	1	2613	362	2976	53.49
Other	Polar bear	0	0	0	2	3	5	0.09
	Unidentified mammals	0	0	0	0	1	1	0.02
Subtotal		0	0	0	2	4	6	0.11
Total sum	15 (reliably identified)	431	751	74	3842	466	5564	100.00

**Table 2.** Number of marine mammal individuals observed from R/V “Johan Hjort”, “G.O. Sars”, “Jan Mayen”, “Smolensk” and “F. Nansen” during the 2006 ecosystem survey (August-September).

Class/suborder	Species name (in English)	“Johan Hjort”	“G.O. Sars”	“Jan Mayem”	“Smolensk”	“F. Nansen”	Total	%%
Cetacea/baleen whales	Minke whale	37	16	3	11	19	86	4.86
	Sei whale	0	0	0	0	1	1	0.06
	Fin whale	14	36	106	3	5	164	9.26
	Blue whale	0	0	4	0	0	4	0.22
	Humpback whale	24	50	21	1	37	133	7.51
	Bowhead whale	0	0	0	1	0	1	0.06
	Unidentified whales	0	0	0	3	19	22	1.24
	Unidentified large whales	7	1	4	0	0	12	0.68
Subtotal sum	6 (reliably identified)	82	103	138	19	81	423	23.89
Cetacea/toothed whales	Sperm whale	6	0	0	0	0	6	0.34
	Killer whale	0	0	0	0	4	4	0.22
	White-beaked dolphin	401	218	79	91	148	937	52.94
	White-side dolphin	0	0	0	16	8	24	1.36
	Common dolphin	0	0	0	3	0	3	0.17
	Striped dolphin	0	0	0	6	0	6	0.34
	White whale	0	0	0	38	0	38	2.15
	Harbour porpoise	0	0	0	14	20	34	1.92
	Unidentified dolphins	11	0	13	3	13	40	2.26
Subtotal	8 (reliably identified)	418	218	92	171	193	1092	61.70
Pinnipedia	Harp seal	0	0	178	3	0	181	10.22
	Bearded seal	0	0	3	0	1	4	0.22
	Grey seal	0	0	0	2	0	2	0.11
	Walrus	0	0	60	0	0	60	3.39
	Unidentified seals	2	0	2	0	0	4	0.22
Subtotal	4 (reliably identified)	2	0	243	5	1	251	14.16
Other	Polar bear	0	0	0	3	0	3	0.17
	Basking shark	1	0	0	0	0	1	0.06
Subtotal		1	0	0	3	0	4	0.23
Total sum	18 (reliably identified)	503	321	473	198	275	1770	100.00



**Figure 3.** Distribution of marine mammals (most frequently encountered species) observed during the 2006 Norwegian-Russian joint ecosystem survey (R/Vs “Johan Hjort”, “G.O. Sars”, “Jan Mayen”, “Smolensk”, “F. Nansen”),

As we can see (Table 1) in 2005 a total of 622 observations of 5 564 marine mammals individuals comprising 15 species were recorded. In 2006 (Table 2) a total of 455 observations of 1 770 marine mammals individuals comprising 18 species were recorded.

In comparing these data we need to note that in 2005 a larger total of marine mammals for all species was recorded than in 2006 (about three times as many), while in 2006 the number of species was higher than in 2005. We believe that this is mainly due to changes in the survey methodology, since in 2006, the research aircraft An-26 “Arktika” did not participate in the survey due to financial problems. It is very well known that research aircraft can survey very wide areas in a short time, including the ice edge area and areas with different concentrations of ice that are very important for the study of marine mammal that inhabit areas of ice (harp seal, walrus and certain others). This was amply confirmed during this year's T-NASS survey, in which six aircraft participated.

Next, since 2006 was generally warmer than 2005 (in terms not only of above-normal sea temperature values but also the spatial distribution of the ice edge) basking sharks were observed in the Barents Sea to the south-west of Bear Island. This is the most northerly record of this species.

In 2005, the most abundant species in individuals terms was harp seal (about 49% of the total number of marine mammals observed), followed by dolphins, of which the white-beaked dolphin was the dominant species (about 29% of the total number of individuals observed). Of the baleen whales, which made up 10% of the total number of individuals observed, minke and fin whales were the most numerous.

Minke whale had the widest distribution of the baleen whales, as these were observed both on and off the shelf and throughout the survey area. Humpback and fin whales were observed on the shelf and the shelf break west of Spitsbergen, and while humpback whales were observed both in the northern and southern Barents Sea, fin whales were more restricted to the central and northern Barents Sea. Sei whales, normally regarded as a southern deep-sea species, were observed both to the west and east of Svalbard and in the central region of the Barents Sea.

Finally, one observation of the rare bowhead whale was made east of Svalbard. Both sei and bowhead whales were observed in open water, about 120 n. miles from the sea-ice edge. Dolphins, predominantly white-beaked dolphins, were observed throughout the Barents Sea.

In contrast, sperm whales were observed off the shelf break only, mainly south of Bear Island. Harp seals were observed east of Svalbard only close to the sea-ice edge or within it, where the concentration was no more than 70%.

