Workshop
»Ecosystem
West Greenland«

Greenland Institute of Natural Resources, Nuuk
29 November - 03 December 2001

A Stepping Stone Towards an Integrated Marine Research Programme

Astrid Jarre
(Ed.)
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Preface

The Greenland Institute of Natural Resources is the Greenland Home Rule Government’s centre for nature research. It also delivers scientific advice to the government, who wishes to secure the sustainable use of the country’s living resources, including conservation of the environment and biological diversity. The Institute’s vision is to understand the interrelationship between ecosystem, climate and human impact.

The Greenland Institute of Natural Resources wishes to stimulate a long-term research programme to incorporate its vision, in order to meet the increasing interest in ecosystem-based advice for management. While the research programme will have a long-term scope, progress will be evaluated after five years. The focus of this research programme will be the marine ecosystem off West Greenland, which is both economically and socially most important to Greenland’s society.

A workshop was conducted at the Greenland Institute of Natural Resources in Nuuk during 29 November to 3 December 2001. It was attended by 38 participants from Greenland, Denmark, Norway, Iceland, Canada and Germany. The aim of this workshop was to

1. Decide on the particular areas of research emphasis during the next five years,
2. Outline research partnerships,
3. Collate a list of concrete project ideas, to be conducted in a coordinated fashion.

The workshop comprised seven sessions on fixed main themes, each of which consisted of the review of knowledge relevant to the ecosystem West-Greenland through short presentations by the participants, a focussed discussion in small groups, and a feedback of the results of these group discussions in plenum followed by a plenary discussion. Finally, one session was devoted to setting up the first five-year phase of the research programme, where the goal and the objectives of the research programme were agreed, and outputs were outlined.

This document is the workshop report. It was compiled on the basis of the participants’ contributions and results of group discussions and edited by Dr. Astrid Jarre for the Greenland Institute of Natural Resources. The document should be cited as

towards an integrated marine research programme.

The new Annex of the Greenland Institute of Natural Resources provides accommodation for the Institute’s guests and additional meeting facilities.
Executive Summary

1. A workshop on the »Ecosystem West Greenland« was conducted at the Greenland Institute of Natural Resources in Nuuk during 29 November - 03 December 2001. The workshop had 38 participants from Greenland, Denmark, Norway, Iceland, Canada and Germany.

2. The workshop consisted of a mix of plenary presentations and discussions, and small task teams tackling workshop tasks in parallel.

3. The abstracts of the short oral presentations given by most of the participants are published in this report. The report further documents the results of the various group discussions and outlines the framework for the first phase of the desired research programme.

4. The agreed goal of the research programme is »to establish a scientific basis for long-term ecosystem-based management in West Greenland waters«.

5. Three interdisciplinary objectives were identified for the first five-year phase of the research programme:
   
   I. Quantify and improve the understanding of physical and biogeochemical interactions (Key words: atmosphere, ice, physical and biological oceanography, pelagic-benthic coupling/vertical flux, lateral coupling (inshore/offshore and north/south));
   
   II. Quantify and improve the understanding of ecosystem structure and functioning (Key words: biodiversity, trophic interactions, spatial and temporal scales);
   
   III. Identify and quantify interactions between human activities and the ecosystem. (Key words: predict ecosystem impacts of harvest at community, species and stock levels (factors affecting stocks, trawling impacts, etc.), socio-economic and management impacts of climate and harvest regimes).

6. An extensive list of possible outputs from the first five-year phase of the programme was elaborated and is reported on page 80. Milestones, deliverables and necessary inputs were not discussed in detail.

7. The management structure of the research programme was agreed upon and is reported on page 73. A small group of scientists was asked to take the results of this workshop further until indication of support for the programme initiative was received, and the management of the programme was in place.

8. In order to gain support for the programme initiative, it was agreed to present the results of this workshop to the Arctic Ocean Sciences Board at its 21st Annual Meeting, 21-23 April 2002, Groningen, Netherlands, as well as to other suitable national and international bodies.
The marine ecosystem is an integral part of life in Greenland.
Eqikkarnera


2. Isumasiaqatiginneq oqalugiarluni oqallissaarinertaqarlunilu atatsimooorluni oqallinnertaqarpoq eqimattakkutaararluni naapeqattaartoqartarluni aalajangersimununisk sammisassaqartitaaffiusunik.


4. Aalajangiunneqarpoq ilisimatusaatigalugu ingerlatassap siunertarissagaa: »Kitaata imartaata pinngortitut ataqatigiisseutut alisinnerusan eqimattakkuutaarlutik oqallinnerit inerlerit assigioonngitsut allaganngorlugit ilanggunneqarput, ilisimatusaatissallu ingerlanissaata alloriarnarera siulliup qanoq ingerlanneqarnissaa allaganngorluneqarluni.

5. Ilisimatusaatigalugu ingerlatassap alloriarnerera siulleeq sumik tunngaveqassneraq suleriaatsit assigioonngitsut tunngavigalugit imaattussatut siunertalorsorneqarpoq:

   I. Pinngortitami uumassusillit uumaatsullu akunnerminni ataqatiginniisa (biogoeeki) paasineqarnissaa annertusaruqeassuq (oqaatsit qitusut: silaanann, siku, sarfap nikerarnereta nassatai kisiilu i m a m i uumasuseqsaseq (fysisk aamma biologisk oceanografi), immmap naqqani immmallu ikerani uumassusillit ataqatigiinneram/immami nukiti immmap naqqaniit qummut ammullu aamalnu sanimet nikerarnerat (pelagisk-bentisk klobing/vertikalflux, lateral klobing) - taakkulu nikerarnerat misissorneqassapput avataani sinerissamullu qaninnerusuuii aamalnu avannaat kujataatalu akornanni sarfap nikerarnereta sunniutai paasiniarlugut.

II. Pinngortitami ataqatigiisuarnera qanoq isikkoqarnera annertunerusuqka paasisaqarfigalugu (Oqaatsit qitusut: uumassusillit assigioonngisi-taassusiat (biodiversitet), nerisaqaqatiiginnermi nikerassuq (trofiske inter-aktioner), piffissaq iniitussuserlu najoqutarafiqit uuttuisarneq).

III. Inuup pinngortitalu imminut qanoq sunniuteqaqatigittarnerat siuenssinarlugu paasinarlugulu (Oqaatsit qitusut: aalisarnerup pininarnera pinngortitamarum inuiaqatiginnulluq qanoq sunniuteqarntarneri siumut takorloorsinnanngorlugit, uumassaqatigii ataasiakkaat kanoruq alemlatigineri, silap kissassutsillu allanggorarneri, aalisarnererit pinin-
artarnerillu inuusaatsikkut aningaasarsiornikkut nakkutiginninnikkullu sunniutigisartagai.

6. Ilisimatuussutsikkut suliaqarluni allioriarnerup siullersaani inernerusinnaasut nalunaarsoqqissaarlugit tulleriiiaarneqarput, taakkulu qupp. 80 (tulliinilu) allaatigineqarput. Alisinnerusoq isigelugu uuttuuitit, tunisassiat atortussallu pisariaqartitat iternga tikillugu eqqartorneqanngillat.

7. Ilisimatuussutsikkut suliaqarnissap qanoq aqunneqarnissaa aalajangjunne-qarpoq tamannalu qupp. 73-mi eqqartorneqarpoq. Ilisimatuut eqimattat amerlanngitsut isumasioqatigiinnerup inernerinik politikkikkut tapersersor-neqalernissap tungaanut suliallu aqunneqalivinnissaa tikillugu aallussisussat toqqarneqarput.

Resumé


2. Seminaret var sammensat af en blanding af mundtlige indlæg samt diskussioner i plenarmøder, og små arbejdsgrupper, der mødtes parallelt, og gav sig i kast med specifikke opgaver.


4. Der blev vedtaget, at forskningsprogrammets mål er »at etablere et viden-skabeligt grundlag for en langsigtet, økosystembaseret forvaltning af de vestgrønlandske farvande«.

5. Tre tværfaglige formål blev identificeret for forskningsprogrammets første fase:
   I. At kvantificere og forbedre forståelsen af fysiske og biogeokemiske interaktioner (nøgleord: atmosfære, is, fysisk og biologisk oceanografi, pelagisk-bentisk kobling/vertikalflux, lateral kobling (indenskærs/udenskærs og nord/syd);
   II. At kvantificere og forbedre forståelsen af økosystemets struktur og funktion (nøgleord: biodiversitet, trofiske interaktioner, rumlige og tidsmæssige skalaer);
   III. At identificere og kvantificere interactioner mellem menneskelige aktiviteter og økosystemet (nøgleord: at forudsige økosystemeffekter af fiskeri/fangst for samfundet, enkelte arter og bestande; socio-økonomiske og forvaltningsmæssige konsekvenser af div. klimaforandrings- og fiskeri/fangstscenerier).


7. Forskningsprogrammets styrelsesstruktur blev vedtaget og er afrapporteret på side 73. En lille forskergruppe blev nedsat for at arbejde videre med seminarets resultater, indtil der modtages politisk støtte for forskningsprogrammet, og den faktiske styrelse af forskningsprogrammet kan nedsættes.

8. For at opnå støtte for forskningsprogrammet, endedes man om, at præsentere seminarets resultater på det 21. årsmøde af »Arctic Ocean Sciences Board«

Human use of the marine ecosystem off West Greenland depends heavily both on the season of the year, and on prevailing climatic conditions.
Section 1
Opening and Introduction

Welcome and Opening
_Lise Lennert, Minister of Culture, Education, Research and Church, Greenland Home Rule Government_

Asasakka isumasioqatigiinnermi peqataasut,

Nunatsinni Naalakkersuisut sinnerlugit nuannaarutigaara «Ecosystem West-Greenland»-imik qulequtserlugu isumasioqatigiinnissamut tikilluaqqusinnaagassi.

Akornassinni kiinnat ilisarnartitakka arlalippassuupput, tassaanerusut Pinngortitalleriffimmi sulisut, aammali kiinnat takornakkakka arlaqarput.

Tamassi tikilluaritsi - immikkullu nunatsinnut Nuummullu tikilluaqqorusuppakka ilisimatusartut avataaneersut, kissaallugillu maaniinnertik nuannersumik misigisaqarfigiumarait.

Dear Participants of the Workshop,

On behalf of the Greenlandic Government I am pleased to welcome you to the Workshop »Ecosystem West-Greenland«. I recognize a good number of well-known faces amongst you, particularly the staff of the Greenland Institute of Natural Resources, but I see some new faces too. Welcome to all of you - and especially to the researchers from abroad, who I would like to welcome to Greenland and to Nuuk with all my best wishes for an enjoyable stay.

I regard the theme of the workshop to be very important. Greenlanders have for thousands of years lived from the natural resources of our country. The development of the modern Greenland has been based on the natural resources - and there is no doubt, that a major factor of the further development of Greenland will depend on living resources too. Research and the building up of science are crucial to the possibilities for further development of our country.

Generally, research in the Arctic falls into two broad categories

- the first is research addressing the special social and economic needs of the Arctic regions, and
- the second is basic research using the opportunities of the Arctic to study issues of common concern.
Research to be presented at this workshop surely addresses the needs of Greenland, as mentioned before, and, in addition, the forthcoming results of the research program will be of common scientific concern.

The overall objective of the research policy of Greenland is to enable research

- to contribute to the improvement of the quality of life of the Greenlandic society - and
- to contribute actively to the development of the society, to support sustainable development and to enter the field of solving problems created by the rapid economic and cultural change of society.

These overall objectives have to be turned into more concrete proposals in order to be effective. The Home Rule Government is trying to do that in several ways. One way is to build up Greenlandic research institutions. This place - Pinngortitaleriffik, the Greenland Institute of Natural Resources - is one of the major research institutions. Another way to specify the overall objective is to select priority areas for the research. The Home Rule Government has selected the following priority areas:

- Existing research on environment, nature and natural resources shall be strengthened. The other priorities are
  - Socio-economic development,
  - Social conditions,
  - Health and nutrition and at last but not least
  - Cultural history and language.

Therefore the theme of the workshop corresponds very well with the research policy of the Home Rule Government. We are looking forward to the results of the workshop, and we recognize and welcome the initiative of the organizers.

As well as other countries, Greenland has limited resources to spend on research, which is why networking is important. I am pleased to see this workshop as a result of international networking. The limited research resources applies for human resources as well as economic resources. I therefore find it very important to combine resources by networking to establish a joint research program. A joint research program will create possibilities for economic resources - and funding for a major research effort. I am sure that the organizers are aware of the importance of getting international funding, for example from the Nordic Council of Ministers and from the European Union. Therefore - we have high expectations to the results of the workshop and to the establishment of a joint research program.
At last - I know that researchers are hard-working people, and that professional discussions do not stop by the end of a daily scheduled program, - and this is quite an impressive program, never the less, I encourage our foreign guests also to take time to get an impression of our beautiful country during your stay here in Greenland.

I wish you all a successful workshop with exciting presentations and creative discussions.

I hereby declare the Workshop »Ecosystem West-Greenland« for open.

Thank you, have a good workshop. Qujanaq, isumasiqatigiilluarisilu.

Welcome and Introduction

Klaus Høyer Nygaard, Greenland Institute of Natural Resources

Minister for Education and Science, members of Board of Directors, members of Advisory Board and last but not least - colleagues from Iceland, Germany, Norway, Canada, Denmark and Greenland. It is a great pleasure for me, to welcome you all here at Greenland Institute of Natural Resources.

To our young institute an opportunity like this is not an everyday event. Indeed this is probably the largest and most diverse gathering of natural scientists in Greenland ever. It is an honour for me to welcome you here, and our appreciation of your interest and the allocation of your time cannot be stressed firmly enough. I and my staff will do our best to make the coming days fruitful, enjoyable and memorable. Not only do we look forward to the scientific discussions, but also to presenting Greenland, and this institute as a place of interest to the international scientific community.

The aim of this workshop is to outline the needs and possibilities for a research programme combining several disciplines in order to better understand the interrelationships between climate, marine ecosystem and human impact in West Greenland.

The background for the initiative is dual. On one side this marine ecosystem is of outmost importance to the livelihood of Greenland. Few other countries are so completely dependent on living marine resources, and knowledge and understanding of the processes in the ecosystem are crucial to our society. On the other side the same system provides an excellent area for studies on large-scale effects of climate change. Through time the oceanographic and ecological conditions in West Greenland have changed dramatically several times. Further the rapidity of change enables even short term research programmes to provide concrete results.
Existing programmes like the Nordic Ocean Climate Programme, German bottom trawl surveys and different Greenland monitoring and research activities - as well as new initiatives - could be linked together to provide synergy and growth in activities and knowledge. Basic as well as applied research could be combined for a better understanding. Monitoring programmes and existing research can be seen as skeletons, from which new projects can emerge and mingle. Databases can be exchanged and new analyses can disclose new relationships.

Comprehensive understanding of all the natural and human induced processes in the ecosystem is not to be expected, and a pragmatic viewpoint will be necessary. The aim is also to include social science and economics in future work, but for this time we managed to bring together natural scientists. Every one of you brings knowledge and experience that is of importance for the development of a sound programme and avoidance of mistakes. Further, it is hoped that the workshop will provide a basis for new interrelations and future collaboration on important issues.

A dramatic increase in sea temperature has occurred in recent years, and the signs are, that cod is coming back to West Greenland waters. What are the reasons behind this, and what are the consequences to the ecosystem and society? If we could answer questions like these - even on a large scale - we would be much better off, both in predicting effects of climate change and in the pursuit of a sustainable use of the resources.

