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REPORT OF THE STUDY GROUP ON COD STOCK FLUCTUATIONS

Towards an implementation plan for the program on Cod and Climate Change (CCC)

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CONTENT

SUMMARY

The Study Group met in Hamburg 16 - 18 April 1991 with the aim to develop an implementation plan for the conceptual hierarchy of models as outlined in the Doc. C.M. 1990/G:50 (Further details in Terms of reference). Appendix 1 shows the agenda. The two first days of the meeting were attended by 33 scientists while 45 scientists were present during the joint meeting with the Working Group on Oceanic Hydrography during the last day.

The meeting took place at Helgoland Biologische Anstalt and was hosted by Hans-Peter Cornus, Institut für Seefischerei.

The meeting started by reviewing the problem and the principles of the model hierarcy as outlined in the Study Group Report ICES CM 1990/G:50.

The meeting was informed that the contributions on the regional description of cod stocks from Georges Bank, Iceland, White Sea, Barents Sea, Faroes, Skagerrak-Norwegian coast, Baltic and North Sea are finalized. The regional descriptions will be submitted for publication by ICES when the remaining contributions are at hand. A check list data base on recruitment for cod stocks is beeing worked out in collaboration with the Recruitment Processes Working Group. These data are partly based on the regional descriptions.

The Study Group reviewed related ongoing activities. There is a number of projects, particularly on biological process studies, which relate to the fundamental processes outlined in the Study Group Report 1990. However, few of them are put into model frameworks, which are the needed elements of the model hierarchy.

There are national programs related to Cod and Climate Change. In particular, there is large activity in Canada, and there is already organized a Canadian/U.S. program on Northwest Atlantic Fisheries and Climate. The WOCE program, and in particular the NORDIC WOCE are important international programs related to Cod and Climate.

The meeting expressed that studies on copepods population dynamics are important for understanding recruitment processes of cod. The Study Group should collaborate with the newly established ICES Study Group on Zooplankton Production to formulate an implementation plan.

An implementation plan for comparative studies on growth and survival of cod larvae/juveniles from the various Atlantic stocks was discussed and approved by the Study Group. The studies will be carried out in Norwegian mesocosms, and attention will be payed to control the effects of both maternal processes and the genetics variability within stocks as well as the environmental factors. The project will start in 1992. The first year only Norwegian stocks will be studied. The project will go on in 1993 by studying Faroese cod and Baltic cod.

During the joint meeting with the Working Group on Oceanic Hydrography the needs for a North Atlantic Circulation Model describing the basin scale climate were discussed. In particular, the variability of the exchange of Atlantic water and cold water across the ridges from Shetland to Greenland playes a profound importance on the marine climate of the habitats of most of the Atlantic cod stocks and of the habitat of the copepods which the early stages of cod depend on.

Relevant models from Institut für Meereskunde and Max-Planck institut für Meteorologie, in Hamburg, Bergen Scientific Centre, Bergen, and Harvard University, Cambrigde were presented. The meeting noticed that considerable advances in the development of numerical circulation and climate models have been made during the very recent years, and it seems that the demands from the Study Group can already be met by present models.

TERMS OF REFERENCE

ICES Council Res. 1990/2:15:

"The Study Group on Cod Stock Fluctuations (Chairman: Mr S. Sundby, Norway) will meet in Hamburg from 16 - 18 April 1991 to develop an implementation plan for the conceptual hierarchy of models outlined in Doc. C.M. 1990/G:50 and, in particular:

a) hold a joint session with the Working Group on Oceanic Hydrography to develop specifications for North Atlantic physical models;

b) revise the text of Appendices III and IV of Doc. C.M.1990/G:50 with a view to its consideration by the NAFO Symposium on "Changes in Abundance and Biology of Cod Stocks and Their Possible Causes" (September 1991), subsequent publication by ICES, and use for comparative studies;

c) plan comparative studies of the biological performance (e.g., growth) of cod under comparable environmental conditions, to be conducted in Norwegian experimental facilities.

The Study Group's report will be submitted to the Demersal Fish Committee and be referenced to the Hydrography and Biological Oceanography Committees."

INTRODUCTION

The ICES Study Group on Cod Stock Fluctuations met in Hamburg 16 - 18 April 1991 with the general aim to develop an implementation plan for the conceptual hierarchy of models as outlined in the Study Group Report of 1990 (ICES C.M. 1990/G:50). The meeting was especially concerned with those items specified in the terms of reference for 1991. Particularly, the planning of comparative studies of growth and survival on larval and juvenile cod from various stocks under controlled mesocosm conditions (Appendix 3), and the needs for a North Atlantic circulation model (joint session with the Oceanic Hydrography WG) was emphasized.

The meeting took place at Helgoland Biologische Anstalt and was hosted by Hans-Peter Cornus, Institut fur Seefischerei. The two first days of the meeting, chaired by S. Sundby, were attended by 33 scientists (Appendix 2), while 45 scientists were present during the joint meeting with the Working Group on Oceanic Hydrography during the last day, chaired by K. Brink. Rapporteurs were D. Cushing, K. Brander, K. Brink and S. Sundby.

THE GENERAL PROBLEM OF COD AND CLIMATE

Since the large part of the participants were new in the Study Group and not familiar with the work over the past year, the meeting was started by reviewing the general problem of cod stocks reproduction and growth as a part of the marine ecosystem, and the idea to approach the problem by building a model hierarchy after the principles outlined in the Study Group Report ICES CM 1990/G:50. As a comment to the hierarchy of models and the trophodynamic philosophy, M.M. Sinclair said that there are examples that populations may respond independently to physical forcing and trophodynamics. It was also claimed that heavily exploited species may be controlled by fishing effort alone. The other part of the meeting had the opinion that the way to the understanding of fish populations variability as a part of the marine ecosystem goes through quantification of the basic processes, which are biophysical processes. Realizing that the biophysical processes are the fundamental elements in ecosystem dynamics implies in principle that the physical environment on all scales must be considered. Even if the overall output of fish production seems independent of changes at different trophic levels, it does not imply that those can be omitted in the calculations to get the output numbers. However, it was a concensus that for all modelling approach, care should be taken to make the system as simple as possible. As for the Atlantic cod stocks, it is clear that they cover a wide range of different climate conditions and different ecosystems. Hence, the importance of the various biophysical processes is different for the various stocks. As for example the temperature signal is very strong in the cod stocks living in the lower range of temperature environment, while it seems unimportant in other regions.

STATUS OF THE STUDY GROUP AND RELATIONS TO OTHER GROUPS AND PROGRAMS.

On the development of an implementation plan for Cod and Climate Change program, T. Osborn said that there is considerable effort on coastal modelling today, with a great potential for support to central problems within the Cod and Climate Program. However, the biologists will be a very demanding client for the physical modellers. There is also considerable national activities on cod research. It is difficult to unify the national programs today, but there should be an amalgamation 3 - 5 years from now. S. Sundby said that it is neither expectable nor desirable for the Study Group to alter existing national activities on cod research. However, it is nescessary to bring physisists and biologists to much closer interaction in new projects to succeed along the lines of ecosystem approach. At present the Study Group should concentrate on developing the international part of the implementation plan, as the two items outlined in the terms of reference: 1. The comparative studies of larvae from various stocks and 2. The development of a suitable basin scale circulation and climate models for the North Atlantic Ocean.