In 2006 we recorded the following: the most abundant species in terms of individuals was the white-beaked dolphin (53% of the total number of individuals observed), which

was observed over large parts of the survey area but predominantly in the southern and eastern parts of the Barents Sea. This situation is quite different from 2005, when the most abundant species in terms of individuals was the harp seal (see above). We believe that the main reason is the change in survey methodology, since in 2006 Russian research aircraft could not participate in ecosystem survey for financial reasons. Thus data could not obtain data from close to the ice edge area and within the ice edge area, which tends to be inaccessible to research vessels.

The white-beaked dolphin's sibling species, the white-sided dolphin, which is usually considered to be a more oceanic species, was also recorded occasionally in the south-eastern part of the Barents Sea. This species was usually observed in groups of 5-15 individuals, which often displayed ship-seeking behaviour. In the south-eastern Barents Sea a couple of observations were made of common and striped dolphins, both of which are thought to be associated with warmer waters and occur occasionally in northern waters due to influxes of warm water masses.

Of the baleen whales (24% of the total number of individuals observed) fin and humpback whales were the most numerous. Humpback whales were observed west of Spitsbergen and around Bear and Hope Islands. Fin whales were observed on the shelf or the shelf break west of Spitsbergen, and otherwise in the central and northern Barents Sea. Minke whales were observed throughout the survey area but apparently in lower abundances than usual at this time of year. One observation of the rare bowhead whale was made in the northern Barents Sea. Several sei whales were observed west and east of Svalbard and in the central region of the Barents Sea. However, in 2006 only one individual was identified west of Svalbard. Blue whales were observed west of Svalbard. The previous year, blue whales seem to have visited quite regularly. A few sperm whales were observed along the continental slope towards the Norwegian Sea. A group of white whales was observed in the south-eastern Barents Sea.

Harp seals and walrus were observed north of Svalbard, which is their expected main area of distribution at this time of the year. However, considerably fewer harp seals were recorded during this period than in previous years, when very large groups were encountered. The main reason for the differences in sightings has been indicated above.

The 2007 ecosystem survey commenced a short time ago, and even preliminary results in the open Barents Sea are not yet available. This year, however, PINRO made two field expeditions to the Kola Peninsula coastline (in May and June-July), in the course of which we counted marine mammals from the coast and from the boat. Our preliminary results suggest that marine mammals were fewer in number than at the same time in previous years for all species who are traditionally observed here. We believe that this may be related to the decrease in SST in the Kola Peninsula coastal zone (average 0.5 – 1.2° C). Marine mammals may be redistributing in other parts of the Barents Sea or may be forming large concentrations in the area between Greenland and Svalbard. Finally, however, we are able to make some

valid deductions after ecosystem surveys carried out using traditional methodology with the aid of both types of observation platforms – R/Vs and research aircraft.

## **Conclusions**

In the Barents Sea some “non-traditional” species of marine mammals were observed, suggesting that their numbers have increased. There were also relative increases in the numbers and areas of distribution of marine mammals, primarily humpback whale, minke whale, and white-beaked dolphin

the trophic role of marine mammals in the ecosystem at present may be regarded as very significant, on the one hand as predators for fish stocks , while on the other, human activities in the sea have a considerable impact on marine mammals

- the above findings all demand an expansion of research on marine mammals, including all directions of research, where the study of distribution and numbers would be based on aerial surveys which can be complemented by vessel survey and coastal observation data, including counting from boats, which has been demonstrated to be successful in several of the most recent ecosystem surveys.

## **Acknowledgments**

The authors are grateful to all IMR and PINRO personnel who participated in the ecosystem surveys on board various survey platforms, including participants in the Barents Sea Coastal Zone Expedition. We particularly thank the crews of the Norwegian and Russian research vessels for their great professional skill. Finally, many thanks to our Norwegian and other international colleagues Mette Mauritzen, Nils Øien, Tore Haug, Kjell Nilssen, Anne Kristine Frie, and Ulf Lindström

# **Polar bears and other ice-associated marine mammals in the Barents Sea**

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In this short article, our aim is to present a brief summary of the current status of research effort on four “non-commercial”, high arctic species of marine mammals that reside in the Northern Barents Sea Region, with populations that should be studied and managed via joint Russian/Norwegian collaborative efforts. The four species are polar bears, walrus, white whales and ringed seals. For each species, we will focus on their movement patterns and population size and on what is known regarding these issues from the Svalbard region, and from the Western Russian Arctic (i.e. the northern Barents Sea Region).

## **Polar Bears (*Ursus maritimus*)**

Polar bears are well studied in the Barents Sea Region, particularly in Svalbard where more than 1000 individuals have been captured and marked during the last 3 decades. Close to 200 satellite collars have been fitted on adult females in this geographic area. Although much less intensive effort has been carried out on the Russian side of the border, several joint Norwegian/Russian research projects make the Barents Sea population one of the most studied polar bear populations within the context of the Russian Arctic. One of the most significant results from our bilateral projects was the production of the first-ever population survey for the Barents Sea polar bear population in 2004. An extensive line transect helicopter survey (Eurocopter AS350 Ecoureuil) produced an estimate of 2997 animals (95% CI approx. 2200 – 4000). This estimate, was derived not only from the counts within the survey area flown, but was also based on bear density data calculated from information derived from satellite tracking, which included areas far north of the ice edge that were not covered by the helicopter flights (Aars et al, submitted manuscript).