Large-scale programmes are costly, and we have to look for both national and international funding. In this respect focus should be directed towards the «6th Framework Programme» of the European Union and the theme »Global Change and Ecosystems«. Greenland has just last week been granted improved admission to EU research programmes, but details of the new agreement have not arrived yet. Greenland alone is probably not capable of getting through the EU-system, and joining forces with other nations is therefore critical.

The Greenland Institute of Natural Resources would like to thank the Home Rule Government and The Commission for Scientific Research in Greenland for supporting this workshop, which we hope will be the kick-off for large scale initiatives towards the marine ecosystem in West Greenland. The workshop will be reported in »Inussuk«, which is the Greenland journal for research, and the outcome of the workshop will come to immediate attention at the political level in Greenland.

I wish us all prosperous days ahead. Thank you for your attention.
Section 2
Abstracts of Oral Presentations

Session 1
Ecosystem-Based Management: What are we Trying to Achieve?

Advice on and management of the West Greenland ecosystem: Present practice

Helle Siegstad, Greenland Institute of Natural Resources

The Greenland economy depends almost entirely on living resources from the sea, and 95% of Greenland’s total export value stems from fish products. The fisheries on shrimp, Greenland halibut and snow crab have been the most important in terms of both economy and total catch during the last decade. Cod was an important component in the ecosystem off West Greenland until the early 1990s, but the importance of the cod decreased drastically after it virtually disappeared from Greenland waters due to changes in the marine environment. Marine mammals and sea birds are also key elements in the ecosystem, both as part of human utilization schemes and through their role as top predators.

The Greenland Institute of Natural Resources is responsible for providing scientific advice to the Home Rule Government on the level of sustainable exploitation of the renewable resources, including long-term protection of the environment and biodiversity.

The scientific advice is mainly based on a) monitoring programmes, which provide indices of the status of the various stocks, b) stock delineations, c) information on reproduction and population biology, d) feeding studies and e) fishing gear studies. The scientific advice to the Greenland government is reviewed through international advisory bodies such as NAFO, ICES, NASCO, IWC and NAMMCO. The Greenland Government regulates the utilization of renewable resources by quotas and technical measures (e.g., mesh sizes or closed seasons). As of today, the scientific advice to the Government is entirely based on single-species assessments given for one year, with no predictive models for the medium or long term.

The existing scientific programmes provide information on the abundance and biology of most important fish and invertebrate stocks in the ecosystem off West
Greenland, comprising the coastal/inshore area, the offshore banks and the deeper waters offshore. However, our knowledge of commercially only lightly exploited, or unexploited, stocks of small fish (capelin, sandeel and Polar cod), is very limited and the status of these resources is unknown, although it is known that small pelagic fish such as capelin play an important role in the ecosystem in other marine ecosystems.

Rapid and drastic changes in species abundance and composition in the West Greenland ecosystem are well-known and documented. However, the understanding of the reasons for these changes is very limited today, although many changes appear to be related to changes in hydrographic conditions.

In order to provide scientific advice to the Government on the West Greenland ecosystem, we need to have a better understanding of the mechanism responsible for the changes. A better understanding of the trophic interactions in the system (including human activities) and the effect of changes in climate on the renewable resources is vital. There is also a clear need for a better understanding of the role of the pelagic species in the ecosystem, as well as the effect of by-catch and trawling on bottom habitat.

**Transition towards ecosystem-based advice (and management)?**

*Gunnar Stefánsson, University of Iceland / Marine Research Institute*

Advice on the utilisation of fish stocks and systems has been built on several foundations including biological, economical and legal aspects. Of these it is important to consider the legal issues to see how they have developed, to evaluate current trends and to see how they can be interpreted so as to provide the logic on which to base actual biological advice. The traditional agreements used by bodies such as ICES, NAFO and others include the Law of the Sea, the Rio Declaration, the Code of Conduct for Responsible Fisheries, followed by the recently adopted Agreement on Straddling Stocks and Highly Migratory Stocks. The most recent such international convention (the Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem) resulted in the Reykjavik Declaration. Going through this sequence of conventions, it is seen that they have provided a series of tools which have been used by advisory bodies to obtain ever-strengthening support for the use of caution when harvesting fish stocks. It is, however, seen that the Reykjavik Declaration is a deviation from this trend, since it appears to be virtually impossible to draw any quanti-
tative statements from this declaration. The development of the form of utilisation is therefore put back to using the earlier conventions as well as bioeconomics.

Multispecies issues in fisheries are very wide-ranging indeed, from gear-technology concerning effects on the benthos to bycatch and discards. The single-species principle of low fishing mortality on each target stock remains the driving principle, however, and in example cases effects on bycatch species might not have arisen except for the excessive effort. Multispecies concerns continue to be important, and it is important to take such issues into account when designing regulatory measures in the longer term. In particular it is seen that the combination of multispecies concerns and low effort leads to much more stringent management requirements than before.

An important remnant issue is the definition of precautionary harvests of a prey species. In cases when it appears that the net economic gain from harvesting a prey appears to be zero, due to reduced food supply for a harvested predator, the question must be raised of whether such a harvest is in accordance with the precautionary approach in a multispecies sense.

When viewing fisheries world-wide, it is seen that the current state of affairs in most fisheries can be described by the words »Marine resources can be harvested using the maximum fleet size economically possible up to that maximum level of fishing mortality which does not demonstrably lead to stock collapse«. Attempts should be made to change this implicit policy and this may be possible by picking up a new tenet: »Marine resources should be harvested using the minimum fleet size possible and at that minimum level of fishing mortality which does not demonstrably lead to a serious long-term loss of catch«. The simple change of premise would go a long way towards providing ecosystem-friendly utilisation of the resources.

CCAMLR and the management of ecosystems in the Southern Ocean

Karl-Hermann Kock, Federal Research Centre for Fisheries

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) came into force in 1982. The convention is unique in that it has an ecosystem approach to management enshrined in its Article II. This article is paramount to the Convention. The CCAMLR Ecosystem Monitoring Programme (CEMP) was started in 1985 and further developed in 1986 and 1987 in order to investigate potential effects of changes in krill abundance on predators on various temporal and spatial scales. This approach was much more complex than the tra-

CCAMLR was aware of the fact that it could not monitor the whole ecosystem and its complexity. They selected a number of species which represent key elements of the krill-dominated ecosystem and for which sufficient biological information was available. These were krill (Euphausia superba), the Antarctic silverfish (Pleuranogramma antarcticum) and early life stages of fish as prey species. Selected predators were crabeater seals (Lobodon carcinophagus), Antarctic fur seals (Arctocephalus gazella), Adelie, chinstrap and gentoo penguins (Pygoscelis adeliae, P. antarctica, P. papua), macaroni penguins (Eudyptes chrysolophus), Antarctic petrels (Fulmarus glacialisoides), cape petrels (Daption capense) and black-browed albatross (Diomedea melanophris). Minke whales (Balaenoptera acutorostrata) were initially included but dropped in 1991 as no suggestion had been forthcoming how the species should be monitored. CEMP is administered by a specialist working group (CCAMLR Working Group on Ecosystem Monitoring and Management) which designed and coordinates the programme.

Changes in the abundance, reproductive performance and other key elements of the life cycle of predators and prey would reflect changes in the ecosystem. Environmental factors in the vicinity of monitored colonies were also found to be of great importance. Prior consideration of goals was important in designing such a large-scale programme at various sites around the Antarctic. Another important aspect was that the programme is reviewed periodically, such as in 1996.

Three Integrated Study Regions (ISRs) were chosen. These were the Antarctic Peninsula - South Shetland Islands, South Georgia and the Prydz Bay region. Predator parameters were chosen for their potential to respond to changes in prey availability and environmental factors. A set of standard methods on predator performance was agreed upon in 1987. Standard methods on environmental parameters were adopted in 1990. In addition to these local conditions, regional sea ice distribution and sea surface temperature are monitored. No standard methods have yet been developed for prey. However, two parameters are collected routinely: krill catch per hour as a measure of krill density and the potential overlap between krill fishing and predator foraging range. In addition, krill biomass in the western Atlantic sector was estimated in an international survey in 2000. Regionally, krill biomass is regu-
larly estimated in the Elephant Island - King George Island (South Shetland Islands) region by American and German scientists.

CCAMLR is conducting a review of predator status based on results from CEMP annually since 1992 by using multivariate statistics. This review is undertaken under two different aspects: identification of trends and anomalies in the time series and an assessment of the implications of those trends or anomalies. This has stimulated the development of a number of models of interaction between components of the ecosystem, krill catch per unit of effort, krill yield, krill recruitment, and fishing vessel behaviour. Models of predator energetics incorporated predator-prey relationships. The consequences to predator populations of harvesting krill have been modelled in a functional relationship between krill and its predators.

In the meantime, CCAMLR was able to incorporate its ecosystem approach into a number of conservation measures regulating fisheries in the Southern Ocean. It was more difficult, however, to develop feedback mechanisms between the results of CEMP and regulatory conservation measures which would eventually lead to the management of krill fisheries. The model currently most advanced is the Butterworth-Thomson model (1995, CCAMLR Sci. 2:79-97). The model is still being developed further and is not used currently to set krill catch limits.

It is encouraging that the CEMP programme has furnished the development of parallel programmes in other parts of the world ocean.
Session 2  
The Impact of Climate Conditions on the Pelagic Ecosystem off West Greenland 

Northwest Atlantic Ocean Climate  
Erik Buch, Danish Meteorological Institute  
The ocean climate of the northwestern part of the Atlantic Ocean is strongly related to the variability of the general ocean circulation of the North Atlantic Ocean, which again depends on the strength of the North Atlantic Oscillation (NAO) i.e. the air pressure difference between the Azores High and the Icelandic Low.

Low NAO conditions mean:
- relatively weak North Atlantic Current;  
- strong Irminger Current i.e. high inflow of Irminger Water to West Greenland;  
- warm conditions in the Northwest Atlantic area;  
- no deep convection in the Labrador Sea.

High NAO conditions mean:
- relatively strong North Atlantic Current;  
- weak Irminger Current i.e. low inflow of Irminger Water to West Greenland;  
- cold conditions in the Northwest Atlantic area;  
- strong deep convection in the Labrador Sea.

The change from low to high NAO conditions around 1970 has changed the ecosystem in West Greenland waters considerably. Previously the fishery was primarily based on a rich cod stock, while it today is almost totally based on catches of shrimp.

The change is caused by:
- decrease in ocean temperatures due to atmospheric cooling, which has lead to a reduction in the West Greenland cod stock;  
- reduced inflow of heat, salt and cod larvae from the Irminger Sea.

The close relations between climate variability and the marine ecosystem off West Greenland strongly support the incorporation of effects of environmental fluctuations in prediction models for fish stock recruitment and thereby in the assessment
of the fisheries resources. This will, however, require increased research in process studies that seek to understand the processes linking fisheries recruitment to environmental factors. These efforts must be supplemented with the development of coupled ocean- and ecological models to increase our knowledge of the interacting physical and biological processes. Realistic forecasts of the ecosystem development must be used in the fisheries assessments work in the future and thereby in the long-term planning of the Greenland society.

**Variability in the Southwest Greenland waters**

*Mads Hvid Nielsen, Danish Meteorological Institute*

During the 20th century the climate along the southwest coast of Greenland has undergone substantial changes. In the period 1920-1965 Greenland, as other parts of the Northern Hemisphere, experienced the warmest climatic condition in many centuries. Since then the climate in West Greenland has generally cooled. In the early 1980s and 1990s Greenland experienced two short extremely cold periods. This has, of course, great impact on the marine environment in the area. The rich fishery of cod developed around 1920, but around 1970 it suddenly disappeared. The following years the stock of cod seems to have expanded but catches declined to almost nil when the second very strong cooling occurred in 1982-1984. To understand these dramatic changes, knowledge of the oceanographic conditions and, in particular, the variability of the climate, is very important.

The waters along the southwest coast of Greenland are strongly influenced by the inflow of water masses originating from various regions in the North Atlantic as well as the Arctic Ocean. The main currents responsible for the southeast Greenland marine environment are the East Greenland Current carrying cold and fresh water into the southwest Greenland fishing banks, and the relatively warm and saline Irminger Current, which is a side-branch of the North Atlantic Current. It is the relative strength of these currents that controls the regional physical oceanography, which is very important for the living species in the sea such as cod, shrimp and marine mammals.

A physical description and understanding of the above-mentioned variability on decadal time scales is the focus in the Greenland/Danish part of the project »West Nordic Ocean Climate«, financed by the Nordic Council of Ministers. A description of the project and its goals is given, which consist of both an observational and a numerical modelling part.
Recent changes in ice conditions in West Greenland

Mads-Peter Heide-Jørgensen, Greenland Institute of Natural Resources, and Harry Stern, Polar Science Center, Applied Physics Laboratory, University of Washington

A major part of the West Greenland ecosystem is covered with sea ice for about half the year. This skin of sea ice, called the «West Ice», transports masses of fresh water south, reflects solar radiation and rejects salt into the seawater below, sometimes causing overturning. It seasonally prevents fishing activities in the ice-covered areas and it is an important habitat for numerous birds and sea mammals and a variety of ice-associated biological activities. The West Ice forms in a predictable pattern from autumn to spring where it gradually expands from central Baffin Bay towards Davis Strait and West Greenland. Disko Bay and Vaigat are, in most years, completely covered with fast ice that continues into the West Ice. South of Disko Bay the West Ice usually reaches the West Greenland coast around Kangaatsiaq. Between Kangaatsiaq and Nuuk «land water» (opening in the ice along the shore) prevails as far west as 50km off the coast. At the latitude of Nuuk the ice edge turns westward towards the Labrador coast. At the peak of its extent the West Ice consists of consolidated pack ice. During spring the ice recedes to the west in Baffin Bay and «land water» appears along the West Greenland coast, allowing migratory species to move north and opening the banks for fishing activities.

The annual formation of the West Ice follows a remarkably regular pattern compared to other Arctic waters, but still an increasing trend in ice coverage has been observed in the Baffin Bay-Davis Strait-Labrador Sea area in the last two decades. This increasing trend has been observed both in satellite-based passive microwave readings of sea ice and in the shrimp fishing operations in March in the areas where sea ice dominates (i.e. west of Disko Bay). It is nevertheless uncertain if the observed trend is part of long-term changes, perhaps related to global climate change, towards heavier sea ice or if the trend is only the downward segment of a cyclical phenomenon. The ice regime in West Greenland is most likely governed by local conditions, including the effects of the North Atlantic Oscillation, the inflow of warm Atlantic water along West Greenland and the inflow of low salinity waters from the Canadian High Arctic and through Smith Sound. An ongoing study utilizing passive microwave data from satellites as well as historic information on ice coverage will attempt to elucidate the cyclical nature of the West Ice and examine if there are general trends beyond the cycles towards increasing ice coverage in West Greenland. Monitoring of changes in sea ice coverage and increased understanding of its biological significance is fundamental to studies of the processes in the West Greenland ecosystem.
Carbon and nutrient cycling in Greenland waters
Søren Rysgaard, National Environmental Research Institute

Since the late 1970s, an overall decrease in sea ice distribution has been observed in the Arctic. Prolonged ice-free periods have been documented on the east coast of Greenland, whereas the West Coast has experienced more sea ice. An ecosystem study from the high-arctic fjord, Young Sound, is presented. The aim of this study is to link biological production to sea ice and hydrographic conditions, in order to predict how expected changes in ice conditions and water column structure will affect high-Arctic ecosystems in the future.