The Study Group members reviewed ongoing activities related to Cod and Climate research (Appendix 5). There is a number of projects which relate to the fundamental processes, the first level processes outlined in the 1990 Study Group Report, particularly on biological process studies. However, few of them are put into model frameworks, which are the needed elements of the model hierarchy. Also few studies are found within the group of physical and biophysical process studies. On the second level of the model hierarchy, the regional environment, there are also a number of regional surveys on distributions, but very limited effort on regional modelling. On the third level, the basin scale environment, the activities are presently taken care of by other scientists than those connected to fisheries research.

A large part of the national activities related to Cod and Climate research are projects without connection to major national programs. The exeptions are the Canadian activities, where large efforts are focussed through the ongoing OPEN (Ocean Production Enhancement Network) and the planned NCSP (Northern Cod Science Plan). The WOCE program and in particular the NORDIC WOCE are international programs which strongly relate to the central CCC-problems of heat fluxes in the North Atlantic.

Two programs are directly linked to CCC: The Canadian/U.S. program on Northwest Atlantic Fisheries and Climate, which is underplanning, is a West Atlantic program under CCC, while the international GLOBEC is the superstructure of CCC. The international GLOBEC, described in Appendix 6, is presently evolving from a joint IOC/SCOR initiative.

Within ICES there are several Working Groups and Study Groups which partly consider problems of interest for Cod and Climate. These are the Shelf Seas Working Group, Multispecies Assessment Working Group, Study Group on

Zooplankton Production, Recruitment Processes Working Group and Oceanic Hydrography Working Group. Presently, the Study Group on Cod Stock Fluctuations has collaborated only with the two latter groups; with the Recruitment Processes WG on the "Check list" for cod and with the Oceanic Hydrography WG on the specifications for a basin scale North Atlantic circulation model.

DESCRIPTIONS OF ATLANTIC COD STOCKS AND THE COD AND HADDOCK CHECK LIST.

On the completion of the regional descriptions of the cod stocks for publication by ICES (the third specified item of the terms of reference) the meeting noted that the regional descriptions of cod stocks from Georges Bank, Iceland, White Sea, Barents Sea, Faroes, Skagerrak Norwegian coast, Baltic and North Sea are finalized. With regard to revision and synthesis, it was noted that the content of the first contributions (appearing in Appendices III and IV of the Study Group report 1990) was rather varied and that some editing and rearrangement would be helpful. Examples of the way in which some of the information could be tabulated and charted were presented. The contributors have now edited their manuscripts in a more uniform layout. The revision, synthesis and presentation of this material was discussed during the meeting and also the use of such information in relation to biophysical process models. The regional descriptions will be submitted for publication by ICES when the remaining contributions are at hand. The regional descriptions has also been an important source of information on the work with the Cod and Haddock "Checklist" by the ICES Recruitment Processes Working Group. An indexed database of references is being compiled at Lowestoft, and it will be available for research on cod and climate.

The Study Group propose that the synopses of information on cod stocks from all areas should be prepared for publication as a Cooperative Research Report in 1992. As well as the regional contributions there should be a synthesis of the information and a review of the gaps in our information base. The area contributions should be edited to a common format by the contributors and an editorial group. The Study Group propose that a paper summarising some of the comparative information from the area synopses be presented at the NAFO meeting in Halifax in autumn 1991.

The purpose of compiling the synthesis of biological information is to provide material for comparative studies and data for the design and implementation of biophysical models. This is an openended process; the detail and quality of information required depends on the purpose for which it is to be used, and it may be necessary to ask further questions from regional contributions in order to meet specific requirements. For example if transport during the pelagic stage is to be modelled, then information on the duration of the pelagic phase and possibly also on vertical migration will be needed. Other questions which it was suggested be added included: Evidence of food limitation affecting cod larval growth and mortality in each area.

Since there will inevitably be a number of such questions which arise during further studies of the cod-climate issue, the Study Group proposed that a list of contributors be compiled who may be able to provide answers for specific areas. The compilation of such a list was initiated during the meeting.

THE NEEDS FOR BIOPHYSICAL AND BIOLOGICAL PROCESS MODELS.

On the discussion on the need of biophysical and biological process models B. Rothschild referred to Beyer's sensitivity analysis of size specific mortality rates and suggested that there were two forms of population dynamics of interest, larvae and adults. The larval models comprise estimates of prey and predator density, (predator-prey) velocity, predator prey encounter rate, perceptive fields and avoidance fields, all of which are needed and describe the feeding processes. The adult model would include growth, gonadal and somatic, the age of maturation and the migration routes. Such biological models would be absorbed in the regional physical models. An important point is that such a physical model might have to be tailored to take in an appropriate biological model.

K. Brander described the Elliott model which is a mosaic of one dimensional models on the physical processes which generate biological production. The chairman noted that there was an array of physical models which might be appropriate. Norway will develop a physical model of the Barents Sea. The United States and Canada will use a combined physical and biological model on Georges Bank. UK will develop further regional phytoplankton models and regional zooplankton models.

G. Laurence gave an account of the physical/biological model on Georges Bank. The stratification process will be modelled physically. A haddock life history model from egg to adult has been constructed. A proportion of larvae do not do well as indicated by (RNA/DNA) ratios. Mortality rates are difficult to estimate.

It was recommended that the general set of models (as described in ICES C.M.1990/G:50) should be considered, by the Cod and Climate Program, and it was recognized that the development of such models will emphasize the different processes in different areas. Regional physical models are needed, which may differ in different regions and for different biological requirements.

H. R. Skjoldal made an introduction on the discussion of copepod models. In the northern North Atlantic *Calanus finmarchicus* overwinters below 500 m. They rise in late winter and spawn in the slowly developing spring bloom reaching copepodite stage IV and V before the peak. Their egg production depends upon food. There is one generation per year and in the autumn they migrate down again to 500 m.

In the open discussion, two major points arose (a) that the predators of cod larvae should be discovered if possible (b) that the advection of *Calanus* onto the shelf be studied for incorporation into regional physical models.

There was some discussion on growth and mortality of copepods. Growth rates are measured in the laboratories but not at sea. Similarly there are few measures of mortality rate. Food limitation occurs when there is growth rates less than the maximal at that age and temperature. It is necessary to measure mortality and growth rates; it was even estimated that VPA be applied to copepod populations. It was concluded that there are many indications that the abundance of *Calanus* is of importance to larval and juvenile cod; this could be tested in a model. Such questions might be considered by the ICES Study Group on Zooplankton Production. Further they should study the production of zooplankton in the areas where the cod larvae live.

COMPARATIVE STUDIES ON GROWTH AND SURVIVAL OF LARVAE AND JUVENILES.

G. Blom presented the plans on comparative studies of growth and survival of larval and juvenile cod from different stocks (Appendix 3). In 1992, Arcto-Norwegian, Baltic and Norwegian Coastal cod were planned to be reared from 5 mature females in Austevoll and Tromsø. After incubation, 20.000 yolk sac larvae with five replicates, are grown in plastic enclosures of 5 cubicmeters; in each there will be 2.000 genetically marked larvae from coastal cod. They are fed filtered natural zooplankton in excess (rotifers, *Pseudocalanus, Temora, Calanus).* Growth rates and survival rates will be measured up to lengths of 20-30 mm. The objective is to analize possible genetic differences in growth between stocks. Other stocks will be reared in later years.