Polar bear

Knowledge about polar bear movements in the Barents Region is available from two primary sources, directly from satellite telemetry and indirectly from molecular markers. Until recently, only adult females from the southern and eastern parts of Svalbard have been equipped with satellite collars on a routine basis. These bears exhibit two very different

habitat use strategies. Some of these animals exhibit quite restricted movement patterns, remaining within small home ranges throughout the year. During summer these bears spend a considerable proportion of their time on land. Other individuals have much larger home ranges, traveling broadly on sea ice to the north and east of Svalbard towards the Western Russian Arctic and back again. These bears, obviously, have a much larger home range encompassed within their seasonal migration pattern (Mauritzen et al. 2001).

The movements of these bears between the Norwegian and Russian Arctic areas underline the importance of a joint management strategy between the two countries, and also the importance of the already ongoing coordination of research. Data from satellite tracking conducted in recent years (Aars et al., unpublished data) shows that polar bears tagged in the northern parts of Svalbard have a very different migration pattern compared to females from the southeast. The bears in the north move to the north and west. This finding is supported by a large-scale study on population genetics of polar bears throughout the circumpolar Arctic that found no significant differences in microsatellite structure between Svalbard and eastern Greenland, or between Svalbard and the western Russian Arctic (Paetkau et al 1999). Thus, polar bears in the Svalbard area seem to interact with polar bears both to the east and west of the Archipelago. Mauritzen et al. (2002) also showed that what we call the “Barents Sea subpopulation” (Aars et al. 2006), actually interacts to a significant degree with polar bears from the Kara Sea area. This is once again in concordance with genetic data (Paetkau et al. 1999).

### **Walrus (*Odobenus rosmarus*)**

Walruses were hunted to the brink of extinction in Svalbard, before they were protected in 1952. But, this species has been increasing in abundance in the Archipelago following its protection, almost certainly via emigration from Franz Josef Land in the Russian Barents Sea. A survey of walruses in Svalbard was conducted in August 2006; all hauled-out walruses at 79 known haul-out sites in Svalbard were counted. Combining the counts with telemetry data from earlier years, it was estimated that the number of walruses in the area was 2,629 (95 % CI approx 2,300 – 3,000) (Lydersen et al, 2008). It is known that the walruses in Svalbard are part of a larger, common Svalbard-Franz Josef Land population. In this population, most of the males spend the summer in Svalbard and most females and calves remain in the Franz Josef Land area. This has been confirmed by satellite tracking studies (Wiig et al. 1996) and genetic studies (Andersen et al. 1998).

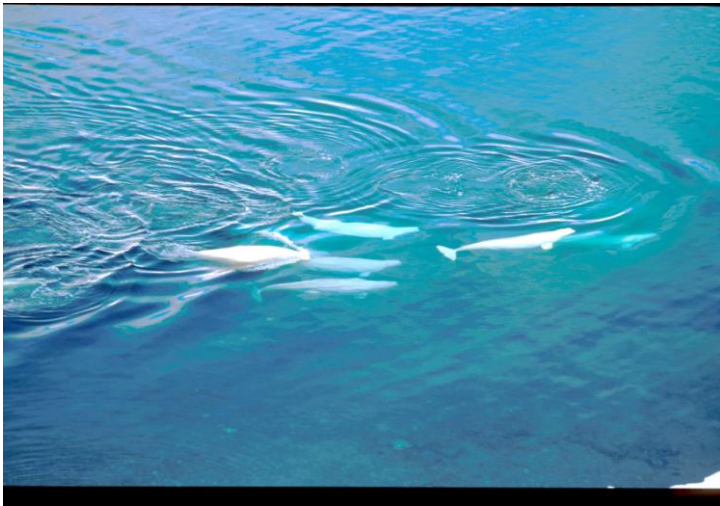
Males from Svalbard undertake annual migrations deep into ice-covered areas between Svalbard and Franz Josef Land during the breeding period in early winter (Freitas et al., 2007). Very little work on walruses has been conducted in Franz Josef Land, and the lack of knowledge from this region represents a major gap in global knowledge for this species. A population size estimate and satellite tracking of females should be top priorities for bi-lateral research programmes.

### **White whales (*Delphinapterus leucas*)**

White whales, or the beluga, is the least-studied of the species discussed in this article. Nothing is known regarding the population size of this species for this area and very little is known about space use or migration patterns. This is somewhat surprising given that it is almost certain that white whales are the most numerous, resident cetacean species in the



northern Barents Sea. Data from some marked individuals in southern Spitsbergen showed very local movements within this area (Lydersen et al. 2001, 2002). However, the tracking periods are too limited to draw any firm conclusions on overall annual movement patterns. The data so indicate that sub-population structure may exist within the Svalbard area and is very likely within the broader Barents Sea Region. Movement patterns between Svalbard and the western Russian Arctic should be studied both by satellite telemetry studies and population genetics. A study on population genetics with material from Svalbard, Greenland and some few specimens from the White Sea in western Russia is currently ongoing.