The presentation will include a description of Young Sound with respect to surrounding land, bathymetry, sea ice conditions, freshwater input and hydrography. Furthermore, primary production by phytoplankton, sea ice algae and underwater plants are discussed in relation to sea ice cover and hydrographic conditions. A tight coupling between primary producers and grazers in the water column of Young Sound has been observed. Grazing in the water column, primarily by copepods, leads to a pulsed vertical export of organic matter to the sea floor where benthic animals and microbes are responsible for further degradation of the organic matter and regeneration of nutrients. The distribution and growth of the dominant bivalves in the fjord has been coupled to the walrus population in the area and is discussed in relation to different sea ice conditions. A carbon budget for the outer parts of Young Sound is presented, including the various producers and consumers of the food web. Finally, expected changes in carbon and nutrient cycling, as a response to future alterations in sea ice conditions, will be discussed.

Will climate change impact pelagic marine biodiversity and processes: a unicellular perspective
Helge Abildhauge Thomsen, Danish Institute for Fisheries Research

Results from selected marine regions indicate that temperature increases may impact species composition among the unicellular biota. Nehring (1998, - ICES Journal of Marine Science 55:818-823) thus argues that the recent introduction of a multitude of new species in the North Sea region may be in part due to increased temperatures. When examining paleoarchival data from the Kattegat and Skagerrak (Thorsen & Dale 1998, - Paleogeography, Paleoclimatology, Paleoecology 143: 159-177) evidence can be provided that temperature-mediated changes in dinoflagellate abundance are apparent.
A prerequisite for identifying similar trends among West Greenland unicellular plankton species is the existence of long-term data series from the area. The investigation of unicellular plankton in West Greenland dates back to the middle of the 19th century. The expedition described by Grøntved & Seidenfaden (1938, Meddelelser om Grønland 82, 5) represents a major milestone in the exploration of phytoplankton from West Greenland waters. Substantial data have additionally been provided recently from the Northwater polynya, Disko Bay and the fishing grounds further south.

Despite the fact that long-term data series with adequate resolution are not available it is still obvious, based on the numerous scattered records, that the West Greenland unicellular flora and fauna are highly reminiscent of that of the North Atlantic in general. Furthermore, most species occur at temperatures that are suboptimal and it is therefore unlikely that a modest temperature increase (e.g. 2-4° C) will have a major impact on species composition per se. However, notable exceptions may be: (1) the contingent of ribbon-shaped pennate diatoms that are associated with water of polar origin or the occurrence of ice, (2) an increased abundance of pico- and nanoplankton species, and (3) an »invasion« of species such as the coccolithophorid Emiliania huxleyi in the southernmost region.

On an ecosystem scale it can be hypothesized for the lowermost trophic levels that an increase in sea temperature and the associated reduction of e.g. sea ice coverage can result in: (1) an initial production deficit (sea ice at present accounts for up to 25% of the annual primary production), (2) a different timing and magnitude of the spring bloom event, (3) overall rate increases, (4) size-spectrum changes, and (5) some adjustments of species composition.

A multidisciplinary and long-term approach will be needed to adequately address some of the biological group-specific scenarios briefly outlined above.

**Life cycle and recruitment of Northern shrimp (Pandalus borealis) in West Greenland waters**

*Søren Anker Pedersen, Greenland Institute of Natural Resources*

The work presented is part of an ongoing project entitled »Hydrographic and biological processes of importance for variability in recruitment of fish and shellfish stocks in West Greenland waters« started in 1999 with financial support from the Danish Research Council’s Committee on North Atlantic Research.
It is of major importance for the shrimp stock assessments to get information on the strengths of the recruiting year classes as early as possible. This is in particular important for Greenland where today’s economy mainly is based on a large shrimp fishery.

In 1999 and 2000 four research cruises were carried out over the West Greenland shelf area with the main purpose of investigating the distributions of shrimp and fish larvae in relation to key hydrographic processes, potential prey and predators. Distributions and abundance indices of different stages and sizes of shrimp larvae were obtained from zooplankton hauls during transect studies across the fishing banks. To evaluate the factors affecting the survival and recruitment of larval shrimp, larval distributions and abundance indices are related to hydrographic patterns, fluorescence, plankton species compositions, abundance indices and sizes (potential food and predators) along transects at different survey time periods and locations. Drift routes of two satellite-tracked SVP drifting buoys deployed in May 2000 are presented. Information on larval distributions, their possible drift and fate are important to understand the life cycle of shrimp populations and their stock-recruitment relationships. The latter information is important in assessing and forecasting shrimp stocks and fishery yields.

A coupled physical-biological model is intended to be used in the future to study the potential distances of shrimp larval transport from hatching sites in spring to settling locations. The physical modelling is based on a 3D hydrodynamic finite element model forced by wind, pressure and temperature field data calculated from the operational atmospheric model for Greenland. Calculated current fields are fed into a particle-tracking model to simulate the transport of ocean drifters. The advection of the shrimp larvae is driven by the physical model component, while a biological model describes growth and the vertical position of shrimp larvae.

Shrimp have pelagic larvae and the time and location of larval settlement are critical components for successful recruitment to the population. Shrimp larvae occur in the surface layers after hatching and have been found in progressively deeper water layers until settling as juveniles. The study will investigate the dynamic processes responsible for the dispersal/aggregation of larvae and larval food using hydrographic and biological data derived from static point-estimates of water-mass characteristics and zooplankton abundance indices over the West Greenland shelf.
Capelin and other small fish off West Greenland: What are they good for?

Jørgen Schou Christiansen, University of Tromsø, and
Per Kanneworff, Greenland Institute of Natural Resources

This talk focuses on two species of small fish that have been little studied off West Greenland; the capelin (*Mallotus villosus*) and the Polar cod (*Boreogadus saida*) of sub-arctic and arctic waters, respectively. Neither species is of particular commercial importance to Greenland. However, both species constitute the key link between low trophic levels and large fish, marine birds and mammals on which the Greenland society is dependent. Thus, a proper understanding of how the West Greenland marine ecosystem functions and how it is affected by climatic fluctuations must inevitably be based on biological knowledge of capelin and Polar cod. Relevant topics for discussions and future research on capelin and Polar cod include:

- Genetic identification of populations and estimation of their abundance;
- Distribution in space and time vs. oceanic temperature, salinity and density fields (*in situ* measurements and data storage tags);
- Life history traits of capelin, in particular (i) growth trajectories of prespawning males and (ii) survivorship of postspawning fish;
- Ecological interactions: Polar cod - capelin - Atlantic cod (*Gadus morhua*);
- Ontogenetic changes and seasonal variability in energy density, i.e. the quality of polar cod and capelin as forage fish;
- Physiological peculiarities and the effect of pollutants.
Session 3
The Impact of Limate Conditions on the Demersal/Benthic Ecosystem

Potential effects of climate change on snow crab (Chionoecetes opilio) distribution and population dynamics

Bernard Sainte-Marie, Denis Gilbert and Amélie Rondeau, Fisheries and Oceans Canada

The purpose of this presentation is to review some of the ways in which snow crab (Chionoecetes opilio) populations may have been influenced by past environmental variability, and how in the future they might be affected by climate change. In the Gulf of Saint Lawrence, close to the species’ most southerly range limit, trawl surveys show that snow crab are limited to bottoms shallower than 500 m and colder than 7° C. During summer, the bulk of the snow crab population occurs on bottoms 40 to 150 m deep at temperatures of -1.5° to 3.4° C. Snow crab are therefore quite intimately associated with the cold intermediate layer (CIL), which lies between the surface mixed layer and the warm, salty deep layer. Because snow crab is such a cold stenothermic species, populations may react quite strongly to local or large-scale cooling or warming trends. Early benthic juveniles and reproductive females, in particular, are the population components likely to be most sensitive to temperature change. Indeed, field observations and experiments indicate that survival and growth of the smallest juveniles may be tightly linked to the existence of bottoms combining a narrow range of sediment types and temperatures, more so than any of the older life history stages. As for reproductive females, there is evidence that an increase in temperature from 0° to 1.5° C, or less, causes them to shift from a two-year to a one-year ovary maturation and egg incubation cycle, with yet unknown consequences for egg quality and embryo survival and growth.

A historical record dating back to the late 1940s shows that the minimum core temperature of the CIL at a constant calendar date has varied by 2° C over the years. The CIL minimum core temperature is inversely related to CIL thickness measured at a given temperature threshold. Consequently, the area of bottom bathed by water below that temperature threshold increases when the CIL core cools and decreases when the CIL core warms. The CIL’s core was warmer in the period 1948-1983 (mean of 0.23° C) than in the period 1984-2001 (mean of -0.49° C). Under the recent cold regime most snow crab females have been reproducing biannually, and there is evidence that snow crab increased in numbers and expanded spatially, especially off...
the Atlantic coast of Nova Scotia and Newfoundland. If recent CIL cooling indeed released environmental constraints on snow crab population growth and distribution in southeastern Canada, then a sustained warming trend could have just the opposite effects.

### Reproductive condition of female snow crab *Chionoecetes opilio* from Disko Bay and Sisimiut, West Greenland

**AnnDorte Burmeister, Greenland Institute of Natural Resources**

Snow crab, *Chionoecetes opilio*, has recently become a commercially exploited species in Greenland. The fishery is distributed from 60°N to 71°N and has been little regulated until 2001 - only males > 90mm carapace length are harvested and females are protected. Landings for the entire area have increased from 997 tons in 1995 to approximately 11,000 tons in 2000.

Biological research and monitoring began in 1996. Since 1997, an annual cruise has been conducted in Disko Bay and in the inshore area of Sisimiut (66°N), West Greenland. In spite of the increasing importance of the snow crab fishery, the research effort on snow crab is relatively limited. Accordingly, the understanding of the biology and stock dynamics of snow crab off West Greenland is poor.

In order to clarify the reproductive cycle of female snow crab, information on egg stage, brood, ovary development and fecundity were obtained from mature females collected in Disko Bay and in the inshore area of Sisimiut. In May - June 1997 - 2001, female snow crab were collected from an exploited stock in those areas to study their reproductive condition. Analyses of ovaries, broods, spermatheca and egg contents were conducted. Eggs hatched mainly in April and May and the fecundity was positively correlated with carapace width. Based on the development of ovaries and brood, females seem to have a two-year reproductive cycle in the fjords near Sisimiut, where bottom temperatures range from -0.8° C to 2.16° C, and a one-year reproductive cycle in Disko Bay, where bottom temperature are higher than 3° C.

### Possible effect of temperature on the biomass of Northern shrimp off West Greenland

**Kai Wieland, Greenland Institute of Natural Resources**

Although water temperatures off West Greenland increased substantially in recent years, cod has not yet returned. Instead, the biomass of Northern shrimp (*Pandalus borealis*) increased by about 30% in the past years, and the present study aimed at
identifying indications of whether the recent changes in biomass of Northern shrimp was directly linked to temperature or whether other factors were dominant.

Catches of Northern shrimp and bottom temperatures recorded during the West Greenland Bottom Trawl Survey were analysed. The survey has been conducted since 1988, but the area coverage and survey design, including the mesh size in the cod-end of the trawl, was variable until 1993. Furthermore, temperatures were first recorded on the trawl sites in the entire study area in 1993, and hence only the most recent 9 years were considered here. The survey is based on a stratified random design with 53 strata in total. For the present analysis, these strata were grouped into four offshore regions of nearly equal range of degrees latitude and one inshore region (Disko Bay). Swept-area estimates of biomass were then compared with mean temperatures weighted by stratum area for each region.

Only in two out of the five regions does shrimp biomass correlate significantly with bottom temperature. These were the southernmost offshore region and Disko Bay (increase of shrimp density by a factor of more than two along with an increase in temperature from 3 to 5 and 1 to 3° C, respectively). In the other regions where temperature ranged from 1 to 4° C, shrimp biomass was almost stable. Possible time lags, e.g. 3 to 4 years, corresponding to the period between hatch and the time when the recruits become an important part of the survey biomass (in terms of weight), could not be studied here due to the short time series available, but water temperature has already been increasing since 1990. It can therefore be concluded that temperature has not been the primary factor determining the recent change in biomass. However, shrimp are likely to be affected if the warming continues, in particular in the southern area where the actual bottom temperature is close to the upper limit of the preferred range (1 - 6° C).

Cod had been abundant in West Greenland waters, the last occasion being in the late 1980s. This was reflected by high survey indices in 1987 when the 1984 year-class had reached age 3. This coincided with a sudden decrease of the commercial catch per unit effort for shrimp. Thereafter, cod abundance declined drastically. Other demersal fish of commercial interest remained at very low biomass levels compared to the early 1980s. Because the importance of demersal fish, including cod, became negligible already from the beginning of the 1990s, the increase in the biomass of shrimp observed since 1997 can most likely not be attributed to a release of predation pressure from these species alone.

Other possible causes for a change in shrimp biomass, which should be addressed in future studies, may include a reduced predation pressure by species not considered
to date and, more likely, improved feeding conditions. Apart from decreased competition with small/juvenile demersal fish, an increase of particle carbon sedimentation associated with changes in seasonal ice coverage may have been important, in particular in Disko Bay and off southwest Greenland.

**Latitudinal gradients in ecological parameters of decapod crustaceans**

*Wolf Arntz and Sven Thatje, Alfred Wegener Institute of Polar and Marine Research*

Research on the biology of decapod crustaceans has been carried out by scientists of the Alfred Wegener Institute in Antarctic waters since 1985 and in the Magellan region since 1994, spanning almost 23 degrees of latitude. The data at hand, combined with information from the Antarctic, Subantarctic and South American literature, reveal a number of gradients in distribution, species richness, population dynamics, reproductive strategies and physiological (non-)adaptations which may be of interest for comparison with the Arctic. These gradients are likely to reflect the impact of both evolutionary and abiotic environmental factors, biological interactions as well as varying energy input into the different ecosystems.

Decapod crustaceans are one of the few taxa for which species diversity seems to follow a bell-shaped curve of latitudinal distribution. However, there are marked differences in the individual subgroups. Species richness decreases towards the Magellan region, where the lowest species richness is observed off the Patagonian ice fields, and declines further to very low values in the high Antarctic, where only few caridean shrimps and few lithodid crabs can live at all. For brachyuran crabs and non-lithodid anomurans, the deep-sea bottoms of the Drake Passage, the circumpolar current, and probably the Antarctic Convergence, represent true present-day faunal barriers. New species continue to be registered in all areas, but only in small numbers, and the overall pattern is not likely to change.

In terms of abundance, galatheid squat lobsters (*Munida spp.*) and brachyuran crabs dominate Magellan waters, whereas caridean shrimps can reach high densities south of the Convergence. The study of population dynamics and reproductive biology faces difficulties, particularly in the high Antarctic, where winter conditions preclude continuous sampling. Furthermore, ageing is difficult in organisms that moult and cannot be tagged, making a combination of size frequencies, morphological approaches, gonad studies and new techniques (e.g. lipofuscin) the only solution. Growth was found to be slower, and mortality lower, in Antarctic shrimp species than in comparable species living at lower latitudes. First maturity occurs at an
advanced age (3-5 years) and size, and longevity is very high (up to 10 years or more) on the Weddell Sea continental shelf. Beside extremely low temperatures around -2° C, food shortages may be responsible for these patterns. However, this is a controversial hypothesis because most shrimps are omnivores and therefore do not depend, at least beyond their larval stages, directly on seasonal primary production.

