The Amoebe Plan

Part 1: Overall plan

A Model-based and data-driven Operational Ecological Biomass Estimator

A 10-year multidisciplinary research and development project to improve the understanding of the dynamics of the marine ecosystems, and to produce a tool to meet the future increasing demands for an ecological approach to marine management based on precautionary principles.

29 October, 2002 ISBN: 82-7461-054-7

Contact person: Einar Svendsen, Institute of Marine Research, PB. 1870 Nordnes, 5817 Bergen, Norway
PHO.: +47 55 23 84 58 /+47 90 99 73 43, E-MAIL: EINAR.SVENDSEN@IMR.N

Foreword

The idea for an AMOEBE was initiated some 30 years ago by professor Jens G. Balchen at the Norwegian University of Science and Technology. This lead to the Norwegian research programme Havbiomodeller (marine bio-models) (1975-1983). Since then several Norwegian and international research programmes have been dealing with studies of the marine ecology, but so far the results have not lead to the qualitative and quantitative knowledge and tools needed for an ecological approach to better fishery management. Due to the complexity and highly variable dynamics of the oceans, this can only be achieved by extensive use of mathematical models in close integration with regular observations and basic knowledge of the marine ecosystem functioning.

In present-day fishery management, species interactions and relations between living resources and the environment are considered only fragmentarily and in rare cases. The management of fish in the Northeast Atlantic is mainly focused on keeping spawning stocks next year high enough for the recruitment not to be severely hampered, with no or little consideration of what is good management on the long run.

- *During the last 25 years, several important factors have changed making the chances of success much higher today:*
- *The knowledge of several basic ecosystem processes is much higher and more quantita tive.*
- *The numerical modelling tools, knowledge and competence are now available at several Norwegian universities and institutes.*
- *The capacity of computers per unit cost has increased by a factor of 10 000 and will continue to increase.*
- *The availability of Internet makes it possible to use jointly distributed databases, compu ter systems and models.*

AMOEBE has now become a joint initiative from all the leading Norwegian institutions within marine research with the mission to strengthen the national competence within marine ecology and to fulfil the vision of ICES (International Council for the Exploration of the Sea) to: "improve the scientific capacity to give advice on the human impact on, and impacted by, marine ecosystems". AMOEBE is also in line with the plans of Global Ocean Observing System (GOOS and EuroGoos), and the EU strategies for the 6th Framework Program. In addition fisheries management are highly international, so strong links are already in place or will be made to the international research community, and industrial partners will deliver well defined technological elements of the system.
AMOEBE will also contribute to the recruitment of scientists, which will be a critical factor in the approach towards the overall visions for Norway as a fishery and fish-farming nation.
So, the motto is:

We can only make it if we try hard enough!!

Einar Svendsen

Editors:

Einar Svendsen[1] (chairman), Jens Glad Balchen[2], Johnny Johannessen[3], Bjarte Bogstad[1], Jo Arve Alfredsen[2], Dag Slagstad[4], Morten Skogen[1], Kurt Tande[5]

with input from individual module descriptions:

Module 1: (to be written)

Module 2: Helge Drange[1] (chairman), Geir Evensen[1], Tore Furevik[6], Lars Jørgen Natvik[3], Francisco Rey[1], Asgeir Sorteberg[7], Einar Svendsen[1], Bjørn Ådlandsvik[1], Else Hegseth[5], Lars Petter Røed[8]

Module 3: Kurt Tande[5] (chairman), Dag Slagstad[4], Webjørn Melle[1], Øyvind Fiksen[6], Stein Kaartvedt[9], Olav Vadstein[2], Are Edvardsen[5], Ole-Petter Pedersen[5], Morten Skogen[1], Einar Svendsen[1]

Module 4: Svein Sundby[1] (chairman), Bjørn Ådlandsvik[1], Øyvind Fiksen[6], Arild Folkvord[6], Tara Marshall[1], Torstein Pedersen[5]

Module 5: Geir Huse[6] (chairman), Jens Balchen[2], Anders Færnø[6], Jørgen Schou Christiansen[5], Einar Svendsen[1]

Module 6: Bjarte Bogstad[1] (chairman), Sigurd Tjelmeland[1]