White whales

### **Ringed seals (*Pusa hispida*)**

The number of ringed seals in the Barents Sea area is unknown, and due to their wide distribution, very aquatic lifestyle, and cryptic breeding behaviour, a good estimate of abundance will not likely become available for the whole area. However, even an estimate with a very wide range of uncertainty would be of interest, since ringed seals are a very important species in the arctic ecosystem. They are the most common marine mammal in ice-covered areas and are an important predator on species lower down in the food chain (Labansen et al. 2007), as well as being the main prey of polar bears (e.g. Derocher et al. 2002). In many places in the Arctic they are also an important food source for coastal peoples.

Based on an aerial survey in the west and north of Svalbard, combined with behavioural data from telemetry and observations that made it possible to fit a model that included a correction factor for animals in the water, approximately 7,600 (95% CI approx. 6,400-9,100) ringed seals spend the spring moulting season in this sub-region of Svalbard (Krafft et al. 2006). However, the observational data referred to above in combination with telemetry data strongly indicate that there is a significant in- and out-flux of seals from the fjords during the moulting period (Carlens et al. 2006, Krafft et al. 2006). Thus, the estimated number may be useful as an index in “trends” studies, but it does not provide a sound estimate of how many ringed seals actually live in the region in total. Satellite telemetry data have shown that ringed seals captured in Svalbard migrate into Russian waters (Lydersen et al. 2004, Freitas et al. in press). Thus, at least to some extent, Norway and Russia share this ringed seal population. However, no studies of population genetics are available to assess the degree of genetic exchange/substructure in the Barents Sea ringed seal population and virtually nothing is

known about densities or abundances of ringed seals beyond the area covered during the recent survey.



Ringed seal

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# **Polyaromatic hydrocarbons (PAHs) in the Barents Sea sediment: Small changes over the recent 10 years**

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## **Extended abstract**

(Full article included in special issue of Marine Biology Research (vol. 4, 2008), celebrating the 50 years of Norwegian-Russian research cooperation)

## **Introduction**

Polycyclic aromatic hydrocarbons (PAHs) are common environmental contaminants which can be derived from technogenic and natural processes including leakage and erosion of fossil carbon, as well as epigenetic processes such as decaying peat. Occurrence of PAHs in environment is a concern due to their toxicity and carcinogenic effects of certain PAH components.

Studies of PAHs in Barents Sea sediments during the years 1992-1998 demonstrate a wide geographical range of total PAH concentrations as well as strong regional differences (Dahle et al., 2006). Over the recent 10 years, off shore production of oil and gas on the Norwegian shelf has more than doubled, and the transport of oil from Russia through the Barents Sea has increased from zero to 12 million tons per year (2005). Our objectives were to (1) assess whether increased oil and gas activities in the Barents and adjacent seas are observed in increased concentrations or changes in composition of PAHs in Barents Sea sediments and (2) compare PAH levels and composition in Barents Sea sediments from different regions over the recent 10 years in order to reveal possible multi-year variability in the environmental levels of PAHs. The study was initiated by the Arctic Monitoring and Assessment Programme (AMAP) and supported by the Norwegian Council of Ministers.

## **Material and methods**

Surface sediment samples were collected in the Barents Seas during the years 2001-2005 by Akvaplan-niva (Tromsø, Norway), Institute of Marine Research (IMR, Bergen, Norway) and Polar Research Institute of Marine Fisheries and Oceanography (PINRO, Murmansk, Russia). Sediment samples were retrieved using both a 0.1 m<sup>2</sup> van Veen grab and a gravity corer with a plastic liner.

The chemical analyses were performed at Unilab Analyse AS (Tromsø, Norway), IMR, and PINRO analytical laboratories. The laboratories are accredited for hydrocarbon analyses according to the European standards and have participated successfully in the Quality

Assurance Laboratory Performance Studies for Environmental Measurements in Marine Samples (QUASIMEME).

Following PAH compounds were measured: naphthalenes, phenanthrene/anthracenes dibenzothiophenes, acenaphthylene, acenaphthene, fluorene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b+k]fluoranthene, benzo[e]pyrene, benzo[a]pyrene, perylene, benzo[ghi]perylene, indeno[1,2,3-cd]pyrene and dibenzo[a,h,]anthracene.

The hypothesis of normal distribution was tested using Shapiro-Wilk's W Test. This hypothesis was not rejected for log-transformed data. Cluster analysis (k-means clustering) was used to group the sampling stations by log-transformed PAH compounds in the sediment samples. Standard T-test was used to estimate significant differences ( $P < 0.05$ ) between the geometric means calculated for the two compared periods.

## Results and discussions

In the 2000s, total PAH concentration ( $\Sigma$ PAH) in bottom sediments of the Barents Sea varied from 27 up to 6026 ng/g d.w. The highest PAH levels were found in north-western part of the Barents Sea. The PAH levels generally decreased towards south and east. PAH composition and sources of PAHs varied in the different regions.