With respect to reproductive strategies, a cline towards larger egg sizes or volumes, lower egg numbers, prolonged embryonic development and lower spawning frequency has been observed in caridean shrimps in the poleward direction. Overall, the whole range of possible solutions from fully planktotrophic (Munida spp., Halicarcinus spp.) to fully lecithotrophic (Lithodidae) larvae has been realised by decapod crustaceans. However, there seems to be a tendency for abbreviated larval development (reduced number of stages) and shorter duration of pelagic life phases towards the pole, e.g. in Campylonotus vagans (Magellan) and Chorismus antarcticus (Antarctic).

Physiologically, adaptation to extremely low temperatures may be the major obstacle in recolonising high Antarctic waters for decapods, the haemolymph of which contains high concentrations of Magnesium$^{2+}$ (e.g., brachyuran crabs). Magnesium considerably reduces activity, particularly under very low temperatures. Caridean shrimps do not face this problem because their Magnesium concentrations are much lower. Despite their elevated temperature tolerance, lithodid larvae from the Beagle Channel had greater problems with moulting at low temperatures.

Future bipolar comparison of decapods may be a useful approach to derive general principles for mechanisms steering adaptation to varying conditions along a latitudinal gradient both on evolutionary and ecological time scales.
**Session 4**

**Tropic Interactions in the Marine Ecosystem off West Greenland**

**Food web structures off West Greenland and coupling to fish stocks**

*Torkel Gissel Nielsen, National Environmental Research Institute*

Historically most research in Arctic pelagic ecology has focused on the larger components of the food web e.g. the diatoms and the large conspicuous calanoid copepods. Research during the last century has documented the annual cycle and population dynamics of copepods of the genus *Calanus* and stressed the key role of these organisms in high latitude ecosystems. This part of the food web is a direct link to the fish stocks, since most fish larvae rely on copepods during their growth. Several of the other key species of birds and mammals also rely on *Calanus* to a large extent.

Research on the microbial food web in the Arctic has been limited because the microbial loop in cold water ecosystems has been considered less important than at lower latitudes. However investigations in Disko Bay, Young Sound and the banks off West Greenland have documented that bacterioplankton and unicellular zooplankton also play a prominent role in the food web of Arctic ecosystems.

Because of the late recognition of the potential role of bacteria and unicellular grazers in high latitude ecosystems, investigations covering all major components of the pelagic food web are few. Judged on the relative biomass distribution, a large part of the annual primary production potentially is channelled through protozooplankton that, due to their small size, have specific grazing and growth capacities an order of magnitude greater than copepods.

When considering the fate of primary production and coupling to the fish stock in high latitude ecosystems, the small grazers have to be considered. They build up high biomasses and have growth rates that make it possible for them to follow the growth of their phytoplankton prey. From a carbon sedimentation point of view, the composition of the grazer community is also essential. The presence of the large copepods accelerates the carbon flux through production of faecal pellets, while the excretion products of the smaller grazers are recycled within the surface water to a much larger extent.
The zooplankton influence the carbon dynamics in several ways: by vertical migration, through their grazing activity, and as accelerators of sedimentation of organic matter through production of faecal material. Important gaps in our knowledge about the pelagic ecosystem that should be addressed in a future research programme of West Greenland are

- What happens during the winter?
- Most of the previous investigations focus on the open water period, but what drives the vertical export of organic matter?

A better understanding of these processes is needed to understand the coupling between the productive surface layers and the benthic ecosystem.

Based on high-resolution annual investigations it is suggested that models be established that integrate meteorological, oceanographic and biological processes at stations representative of the West Greenland ecosystem.

**On species coupling in multi-species models**

*Lars Witting, Greenland Institute of Natural Resources*

In basic science, models are used in a learning process, where we gain an increased understanding of natural systems by developing and testing alternative models. In applied science like resource management, however, we need ‘correct’ models in order to provide predictions and management advice. By focussing on a few basic principles of species linkage, it is illustrated that our current understanding of species interactions may not be sufficiently advanced to warrant multi-species models in resource management.

**Yet to be invented - statistical tools needed for food-web analysis using tracer elements**

*Michael Rosing, Greenland Institute for Natural Resources*

Although food-web analyses using tracer elements such as stable isotopes, heavy metals and fatty acids have been performed for some years, insufficient attention has been given so far to the statistical analysis of such data. The list of problems that one might encounter when using tracer elements include the lack of a recognized method to deal with underdetermined systems, the lack of a method to include variation in the results obtained, and the inability to determine whether a given experimental design is able to distinguish between competing food web models. For a large ecosystem analysis project, this may lead to the inability to predict the possible resolution
of the food web interactions one wished to elucidate, and in the extreme case the inability to assess whether a given sampling scheme will enable the researcher to answer the question posed or not.

**Cod (Gadus morhua) predation on snow crab (Chionoecetes opilio) in the Gulf of Saint Lawrence, eastern Canada**

Denis Chabot, Karine Briand and Bernard Sainte-Marie, Fisheries & Oceans Canada

In the Gulf of Saint Lawrence, snow crab (Chionoecetes opilio) recruitment to the fishery apparently oscillates from low to high levels with a circa-decadal periodicity, and some of this variability has in the past been attributed hypothetically to cod predation. To evaluate the importance of cod predation on snow crab, we have examined stomachs from Gulf of Saint Lawrence cod that were collected during the shrimp-groundfish survey of summers 1993 to 2000, as well as during the Cod Sentinel fishery conducted from July through October of 1995 to 1999. Our objectives were to quantify the contribution of snow crab to cod diet in relation to cod size, to determine the predator-prey size relationship, and to establish which snow crab life history stages are most susceptible to cod predation.

A preliminary assessment of the data from some 13 251 stomachs of cod ranging in length from 10 to over 90 mm has been done. All length-classes of cod consumed snow crab. On average, however, the mass of ingested crabs represented no more than 15% of total stomach content of any given 10-mm length class of cod, and only about half of those crab remains could be unequivocally ascribed to snow crab. The carapace width (CW) of ingested snow crabs was measured when possible, revealing a positive trend between cod length and size of crab prey. Cod apparently preyed on snow crab belonging to instars II to VI (i.e., 5 to 20 mm CW) more frequently than on other instars.

Given that snow crab instars II and VI have a post-settlement age of approximately 0.5 and 3.5 years, respectively, and that the time required to reach legal size (95 mm CW) from settlement is 9 years, any effect of cod predation on snow crab recruitment to the fishery would become perceptible about 6 to 9 years after the interaction between cod and crab occurred. Based on various data, however, it seems unlikely that cod predation can account for the large oscillations in snow crab abundance that have been recorded in the Gulf of Saint Lawrence. Nevertheless, the analysis of cod stomach contents may provide useful information on the spatial distribution and dynamics of recruitment of juvenile snow crab.
Ecological studies of Barents Sea harp seals

Kjell Tormod Nilssen, Norwegian Institute of Fisheries and Aquaculture

In early summer, Barents Sea harp seals (Phoca groenlandica) migrate to northern areas of the Barents Sea, where they feed in open waters and along the drifting pack-ice during summer and autumn. In late autumn the seals migrate southwards, and in winter and spring the stock is usually concentrated in the southeastern areas of the Barents Sea and in the White Sea. Breeding (in late February to early March) and moult (April - May) occur in these southern areas.

To increase the ecological knowledge and to estimate the prey consumption of the harp seal stock, sampling of seals was carried out throughout the year in various areas in the Barents Sea in the period 1990 -1996. Data on seasonal variation of harp seal diet and body condition were collected, and resource surveys and prey preference studies were conducted. Seasonal variations in the body condition of the seals indicate that summer and autumn are the most intensive feeding periods. Krill and the pelagic amphipod Parathemisto libellula appear to be the dominant prey species from August to mid-October. During October, a shift in the diet from crustaceans to fish seems to occur. Capelin and polar cod are major prey during the autumn and winter, and in late winter herring is also important in the southern Barents Sea. The energy reserves stored during summer and autumn are maintained until February. During breeding and moult the stores of blubber decrease rapidly, indicating restricted food intake at this time.

In 1998, the total Barents Sea harp seal stock was estimated to comprise 2.2 million seals, based on a mean annual production of 301 000 pups. The annual food consumption of this stock was estimated under the assumption that there are seasonal changes in basal metabolic rate associated with changes in body mass, and that the field metabolic rate of the seals corresponded to two times their predicted basal metabolic rate. When capelin was abundant, the total annual consumption was estimated to be 3.35 million tonnes, of which approximately 1.2 million tonnes were crustaceans, 800 000 tonnes were capelin, 600 000 tonnes were polar cod, 200 000 tonnes were herring, 100 000 tonnes were cod and 400 000 tonnes were »other Arctic fish«. A very low capelin stock in the Barents Sea (as it was in the period 1993 -1996) led to switches in seal diet composition, with increased consumption of polar cod, cod, haddock, saithe, herring and »other Arctic fish«. The estimates are sensitive to the model assumptions. The most critical parameter for the total food consumption examined in the model was prediction of the field metabolic rate. When the field metabolic rate was increased from two to three times the basal metabolic rate, the estimated food consumption increased by approximately 40%.
In order to improve the estimates, more data on spatial and temporal distribution of the seals (satellite tracking) are needed. More diet data from seals in offshore waters, in particular during spring and summer, should be collected. Additional methods, such as fatty acid profiles, to estimate the diet should be used. Better seasonal estimates of the field metabolic rate of the seals and more data on seasonal variation of the energy density of various prey species are recommended.

**Seals off West Greenland**

*Aqqualu Rosing-Asvid, Greenland Institute of Natural Resources*

An overview and evaluation of the role and relative importance of the various marine mammal species off West Greenland are given. Harp seals are the most important consumers quantitatively, however, the bulk part of their diet is made up by capelin and other species, currently of no commercial value in Greenland. Hooded seals are the second most important consumer quantitatively, and approximately half of their diet is believed to be of valuable fish species like redfish and Greenland halibut. Hooded seals are considered to be an important cause of natural mortality among valuable fish species of commercial size, and this puts them into direct conflict with the fishery. Harp seals are likely to play a key role in the pelagic part of the ecosystem, where cod only play a minor role at present.

The West Greenland ecosystem is very dynamic and major shifts in the numbers and distribution of various marine mammals have taken place in the past century. Harp seals were, for instance, only a small and negligible component in the ecosystem 30 years ago. It is therefore suggested that a model of the West Greenland ecosystem, in order to be predictive, has to focus on the changes that take place along with a new trend in climate, as well as the changes that are likely to occur because of the general recovery of various species of marine mammals.

Harp and hooded seals are very important consumers at present, but data that describe the distribution of these two seal species throughout the year are needed, in order to estimate their seasonal consumption of various prey species.

The three most important studies to conduct in order to improve our knowledge about the role of seals in the West Greenland ecosystem at present would be:

- a) A satellite telemetry study on the earliest moulted harp seals;
- b) Collection of harp seal stomach samples from offshore areas;
- c) A satellite telemetry study on hooded seals.
Seabirds off West Greenland - indicators of food items and other distributing factors

Anders Mosbech and David Boertmann, National Environmental Research Institute

Seabirds constitute a conspicuous component of the West Greenland ecosystem exemplified by the high hunting bags for Brünnich's guillemot (>200,000) and eiders (>80,000). However, during summer the offshore seabird density is relatively low, mainly consisting of long-range foraging or non-breeding surface-feeding species like fulmars and gulls (kittiwake, glaucous gull and Iceland gull). Minor numbers of pursuit-diving species like Brünnich's guillemots and puffins, either non breeders or birds from local colonies, also forage outside the fjords and on the banks during summer. Focusing on West Greenland south of Disko Bay (69°N), breeding numbers of pursuit-diving seabirds are small compared to further north, probably due to a combination of food availability and hunting/disturbance. In contrast to the summer, the offshore density of pursuit-diving seabirds south of Disko Bay is high during autumn, winter and spring, although only few data from the winter are available. The winter offshore seabird community is dominated by pursuit-diving Alcidae (Brünnich’s guillemot, black guillemot, little auk) and bottom feeding king eider on the banks, and to a much lesser extent by surface-feeding gulls and fulmars. Crude estimates of the food requirement for the key species offshore from October to April could look like this:

Brünnich’s guillemot (900 g) dives to 100 m, feeds on small fish (capelin) and crustaceans (euphausids), avoids dense ice, and concentrations are seen on banks and slopes. A guessestimate of 1.5 million birds wintering in the area gives a food requirement of 72,000 ton wet mass/6 months.

Little auk (150 g) dives to 30 m, and feeds presumably on copepods. An estimated 20 million pairs breed in Avernarsuaq (Thule) and migrate through the Davis Strait, and an unknown but presumably high fraction winter in the Davis Strait. A guess of 5 million birds wintering in the area gives a food requirement of 74,000 ton wet mass/6 months.

Black guillemot (400 g) dives to 30 m and occurs in winter at the coast and is widely dispersed in the pack ice where it feeds on ice-associated fauna, presumably polar cod and epontic amphipods as described for the Barents Sea. A guess of a population size of 100,000 birds gives a food requirement of 2,700 ton wet mass/6 months.

King eider (1600 g) dives to 50 m and feeds during winter on benthic invertebrates on the shallow part of banks (Store Hellefiskebanke and Fyllas Bank) and at the
coast. A guesstimate of 200 000 birds wintering in the area gives a food requirement of 13 000 ton wet mass/6 months.

These four species could thus have a food requirement of about 162 000 ton wet mass from October to April compared to, for example, an annual commercial catch of shrimp of about 80 000 ton.

Although these are crude estimates, there is no doubt that the winter population of seabirds in West Greenland is of ecological as well as international conservation importance, and for both management and scientific purposes it is relevant to:

- locate recurrent hot spots with high seabird concentrations;
- identify bottlenecks for selected seabird populations;
- use seabirds as indicators of ecological changes.

A seabird component could include:

- distribution and numbers synchronized with oceanographic factors;
- stomach contents, food for young;
- fatty acid markers;
- breeding success;
- population size.

**Seabirds as ecosystem monitoring tools**

*Knud Falk, Danish Polar Center*

As top predators, seabirds respond clearly to temporal and spatial changes in prey availability, and hence serve as «cheap sampling devices» of the marine environment. Due to their differences in foraging methods and degree of diet specialization in pelagic zooplankton, fish and benthic invertebrates, different seabird species serve as appropriate indicators of various types of environmental change.

Studies of seabird diet and the associated effects on measurable parameters, such as timing of breeding, reproductive success, growth rates, adult time allocation and annual survival, are classic tools which, however, have not yet been widely used in Greenland. Among the few studies conducted in Greenland waters, the Thick-billed Murre, a diving fish-predator, has been shown to respond to regional differences in oceanographic conditions by differences in foraging time allocation, dive depth, breeding phenology, chick growth rates and diet. The surface-feeding Kittiwake shows distinctly different responses, but has clear annual and regional differences in breeding success and timing of breeding. The Dovekie, a diving zooplankton-
feeder, shows seasonal shifts in diet reflecting prey availability. Murres wintering in Newfoundland have changed their diet significantly over a 12 year time span - possibly related to local changes in zooplankton and fish stock distribution and composition; data are available to test if similar changes have occurred in West Greenland.

Based on these examples, it is proposed to include seabirds as components in long-term studies of the marine ecosystem in West Greenland. The area is significant for breeding- as well as wintering- seabird populations - serving as important hunting resources - and it would be possible to select study sites and species for cost-effective monitoring of a range of parameters to supplement other efforts.