In the following discussion it was mentioned that the optimal temperature for growth is 12 - 14 degrees C. It was therefore questioned if the experiment needed to be executed at a range of temperature. It was answered that all cod stocks grow at sub-optimal temperatures, particularly during the larval stages. The plans also include parallel experiments to be executed in Tromsø and Austevoll, where the environmental temperature differs by about 5 degrees C. It was questioned if a mesocosm was needed for the experiments. G. Blom replied that rearing of cod larvae is now a well known technology developed over the past 11 years. The survival rate from hatching to 30 mm juveniles is about 30 %. However, in laboratory we are still unable to rear juvenile cod in large numbers.

G. Laurence described two U.S. mesocosms, one floating and the other landbased (MERLE). In the latter, haddock larvae were grown for a month in mixed and stratified water; the food organisms were above the thermocline. Because the temperature can be controlled experiments on maximal growth rate at different temperatures could be executed.

Although two of the participants expressed scepticism to the possible outcome of the comparative studies, the meeting recommended that the comparative studies be executed in Norwegian facilities according to the plans outlined in Appendix 3.

OTHER COMPARATIVE STUDIES

Antifreeze proteins in cod at low temperatures.

Investigations at the Marine Science Labs, Logy Bay, Newfoundland have established that adult Atlantic cod from the NAFO Division 2J, 3KL stock manufacture antifreeze proteins in response to cold temperatures. In relation to the effect of climate change on cod distribution it would be useful to test whether similar antifreeze proteins occur in stocks from other parts of the Atlantic.

Plasma samples (1 ml) frozen at -20 degrees C, collected from juvenile and adult cod during January or February would allow this to be investigated for different areas. The location, depth and temperature at capture and the fish length for each sample should be recorded. The Study Group recommend that any research workers who may be able to supply such material should contact :

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Stable isotope methods for analyzing trophic structure.

The Multispecies Assessment Working Group considered (during their meeting at Woods Hole, December 1990) a secondary method to independently verify trophic structure of marine ecosystems. It was presented by Drs. Sam Wainright and Brian Fry, Marine Biological Laboratory, Woods Hole. The methods have the potential for retrospectively evaluating changes in the trophic economies, based on time-series of archived aging materials from fish. For example, nitrogen isotope measurements indicate a decline in trophic position of haddock at Georges Bank between 1925 and 1988. They are planning a study of feeding relations of cod and haddock in several regions of the North Atlantic, including Georges Bank, the Grand Banks, Iceland, Greenland, the North Sea, Barents Sea and the Baltic. A Norwegian archive, including sixty years time series of otolith samples from the Barents Sea cod, will be available for this study. The Report of the Multispecies Assessment Working Group has further details of the method.

CIRCULATION MODEL FOR THE NORTHERN NORTH ATLANTIC

The joint session (with the Oceanic Hydrography Working Group) on specifications for a North Atlantic circulation model was chaired by K. Brink. In his introduction, the chairman of the Oceanic Hydrography WG, B. Hansen, noted that it seems to be a general feature that the cod spawn where the North Atlantic Current hits the land, and consequently the properties of the current must be important for cod stocks. The chairman of the Study Group presented the background document "Cod and Climate and Needs for a Circulation model of the Northern North Atlantic" (Appendix 4). He said that the cod stocks live in waters cooler than the optimum for growth of the individual. He also pointed out that the observed temperature is often a proxy for other variables. He referred to the possible hierarchy of models, from biophysical models on a small scale to larger physical models of the circulation. He asked what drives the northward flux of warm Atlantic water and the southerly flow of cool water and how can they be modelled. What controls variation from year to year, and how does it affect the production of zooplankton?

T. Aukrust and J. Oberhuber presented an isopycnal model for the North Atlantic. The model is developed by J. Oberhuber, and T. Aukrust has applied it on the problem of bottom water formation in the Greenland-Iceland-Norwegian Seas (GIN Seas). The driving forces of the model are the atmospheric processes in general, including wind, heat budget and fresh water budget for the whole North Atlantic between the Arctic and the Equator. It has a high resolution capacity embedded within a lower resolution on a broader scale. The model included the Arctic basin. The north-east region, the GIN Sea, was shown in high resolution. The current distributions were displayed in detail both at the surface and in deep water, 700 m. The inflow through Faroe Shetland Channel peaks in August, September and October. The Greenland-Iceland outflow is minimal at this time, but reaches a peak in spring. Convection was charted, showing where the patches lay. From a question, the seasonal cycle is well described. However, the limitations are more on the quality of the input atmospheric data.

J. Oberhuber said that the technique of embedding a higher resolution in selected regions makes separate regional scale models redundant. In addition to the present application by Bergen Scientific Centre (IBM Centre) five other institutions are working with this model: Livermore, San Francisco, on JGOFS problems, Scripps Institution on El Nino processes, McGill University on Hudson bay fresh water run off and possible influence on the Mid Seventies Anomaly, Rendell Center, Southampton, eddies within the WOCE program and IOS, Vancover, on Pacific Ocean processes.

V. Gangopadhyay presented a set of models, each one dedicated for special process studies. He described some aspects of regional modelling, including ring formation, eddy/front interaction and dynamical models; the Gulf Stream region and JGOFS region are examples. The GAP region (Iceland-Faroes ridge) was shown in more detail in quasi-geostrophic mode and in primitive equation mode. The front was described as was the distribution of mixed layer depth. The biological model is based on a Michaelis-Menten formulation and shows the eddy patches of upwelling in the JGOFS region. An updating model was used to describe the distribution of the Gulf Stream. There will be a series of regional studies in the North Atlantic.

C. Heinze described a model of the Nordic Seas with a 20 km resolution and open boundaries, developed at the Institut für Meereskunde, Hamburg. With a two year spin up with climatological and actual data, the model transports matched the observed. The high variance off the Norwegian coast in the Lofoten region appears to be linked to along-shelf waves which take perhaps twenty days to travel from the Faroe Shetland Channel to the Lofoten region.

The chairman of the joint session (K. Brink) summarized the presentations of T. Aukrust, J. Oberhuber, V. Gangopadhyay and C. Heinze and described them as part of the model hierarchy, each having further degrees of sophistication:

(a) mosaic of one dimensional models, based on MLD.

(b) shelf models, barotropic and with active stratification.

(c) regional models (e.g. Harvard; based on quasi-geostrophic and primitive equations).

(d) basin scale models which describe the circulation in the Nordic Sea properly.

(e) complex models in which shelf and basin processes are resolved at the same time.

One might imagine embedding biological models in the physical, simple or complex.

In the following discussion T. Osborn suggested that the long shelf waves on the Norwegian coast be studied analytically, that egg and larval stages needed MLD models; he also noted that Langmuir cells developed immediately after the wind started. B. Rothschild proposed that biological/physical models be developed together, i.e. not merely put biological parameters in a physical model. He cited the effects of wind forcing on the biology and the sequestration of nitrate and ammonia in distinct food chains.

J. Meincke asked if the cod stocks were isolated. If so, why are broad scale models needed? There were three responses (a) that the West Greenland cod was colonized in the thirties from Iceland when four strong year classes appeared at Iceland. (b) that the copepods are distributed broadly and the very strong year classes are common across the Atlantic. (c) Some populations can be treated as isolated for long times. There was some discussion on the Aukrust version of the Oberhuber model. K. Brander pointed out that the spawning areas were specific in time-space, that the early life history was of great importance, that the local productivity was of importance as was the drift of larvae away from the spawning area. Also cod spawn inside local fronts and so the transports are locally defined.