Module 7: Sigurd Tjelmeland[1] (chaiman), Steinar Sælid[12], Harald Yndestad[10], Erling Moxnes[6], Geir Ottersen[1], Jan Erik Stiansen[1], Peter Corceron[11]

Module 8: Jo Arve Albretsen[2], (chaiman), Johnny Johannessen[3], John Dalen[1], Jens Glad Balchen[2]

Module 9: Rolf Henriksen[2] (chairman), Kari Brusdal[3],[13], Hans Julius Skaug[1], Paul Budgell[1], Gudmund Høst[14], Alf Harbits[11]

Module 10: Marit Natvig[2] (co-chairman), Rolf Korneliussen[1](co-chairman), Vinjar Wærensk jold[15], Kåre Villanger[15], Harald Gjøsæter[1], Lars Vognhild[16], Sigbjørn Mehl[1], Kjell Nedraas[1], Einar Svendsen[1]

Module 11: Einar Svendsen[1] (chairman), Bruce Hackett[8], Kjell Røang[15], Bjørn Ådlandsvik[1], Roald Sætre[1], Vinjar Wærenskjold[15]

1.Institute of Marine Research, 2.Norwegian University of Science and Technology, 3.Nansen Environment and Remote Sensing Centre, 4.SINTEF, 5.University of Tromsø, 6.University of Bergen, 7.Bjerknes Centre for Climate Research, 8.met.no, 9.University of Oslo, 10.Aalesund University College, 11.Fiskeriforskning, 12.Predictor, 13.Norsk Hydro, 14.Norwegian Computing Center, 15.Christian Michelsen Research, 16.NORUT-IT

Content

SUMMARY AND MOTIVATION

Fisheries and fish farming represent Norway's largest export value based on renewable resources (second largest in total), and Norway is the world's second largest export nation of fish and fish products. The national goal is to increase the export value from 30 to 150 billion NOK in the period 2000 to 2020. The value of the fisheries for the national economy is assumed to be manifold of the export value.

To reach this goal investments are needed in many fields, not the least on creating new knowledge related to the fisheries and the marine environment. Therefore the broad Norwegian research communities within oceanography, meteorology, fishery and marine biology, ecology, mathematics, system theory and fisheries management have decided to cooperate in the development of AMOEBE. AMOEBE is a 10-year research project for developing a model based tool to **integrate** existing and new multi-disciplinary knowledge and data from physics to whales into a new system for assessing the historic, present and future states of the marine ecosystems of the high north, as a function of the main driving forces on the systems; variable climate/weather and harvesting/fisheries. Effective observations of the ecosystems include complementary observations from ships, satellites, buoys and maybe aircraft and autonomous underwater vehicles (AUV). This includes the development and implementation of modern technology within the fields of marine instrumentation, information and communication.

Since there will be a shortage of marine scientists, the involvement and training of PhD students will be a significant activity within AMOEBE. This may amount to 30-50 candidates, most of which will continue as post docs on the project.

The development of AMOEBE will yield significant impacts upon a number of important sectors of the Norwegian society, being an investment not only for increased knowledge, but also to prepare for the future international demands to proper management of the oceans. Demands for documentation of sustainable fisheries management within healthy oceans may be a significant "driving force" on the export market and the fisheries, (as already seen in the US Pollock fisheries where lack of ecosystem knowledge and documentation leads to quotas far below precautionary principles). In this respect AMOEBE will also have to deal with large-scale transport and distribution of pollution (nuclear waste, organic pollutants, production water from offshore industry, harmful algae, etc.). Not just because the pollution may have an effect on the ecosystem, but also because it may have a major effect on the export market.

In addition to improved qualitative and quantitative multi-disciplinary knowledge of the marine ecosystems supporting the new demands to ecosystem management, we foresee:

- Significant contributions to a sustainable management of the marine biological resources with a potential gain of 20 % in an economic sector with at present an annual export value of 30 billion NOK, (expected to increase to 100-200 billion within 2020).
- Participation of a number of small to large Norwegian companies within engineering an information/communication technology being potential suppliers of subsystems and serv ices in the development and operation of the AMOEBE system (Telenor, ABB, Oceanor, Kongsberg Maritime, Simrad, Scanmar, Aanderaa Instruments, Predictor, Triad, etc.)