**Past and present research on trophic interactions between seabirds and forage fish in Norwegian waters**

*Tycho Anker-Nilssen, Norwegian Institute for Nature Research (NINA)*

In Norway, main approaches for studying trophic interactions between fish-eating seabirds and their prey stocks include long-term (decades) monitoring and population studies, shorter-term (1-5 years) *in situ* and experimental studies of seabird-fish interactions, and theoretical modelling. A national monitoring program for wintring seabirds was established in 1980 and extended in 1988 to include breeding seabirds. However, the longest time series dates back to the early 1960s. Due to very limited funds, the national monitoring programme has primarily been focussed on documenting population trends. Other key population parameters have only been monitored regularly by independent studies of a few selected populations, mainly on Røst (67°30’N) in the Norwegian Sea, and Hornøy (70°23’N) and Bear Island (74°30’N) in the Barents Sea.

This presentation focuses on the value of long-term population data when exploring fish/seabird interactions, illustrated by using results from a 38-year study of Atlantic puffins *Fratercula arctica* at Røst, an offshore archipelago at the tip of the Lofoten Islands. The population of puffins at Røst has decreased by 69 % from nearly 1.5 million pairs in 1979 to only 450,000 in 2001. 0-group herring *Clupea harengus* from the Norwegian spring-spawning stock is the key prey for these puffins in the breeding season. The abundance of this food source is closely correlated to ocean climate fluctuations (Toresen & Østvedt 2000, Fish & Fisheries 1:231-256). VPA estimates of 0-group herring numbers explain almost 90% of the variation in puffin breeding success at Røst during 1975-1997 and 84% of the inter-annual variation in adult survival rates during 1990-1997. The size of herring in the chick diet of puffins is an equally good indicator of the 0-group year-class strength. The breeding
condition (body mass) and post-breeding migration (tracked by satellite transmitters) of adult puffins in failed seasons suggest that significant reduction of their survival occurs in the autumn in years when few young herring reach important feeding areas for the puffins in the Barents Sea. The abundance of 0-group herring also explains more than 60% of the variation in the reproductive success of black-legged kittiwakes *Rissa tridactyla* at Røst in 1980-1998.

Parallel to the puffin studies at Røst, several complementing shorter-term studies have been or are being carried out, including 1) an experimental study of growth allocations in puffin chicks in relation to food supply, 2) a study of the diet of adult puffins as indicated by ratios of stable isotopes, 3) automatic time-lapse monitoring of adult attendance patterns, 4) a study of feeding frequency and energy use of chicks in relation to optimal foraging strategies, 5) a study of post-breeding migration with satellite transmitters, 6) a study of the feeding ecology of black guillemots *Cepphus grylle* and 7) several collaborative surveys with the Institute for Marine Research (Bergen) to study puffin-herring interactions in offshore foraging areas by recording their spatial overlap, the puffins’ foraging ranges, prey availability, foraging behaviour and diet, and the behavioural responses of the prey. Additionally, we currently use the long-term data series for the Røst puffins in a multi-disciplinary project exploring the effects of climate fluctuations and change throughout the trophic chain of the puffins.

A long-term study of chick diet composition of Atlantic puffins and common guillemots *Uria aalge* on Hornøy, eastern Finnmark (Barrett *in press*, Marine Ecology Progress Series) documents close relationships ($r^2=0.66-0.88$) between the diet proportion of young herring in both species and the corresponding stock measures of 0-group and I-group herring in the Barents Sea. For the puffins, similar relationships were also found for the diet proportions of cod *Gadus morhua* ($r^2=0.60$) and capelin *Mallotus villosus* ($r^2=0.34$) and the respective abundances of these prey stocks. The reason for the lack of a similar relationship between the capelin stock and guillemot diet is not clear, but could be due to the very short nestling period of guillemots compared to puffins or any confounding effects of other prey available only to the guillemots (which are much larger and dive deeper than puffins).

As a part of the work within the ICES Working Group on Seabird Ecology (WGSE), the total food consumption by seabirds in a number of ICES/NAFO areas is estimated. Within the Circumpolar Seabird Working Group (CSWG) of CAFF there is an ongoing study trying to link long-term population trends of common guillemots and Brünnich’s guillemots *Uria lomvia* in the Arctic countries to climate change, as reflected by variation in sea surface temperatures.
Human impact on eiders

Flemming Ravn Merkel, Greenland Institute of Natural Resources

Humans constitute a major interacting member of the west Greenland ecosystem. Species of the ecosystem can be affected directly by harvest, by human depletion of their food items, or as a consequence of habitat destruction etc. Several species of seabirds belonging to the west Greenland ecosystem, have been reduced due to human activities, and in most cases hunting has been assigned as the main impact factor. This is also the case with the common eider. At least 57 000 common eiders are bagged annually in Greenland, which corresponds to app. 12% of the total winter population estimated in west Greenland. According to computer simulation, using a model recently developed by Canadian researchers, the West Greenland winter population can only sustain a take of app. 8%. As a consequence the model predicts the west Greenland breeding population to decline by 3,2% per year, which is close to survey figures detected at breeding grounds.

However, hunting affects seabird populations not only by killing birds. Delayed effects on fitness may arise due to embedded shots and disturbance factors, such as interrupted feeding opportunities, displacement from preferred feeding habitats, and increased energetic expenditures due to flying - which eventually may affect body condition and subsequently reproductive success.

The common eider is a useful study species when studying impacts of disturbance, as they are heavily hunted in west Greenland. Furthermore, eiders wintering far to the north are also considered more vulnerable to disturbances as a result of ecological constraints during wintertime. Here they are faced with cold and harsh weather conditions, variable ice conditions, reduced day length, and possibly time constraints due to low energy food items. Furthermore, most of the eiders wintering in southwest Greenland breed far away in northwest Greenland or in the Canadian Arctic, and must rely on accumulation of body nutrients to migrate back and forth.

Impacts of hunting and disturbance on eiders are now being addressed by means of a comparative study involving scientists of the Greenland Institute of Natural Resources, the National Environmental Research Institute, Ornis Consult, the University of New Brunswick and the Canadian Wildlife Service. Coastal habitats next to Nuuk.
are compared to more remote habitats within the adjoining fjord system. In terms of human activities these habitats are very distinct. More than 90% of all eiders bagged in the Nuuk community originate from a rather small area at the coastal zone, while only very few eiders are shot deep inside the fjord system.

The study combines information gained by several methods. Eiders are collected from both coastal habitats and fjord habitats. These are all X-rayed to detect differences in inflection rate. Subsequently eiders are dissected to quantify body condition, and to study selected prey items. By means of surveys of eider harvest at the local market in Nuuk, harvest composition is studied throughout the winter, and hunting activities are mapped. Birds from both locations are being implanted with satellite transmitters to quantify the degree of interchange between coast and fjord habitats, and to calculate their home range probability. Site fidelity during winter is a key factor, which to a large extent determines how sensitive birds are to human activity in a particular local environment. Finally, behavioural studies aim to obtain information about the immediate impact of disturbance on eiders. How much time is actually allocated to disruption behaviour, and are birds otherwise constrained in feeding opportunities, for instance due to darkness and tide?

**Gadget: A generic multispecies modelling tool**

*Gunnar Stefánsson, University of Iceland / Marine Research Institute*

Detailed multispecies models of marine populations need to be developed by taking into account the same issues as in species models but, in addition, biological and technical interactions should be described. Once several species are taken into account, questions are raised concerning the availability of one species to another, which typically varies both spatially and temporally, and there is often a need for a fine temporal scale of e.g. one month as opposed to the common yearly scale used in single species population dynamics models. It has also been seen that statistical issues such as the choice of error distribution can have a considerable effect on results, and in some cases incorrect distributional assumptions can give results far from the truth.

A model which takes all these concerns into account is currently under development. This model has been termed Gadget (Globally applicable area-disaggregated general ecosystem toolbox). The model is based on a forward-projection (i.e. deterministic simulation) model coupled with a likelihood function which can then be maximised in order to estimate unknown parameters (such as recruitment of individual species). Although based on an earlier model, Bormicon, present work is a col-
laborative effort among 8 organisations in 6 countries, aiming at testing the model on 4 different ecosystems or stock complexes.

In addition to the above, the computer implementation includes several features, with an emphasis on flexibility in all components. Thus, a »stock« in the model can be a predator on some other »stocks« and a prey to others. The »stock« may exist in some areas but not in others and may migrate between some areas in some years. The »stock« may be e.g. immature fish, which subsequently »migrate« into the mature stock. Given the flexibility of the model, it is more appropriately thought of as a framework for modelling fish population dynamics and assessments, since it allows an enormous variety of different models to be set up and evaluated.

Since the model is a statistical one, data may be missing on individual components. For example there is nothing in principle against not having any ageing data on a given species, but only including length distributions in the likelihood functions. The internal model will still be an age- and length-based model but length data alone are used to estimate its parameters.

Immediate work on the model involves extending the likelihood functions. As a first step the likelihoods will be made more complete in order to facilitate the estimation of variances. The next statistical steps involve including the possibility of Bayesian estimation and more likelihood functions. The next step in the biological part of the model will be to develop and test further the 0-group stage so as to close the life cycle of individual species.

Quantitative ecosystem indicators for fisheries management

Astrid Jarre, Danish Institute for Fisheries Research / Greenland Institute of Natural Resources

A new working group on »Quantitative ecosystem indicators for fisheries management« is introduced, which is supported by the Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC). Its terms of reference are to

• Review the state of knowledge relevant to the development of indicators;
• Review theories and indicators developed in terrestrial ecology for their utility in marine systems;
• Develop new indicators to study the functional role of species in ecosystems, exploitation and environment;
• Apply these indicators in a comparative way to characterise ecosystem state, changes and functioning;
• Assess the utility of these indicators for management purposes.

The working group has truly international membership, and combines expertise from natural and social sciences. It held its first meeting in October 2001 in Reykjavik, Iceland. Two more working group meetings are planned, and an international symposium will be prepared for early 2004. The work will proceed in eight task groups: (i) Environment and habitat changes; (ii) Species-based approaches; (iii) Size-based approaches; (iv) Trophodynamics; (v) Integrated indicators; (vi) Data sets for case studies; (vii) Selection criteria for indicators; and (viii) Management framework and use of indicators in management.

In order to increase the usefulness of the working group output for Arctic marine ecosystems, it is suggested to revise and, if possible, to refine existing, preliminary multispecies models and to include them into the working group as case studies for testing ecosystem indicators. In order to link the process into the advisory process, this refinement of models must proceed within the institutes where the scientific expertise on the respective systems resides, and must be based on co-operation with the experts on the various components of the ecosystems. It should result in multi-authored, peer-reviewed scientific contributions documenting the present state of knowledge, as well as highlighting and prioritising research gaps following holistic analyses of the models.

As an example, the impact of changes in discarding practices are simulated using the EcoSim software (www.ecopath.org), based on a slightly modified version of the box model of Pedersen and Zeller (2001, In Guénette, S., Christensen, V. & Pauly, D. (eds.) Fisheries impacts on the North Atlantic ecosystems: models and analyses. Fisheries Centre Res. Rep. 9(4), in press. Fisheries Centre, University of British Columbia, Vancouver, Canada.) of the ecosystem off West Greenland. Preliminary results of the simulations suggest that indirect effects of fishing exist in the ecosystem off West Greenland. These effects of the different fisheries on non-target species need to be studied in more detail, especially with regard to other groups of potential prey, notably cephalopods, capelin and sandeels.
Trends and habitat restrictions of selected cetaceans in Davis Strait

Mads-Peter Heide-Jørgensen, Greenland Institute of Natural Resources

About 8 species of toothed whales and 6 species of baleen whales are regularly found in West Greenland waters and most of these stocks number several thousand individuals. In West Greenland waters the whales are feeding on a variety of trophic levels ranging from copepods and euphausiids among the slow baleen whales, to squid and fish species in both the fast baleen and toothed whales and even predation on marine mammals by the killer whales. The quantitative impact of the predation depends heavily on the residence times of the whales in West Greenland and possibly also on the number of whales that visit West Greenland during summer; a factor presumed to show annual variations. The significance of predation by whales is, however, not only dependent on the amount consumed but also on the target species and the age classes selected by the whales. Some whale species prey on fish species and size classes that are recruited to the fishery that will increase the competition with the fishery.

For insight into the ecology of the whales, the importance of long-term time series cannot be overemphasized. All types of data collection from whales are notoriously difficult and major biological parameters are unlikely to show short-term changes. Trends in population size derived from robust surveys need to be accompanied by reliable catch statistics and knowledge on population structure. A promising way of elucidating the complex population structure of whales in offshore areas is through tracking of individual whales by satellite. This has, for example, illustrated how different summering stocks of narwhals also have either separate or common wintering grounds in northern Davis Strait. It also shows how different narwhal stocks may supply the hunt in certain areas, thereby linking population estimates derived at summering grounds to hunting at other seasons. Satellite tracking also provides opportunities for describing the diving habits of whales and thereby showing how the different portions of the water column are used by the whales and the possible interaction between whales and fishery. Many of the larger whale species depend heavily on the ability to locate abundant prey resources at certain seasons. Tracking of individual whales evidently indicate where such prey concentrations can be found and can be used for guiding effort of surveys (or fisheries) aimed at quantifying (or utilizing) the resources. Whales can also be used as oceanographic platforms permitting collection of hydrographical data from remote and inaccessible areas at a higher sampling rate and for smaller expenses than with traditional methods.
Whales in West Greenland are restricted both in habitat and prey choices. The species that visit West Greenland in summer and autumn (e.g. minke whales and fin whales) may seek other areas in the North Atlantic if unfavourable ecological conditions develop in Davis Strait. The species that stay year round in Baffin Bay and adjacent waters (the bowhead whale, narwhals and belugas) can be severely impacted by both changes in ice conditions and in production or competition with fisheries.
Session 6
The Use of Long-Term Data Series

Overview over time series from surveys at West Greenland aimed at fish and shrimp

Ole Ankjaer Jorgensen, Danish Institute for Fisheries Research

The Greenland Institute of Natural Resources (GINR) and its predecessors have established a number of time series on shrimp and fish that might be relevant as reference data for further studies on the ecology of West Greenland waters. The most comprehensive and recent time series were briefly introduced. From 1968 to 1974 the GINR research vessel »Adolf Jensen« sampled shrimps and fish monthly at three standard stations (Maniitsqoq/Sukkertoppen Deep, Nuuk/Godthåb Deep and off Frederikshåb Isblink north of Paamiut). In the period 1975-1987 annual surveys, mainly aimed at shrimp, were conducted by R/V »Adolf Jensen« in the area between Nuuk and Disko Island, including Disko Bay.

From 1988 to date the shrimp surveys have been conducted by GINR’s research trawler »Paamiut« or vessels of a similar size class. The survey area has varied during the years but, at present, the survey covers the area between Cape Farvel and 71.30°N. During 1987-1995 annual bottom trawl surveys were conducted jointly by Japan and Greenland. The surveys covered the area between Cape Farvel and 73°N down to 1500 m depth, but most effort was put into the area off central West Greenland with Greenland halibut and roundnose grenadier as target species. Since 1997 the deep sea surveys have been continued by FRV »Paamiut«. These surveys have also focused on Greenland halibut and roundnose grenadier off central West Greenland. In 2001 the survey also included the area north to 74°N. Further, Germany has conducted an annual bottom trawl survey since 1982 off East and West Greenland.