K-means-clustering of the 2001-2005 datasets groups the hundred sampling stations into five distinct geographical areas based upon levels and compositions of PAHs. The five areas are Svalbard offshore, Bear Island Trough, SW Barents Sea, NE Barents Sea and SE Barents Sea. The highest PAH levels were found in sediments from Svalbard offshore area. The fine-grained fraction of the sediments was dominating; pelites made up 80% on average. Total PAHs concentrations ( $\Sigma$ PAH=sum of 27 PAH analytes) in sediments from this area varied from 2698 ng/g to 6026 ng/g d.w, with a geometric mean 4383 ng/g d.w. Alkyl-substituted homologues of naphthalene and phenanthrene prevailed in the PAH composition. High values of Fossil Fuel Pollution Index (FFPI) (54-79%) suggest a predominance of petrogenic PAHs. Comparative analysis of PAH patterns in bottom sediments from Svalbard offshore area and in Spitsbergen's coal samples show compositional similarities (Dahle et al., 2006). This suggests natural erosion and weathering of coal-bearing formations on Svalbard archipelago to be a main source of PAHs in sediments from this area.

The Bear Island Trough is 400-500 m deep and dominated by Atlantic water. Total sediment PAH concentrations ranged from 893 ng/g to 2206 ng/g dw. Sediments from Svalbard offshore and Bear Island Trough areas exhibit similar PAH patterns, with a predominance of two- three-ring PAH compounds. However, the two areas differ in their relative content of pyrogenic PAHs ( $\Sigma$ PyrPAH = sum of four- to six-ring PAHs perylene excluded).

In addition, we observe higher PAH ratios ( $ANT/178 = \text{anthracene}/(\text{anthracene} + \text{phenanthrene})$ , and  $IND/276 = \text{indeno}[1,2,3\text{-cd}]\text{pyrene}/(\text{indeno}[1,2,3\text{-cd}]\text{pyrene} + \text{benzo}[ghi]\text{perylene})$ ) for Bear Island Trough compared to Svalbard offshore area indicating a relatively high content of combustion PAHs. This may be due to stronger inflows of Atlantic water.

NE Barents Sea includes the eastern part of the Great Bank and Central Trench areas. Total PAH concentrations ranged from 406 to 1136 ng/g dw. Perylene and benzofluoranthenes were the most abundant PAH compounds. Geometric mean PAH concentration was similar to those

measured during the 1990s. The limited temporal variability in PAH concentrations in this area was supported by our data on down core PAH distribution.

The range of  $\Sigma$ PAH concentrations found in sediments from SE Barents Sea was 137-860 ng/g d.w with a prevalence of pyrogenic PAHs. Benzofluoranthenes and indeno[1,2,3-cd]perylene were the most abundant. Mean  $\Sigma$ PAH and  $\Sigma$ PyrPAH concentrations found in the 2000s and 1990s did not differ significantly. However, the levels of  $\Sigma$ NPD (sum of naphthalene, phenanthrene, dibenzothiophene and their alkylated homologues) and FFPI in samples from 2000s were significantly higher than in the 1990s. At the same time, the ANT/178 ratio found in the 2000s was significantly lower than in the 1990s, and at a level which indicates a dominance of petroleum sources (Yunker et al., 2002)

In SE Barents Sea, the range of total PAH concentrations was 137-860 ng/g d.w. Pyrogenic compounds dominated in the PAH composition; indeno[1,2,3-cd]pyrene, benzofluoranthenes and benzo[ghi]perylene are the most abundant compounds. Concentrations of  $\Sigma$ PyrPAH and  $\Sigma$ NPD from this area in the 2000s were significantly higher than in the 1990s. However, in contrast to the SW Barents Sea area, an increase of  $\Sigma$ NPD was not accompanied by an increase of FFPI, but by a significant increase of FLT/202 (fluoranthene/fluoranthene+pyrene) and IND/276 ratios. It is suggested that the increase of PAH concentrations in SEBS sediments reflects higher input of combustion or/and anthropogenic PAHs.

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## How does ice cover affect the benthic fauna in the Barents Sea?

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Ecological surveys have been carried out in the Barents Sea for many decades, but until recently, most expeditions have been carried out on either one or other side of the political boundary that divides the area. With today's large-scale fisheries and petroleum exploration activities, there is a pressing need for joint ecosystem-based environmental management of the area as a whole. To do this we need environmental data that is compatible, and which spans both Russian and Norwegian waters. Both spatial and temporal data are necessary in order to document natural variations and distinguish these from anthropogenic impacts. In some cases, indicators for environmental health or state may be selected, to make data collection manageable. Such joint data shall serve to evaluate the current ecosystem status and to make projections in the event of environmental changes. Ultimately, the knowledge gained shall be used as feedback to operational processes, which aim for best environmental practices. We present two large-scale joint Russian-Norwegian surveys of environmental conditions and benthic fauna in the Barents Sea.