- The knowledge and operationality of AMOEBE offers a global market for Norwegian products and services, with unforeseen spin-off effects as seen e.g. in relation to the US space programme.
- Information of significant interest to a number of offices within the Norwegian state administration.

It is a great organisational, communicational and management challenge to have the "whole" marine research and technology sector working together towards a common goal. Therefore the work is organised in 11 modules (see list of content), with short descriptions below and detailed descriptions and plans in Part 2 of The AMOEBE Plan. When funding is made available, detailed action plans and milestones will be made where the work and funding is distributed among participating institutes (including purchase of foreign competence) according to who is best suited for solving the individual challenges. The action plans will be updated annually. Parts of the work and funding will be made open for competition and held back for solving unforeseen but necessary challenges.

OBJECTIVES AND EXPECTED ACHIEVEMENTS

The overall objective of AMOEBE is to improve our understanding of the ecosystem dynamics and to apply this in an ecological approach towards the future demands to management advice based on precautionary principles. The specific goals are through national and international cooperation to develop an operational model-based system for describing and quantifying the various levels and interactions of the ecosystem related to the commercially exploited (or exploitable) stocks of fish, plankton and marine mammals in the Norwegian Sea and the Barents Sea. This includes further development of the methodology and technology to measure the state variables in the ecosystem and to estimate the standing and future stock sizes and distributions. It also includes the establishment and evaluation of "optimal" harvesting control rules.

This formulation of objectives is to a large extent overlapping with the four first strategic goals for ICES:

1. Understand the physical, chemical and biological processes in marine ecosystems.
2. Understand and quantify human impact on marine ecosystems, including the living marine resources.
3. Evaluate options for sustainable marine industry, specially fisheries and fish farming.
4. Develop protocols for sustainable use of living marine resources and protection of the marine environment.

The main planned and expected achievements will be:

- Advanced integrated knowledge of the northern marine ecosystems.
- Advanced methodology related to quantitative marine ecologic understanding and assess ment of marine resources, including uncertainty estimates.
- Advanced operational information on the present and future state of the marine ecosys tems.
- Advanced methodology to quantify the development of the stocks for the following years

under varying climate and harvesting strategies.
- Advanced competence, knowledge and methodology for producing management advice and strategies for sustainable harvesting of the marine resources.
- Increased recruitment of scientists to the marine sector.

Additional achievements will be

- Evaluation of future feed sources (also plankton) for fish farming and the possible effect on the ecosystems.
- Improved methodology for estimating the threats from pollution against the marine ecosystems and the fish farming industry.
- A major step to fulfil our international obligations and the future demands for a docu mented ecological approach to fisheries management based on precautionary principles.
- Position Norway internationally on top within marine ecology and resource management, with a potential gain of 20 % in an economic sector with at present an annual export value of 30 billion NOK, (expected to increase to 100-200 billion within 2020).
- Creation and implementation of new technology, products and services with unforeseen spin-off effects for Norwegian industry.
- Evaluation of cost/benefit improvements within the total management advice system.
- A unique national (and international) cooperation within marine ecology, which will continue long after the project termination and secure more focused connections between fisheries and science.

INNOVATION

Two main key words of AMOEBE are multidisciplinary **integration and cooperation**. Today a lot of good knowledge on parts of the ecosystem, data and observational systems, modelling tools and management advisory experience are spread all over Norway and internationally. Internationally we have the 100-year old ICES organisation a good job in integrating the fishery data is maintained. For the North Atlantic, ICES is the main organisation for developing annual advices to the governments on the harvesting policy purely based on the biological status.

However, in present-day management, species interactions and relations between living resources and the environment are considered only fragmentarily and in rare cases. The management of fish in the Northeast Atlantic is mainly focused on keeping spawning stocks next year high enough for the recruitment not to be severely hampered, with no or little consideration of what is good management on the long run. These are basic national and international challenges and the innovation of AMOEBE.