Inshore gillnet surveys for young cod have been conducted annually since 1985 around Sisimiut, Nuuk, and in southern West Greenland. An annual inshore long-line survey for Greenland halibut has been conducted in the areas around Ilulissat, Uummannaq and Upernavik since 1996. The data of most of the survey series are registered in electronic form.
Data series from fishing and hunting

Helle Siegstad, Greenland Institute of Natural Resources

Fishing and hunting data are often used together with data from scientific surveys and other biological studies to form the basis for the assessment of stock status. Historical data series from hunting and fishing are available at the Greenland Institute of Natural Resources. An overview of existing data series from fishing and hunting, as well as data series from biological studies, is available in a meta-database at the Institute.

Data from fishing and hunting that are used in a general assessment of a stock provide information on a) the total removal from a population by hunting and fishing, both in weight and numbers, b) biological data on length, age and weight in the removals, c) total effort and any changes in effort from year to year, d) changes in hunting and fishing patterns and e) migration, from returns of tags. Local knowledge studies could also improve and support assessments.

The Greenland shrimp fisheries data series is illustrative of the use of fishing data in the assessment of stocks: logbook data, available from 1976, provide information on the spatial distribution of the fishery and the overall distribution of catch, effort and catch rates (catch per unit effort) by year, month and areas. As a proxy for the stock biomass, standardized catch rate data are calculated by means of a multiplicative model. Annual size compositions of shrimp catches were obtained from samples taken before processing by fisheries observers onboard vessels, and used to provide information on the size/age composition in the removals, as well as the total shrimp taken out annually. The shrimp fishery data are used together with biological studies to form the basis of the annual advice on total allowable catches (TACs).

There is a pronounced need for predictive models in any fish stock assessment for providing advice in a multiyear concept. A predictive model using a Bayesian approach to the shrimp stock assessment for West-Greenland was presented to NAFO in 2001. Cod and shrimp fishery data series from 1955 as well as data series from biological surveys from 1988 form the basis of the model. Biomass indices from surveys and standardised commercial catch-per-unit-effort series, catch, cod stock size estimates and prior estimates of model parameters provided information for the models.

To be able to give better scientific advice, there is a need for a better understanding of factors influencing the different stocks, as well as development of more reliable and predictive models. Fishing and hunting data are relatively easy and cheap to col-
lect, and can be used for model improvement, supplementing data from biological research.

**Historic zooplankton time series off West Greenland**

*Søren Anker Pedersen, Greenland Institute of Natural Resources*

Abundance indices of zooplankton, obtained in offshore plankton surveys carried out in June-July during 1950-1984 off West Greenland, were analysed for relationships with e.g. sea temperature and salinity measurements. The zooplankton displacement volume and most of the zooplankton taxa analysed showed higher abundance indices in the relatively warmer and more saline period 1950-1968. Only a few taxa such as hyperiids, the pteropod *Limacina helacina*, and sandeel were more abundant in the relatively colder and less saline period 1969-1984. Associations with temperature and salinity differed among zooplankton taxa e.g. Atlantic cod and American plaice larvae were positively but sandeel larvae were negatively related to temperature. Of all correlations with temperature, zooplankton displacement volume showed the highest positive correlation (r=0.28) whereas other correlations of zooplankton taxa with temperature or salinity were even weaker. The trends and associations of zooplankton taxa with temperature indicate decreased zooplankton productivity and changes in the ecosystem food-web over the years 1950-1984. It was not possible to find clear relationships between hydrography and abundance indices of zoo- and ichthyoplankton. The failure of the 1982 year-class of Atlantic cod and the inability to relate abundance indices of larvae to subsequent recruitment were the main reasons that put the end to the time-series of zooplankton collections off West Greenland in 1985.

Progress in understanding recruitment success of fish and shellfish in West Greenland water requires process-oriented studies of zoo-, ichthyoplankton and hydrography. Multivariate models, which take into consideration variables like ocean temperature, spawning stock biomass, larval drift, species interactions (cannibalism), food production and food availability for each individual species in focus should prove to increase the ability to predict recruitment of fish and shellfish. However, model outputs will continue to require validation through scientific samples.
Session 7
The Institutional Framework

Norwegian Multidisciplinary Marine Research Programmes during the last 20 years: Lessons learnt

Kurt Tande, Norwegian College of Fisheries, University of Tromsø

Promare and Marenor were the two marine programs in Norway executed during the 1980s and 1990s. They were multidisciplinary, focusing on understanding the basic functioning of marine systems in the Barents Sea and along the North Norwegian Coast. Both were said to have an ultimate goal to improve our management policy in Norway.

The two programmes were basically similar in approach and said to focus on i) the functioning of marine ecosystems, ii) improve the basis for management, and iii) build our national competence in marine science. Grouping the number of papers given at the final symposia into thematic areas, provides a basis for comparing the main difference between the two programmes.

The main change from Promare to Marenor was the shift in balance between themes: One would say that the fish ecology component was small in Promare compared to its importance in the Barents Sea. In Marenor stronger components on kelp/sea urchin interactions and on top predators (fish/birds/mammals) were established. This resulted in a proportionate reduction in the output from studies of the lower trophic levels.

These two programmes were built along the axis: basic curiosity-driven research, mechanisms (basic understanding) and then onto management. In the aftermath, it is fair to say that this was a loose concept for transferring knowledge into management bodies or models. The reason for the low transfer efficiency, was the lack of appropriate structuring of the programmes during the planning period.

In conclusion, I would stress the importance of determining the end products of a programme like this for the West Greenland coast. A good blend will be required between long term and short term driven research, and between curiosity-driven and management-driven activities.

The products of the programme are, to a large extent, defined at the outset, and it may be hard to rearrange during the lifetime of the project. I cannot give the direction, but I strongly recommend the planning group to set aside time to formulate
a vision for Ecosystem Based Management of the West Greenland Coast, and then use this concept to draw the overall structure of the programme. Having this in place, there will be no problem for the various science groups to design the detailed scientific objectives, and draft a science programme which will be competitive on the international scene.

**North Water Polynya Programme: Lessons learnt**

Knud Falk, Danish Polar Center

The North Water Polynya (NOW) project was part of a long-term »International Arctic Polynya Programme« (IAPP) initiated by the Arctic Oceans Sciences Board (AOSB); IAPP first focused on the Northeast Water off North East Greenland 1992-94, then turned to the North Water between NW-Greenland and Ellesmere in Canada 1997-99. Currently, there are plans to continue the polynya effort north of Canada (Cape Bathurst), but based on the very successful NOW program, ideas are emerging to also return to a more long-term effort (approx. 10 year scale) in the NOW to make use of the strong baseline data established in this most productive polynya in the Arctic.

What lessons learned from NOW can be used in planning the Ecosystem West Greenland programme?

**Organisational setup.** The successful outcome of NOW was ensured by *international* collaboration within *multidisciplinary* research themes. The collaboration was promoted by a strong central coordinator, assisted by a very skilled and efficient technical support group, to carry out many of the practical duties. The overall NOW programme was working towards a central goal, where four cross-disciplinary research themes served as umbrellas for individual projects that contributed to these themes. Each theme was headed by a senior »team leader« responsible for compiling their part of the research proposal, and directing the individual projects towards the common goal. This setup ensured a productive interdisciplinary programme - that so far has resulted in many individual research papers and two special volumes on the oceanography/ice conditions (Atmosphere-Oceans vol. 39 October 2001) and the biological oceanographic (Deep Sea Research, early 2002) components respectively.

**Improvements.** The Greenland Institute of Natural Resources is uniquely positioned to counter the two weak points in the NOW programme: being a Greenlandic agency, GINR will be able to cooperate better with the resident population in the research area and gain general support for the operations. In addition, with GINR's
strong experience with fish population studies, research in this important component of the marine foodweb can be included in the future programme, thereby establishing the needed links to the upper trophic levels, including commercial exploitation.

_Lateral links._ During the 4 years of operations, the NOW programme conducted the most in-depth study of e.g. oceanography, carbon flow, benthic-pelagic coupling, and particle flux into the Baffin Bay ever conducted in West Greenland waters, and this huge effort can now be used in more long-term studies of possible changes and associated ecological implications. Although the research programme »Ecosystem West Greenland« will focus mainly on the region from Disko Bay southwards, the lateral coupling to the Baffin Bay oceanography - and the migrating resources - may warrant tight collaboration between the new GINR initiative and future international NOW plans. For this reason - and because general international attention can be beneficial - it is recommended that the research programme »Ecosystem West Greenland« be promoted through AOSB.

Finally, the NOW approach of a major international »burst« of effort for a short period (3-4 years), followed by long-term plans for continuation of selected components, could be a model for a long-term programme in West Greenland.


_Coleen Moloney, Zoology Department, University of Cape Town_

Despite huge differences in climate and the ecology of their marine ecosystems, Greenland and South Africa share the property that both countries are highly developed and operate on high technical standards in some respects, but are still developing in others. Both countries are young democracies with a multilingual administration. Because the governments of both countries need to address important economical problems with high priority, national funding for science is limited. Isolation is a factor in science, again partly due to the geographical placement of the countries, but at times aggravated by political decisions.

The Benguela Ecology Programme (BEP) is a regional, ecosystem-oriented marine research programme that was initiated in 1981. It involves universities, museums, other public research institutions, government departments and the fishing industry. The experience in developing an effective institutional framework, gained from 20 years of regional collaboration, is summarised into seven points that act as »hints«
for programme development, and one process that serves to link the various elements:

Hint 1: Bottom up. Develop and support the programme using a participatory approach. Research results that address broad objectives will only be produced by keenly motivated researchers who feel that they have an impact in the progress of the programme. Acceptance of management decisions (eventually arising from this research) by stakeholders is not a trivial issue, and has probably been unduly neglected in the past.

Hint 2: Top down. Political buy-in and top-down support is crucial. This is true at all levels, from project working groups to research institutes, national and regional governing bodies - and funding agencies.

Hint 3: Flux. Expect all kinds of change during the development of the programme, including change in the socio-political climate under which the research is conducted. A moderate example of this is the paradigm shift from »monitoring and enforcement« towards »co-management« that has taken place in fisheries management in South Africa.

Hint 4: Vision. A vision supported by a good plan is essential. While the vision might not be realized within a researcher’s working life, research plans for foreseeable periods (e.g., 5 years) will focus action on issues considered of particular importance in relation to the present understanding of the ecosystem structure and functioning. The vision for the BEP is »to provide scientific information on the structure and functioning of constituent ecosystems, to complement the knowledge that is required for the management of the renewable natural resources of the Benguela Current region«.

Hint 5: Patience. Everything takes longer than expected - planning a long term programme is important.

Hint 6: Confusion. Everything is more complicated than expected - be open-minded and flexible. It is likely that some surprising results will emerge with time, and textbook knowledge on the functioning of the ecosystem will need to be revised and updated.

Hint 7: Perspective. Have a broad, multidisciplinary view from the start.
Linkage: *Communication*. The importance of effective communication cannot be overemphasized. Communication within the Benguela Ecology Programme was based on (i) weekly research seminars, (ii) quarterly newsletters, (iii) five-yearly international symposia, and (iv) scientific and management committees. It was enhanced by a small scientific community, a limited geographic area, and scientists working near the ecosystem, and close to the fisheries.

In conclusion, building a successful ecosystem research programme can be compared to preparing a good meal, based on straightforward ingredients and a simple recipe. The ingredients would read

- Take interesting science, in order to involve academic researchers;
- Take the management context, in order to involve government scientists;
- Place them into a melting pot of effective institutional collaboration.

And the recipe would be

- Communicate well and frequently at all levels and on all issues.
Section 3
Results of Group Discussions:
Key Questions of the Research Programme
»Ecosystem West-Greenland«

Session 1
What Improvements over the Present Practice of Generating Advice are Desirable?

The discussion on necessary improvements in generating management advice related to the ecosystem off West Greenland highlighted parallel needs on several major issues, leading to

- Improved knowledge of the key components of the ecosystem, their status and their dynamics.
- Improved understanding of the impact of climate on the ecosystem components, and the relationships between the various components of the ecosystem.
- Shift towards a long-term view in generating scientific advice, supported by improved monitoring.
- Improvements in the process of management of human activities in the ecosystem off West Greenland, e.g. through the development of management goals and management plans.

**Improved knowledge of the key components of the ecosystem, their status and their dynamics**

Whereas monitoring and stock assessment of species with a long history of commercial exploitation follows internationally recognised procedures, knowledge of particularly commercially unexploited species, or those only recently subjected to commercial exploitation, is incomplete. From an ecosystem point of view, it would be necessary to identify key components for each important subsystem off West Greenland, e.g., pelagic (e.g. capelin, squid, Polar cod), and benthic (e.g., Northern shrimp, cod, sandeels, snow crab). It would be desirable to obtain coherent descriptions of the dynamics of all key components, including top predators, e.g. marine mammals and birds, and develop predictive models where possible.
This information need not necessarily be based on data from research cruises alone. In order to generate more data, co-operation with the fishing industry, and small-scale fishers and hunters can be improved, and improved use can be made of logbook information.

**Improved understanding of the impact of climate on the ecosystem components, and the relationships between the various components of the ecosystem**

Along with the description of the dynamics of the key components of the ecosystem, an understanding of the factors that drive the dynamics is desirable. More knowledge is needed on (i) the coupling between climate, hydrography and biology, (ii) the interaction between different trophic levels, as well as (iii) possible effects of fishing/hunting, both in terms of removal/harvest and disturbance.

Tackling these questions will require interdisciplinary co-operation, and will result in a suite of ecosystem models with predictive capacity. These ecosystem models are expected to be useful for exploring the development of the system under different climate and management scenarios.

Improved knowledge of the sensitivity of ecosystem components to climate change and human impact should also lead to a scientific basis for the definition of protected or closed areas, in order to restore ecosystem complexity where necessary. To identify human impact, unexploited systems (or only lightly exploited systems), are needed for comparison.

**Shift towards a long-term view in generating scientific advice, supported by improved monitoring**

Addressing the possible effects of climate change, or questions of habitat restoration or stock rebuilding, requires a long-term perspective, based on the understanding of the dynamics of the components of an ecosystem, and their variability. This long-term view can only be based on long-term data, i.e., on an effective monitoring programme.

Major resources in the ecosystem off West Greenland are being monitored, and some time series exist. However, major improvements can be achieved through a strong overall co-ordination of sampling strategy. Further, a tight coupling between monitoring and research is necessary.
Greenland cannot maintain an extensive programme of research surveys. However, other means of sampling can be used to a greater extent than to date. Information on ecosystem components may, e.g., come from an exploratory commercial fishery, if licence conditions are applied (e.g., through area allocation), and bycatch is monitored (by observers/biologists on commercial vessels). The information gained through such collaboration could further be used in research projects, e.g., on determining the trophic relationships through (i) identification of the diet composition of target species and bycatch, (ii) identification of trophic relationships through methods other than stomach sampling, e.g., stable isotope analysis. Other research projects may aim at developing alternative indicators of stock status, or improvement of stock-recruitment relationships by using alternative measures for spawning stock biomass.

**Improvements in the process of management of human activities**

Improved management of human activities in marine ecosystems must be based on participation and mutual understanding between three groups of stakeholders: scientists, users of the resource, and management officials. This calls for a truly multidisciplinary approach in management issues related to the ecosystem off West Greenland that leads to agreement on management goals and the development of management plans. These management plans need to explicitly include economic, cultural and social needs.