The project "Benthic fauna at the Barents Sea ice edge in a changing climate" (BASICC), financed by the Norwegian Research Council, was initiated in 2003. Quantitative, replicated sampling and analyses of benthic infauna and sediments, together with productivity and ice regimes were carried out at 47 stations extending across approximately 400 000 km<sup>2</sup>. Around 600 taxa were recorded. Ice cover showed a clear inverse relationship with both infaunal abundance and the overlying primary productivity regime

The first two years (2006 and 2007) of the ongoing annual monitoring programme "Russian-Norwegian Joint Annual Ecosystem Surveys" (JAES) sampled zooplankton, pelagic fish, bottom fish, benthic animals, and oceanography from over 1000 campelin trawl hauls in the Barents Sea. Joint publishing is in progress where we present results of benthos caught as 'bycatch' from approx. 500 hauls. Biomass ranged from under 1 kg to over 2 tonnes in the sponge-rich south-eastern area and highest numbers of taxa occurred around the Spitsbergen Bank.

Traditional faunal grab sampling is most efficient for capturing the small, numerically abundant benthic organisms, and tends to show a dominance of worms and molluscs. Trawling, on the other hand, mostly samples larger organisms, and due to the sheer area of sea floor covered, also sparsely distributed organisms can be well-represented. Grab sampling is a quantitative technique, for a small area of sea floor, whereas trawl samples can give only qualitative, or semi-quantitative information, but over a large area of sea floor. Therefore, both techniques have different strengths and shortcomings, and the respective results cannot directly be compared or integrated into a single analysis. However, used in combination, grab and trawl samples can provide a more comprehensive picture of benthic conditions than each method alone.

Similarly, until recently, Russian and Norwegian benthic research was carried out largely independent of each other, even though both sides have worked in similar areas. Due to slight differences in methodology, equipment and working practices, the results have not always been directly compatible. By conducting joint cruises and data analysis, the BASICC and JAES programmes make a substantial contribution to generating large-scale inter-compatible faunal data from the Barents Sea.



# **Ecosystem dynamics and fisheries management in the Barents sea**

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

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

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

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

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

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

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

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

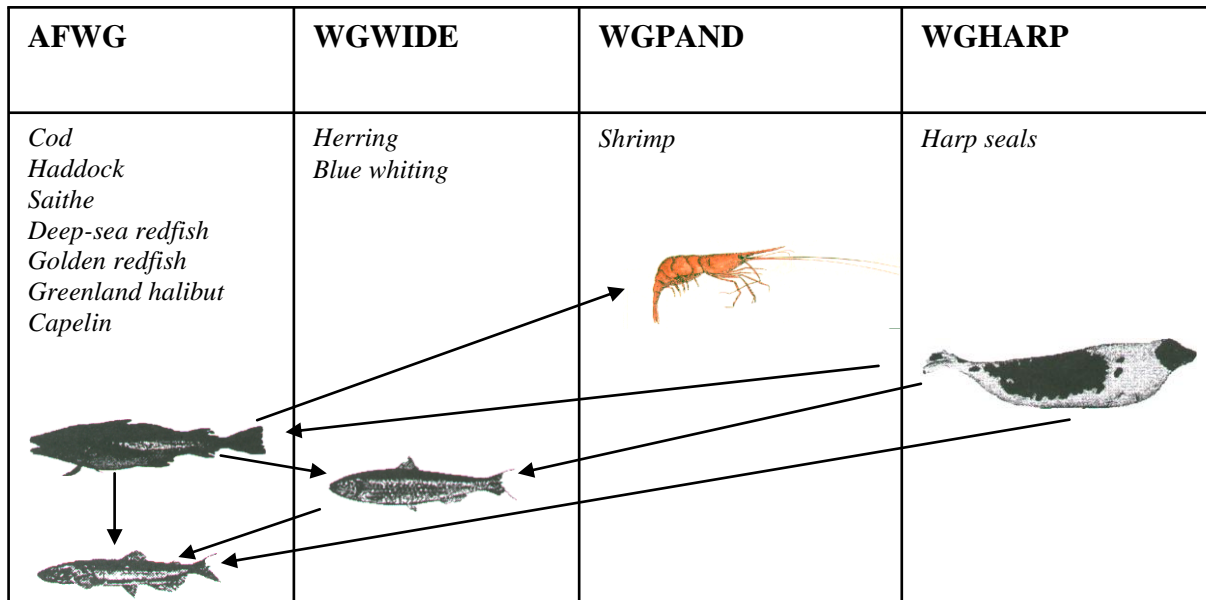
The main feature of the Barents Sea ecosystem is large fluctuations in environmental conditions. Dynamics of the ecosystem is governed by the inflow of Atlantic water masses, which determines distribution, recruitment success and growth of the main commercially important species. Historically, there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

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

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

The current and expected state of the Barents Sea ecosystem has been considered routinely at the AFWG since 2002. Last years the informational basis for this was the "Joint PINRO/IMR report on the state of the Barents Sea ecosystem". This report summarized and analyzed ecosystem monitoring information for evaluation of the current situation, making projections

and putting the knowledge into operational use. Jointly, IMR and PINRO have developed long time series for main components of the Barents Sea ecosystem, including climate, plankton, benthos, fish, marine mammals and sea birds. Furthermore, there are time series on species interactions – particularly on the diet of Northeast Arctic cod and on influence of the climate on recruitment of commercial species of fish.