B. Rothschild reviewed the population dynamics as viewed from the model hierarchy. The birth and death rates to which growth rates are added generate biomass. Two populations, grazers and algae may be linked in particular ways. Growth, mortality and reproduction are all affected by trophodynamics, on which density dependence and population regulation depend. He went on to describe predator/prey reactions in terms of encounter, relative velocities and light. Large scale models would describe events in general and one dimensional models might deal with events on the very small scale.

J. Bartsch pointed out that baroclinic three dimensional models were available for the North Sea and Georges Bank and that for the Barents Sea was being constructed, and these should be applied as a start in the Cod and Climate Change Program.

K. Brink said that five point must be considered in the Cod and Climate context:

1. How sophisticated do the models have to be?
2. Is the data base adequate for initialization, model driving and evaluation?
3. What gaps are there in physics and biology process knowledge?
4. Is the cod population predictable? Is it chaotic?
5. What phenomena need to be resolved by the models?

The meeting noticed that considerable advances in the development of numerical circulation and climate models have been made during the very recent years, and it seems that many of the demands from the Study Group can already be met by present models.

RECOMMENDATIONS

1. Acknowledging the large importance of the North Atlantic Current on several of the major cod stocks, the Cod and Climate Study Group considers the Nordic WOCE to be a very important project and recommends its implementation. Also the Study Group on Cod Stock Fluctuations encourages the participation of biologists at the Nordic WOCE field work. This work will improve the observational matrix in the Nordic Seas and the benefit of our knowledge of the environment in which the cod lives.

2. A variety of physical-biological models might be developed, for example calculations be performed on the North Atlantic Current which will improve our understanding of the migration routes and larval dispersion of the North Atlantic cod.

3. The development of coupled physical and biological models should be emphasized, for example in the study of cod spawning and early life history with respect to transport and productive cycles.

4. Comparative studies on growth and survival of larval and juveniles cod be executed in Norwegian facilities according to the plans outlined in the document by G. Blom (Appendix 3).

5. The synopsis of information on cod stocks from all areas should be prepared for publication as a cooperative research report in 1992.

6. Regional shelf models should be developed in promising areas, the Barents Sea, North Sea and the Gulf of Maine with the object of establishing particle tracking models of eggs and larvae.

7. The study group notes the interesting progress in basin scale and regional physical models and is encouraged by the state of art on the combination of biological and physical processes. In order to support and accelerate the work, ICES should enhance the communication and interaction between national activities focussed on combining physical and biological modelling together to understand the effect of climatic change on cod stocks.

Appendix 1

ICES STUDY GROUP ON COD STOCK FLUCTUATIONS.

Meeting in Hamburg 16. - 18. April 1991

AGENDA

TUESDAY 16. APRIL

1. THE PROBLEM.

   The cod and climate problem as a part of marine ecosystem dynamics.

2. THE SOLUTION.

   The hierarchy of physical and biological models, and further plans.

3. STATUS OF ICES STUDY GROUP ON COD STOCK FLUCTUATION.

4. STATUS OF RELATED ACTIVITIES.

   ICES Shelf Seas Working Group. ICES Multispecies Assessment Working Group. Recruitment Processes Working Group.

5. STATUS OF RELATED ONGOING PROGRAMS.

6. BIOLOGICAL PROCESS MODELS.

   Most important processes to be modeled during the recruitment stages and the adult stages. Copepod models. Multispecies interactions.

WEDNESDAY 17. APRIL

6. BIOLOGICAL PROCESS MODELS (continued..)

   Copepod models (continued..)

   Design of comparative growth studies in mesocosm.

7. THE INTERACTION BETWEEN BIOLOGICAL PROCESS MODELS AND PHYSICAL MODELS.

Linking biological process models to physical models.

Using physical models as administrative models between biological process models.

8. SCOPE OF IMPLEMENTATION PLAN

National parts of the program.
International parts of the program.
The role of related WGs.

THURSDAY 18. APRIL (Joint session)

9. THE HIERARCHY OF PHYSICAL MODELS

Linking basin scale processes to regional processes.
The needs for the purpose of Cod and Climate Studies.
Specification of northern North Atlantic Physical Model.
The driving forces of a northern North Atlantic Physical Model.

10. FINALIZING IMPLEMENTATION PLAN

Appendix 2

ICES STUDY GROUP ON COD STOCK FLUCTUATIONS

Participants at the meeting 16. - 17. April 1991

Astthorsson, O. S., Iceland
Blom, G., Norway
Borovkov, V., USSR
Brander, K., U.K.
Brink, K., USA
Campbell, S., Canada
Cornus, H-P., FRG
Cushing, D., UK
Daan, N., The Netherlands
Ehrich, S., FRG
Fuchs, F., FRG
Gangopadhyay, A., U.S.A.
Gratton, Y., Canada
Hansen, B., Faroe Islands
Heessen, H., The Netherlands
Hovgård, H., Denmark
Jakobsen, T., Norway
Jakobsson, J., Iceland
Larsson, P-O., Sweden
Laurence, G., USA
Malmberg, S-Å., Iceland
Netzel, J., Poland
Osborn, T., UNESCO
Rothschild, B. J., USA
Schnack, D., FRG
Schopka, S.A., Iceland
Schulz, N., FRG
Serebryakov, V., USSR
Sinclair, M.M, Canada
Sundby, S., Norway
Toresen, R., Norway
Weber, W., FRG
Ådlandsvik, B ., Norway

ICES STUDY GROUP ON COD STOCK FLUCTUATIONS
ICES WORKING GROUP ON OCEANIC HYDROGRAPHY

Participants at the joint meeting 18. April 1991

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Bartsch, J., FRG
Becker, G., FRG
Blindheim, J., Norway
Blom, G., Norway
Borovkov, V., USSR
Brander, K., UK.
Brink, K., USA
Buch, E., Denmark
Campbell, S., Canada
Candouna, M., FRG
Cornus, H-P., FRG
Cushing, D. H., UK
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ICES STUDY GROUP ON COD STOCK FLUCTUATIONS

COD AND CLIMATE - DESIGN OF COMPARATIVE GROWTH AND SURVIVAL STUDIES IN MESOCOSMS

by

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NORWAY

Introduction

Large scale production of juvenile cod (*Gadus morhua* L.) in mesocosms has been successfully carried out in Norway during the last decade (Tilseth *et al.*, in press). However, mesocosms have not only been applied to develop extensive production methods of juvenile marine fishes, but also to study population dynamics during the early life stages of fishes, especially cod. Findings from enclosure studies in Norway have significantly contributed to elucidate the importance of predation as a regulatory recruitment mechanism (Øiestad, 1985). Accurate estimates of growth and particularly survival of cohorts of fish larvae in the sea are difficult to obtain due to ageing and sampling problems, and modest changes in daily growth or mortality rates can cause major changes in recruitment levels, especially if they occur during the larval stage (Houde, 1987). An experimental approach is to investigate these processes is in enclosures or mesocosms. Mesocosms can be experimentally manipulated to determine how larval growth, stage duration, and survival can be affected by variations in prey levels, temperature, light etc. and the predators that have access to the larvae, an advantage over field survey approaches. The results from such studies can be used to develop models e.g. feeding and predation models, growth and survival models (e.g. Blom *et al.*, in press)

In the Doc. C.M. 1990/G:50, the ICES Study Group on Cod Stock Fluctuations emphasized that comparative studies of the biological performance of different stocks of cod under comparable environmental conditions should be initiated, and preferably in Norwegian experimental facilities. Major problems to study are e.g. growth and survival potential of different cod stocks at similar temperature and light conditions, level of activity, behaviour disparities with respect to cannibalism or prey preference, and the significance of day-length on growth. Laboratory studies could also be included e.g. food consumption or oxygen consumption rates with increasing temperatures (included Q_{10}). The aim of these studies should be to get better knowledge of the phenotypic and genotypic differences between stocks at all stages in the life history, particularly from hatching to the juvenile stage (length of cod: 60-80 mm). The results from these studies should constitute the basis of the development of Basic Biological Process Models (BBPM), and BBPM should comprise common and essential elements in the population dynamics of all stocks and their environments. In addition, it might be possible to establish broodstocks of the different Atlantic cod stocks in Norway.