The approach of the »Valued Ecosystem Component (VEC)« used in the Adaptive Environmental Assessment and Management (AEAM) procedure as, e.g., applied in the management plan for Svalbard, Norway, was suggested as a possible way forward. In this approach, all factors affecting a given valued ecosystem component are included in a diagram, and split into anthropogenic and natural factors as far as possible. These factors are subsequently connected with arrows indicating impact. The importance of the arrows is then valued by the various stakeholder groups, and it can then, e.g., be made explicit where more knowledge is needed, and/or how priorities should be set. As an example, let a given species of seabirds be the VEC. Their population is influenced by recruitment on the one hand, and survival on the other. Survival itself is impacted by (the availability of) prey, which in turn is impacted by climatic conditions. Humans impact the recruitment of the VEC by egg collection on the one hand, but on the other hand also by hunting on the survivors, and fishing on their prey.
Session 2
Key Questions Concerning Climate Impact on the Pelagic Ecosystem off West Greenland

The impact of climate variability, e.g. through the North Atlantic Oscillation, on the ecosystem off West Greenland is well documented. However, interdisciplinary scientific research is needed to understand the physical, chemical and ecological processes behind changes in the marine ecosystem caused by climate change.

Models of circulation in the atmosphere and in the ocean are under development in the Northwest Atlantic Ocean Climate Programme. Different scenarios of distribution of water masses/temperature/spring layer need to be explored based on these models. The physical models must be coupled to biological models, in order to investigate climate-induced changes in the drift of fish larvae, but also changes in the dynamics of zooplankton, notably *Calanus spp.*, which is an important food for many ecosystem components.

Modelling will always be carried out with a view to optimising the *in situ* and satellite observation network, and identifying key parameters for monitoring in the future.

Harmful algal blooms in temperate marine ecosystems have recently obtained much attention. It may be relevant to monitor their occurrence off West Greenland, and to investigate their effects on reproduction at higher trophic levels.

The mechanisms of pelagic-benthic coupling in the ecosystem off West Greenland are largely unknown to date, but are expected to be affected by climate change. What influence will changes in the pelagic-benthic coupling have in the ecosystem off West Greenland?

With regard to large invertebrates and fish, a few key species should be defined and their responses to temperature change investigated. Which of them are sensitive to climate change? How will climate-induced changes of these species’ populations be passed on in the food web? What are the effects of climate change on fish habitat, e.g. size and location of nursery areas, and fish migration routes?

Top predators are expected to be subjected to changes in their physical habitat as well as to changes in the abundance and distribution of their prey. What is the relative importance of abiotic and biotic change, and how are they going to affect the various top predator populations?
Apart from looking at single components of the ecosystem, mechanisms/processes related to changes in temperature and/or ice cover need to be investigated on the ecosystem scale, e.g. through energy flow models.

In order to focus efforts geographically, co-ordinated research was suggested in two areas, i.e.

1. The Nuuk Fjord and Fyllas Bank
2. Disko Bay

Whereas the former will also allow improvement of the knowledge of connections between coastal and open ocean processes, the latter will allow a link to ice-covered areas.

On the institutional side, it was emphasised that studies linked to climate impact in the ecosystem off West Greenland will benefit greatly from a wider perspective, e.g. through improved links with

- studies of climate impact on other Greenland ecosystems, e.g., in the North Water Polynya, and East Greenland;
- ecosystem studies in similar arcto-boreal systems, e.g. Barents Sea, Bering Sea;
- ongoing monitoring programmes in the Arctic, e.g. the Arctic Climate Impact Assessment Programme (ACIA, www.acia.uaf.edu).
Session 3

Key Questions Concerning the Impact of Climate Conditions on the Demersal/Benthic Ecosystem off West Greenland

Typically, and in contrast to the pelagial, benthic ecosystems consist of a large fraction of sessile or poorly-mobile organisms. In cold waters, their species- and community- diversity typically is high.

The benthic/demersal ecosystem off West-Greenland is poorly known, and baseline studies would therefore be necessary before processes, such as climate change, could be assessed or scenarios be modelled. As a start, a few benthic communities could be monitored as pilot communities. At the same time, monitoring of the commercially important species (Northern shrimp, Greenland halibut, snow crab, scallops, cod) would continue, and through time be complemented with monitoring of benthic indicator species (e.g., prey species for diving birds or mammals) as defined in an early phase of the ecosystem research programme.

The baseline study would aim at

- Investigating the present faunal/floral composition, distributional limits and gradients, species and community diversity;
- Habitat mapping using an existing classification scheme;
- Gathering basic knowledge of the biology of key elements (e.g., life history characteristics, stage-specific diets);
- Investigating the main trophic relationships in the benthos;
- Understanding the effect of primary production input to the benthic community from the pelagial or from the sea ice - what are the spatio-temporal patterns, and the mechanisms of pelagic-benthic coupling?
- Investigating the present impact of fishing on the benthic ecosystem.

Key questions related to the effects of climate change that could subsequently be addressed include

- How will climatic change alter the distribution of water masses and bottom temperatures? Can models of physical parameters relevant to demersal species and bottom communities be developed?
- How is the biogeography and biodiversity expected to change under shifts in temperature and/or ice cover?
• What are physiological responses at the species level to changes in the environmental parameters? How are key population parameters expected to respond to climate change?
• In which way will the pelagic-benthic coupling be affected, and what will be the effect on demersal communities?
• Which of the major trophic relationships are temperature-sensitive? How are the trophic relationships expected to change?
• What would be the effect of changes in sea-ice cover on access to benthic resources, e.g., by diving seabirds and marine mammals?
• How is present exploitation affecting the demersal/benthic system under climate change? Could present-day human impacts have an effect on the resilience of the system to climate change?
Session 4  
Key Questions Concerning the Trophic Interactions in the Marine Ecosystem off West Greenland

In order to understand trophic interactions off West Greenland, the group discussions emphasised the need to identify keystone species from an ecosystem point of view, and to identify and quantify the most important trophic interactions by in-depth studies of these keystone species. This suite of species should cover the entire ecosystem, from planktonic and benthic invertebrates to fish and top predators. It was further emphasised that keystone species are not necessarily those for which management advice is generated at present. Is the Northern shrimp a keystone species, and what is the importance of capelin, Polar cod and cephalopods?

For investigations of the lower trophic levels, it was suggested to focus on a small number of study sites that would be sampled with a high temporal resolution. Three areas were suggested:

- Nuuk Fjord and Fylla Bank;
- Disko Bay;
- Qaqortoq/Julianehåb Bight for southwest Greenland.

At the same time, it was suggested to map the primary production, in order to identify hot spots in time and space. Similarly, the carbon flow in the food web should be mapped, aiming at refined box models.

For the intermediate trophic levels, it was suggested to concentrate on the key forage species in the ecosystem off West Greenland, and the interactions with their predators. Studies should aim to separate «natural» effects from anthropogenic effects on the keystone species. Key questions would include:

- What is the flow control in the ecosystem through the forage species? Do wasp-waist effects exist?
- If cod returns to west Greenland, can its effect on Northern shrimp be quantified?
- What is the role of capelin in the ecosystem? What is the interaction between capelin and cod? What impact of capelin on seals would be expected if the capelin stock decreased, e.g., following the introduction of a capelin fishery?
Concerning top predators, it was suggested that the spatial and temporal distribution of their consumption in the West Greenland ecosystem should be estimated, both inshore and offshore.

The ecosystem off West Greenland supports both traditional and industrialised fisheries.
Session 5
Key Questions Concerning Human Uses of Goods and Services of the Ecosystem off West Greenland

Human uses of the ecosystem off West Greenland include commercial exploitation (e.g., fishery), non-commercial exploitation (e.g., subsistence hunting and recreational fishing) and non-consumptive uses (e.g., eco-tourism). Sustainability of the human utilisation of the system is the key issue.

Sustainability is based on optimal management of the human activities impacting the marine ecosystem. Optimal management will be based on agreed management goals, and be strongly supported by optimal management advice. Elements that will improve management include, *inter alia*, progress in

- natural sciences, e.g., through the development of long-term advice, including scenarios of climate change and different management strategies;
- social sciences, e.g., through research into the management system, including dialogue with resource users;
- legal considerations, e.g., through obligations for users to provide reliable statistics and necessary samples.

On the natural science side, understanding of the magnitude and significance of human impact on the ecosystem West Greenland is the most important issue. Questions that need to be addressed include

- What is the geographic distribution of the harvest of the various fisheries, and what is the long-term consequence of this distribution on the ecosystem?
- What are the amounts of bycatch and discards in the various fisheries, and what potential damage is inflicted upon the ecosystem by taking these bycatches and discards?
- What is the importance of fish offal and discards as food for fish, seabirds and mammals?
- To which extent do human activities disturb habitat (e.g., by physical destruction, noise disturbance, oxygen depletion), and what are the consequences for the ecosystem?
- What are the needs/possibilities for remedial action?
- What need exists for the development of fishing and hunting gear that minimises ecosystem impacts, e.g., by causing the least habitat disturbance?
In order to be better able to separate anthropogenic from natural effects, stock assessment models may need to be improved.

The inclusion of the results of socio-economic studies into management advice was advocated by most discussion groups. As most of the workshop participants were natural scientists, only a few general questions were stated, highlighting the need for co-operation with experts in the field.

- How does the structure of the society today impact the ecosystem off West Greenland? How is society predicted to evolve (centralisation, de-centralisation, consequences for effort-allocation)? Studies should include economic as well as non-economic incentives for geographical placement, e.g., way of life, quality of food.
- What are the costs (monetary and non-monetary) and benefits of eco-tourism to the Greenland society under various management scenarios?
- What is the most effective management system for human activities in the ecosystem West Greenland? How can exploitation and conservation best be combined?

Aspects relating to management and improvements in generating management advice had already been addressed in Group Discussion 1. Questions that will arise in connection with the development of management plans will include

- Should species that are harmful to exploited/exploitable species be suppressed?
- In case of conflicting interests, e.g. hunting and eco-tourism: Is harvesting or conservation going to be the primary goal?

Future challenges might include the assessment of bioprospecting.
Session 6
Key Questions Concerning Long-Term Data Series

Existing and future time series will be used

- to understand the dynamics of the variables measured,
- to detect relationships between ecological variables,
- to attempt to predict the future,
- to estimate variability in the system, and
- to evaluate significance of recent changes.

The most important questions relating to the use of long-term data series are

1. How can existing time series be used in an ecosystem context?
2. How can data gaps be filled?
3. Is extension or shift of focus required?

The issues stated in the following will need to be addressed at the beginning of a research programme, and will require periodic evaluation and re-assessment.

Use of existing time series in an ecosystem context

- Compilation of an inventory of existing historic samples. E.g., can the record of fish larvae in the zooplankton series be extended? A re-analysis of existing samples (i) must include a data quality backcheck; and (ii) can be used for the refinement of information, e.g., crab categories, or (iii) can be used for gathering additional information, e.g., morphometry.
- Completion of the electronic compilation of data sets. Integration of hydrographic and biological data sets, design all data sets for easy use.
- Re-analysis of the data with specific hypotheses in mind - probably through data workshops with specialists.

Filling of data gaps

Individual years that are missing in an existing series can be interpolated using statistics. For missing species, or a limited historical perspective, it is recommended to use the following possibilities

- Explore linkages to other time series existing for similar systems, e.g., the Labrador coast, Faroe Islands and Barents Sea;
• Analyse stratigraphic records from sediment cores, sea whips, hard corals or long-lived bivalves as archives of hydrographic / productivity history;
• Link with the paleogeographic/archaeological approach, e.g. through marine mammal- and bird- remains at settlement sites;
• Dig in historical archives.

Possible extension or shift of focus?
The current monitoring is directed at exploited species, and the time series may not be sufficient in an ecosystem context. Apart from consistent recording of all species in fishery surveys, and optimising the consistency of the hydrographic dataset, it is therefore recommended to

• Re-establish zooplankton monitoring;
• Establish phytoplankton/nutrient monitoring;
• Monitor benthos at selected sites;
• Monitor potential human health hazards: toxic algal blooms and parasites;
• Periodically investigate stomach contents of predators;
• Extend seabird monitoring, with a suggested focus on murres, kittiwakes and eiders. Monitoring should include the (i) breeding season (information on foraging strategies and response to ecosystem variation), (ii) winter distribution in relation to key prey items (in the context of a multidisciplinary survey), and (iii) harvest composition.
• Extend monitoring of large and small cetacean populations and their potential pelagic prey, notably capelin. Are whales a useful indicator of highly productive areas, can they be used as guides to identify the main distribution areas of forage fish, e.g., capelin?

Experience from other extensive databases has shown the need to develop rules of access to the data base (and use of the data). As a database on the ecosystem of West Greenland will consist of the contribution of several institutions, it is urgently recommended that such rules be developed and agreed upon by the contributors.

The usefulness of models for driving data collection (e.g., spatio-temporal resolution of plankton sampling based on the results of the ocean model) was emphasised. As a start for plankton monitoring, an annual plankton study across Fyllas Bank was recommended. Similary, data series on exploited species could initially be used to help identify indicators of ecosystem changes, and monitoring of other components necessary to explain such changes could be established as necessary.
In order to free resources for monitoring of ecosystem components other than exploited species, it was suggested to conduct cost-benefit analyses of the existing surveys. E.g., could the shrimp survey be conducted every second year only, and the gained time and financial resources allocated to other monitoring or research tasks?

Macrobenthos research on board R/V "Adolf Jensen"
Session 7
Institutional Setup for the Future Research Programme

The discussion groups were asked to address the questions:

- What is the best institutional setup for the future research programme on the ecosystem West Greenland?
- How should co-operation be designed on local-regional-global scales?

Several models of a management structure were presented as a result of the group discussions. Generally, it was pointed out that

- The programme should be co-ordinated by the Greenland Institute of Natural Resources;
- It was important to ensure effective communication within and among the various teams, and to enable transparency of the programme progress, e.g., by making extensive use of internet possibilities;
- Research projects would be designed as part of the overall structure, but conducted independently;
- It would be important to involve managers at the top steering level of the programme;
- Socio-economic research should be made an integral part of the research programme.

The agreed management structure is depicted below. A steering group will oversee the programme, address funding agencies, promote the programme, and solicit funding for major programme blocks. It will be chaired by the Director of the Greenland Institute of Natural Resources. A full-time Programme Leader will act as the central co-ordinator of the programme, schedule/co-ordinate meetings and secure effective communication. His/her work should be supported by a secretariat. Team Leaders will represent strong interdisciplinary scientific expertise, and will oversee progress of the scientific work in their teams. Teams will represent several research projects and their staff. The group of Team Leaders will constitute the Coordinating Committee. It is expected that major proposals for funding will be written by the Programme Leader together with the Team Leaders, and that Team Leaders will identify additional sources of funding for projects in the area of expertise of their team.
It was further suggested to establish a project drafting group before the end of the meeting, which would work towards a presentation of the planned programme at the Arctic Ocean Science Board meeting in April 2002. This drafting group would outline the scientific content of the Programme’s first phase and prepare an implementation plan, outline management issues to be addressed, further analyse funding issues, and consider logistic issues on the large scale. Along with the report of this workshop, the document prepared by the drafting group would serve as a background document for

- Hiring a Programme Leader at the Greenland Institute of Natural Resources, e.g., a research professor with an ecosystem-oriented approach and some administrative expertise.
- Exploring funding issues.
- Soliciting draft research proposals.
- Informing appropriate international bodies (e.g., Arctic Ocean Science Board, ICES/NAFO, etc.).

Mr. J. Boje (GINR), Dr. E. Buch (DMI), Dr. M-P. Heide-Jørgensen (GINR), Dr. A. Jarre (DIFRES/GINR), Mr. M. Kingsley (GINR), Dr. A. Mosbech (NERI), Prof. Dr. T.G. Nielsen (NERI), Dr. S. Rysgaard (NERI), and Dr. B. Sainte-Marie (DFO) were asked to be members of this drafting group, with Mr. Kingsley as its Chair.
Opening the Doors for Social and Economic Research in Fisheries off West Greenland Within the Research Programme

Realising the agreement among the workshop participants for the need to include social and economic research, and the limitation for more discussions imposed by the workshop programme, a small group of workshop participants met with the aim of giving guidance about socio-economic studies that should be initiated within the first phase of the research programme. The section below reflects the result of this discussion.