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

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

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

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

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

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

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

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

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

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

- Prediction of growth rate of cod by STOCOBAR model;

- Prediction of cod recruitment by regression models;

- Expected stock parameters of cod and capelin based on qualitative analysis of ecosystem impact.

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

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

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

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

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

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

phase (2005-2007) empirical relations will be used to evaluate prospects for long-term yield of cod. During the second phase (2008-2014) other species will be included.

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

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

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

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## **Appendix 1: Symposium programme**

### **The 12<sup>th</sup> Norwegian- Russian symposium**

#### **on Long term bilateral Russian-Norwegian scientific co-operation as a basis for sustainable management of living marine resources in the Barents Sea**

*Polar Environment Centre, Tromsø, Norway, 21-22 August 2007*

Organized by

The Institute of Marine Research (IMR), Norway and

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

#### **Participation**

The symposium addressed scientists, fishery managers and representatives of the fishing industry.

#### **Scope**

To mark the 50-year anniversary for a formal and active cooperation between Norway and Russia in marine research, IMR and PINRO arranged the 12<sup>th</sup> joint Norwegian-Russian symposium in Tromsø in 2007. The prime scope of the symposium was: “*Long term bilateral Russian-Norwegian scientific co-operation as a basis for sustainable management of living marine resources in the Barents Sea*”. Contributions were organized under three theme sessions: I) Establishment and maintenance of long time marine data bases; II) Development and implementation of new methods and models; III) Long term changes in the Barents Sea ecosystem.

#### **Proceedings**

The Proceedings of the symposium will be edited by the Norwegian part of the symposium programme committee, and published in the IMR/PINRO Joint Report Series.

#### **Co-convenors**

Ole Arve Misund, Research director, IMR

Yuri Lepesevich, Research director, PINRO

#### **Symposium program committee**

From Norway:

O.A. Misund, IMR

H. Gjøsæter, IMR

T. Haug, IMR

I. Røttingen, IMR

J.-E. Eliassen, NHF/UIT

C. von Quillfeldt, NPI

From Russia;

Y. Lepesevich, PINRO

O. Titov, PINRO

#### **Local organizing committee:**

T. Broks, IMR and V.H. Lund, IMR

# Programme

21 August 2007

**0800-0900 Registration**

**0900-1000 Opening addresses (Chair: T. Haug)**

Opening statements by convenors **Ole Arve Misund (IMR) & Yuri Lepesevich (PINRO)**

Opening statement by State Secretary **Vidar Ulriksen**, Norwegian Ministry of Fisheries and Coastal Affairs

Opening statement by PINRO (Research Director **Yuri Lepesevich**)

Opening statement by IMR (Research director **Ole Arve Misund**, on behalf of director **Tore Nepstad**)

**1000-1030 Invited keynote speaker (Chair: T. Haug)**

**Guðrún Marteinsdóttir (Marine Research Institute, Reykjavik, Iceland):**  
Has man learned to manage cod?

**1030-1100 Coffee break**

**1100-1400 Theme session I: Establishment and maintenance of long time marine data bases (Chair: T. Haug)**

N.A. Yaragina (PINRO), B. Bogstad (IMR) & Yu.A. Kovalev (PINRO): Reconstructing the time series of abundance of Northeast Arctic cod (*Gadus morhua*), taking cannibalism into account.

N.V. Zuykova (PINRO), P. Aagotnes (IMR), V.P. Koloskova (PINRO), H. Mjanger (IMR), K. H. Nedreaas (IMR), H. Senneset (IMR), N.A. Yaragina (PINRO) & S. Aanes (IMR): Age reading of Northeast Arctic cod otoliths through 50 years of history. (Presented by K. Drevetnyak, PINRO)

A. Pedchenko, A. Karsakov, V. Ivshin, & V. Guzenko (PINRO): Russian research on oceanographic sections in the Barents Sea.

V. Ivshin, A. Pedchenko (PINRO), Ø. Skagseth & R. Ingvaldsen (IMR): Study of the spatial variability in thermohaline characteristics and water structure on the standard sections in the western Barents Sea.

E. Eriksen (IMR) & D. Prozorkevich (PINRO): Long time survey series on 0-group in the Barents Sea

A. Dolgov, N.A. Yaragina, E.L. Orlova (PINRO), B. Bogstad, E. Johannesen, S. Mehl (IMR): 20<sup>th</sup> anniversary of the PINRO-IMR cooperation in the investigations of feeding in the Barents Sea – results and perspectives.

P. Fauchald (NINA): Seabird monitoring and the Barents Sea ecosystem.

S.-R. Birkely (Akvaplan-niva) & B. Gulliksen (NFH): Establishment and maintenance of regular photographic monitoring of rocky bottom localities from North Norway to Spitsbergen



**1400-1500** Lunch Served at the symposium venue

**1500-1800 Theme session II: Development and improvement of new methods and models (Chair: Y. Lepesevich)**

N.A.Yaragina (PINRO), K.H. Nedreaas (IMR), V. Koloskova (PINRO), H. Mjanger (IMR), H. Senneset (IMR), N. Zuykova (PINRO) & P. Ågotnes (IMR): Fifteen years of annual Norwegian-Russian cod comparative age readings. (To be presented by K. Drevetnyak, PINRO)

A.K. Frie (IMR) & V. Svetochev (SevPINRO): Building time series from IMR and SevPINRO data sets on reproductive parameters of harp and hooded seals.