Experimental design

Location of the facilities

From 1992, parallel studies are planned to be conducted at the Austevoll Aquaculture Station in western Norway, 40 km south-west of Bergen, and at the Norwegian College of Fishery Science, University of Tromsø, northern Norway, thus having two distinct temperature and light regimes.

Facilities

Black, plastic enclosures (2.0 m in diameter, and 3.5 m deep with a conical bottom) with a volume of 5 m^3 are used as rearing units, and they are mounted in enclosed, marine ponds (see Fig. 1).

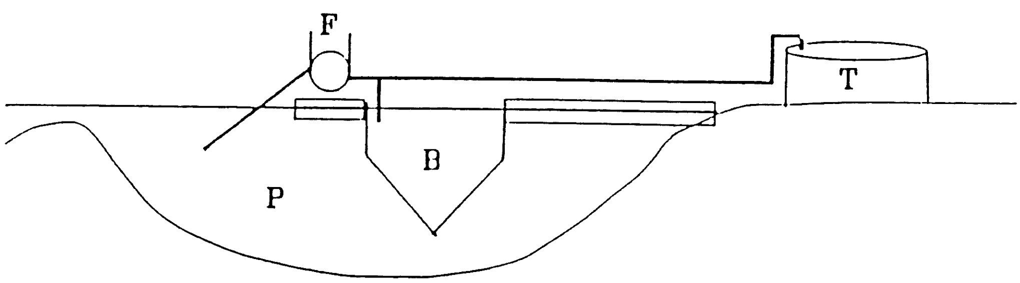

Fig. 1. Principles of the enclosure technique. P: enclosed sea water pond or productive site; F: filter for concentrating zooplankton; B: rearing bag and T: rearing tank. From Tilseth et al. (in press).

The enclosures are equipped with an outward hose from the bottom to the surface for renewal of the bottom water, and one internal flexible hose with a cod end of plankton-net (350-1000 μm) to maintain the water level in the enclosures. Before cod larvae are stocked in the enclosures, they are filled with filtered (265 μm) seawater, and zooplankton inocula (mainly copepod nauplii) to establish densities of 100-500 microzooplankters/l. The salinity in the enclosures is usually > 31 ppt before yolk-sac larvae are introduced. Filtered, natural zooplankton constitute the food items for larval and early juvenile stages of cod in the experiments. Main zooplanktoners in the marine ponds are usually rotifers (*Synchaeta* sp.), and nauplii and copepodites of calanoid copepod species as *Temora longicornis*, *Centropages hamatus*, *Pseudocalanus* sp., *Calanus finmarchicus*, and *Acartia* spp. The filtering unit consists of a pump (capacity > 5 m^3/min), and a tank with 2 rotating wheels. Applied prey densities in the enclosures are 50 to 500 copepod nauplii/l from 1 to 3 weeks after the release of of larvae, 20 to 150 copepodites/l from 3 to 6 weeks after release, and 5 to 30 large copepodites (preferentially *Calanus*)/l from 6 weeks after release. The larval and early juvenile cod are fed **in excess** through the study period.

Plan for 1992

In 1992, a comparative growth and survival study of Arcto-Norwegian cod, western Baltic Sea cod, and Norwegian coastal cod is planned. Genetically marked Norwegian coastal cod is used as a control group. Recently, a genetically marked broodstock was produced at the Institute of Marine Research, Bergen. These fish are homozygous for the rare 30-allele in the enzyme phosphoglucose isomerase (*PGI-1*) expressed in white muscle, and can be detected by starch gel electrophoresis from the yolk-sac stage and onwards (Jørstad *et al.*, 1987; Blom *et al.*, 1990).

Eggs from 5 different mature females (length: > 65 cm) from each stock are fertilized with milt from 1 male in the originating area or country, and separately packed and transported by air to Bergen and Tromsø. It is important that vital data (e.g. length, weight, condition factor, egg batch and total fecundity) of the parental fish are recorded. Dr. Per Solemdal at the Institute of Marine Research will prepare guide lines for the parental fish measurements and fertilization procedures.

Reception of fertilized egg should occur between 1 March and 10 April at Austevoll, and between 1 April and 10 May in Tromsø. Incubation of eggs from each **family** (1 ♀, and 1 ♂) takes place at Austevoll and in Tromsø. Approximately 20.000 yolk-sac larvae from each **family** (1-3 days old) are released in separate enclosures, giving 5 replicates of each stock. In addition, c. 2.000 genetically marked yolk-sac larvae of one **family** of Norwegian coastal cod are released in each enclosure. The enclosure experiments are ended when the cod has reached a length of 20-30 mm. Later, the collected juvenile fish from each enclosure might be transferred to separate tanks and offered formulated feed in excess (e.g. dry feed), and grown to a size of 60-80 mm.

It might be possible to study the temperature effect more specifically by releasing e.g. two cohorts of larvae of the same stock, thus having two temperature regimes, however, this will make the study more expensive and complicated.

Hydrography (temperature, salinity and oxygen level), prey densities, light intensities, and the water exchange rate in the enclosures are monitored 2-3 times a week. Egg diameter, buoyancy and hatching time are recorded, and larval standard length and weight of each **family** from the different stocks are measured at release. At the end of the enclosure experiment, the total number of fish in each enclosure is recorded. The cod are measured for standard length and wet weight, and frozen at - 70 °C within few hours after sampling. The frozen materials are later analysed by starch gel electrophoresis, for identification of *PGI-1* genotypes to distinguish between control group and the different stocks applied. The same procedure might be used after the on-growing experiments in tanks.

This experimental design makes one able to estimate growth and survival rates between the yolk-sac stage and the juvenile stage, and the variance in growth and survival **within** and **among** stocks, and also of importance the variance **among** enclosures (control groups).

A preliminary estimate of the economical expenses connected to a comparative study conducted both at Austevoll and Tromsø, amount to about 1.5 million NOK (US$ 230.000).

Preliminary plan of future experiments

Table 1 shows a preliminary plan of comparative studies of different cod stocks between 1992 and 1996.

Table 1. A preliminary time schedule for comparative studies of different cod stocks.