The need for socio-economic research in West Greenland fisheries - and efficient communication

The Greenland society has, in a very short period of time, undergone vast changes. In the course of only a few decades, large parts of Greenland’s west coast have developed from traditional, underdeveloped areas to efficient, industrialised communities, especially with respect to the fishery. This development has brought large socio-economic changes to the society, or at least major parts of it. The focus has been mainly on the development of the fishery, resulting in larger trawlers and enlargement of the land-based production facilities. This focus has pushed the discussion of the living resources and the ecosystem aside, at least for a number of years. During the last few years, emphasis has been placed on traditional hunting and its impact on the living resources. However, members of the Greenland society are becoming more and more aware of the ecosystems around them, and their use of the country and its adjacent marine areas, both as professional as well as recreational fishers and hunters. In order to proceed with the discussions and in the growing awareness of the marine ecosystem, the following problems will need to be addressed.

Traditional fishing and hunting and its impact on living resources

In spite of the huge socio-economic changes, traditional target species such as marine birds and mammals are still an important cultural and economic foundation for parts of the Greenland society. In the past, it was not possible to sell daily catches for processing in many West Greenland settlements, and trading of seal skins was the only possibility in several of these small settlements. This one-sided economy needs to be investigated with regard to its consequences for exploitation pressures - not only with respect to seals, but also concerning implications of these trading regulations for other species.
In the last few years, several co-operatives have been established that purchase several species suitable for processing, mainly for the local market. These co-operatives have generated a form of »stable« income, not only in the towns but also in the settlements. As with so many other enterprises, they depend to a large extent on supply of the resources and demand for the products, and thus can have a high impact on fishing and hunting pressures on several »target« species. The need for a deeper understanding of the relationship between trading possibilities, and consequently supply and demand, and the ecosystem consequences of hunting and fishing, has increased in the course of the last few decades. This increase can also be seen as a result of the increased efficiency of fishing and hunting gear, made possible through increased incomes.

**The coastal fishery**

The coastal fishery saw its heydays in the period when the cod stock was large. The number of trawlers increased, again as a consequence of stable and high income. This enhanced the capability to target other species when the cod fishery declined, such as Northern shrimp, Greenland halibut or, later, snow crab. There is a pronounced need for a coherent evaluation of the West Greenland fleet of coastal fishing vessels, their socio-economic importance, and, not least, the impact of this fishery in the fjords and coastal areas of the West Greenland marine ecosystem.

**The offshore trawling fleet**

Above all, it is the offshore trawl fishery that is the most important basis of the Greenland economy. The trawler fleet has grown since the beginning of the 1980s, albeit with varying speed. In particular, the fleet of shrimp trawlers has been increasing, not only regarding the number of vessels, but also their efficiency and capacity. The high demand on Northern shrimp, especially from the Asian market, is one of the reasons for the almost explosive development during the 1980s and partly during the 1990s. Interestingly, the Greenland public, as represented by the Home Rule Government, is also deeply involved in the offshore trawl fishery. This involvement implies that the Greenland public occupies a double role, both as manager of the resource and investor in its exploitation.

This double role, which at the same time is a socio-economic interdependency, can turn out to be extremely problematic, both ecologically and economically. In this respect, an in-depth study of the developments of the private and the public trawling fleets, regarding both capacity and economics, would be desirable. At the same time, there is a need for clarification of the public economic involvement in the fishery,
among others the economic dependency of the fleet. The trawling fleet’s economic basis, as well as its impact in the marine ecosystem, needs to be investigated.

The need for communication on management issues

»In the end it is the person with the finger at the trigger or the person setting the net, who decides whether their action is complying with, or violating the laws,« said Paviaraq Heilman, then member of the Home Rule Government, during the seminar on Greenland living resources conducted by the Greenland Institute of Natural Resources in 1998. In a country where it is practically impossible to control compliance with hunting and fishing regulations, it is the people’s knowledge, understanding and acceptance of management measures that leads to compliance with regulations.

Information is not generally sufficient if its aim is to convince the recipient of the information to change their behaviour, e.g., obey new quotas or closed seasons. In connection with strategies for sustainable exploitation, experts and practitioners have been analysing for a number of years how the needed change of behaviour can be achieved. Consensus is growing that active participation in the management process is one of the necessary conditions.

The process of reaching consensus has been named »environmental communication«. In a reader »Communicating the environment« (Oopen and Hamacher 2000, Peter Lang, Europäischer Verlag der Wissenschaften, Frankfurt am Main), compiled for the German developmental agency GTZ in co-operation with FAO, IUCN and OECD, the authors arrive at the above conclusion based on experience from a number of international case studies. They define environmental communication as »a two-way social interaction process enabling the people concerned to understand key environmental factors and their interdependencies, and to act upon related problems in a competent way«. They define the difference between stakeholders and shareholders as follows: »Conflicts of interest are fought by stakeholders, not negotiated by shareholders. Confrontational approaches lead to one-way information dissemination disregarding understanding, instead of relying on two-way communication towards ‘shared meaning’ and ‘win-win’ situations.« Key terms in a model for environmental communication are »process, feedback, dialogue, and people. Its horizontal, community-based approaches can be complemented very well with vertical support systems involving the mass media.«
Solution co-management?

In IUCN, WWF and the Arctic Council, co-management is propagated as the best solution to management issues. In the report »Arctic Flora and Fauna. Status and conservation« (CAFF (ed.) 2001, Edita, Helsinki. 272 p.) it is concluded that »One of the most notable recent innovations is the involvement of hunters and fishers in wildlife management. In theory, hunters and fishers who help develop the regulations will better understand the rationale for them and be more willing to abide by them. In practice this approach has enjoyed success in North America, where support for co-management has grown widely, although difficulties remain.«

Acknowledging that co-management in Greenland is only in its infancy, the Directorate for Environment and Nature of the Home Rule Government published a »programme proposal for local engagement in management of natural resources in Greenland«. Quoting from the proposal, »The programme's aim of seeking a broader basis for management principles - and letting the process of reaching agreement on the basic principles become a part of the programme, thereby creating local awareness of the consequences of a general natural resource policy - is new in Greenland«. The programme has not yet received funding.

Kaassasuk and the Spirit of Might, sculptured by Simon Kristoffersen
Section 4
Setting up the First Phase of the Research Programme

One working day of the Workshop was devoted to setting up the first five-year phase of the planned research programme. A logical framework approach was used. First the Workshop participants agreed on the goal of the research programme, and they then proceeded to discuss objectives and outputs.

It was considered premature to enter into detailed discussion of inputs (necessary to generate the outputs) or concrete project planning at this stage. Meaningful discussion of the necessary inputs would have required an even wider circle of expertise and more time. Concrete project planning can only proceed based on institutional commitment and indications of wider funding support, and this requires another feedback loop in the planning process.

Discussions proceeded partly in plenary, and partly in discussion groups that, in order to maintain the focus on the first phase (five years) of the research programme, were structured according to disciplines: physical oceanography, plankton, benthos, fish, marine birds, and marine mammals. However, in order to avoid getting stuck in disciplinary discussions, all groups were asked to explicitly address interdisciplinary issues. Along these lines, it was believed to be unnecessary to create a separate group on multispecies modelling.

Goal
The agreed goal of the research programme »Ecosystem West Greenland« is »To establish a scientific basis for long-term ecosystem-based management in West Greenland waters«

Objectives
The agreed programme objectives contributing to the overall goal are

Objective 1: Quantify and improve the understanding of physical and biogeochemical interactions
Key words:
- Atmosphere, ice, physical and biological oceanography,
- Pelagic-benthic coupling/vertical flux,
- Lateral coupling (inshore/offshore and north/south).

Objective 2: Quantify and improve the understanding of ecosystem structure and functioning
Key words:
- Biodiversity,
- Trophic interactions,
- Spatial and temporal scales (patchiness etc.).

Objective 3: Identify and quantify interactions between human activities and the ecosystem.
Key words:
- Predict ecosystem impacts of harvest at community, species and stock levels (factors affecting stocks, trawling impacts, etc.)
- Socio-economic and management impacts of climate and harvest regimes.

Outputs
The list of outputs given below outlines desirable project results after the first phase of the programme (five years). The list was derived from the results of group discussions during the last day of the workshop, where each group was asked to give a list of three outputs for each objective, in order to achieve some prioritisation of the research.

In order to complete this list, some items could be added resulting from the group discussions during the previous days (as detailed in Section 3 of this report), or brought forward the participants’ presentations (as summarised in Section 2 of this report).

Objective 1: Quantify and improve the understanding of physical and biogeochemical interactions

Results of group discussions during the final day of the workshop

- Database with physical, chemical and biological data reflecting the annual cycles in Disko Bay, off Sisimiut, in the Nuuk Fjord-Fylla Bank area and Qaqortoq/Julianehåb Bight;
- Coupled 3D physical-biological model: description of circulation and larval transport, including relationship to Iceland, east Greenland and Canada;
- Model that predicts the effects of changing ice coverage on the habitats of marine mammals and seabirds;
- A coupled atmosphere-ice-ocean-biogeochemical model;
- Scenario runs on the effects of climate change on primary and secondary production;
- Scenario runs on the effects of global warming on the marine ecosystem off West Greenland as input to models of trophic interactions (see Objective 2);
- Identification of mechanisms for exchange between inshore and offshore waters (physics, biology and behaviour) in the Nuuk Fjord/Fyllas Bank area;
- Description of fjord-sea interactions emphasising no-sill versus sill fjords;
- Identification of mechanisms for exchange between pelagic and benthic communities (physics, biology and behaviour);
- Description of latitudinal and depth gradients of energy/nutrient exchange of pelagic and benthic subsystems;
- Description of climate-induced changes in migratory or behavioural patterns, based on a re-analysis of historic data sets.

**Objective 2: Quantify and improve the understanding of ecosystem structure and functioning**

*Results of group discussions during the final day of the workshop*

- Identification of key species covering the entire ecosystem, compilation of their life history parameters (distribution/growth/maturity/reproduction/physiology);
- Identification of spatio-temporal gradients in life history parameters of commercial and key species (e.g., latitudinal gradients or habitat-related differences in growth/reproduction);
- Implementation of new techniques to describe origin and migration of key fish species (e.g., Greenland halibut, redfish, capelin, cod), evaluation of spatio-temporal stock structure;
- Improved recruitment indices based on forecasts from 3D physical-biological models;
- Improved single species understanding and their incorporation in the ecosystem context;
- Improved single-species stock assessment models feeding into the advisory process;
- Identification of spatio-temporal gradients in the diet and food consumption of commercial species and key species;
- Documentation of diet composition and abundance of key seabird species (e.g., Thick-billed Murre, Dovekie, Kittiwake, Common and King Eiders) and their main prey;
- Verification of trophic structure as derived from diet studies based on appropriate experiments on selected rates/processes and analyses of biomarker transfer;
- Comparison of biomarker methodology - stable isotopes, lipids, fatty acids;
- Development of new tools/methodology for monitoring trophic interactions;
- Quantitative description of interaction of key species seasonally and interannually;
- Quantitative model for trophic, spatial and temporal relationships in a coast/offshore gradient;
- Quantification of interaction between (i) shrimp, capelin and cod, (ii) capelin, Polar cod and marine mammals; and (iii) Greenland halibut, hooded seal and narwhal;
- Dynamic model of the effect of predation by cod and other fish on shrimp;
- Estimates of predation mortality inflicted spatially on major fish and shellfish species in the ecosystem by predators, including marine mammals;
- Evaluation of the relative importance of various species of small fish (e.g., capelin, Polar cod) and invertebrates (shrimps) as food items;
- Assessment of the variations in trophic interactions and their effects on the seabird populations in a long-term perspective;
- A biodiversity inventory of the selected target areas;
- Quantitative description of genetic diversity of selected key species;
- Quantitative description of the species diversity of the deep-sea fish community off West Greenland;
- Quantitative description of gradients of benthic species and community diversity;
- Quantitative description of benthic density gradients (focussing on macrofauna as long-term integrators, but also including meio- and microfauna).

**Objective 3: Identify and quantify interactions between human activities and the ecosystem.**

*Results of group discussions during the final day of the workshop*

- Documentation and validation of the annual harvest and bycatch levels in relation to the population status of target species;
• Assessment of the amounts of discards in the trawl fishery by area, and evaluation of the implication for the recovery of depleted species;
• Quantitative estimates of the effect of sorting grids or meshes on the mortality of ecosystem key species;
• Quantification of effects of fisheries on resource dynamics in a multispecies model explicitly including the fishery;
• Quantification of ecosystem impacts of fishing on forage fish;
• Description of ecosystem impacts of trawling, e.g. contrasting trawled with non-trawled habitats (standing gears, e.g. traps only, or no fishing at all);
• Baseline data for currently unexploited or only lightly exploited species (e.g., Hyas, sea urchins);
• Improved medium-term and long-term advice based on different management regimes explored with multispecies models;
• Cost-benefit model for different management/exploitation scenarios;
• Functional response of harvest regime to shift in the prey abundance;
• Socio-economic scenarios based on multispecies and climate model output;
• Improved information and education of the Greenland public, and improved dialogue with all shareholders of the ecosystem.
Workshop snapshots

Above: Participants listening to Director Klaus H. Nygaard's welcome speech.

Middle: (l) Discussions in small groups; (r) the organiser and editor at work.

Below: Discussions span over lunch in the Institute’s canteen.
Acknowledgements

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Michael Rosing, Flemming Ravn Merkel, Mads-Peter Heide-Jørgensen, Erik Palo Jakobsen and Thomas Peitersen took photographs during the workshop. Emma Kristensen assisted with the selection of photographs. Thank you for your extra efforts!

Many thanks to all participants for enthusiasm and constructive discussions, and to their home institutes for support through allocation of staff time and additional travel and subsistence support. Special thanks to Dr. Coleen Moloney for not only finding time in her busy schedule to share her professional expertise in management-oriented ecosystem research, but also for spotting linguistic inconsistencies in the final version of the report!

Last but not least, many thanks to the administration of the Greenland Institute of Natural Resources for practical help with conducting the workshop. In particular, the support of Lars Kreutzmann, Ella Nørlund, François Pages and Thomas Peitersen during the workshop, often outside office hours, has been an important contribution to its success.
List of Acronyms and Abbreviations

ACIA  Arctic Climate Impact Assessment Programme, www.acia.uaf.edu
AOSB  Arctic Ocean Sciences Board, www.aosb.org
CAFF Conservation of the Arctic Flora and Fauna, www.grida.no/caff
CEC  Commission of the European Communities, www.europa.int/comm
DIFRES Danish Institute for Fisheries Research, www.dfu.min.dk
DFO Fisheries and Oceans Canada, www.dfo-mpo.gc.ca
GINR Greenland Institute of Natural Resources, www.natur.gl
IAPP International Arctic Polynia Programme, www.aosb.org/IAPP.html
IASC International Arctic Science Committee, www.iasc.no
ICES International Council for the Exploration of the Sea, www.ices.dk
IUCN World Conservation Union, www.iucn.org
IWC International Whaling Commission, www.iwcoffice.demon.co.uk
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<td>NAO</td>
<td>North Atlantic Oscillation</td>
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