T.I. Bulgakova (VNIRO, Moscow): The simulation of Norwegian spring spawning herring dynamics to evaluate various variants of the harvest control rule.

O.A. Bulatov, V.M. Borisov, B.N. Kotenev & G.S. Moiseenko (VNIRO, Moscow): The estimation of the Barents Sea cod stock by the GIS-methodology.

B.M. Shatockin, A.D. Gomonov, E.I. Gula, M.K. Tshiekals (NATSRBYBRESURS, Murmansk), D.N. Klochkov, S.I. Boichuk (Morskaya Informatika, Murmansk), V.M. Borisov, G.P. Vaniushin & B.N. Kotenev (VNIRO, Moscow): Basis of methodology of fisheries - ecological monitoring and new approaches to stock and estimation of living marine resources.

L.B. Klyashtorin (Federal Institute of Fisheries and Oceanography) & A.A.Lyubushin (Institute of Physics of the Earth, Russian Academy of Science): Cyclic changes of climate and major commercial stocks of Barents Sea. (Presented by V. Borisov, VNIRO)

S. Bakanev & B. Berenboym (PINRO): Applying the Bayesian approach in assessment of red king crab (*Paralithodes camtschaticus*) and northern shrimp (*Pandalus borealis*) stocks in the Barents Sea.

I. Shafikov (PINRO): Probabilistic approach to the estimation of marine biological objects by the data of aerial surveys (To be presented by V. Zabavnikov, PINRO)

**1930 Dinner** Served at the symposium venue.

**22 August 2007**

**0900-1100 Theme session III: Long term changes in the Barents Sea (Chair: H. Gjøsæter)**

Ø. Skagseth (IMR), T. Furevik (UiB), R. Ingvaldsen (IMR), H. Loeng (IMR), K.A. Mork (IMR), K.A. Orvik (UiB) & V. Ozhigin (PINRO): Transports and propagation of anomalies in the Norwegian and Barents Seas

E.Orlova (PINRO), V.Guzenko (PINRO), P.Dalpadado (IMR), T.Knutsen (IMR), V.Nesterova (PINRO) & O.Yurko (PINRO): Climate variations and state of zooplankton in the Barents Sea.

S. Falk-Petersen (NPI): Climate swings and ecosystem effects.

H. Gjøsæter, B. Bogstad & S. Tjelmeland (IMR): Why did the three capelin stock collapses in the Barents Sea during the three last decades affect the ecosystem differently?

V.L. Tretyak (PINRO): Long term variation and adaptive relationship between the life cycle parameters of the north-east Atlantic cod *Gadus morhua*.

K. Drevetnyak (PINRO) & K.H. Nedreaas (IMR): Spatial migration pattern of deep-water redfish (*Sebastes mentella* Travin) in the Barents Sea as inferred from long-term research survey series.

**1100-1130 Coffee**

**1130-1330 Theme session III (continued)**

M-A. Svenning (NINA), A. Zubchenko (PINRO), S. Prusov (PINRO), B. Dempson (DFO-Canada), E. Niemele (RKTL-Finland), R. Borgstrøm (UMB) & J. Erkinaro (RKTL-Finland): Where do all the northern Atlantic salmon feed during their sea residence?

S. Egorov, V. Zabavnikov, & S. Zyryanov (PINRO): Marine mammals distribution and numbers in the Barents Sea in modern stage with connection of climatic changes. J. Aars, K.M. Kovacs & C. Lydersen (NPI): Polar bears and other ice-associated sea mammals in the Barents Sea.

S. Dahle (Akvaplan-niva), N. Ploitiotsina (PINRO), J. Klungsøyr (IMR) & T. Savinova (Akvaplan-niva): Oil hydrocarbons and PAH in the Barents Sea sediments.

S.J. Cochrane (Akvaplan-niva), S.G. Denisenko (ZIN) & L.L. Jørgensen (IMR): How does ice cover affect the benthic fauna in the Barents Sea?

A. Filin (PINRO), S. Tjelmeland (IMR) & J.E. Stiansen (IMR): Ecosystem dynamics and fisheries management in the Barents Sea.

**1400 Lunch**

Lunch was served onboard RV “GO SARS” en route to Skjervøy. O.A. Misund (IMR) was the host on the research vessel, and a presentation was given of the recent joint ecosystem report by H. Gjøsæter (IMR) and A. Filin (PINRO) during the trip.

**1945 Departure from Skjervøy, MS “Polarlys”.**

The coastal vessel MS “Polarlys” took the participants back to Tromsø.

**2030 Symposium dinner** Served in the restaurant onboard the coastal vessel, MS “Polarlys”.

**2345 Arrival in Tromsø**

## Appendix 2. List of participants

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