Cod stocks	1992	1993	1994	1995	1996
Arcto-Norwegian cod	X				
Baltic Sea cod	X				
Canadian cod				X	
Faroes cod				X	
Georges Bank cod		X			
Icelandic cod		X			
Irish Sea cod			X		
North Sea cod					X
Norwegian coastal cod	X	X	X	X	X
West Greenland cod			X		
White Sea cod					X

Before the egg materials from the different stocks are transported to Norway, a certificate of the potential diseases of the broodstocks must be available.
The certificate should contain information about:

1. Disease outbreaks and parasites experienced.
2. Pathogens or parasites the broodstock have been shown to harbour.
*3. Pathogens or parasites the broodstock have been shown **not** to harbour.*
4. Pathogens or parasites the broodstock could be expected to harbour.

The experiments in Norway should be carried out in accordance with the ICES Document CM 1990/F:37: A Report of the ICES Working Group on Introductions and Transfers of Marine Organisms (Code of Practice). Hence, incubation of eggs, enclosure experiments, and tank experiments should be conducted in an approved quarantine situation.

Limitations and what we can expect to gain from comparative studies

Limitations

Larval growth and survival rates in comparable enclosure experiments have been somewhat variable, and hence the replicability between enclosures may vary from one experiment to another. This has to be taken into consideration when planning the comparative experiments between cod stocks, and is of importance if the purpose of a comparative study e.g. is to demonstrate growth and survival differences among stocks.

A comparative study of different stocks is **totally dependent** on a well organized and accurate timetable with respect to egg fertilization and transport of eggs to Norway. Thus, the collection of parental fish and preparation of the disease certificate in the the native country or area should be organized in proper time.

There is an increasing problem with fish diseases in Norway due to the comprehensive fish farming, and to prevent further spreading of diseases the regulations have become much more rigorous, recently. Before egg material is imported from other countries, a permission certificate must be issued from the Dept. of Agriculture. At this moment, it is difficult to conclude whether future regulations may render impossible import of eggs to Norway from other countries.

The experimental design should be based on clearly testable hypotheses, thus suggestions for future research and main objectives of the comparative studies should be discussed in relation to the aims of the Cod and Climate program. The financial aspects must also be taken into consideration when planning future experimental designs.

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ICES STUDY GROUP ON COD STOCK FLUCTUATION
ICES WORKING GROUP ON OCEANIC HYDROGRAPHY

COD AND CLIMATE CHANGE AND NEEDS FOR A CIRCULATION MODEL OF THE NORTHERN NORTH ATLANTIC

BACKGROUND DOCUMENT FOR THE JOINT SESSION OF THE ICES WORKING GROUP ON OCEANIC HYDRGRAPHY AND THE ICES STUDY GROUP ON COD STOCK FLUCTUATION, IN HAMBURG 18 APRIL 1991.

The biological basis.

The Atlantic Cod stocks are distributed from the Spitsbergen and Labrador regions to the Bay of Biskay and Chesapeake (Figure 1), covering a wide temperature range, from below 0 °C about 15 °C. The total biomass of the stocks is, however, assymetrically distributed over the temperature range with the median at about 4 °C (yearly mean), implying that areas in the boundary regions between the Arctic and the Subarctic are the most important. Figure 2 shows the spawning stock biomass distribution over the temperature range. Hence, the most frequent ambient temperature for cod is considerably lower than the optimum temperature for growth, which is near the upper temperature bound.

It has been demonstrated that the recruitment of stocks in the lower temperature range is influenced by the temperature during first months after spawning, low sea temperatures giving poor year classes, while high temperature has the potential of forming a strong year class. The difference between "low" and "high" temperatures in this context is no more than 2 °C. On this background it should be expected that even moderate changes of climate would substantially influence reproduction, growth and distribution of Atlantic cod stocks.

Temperature influences a large number of basic biological processes in relation to cod, like maturation, spawning, feeding, growth, mortality and migration. All of these processes interact in a number of ways at different time intervals in forming a new year class. The timing of larval production in relation to copepod production, the main food

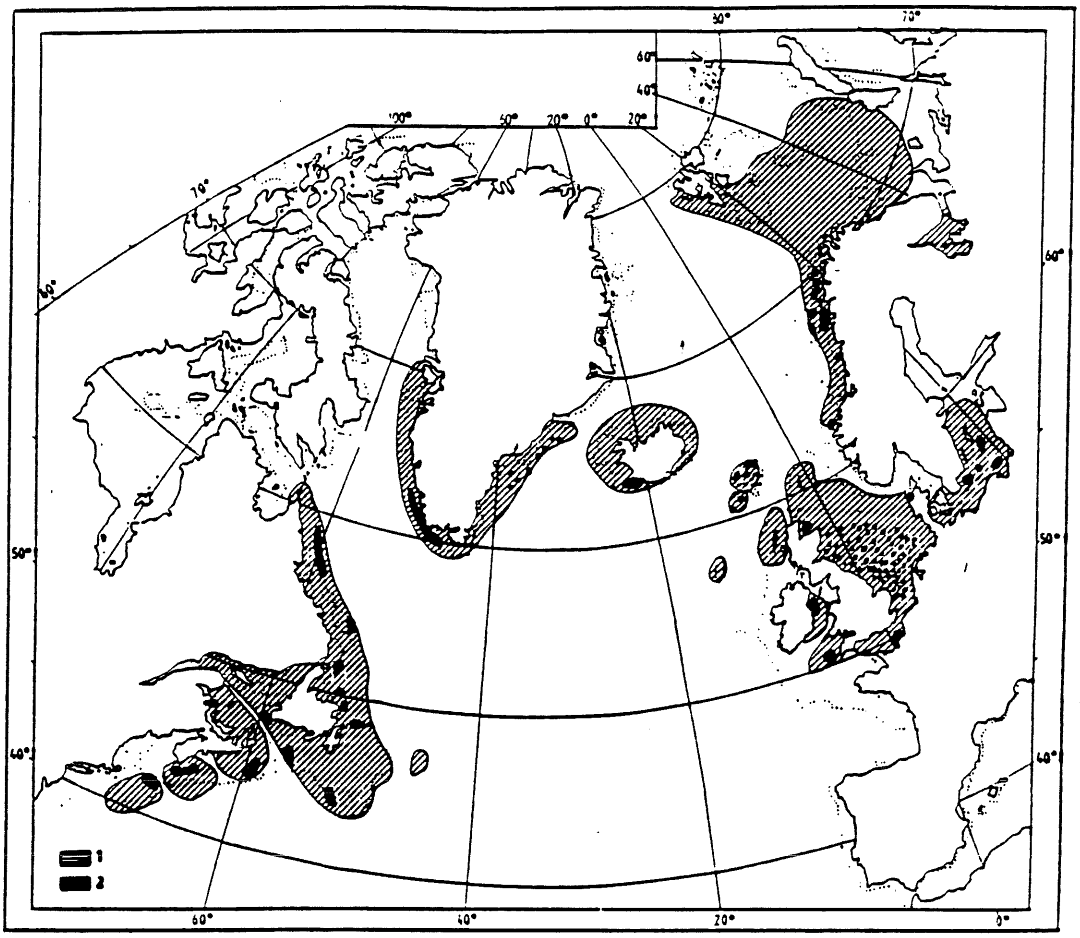

Figure 1. Distribution of cod stocks in the North Atlantic.
1) Area of distribution. 2) Area of spawning.

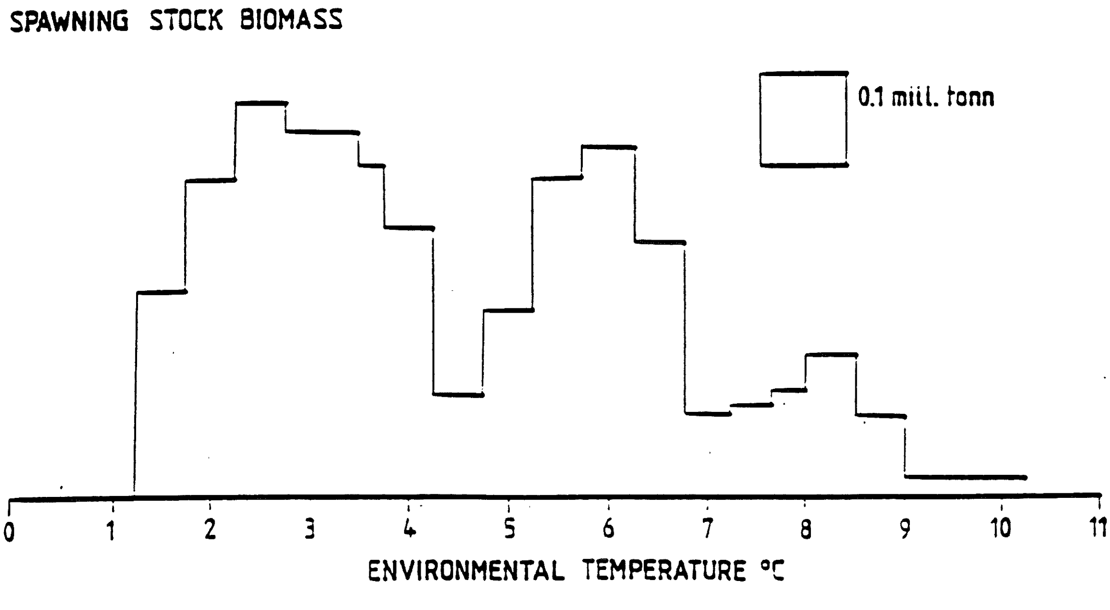

Figure 2. Distributon of Atlantic cod spawning stock biomass over the range of environmental temperature. .(The stocks of Gulf of St. Lawrence and Baltic Sea is not included).

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item for the important early life stages of cod, is considered to be an important mechanism for the recruitment (e.g. Cushing 1990). The growth rate itself of fish larvae through the vulnerable early stages is considered to be another important recruitment mechanism. All of these processes and mechanisms are regulated by the temperature, and it becomes increasingly important at the lower part of the temperature range.

In addition to the direct influence of climate on the successive life stages of cod, climate influence the cod through the interacting species, as examplified above by the timing of copepod production. The general importance of the interacting species for the production of cod is also clearly indicated by the difference between the most important ambient temperature for cod (Figure 2), and the optimal temperature for growth (and prefered temperature during laboratory conditions) which is 12 - 14 ^{0}C.

Probably the most important interacting species are the copepods which dominate the diet of the early stages. Particularly Calanus finmarchicus is the dominant species of the Northeast Atlantic and Pseudocalanus of the Northwest Atlantic. The population dynamics of copepods are strongly linked to the physical processes both directly and through the primary production, and this focusses on a set of physical processes and other climate parameters than temperature, e.g. light, turbulence, stratification and nutrient fluxes.

The model hierarchy.

The biological basis for the Atlantic cod stocks (outlined above) focusses on a number of physical processes important for reproduction and growth of cod stocks. To be able to understand the variability in cod production, the relative importance of the single processes must be understood, which implies that the problem should be approached by modelling the basic biological processes, as outlined in the Cod and Climate documents (ICES CM 1990/G:50). A temperature change is linked to changes in a number of other physical parameters (wind force and direction, fluxes of water masses, cloud cover and light intensity) all of them having the potential to influence fish stocks production. The effort from the physical side to understand more of in which way the different climate parameters are linked to each other and what are the driving forces, therefore, coincides whith the needs of the model hierarchy concept of the Cod and Climate Change Program.

Regional shelf sea models has proven to explain fairly well physical changes caused by the regional wind field. More developed shelf sea models which include the processes of air-sea heat exchange have the potential of describing in more detail the climate of the ambient water masses for fish stocks. Such models will be valuable for studying the drift of larvae and their growth potential. However, regional shelf sea models can not describe important processes of the large scale year-to-year and multi-year climate variations. The mid-seventies anomaly of the northern North Atlantic (Dickson et al., 1988) is an example of that longer term climate changes must be caused by large scale processes, and that such changes may induce large changes in the primary production of the sea (Cushing, 1988), which in turn influence the production through the whole ecosystem.

The northern North Atlantic - Processes and needs for modeling.

Even though the cod production is limited to the shelf regions of the North Atlantic, the adjacent deep sea regions (e.g. Norwegian Sea, Greenland Sea and Labrador Sea) are important areas of copepod production. Consequently, the importance of advection of properties from the ocean regions onto the shelf seas is not limited to physical properties, but includes the advection of biomass from the secondary production. For the Northeast Atlantic it has been demonstrated that variations in the influx of Atlantic water across the Faroe-Shetland Ridge may propagate all through the Nordic Seas. It is to be expected that similar variation should be found in the Northwest Atlantic.

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This focusses on particular problems linked to processes of the northern North Atlantic:

* what are the driving forces of the northward flux of warm Atlantic water and the southward flux of cold Polar water and Bottom water.

* how can these fluxes be modeled.

* which processes cause the year-to-year variability of the fluxes.

* how does the variability of the fluxes influence the plankton production, in particular the copepod production of the Labrador, Greenland and Norwegian Seas.

* how does large scale ocean processes (physical and biological) influence on the shelf sea dynamics and production, and which role does advection of properties onto the shelves play.

Many of these problems are similar to problems already posed in other international programs although they may be differently articulated. In particular for the Nordic WOCE program and the Greenland Sea Project the objectives are very similar, and preliminary results already point towards answers. However, the processes should be modeled to make them applicable for the adjacent regions.

Present basin scale models of the Atlantic fails to adequately model the very important flux of Atlantic water into the Nordic Seas, one of the main sources for climate variation in this region. Consequently, they will neither model adequately the southward fluxes of Arctic water. The reason for this shortcoming may be partly due to the model resolution and partly due to processes which are not included:

* the model topography is insufficiently detailed in the northern part.

* the Arctic Basin is not included.

* the ice cover is not properly modeled.

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* atmospheric forcing of in the Arctic is insufficiently modeled, particularly the air-sea heat exchange.

* the process of bottom water formation in the Labrador-Greenland-Norwegian-Barents Seas is not included.

Can we cope with these limitations by constructing a dedicated northern North Atlantic circulation model, or is it possible to make the present basin scale models more sophisticated to include the above details? These are key questions in modeling the ocean climate of the Atlantic Cod stocks' environment.

Appendix 5

Overview of present national plans and activities related to problems of Cod and Climate.

Canada

Department of Fisheries and Oceans conducts a number of "regional" studies on cod biology in support of assessments. There is an oceanographic monitoring program (AFAP) on the Scotian shelf and in the Gulf of Maine.

The largest effort on cod research is now in the OPEN program (Ocean Production Enhancement Network), a 3 years program, and in NCSP (northern Cod Science Program), a 5 years program. Both these programs aim at cod ecosystem research, and hence cover a wide range of topics. The motivation of the programs are to improve fish production and the assessment, and it is realized that this can only be achieved through an interdiciplinary approach.

There are now plans on a joint US/Canadian CCC-program on the West Atlantic cod stocks (See Appendix 6), at this stage it covers investigations on the Georges Bank, and a Canadian working group on CCC has been established.

Denmark

The work on cod research has been focussed on the Greenland cod stock. Presently the capacity for other work than stock assessment is low. However, the study of time series of stock adundance and how it relates to climate fluctuations will be followed up by studying old literature from various sources.

On the ocean climate research Denmark will participate in the Nordic WOCE program.

In the Baltic there are studies on development of cod eggs at low oxygen concentrations.

Faroe Islands

The asssessment of the two Faroese cod stocks include stratified groundfish surveys and 0-group survey.

The ocean climate is studied by hydrographic surveys, and focus is put on the dynamics of the North Atlantic Current past the Faroes, where the main inflow to the Nordic Seas occurs.

A special project is carried out to reveal whether the difference in growth rate between Faroe Plateau Cod and The Faroe Bank Cod is genetically caused or environmental.

Germany

German activities on cod research are found in various regions: West-Greenland, East-Greenland, the Baltic and the North Sea.

Off West-Greenland BFA has run groundfish surveys, and time series exist.
IFM has studied trophic relations of cod and others species. IFM has also conducted studies on larval drift and ecology in 1990, and there are plans to continue. In connection with the Icelandic 0-group survey, ecology of young fish is studied.

Off East-Greenland BFA has run groundfish surveys.

In the Baltic Sea BFA is conducting groundfish surveys. In the Western Baltic there is an ichtyoplankton monitoring program with surveys all through the year. The time series show low abundance of cod larvae. There are plans of cod sea ranching.
In the Central Baltic (Bornholm Basin) abundance and distribution of eggs and larvae are surveyed, and there are detailed studies on vertical distribution and drift in relation to the pronounced stratification (salinity, oxygen, circulation). Experiments are also conducted on the effect of reduced oxygen and predation by herring and sprat.

In the North Sea BFA is conducting quarterly ground fish and young fish surveys for stock assessment. Small scale experiments to assess the influence of different parameters (e.g. wind strength, light, turbidity) on the catch data and a stomach sampling program are parts of these investigations. Experiments on a feeding model are planned, e.g. digestive rate related to the stress factor.

Iceland

The assessment of cod includes stratified groundfish surveys giving biomass indices, recruitment (1 -2 year), distribution and temperature. There is a time series on stock size and recruitment by VPA since 1940. The quota regulated fishery also gives data from commercial fishing vessels on distribution and CPU.

0-group surveys have been conducted each year in August since 1970. There are studies on cod/capelin interactions including the environmental variables. At the spawning sites off the southwest coast of Iceland the spawning ecology in relation to phytoplankton, zooplankton and hydrography is studied.

The ocean climate around Iceland is monitored 4 times per year, in February, May, August and November, and there is a project on current measurements of the Atlantic inflow.

The Netherlands

Present research on cod is mainly restricted to a number of routine programmes, and there is no programme specifically directed towards Cod and Climate.

1. - Participation in quarterly coordinated international trawl surveys, covering the whole North Sea, mainly to a) provide recruitment indices, b) describe changes in fish distribution, c) the data also provide possibilities to study changes in growth and maturity (one of these surveys runs since the late '60s).

2. - Participation in the Stomach Sampling Programme. Netherlands Institute for Fisheries Investigations is responsible for the analysis of cod stomachs.

These two programmes together with the routine market-sampling, consume most of the available time for cod research.

Tentative plans for 1992 may be:

1. - Cooperate with our colleagues in Scotland who intend to study egg production in haddock as a start of recruitment studies in haddock.

2. - Cover the southern part of the North Sea and hence get a complete coverage of cod spawning in the North Sea.

3.- Research on early juveniles of cod in the southern North Sea.

Norway

MARE NOR is a program on the coastal ecology of northern Norway where studies on copepods and coastal cod are important parts. It is a 3 year program in its second year, but there are plans to carry on for another 3 year period.

Work is now going on to implement the Blumberg and Mellor circulation model for the Barents Sea and eastern Norwegian Sea. The first application of the model will be to study transport, spreading and mortality of early juveniles cod compared to time series of 0-group distribution and abundance.

A physical model (on a Coriolis-table) has been constructed in 1991 to study the initial spreading of eggs and larvae from the spawning areas in Lofoten, and particularly the role of tides has been demonstrated.

A research program on stock enhancement of coastal cod has now been terminated and is followed up by a commercial program to enhance coastal cod stocks. Mass production of cod in mesocosms from the egg stage to 30 mm juveniles is a part of this program.

The monitoring of the Barents Sea cod includes distribution and abundance of early juveniles, 0-group (in cooperation with USSR), 2-group. An extensive trawl survey on adults conducted by a number of commercial trawlers together with research vessels is now also a part of the assessment. There is time series on VPA from 1946.

Plans are now worked out to implement a multispecies model of the Barents Sea emphasizing on cod.

Sweden

Research is focussed on the Baltic cod stocks. Ecological studies of the early stages are done at the Institute of Marine Research and Stockholm University. It includes physiological investigations on eggs, sperm, fertilazation and the early development in relation to salinity/density.

Rearing experiments are carried out at the Institute of Marine Research who is also responsible for the assessment work.

UK

Routine research surveys and assessments provide time series of population data for cod stocks around the British Isles.

The distribution and growth of cod larvae has been studied in the Irish Sea, in relation to the physical environment. Further modelling and field work is planned on the influence of physical variability on plankton food chains leading to cod larvae.

The comparison of biological characteristics of cod populations throughout the North Atlantic (from information supplied on checklists) is being coordinated at Lowestoft, and a bibliographic database is being prepared.

USA

Many of the projects related to CCC are being conducted and planned at the Northeast Fisheries Center, and many of them relate to the recruitment stage:
1. Cod recruitment on Georges Bank - role of predation. 2. Stratification study on Georges Bank and its effect on larval fish survival. 3. Copepod *Calanus Finmarchicus* as an indicator of climate change in the North Atlantic. 4. Effects of temperature and water column structure in the Gulf of Maine on the production rates of zooplankton and larval fish. 5. Retrospective analysis of Ichtyoplankton by using the MARMAP time series. 6. Effects of climate change on ecosystem responses: A mesocosm approach using the MERL system with cod as the fish component.

A numerical circulation model based on finate element mesh has been constructed for the coastal region covering Georges Bank, Gulf of Maine, Bay of Fundy and the southern parts of the Scotian shelf.

In addition to the US/Canadian plans on a Northwest Atlantic CCC (Appendix 6), IOC and SCOR are now working out plan to develop GLOBEC (Global Ecosystem Dynamics) into an international progam (Appendix 7).

USSR

In addition to the work on the assessment of the Barents Sea cod, the abundance and distribution of early juveniles are monitored together with the distribution of food and environmental parameters. Egg surveys are carried out at the off shore spawning areas off Northern Norway, and there are investigations on stock fecundity.

The 0-group survey in August/September is carried out in cooperation with Norway.

There have been studies on the influence of low temperature on the survival of 1- 2- and 3- group cod.

There is an extensive monitoring on the ocean climate of the Barents Sea, a very long hydrographic time series exist for the Kola section (since the beginning of this century). In particular, these data have been used to study the various frequencies of ocean climate variability and their causes.

The White Sea cod is mainly studied from the Moscow University, and they focus on ecological and early life investigations.