In Norway, the Institute of Marine Research (IMR) in many ways acts as a miniature ICES. However, much of the marine ecosystem and technological knowledge are located outside IMR, and still the research funding policy is based on national competition rather than cooperation. Within EU they have also seen the problems with lack of cooperation and integrated and useful knowledge. Therefore they are planning on having Large Integrated Projects within the 6th Framework Programme. It will be highly desirable to have the “whole” Norwegian marine research community (in cooperation with industry and international research and management bodies) cooperating towards a multidisciplinary and integrated system (AMOEBE) for understanding and quantifying the dynamics of the northern ecosystems, with the aim of serving the goals for sustainable long term management based on ecological and precautionary principles. We anticipate this will lead to a new curriculum and exiting future perspectives for marine science and ecosystem management.

To design, implement and operate such a multidisciplinary system (never built before) is very demanding and will require an innovative approach to reach optimum solutions. First of all it will be a technological and scientific challenge of System Integration, to have the 11 different modules of AMOEBE to work together and exchange necessary information to ensure that the final deliverables are given with sufficient quality and reliability. A major challenge will also be the proper handling and assimilation into the model system of the many different kinds of observations in the form of remote sensing data, catch data, buoy data, tagging data etc. This also includes the validation of the usefulness of data and the need for new critical data to improve the system behaviour. It also includes improvements of mathematical process formulations/parameter estimations and uncertainty estimates of individual state variables. Furthermore, it is a general challenge for the development and dissimination of new products (described below) to be operational useful for management and of interest to other scientists, industry and the general public.

Obviously the AMOEBE concept has to obtain an international scientific acceptance and usage first of all within the ICES system. Except for minke whale (assessed by the International Whaling Commission), the assessment of all the key stocks in AMOEBE is carried out in different ICES working groups with quality control and final advice through the ICES Advisory Committee in Fisheries Management. The annual management decisions (quotas and other regulations) are for several of the northern stocks made by the mixed Norwegian-Russian Fisheries Commission. Herring is handled by a 5-part group (Norway, Russia, the Faeroes, Iceland, EU). Regulations for saithe and minke whale are made by Norwegian authorities.

One of the main problems with fisheries management today is that the managers do not sufficiently follow the scientific advice. Innovative thinking is therefore also required on how to communicate the developed harvesting control rules and the medium to long-term effects of different harvesting strategies.

At last we anticipate that the development of new technology or new composition or use of existing modern technology may give benefits to industry, and that the know-how built in AMOEBE may in itself be exportable and have unknown spin-off effects.

MAIN DELIVERABLES

The main product for the fisheries management is to develop an operational system which through increased understanding of the dynamics of the ecosystems can improve the advice to the management with respect to fish and marine mammal stocks of the Barents Sea and the Norwegian Sea, where Norway along with Russia dominate the fisheries. The most important stocks are: Northeast Arctic cod, Norwegian spring-spawning herring and Barents Sea capelin. Other important stocks to be considered are: Shrimp in the Barents Sea, polar cod, Northeast

Arctic haddock, Greenland halibut, Northeast Arctic saithe, blue whiting, mackerel, redfish, harp seal and minke whale. (The Institute of Marine Research (IMR) in Bergen and Tromsø has the responsibility for providing management advice for all these stocks). In addition zooplankton may become an important food-source for the fish farming.

The **specific products** (in addition to the achievements mentioned earlier) the system shall deliver can be arranged according to forecast, nowcast and hindcast, and shall include:

- Estimates of the historic to present stock sizes (numbers at age and length, biomass) and their spatial distribution.
- Prediction (time scale: season-some years) of the above quantities (based on recruitment success, mortality, growth rate, maturation and condition factor) for given fishing sce narios and predicted climate or climate scenarios.
- Long-term (decades) prognoses.
- Quantification of uncertainties of the above estimates.
- Synthesis of optimum harvesting strategy in relation to ecological objectives, precaution ary principles, and/or single species long-term biological objectives, combined with s imple economical or political management objectives.

To be able to deliver these products, a set of "continuous" (bottom-up)
sub-products will be delivered:

- Ocean circulation and marine climate status and short time prediction (years-season-days) that may affect the stocks.
- Concentration and distribution of marine primary production (food for zooplankton) and underwater light intensity (affecting vertical migration and visual predation).
- Concentration, distribution, stage composition and stock size of zooplankton (especially C. finmarchicus), and prediction of next year stock size.
- Overlap in time and space ("exposure time") between prey and predators (drift and migration) for estimation of mortality and growth (affecting recruitment, maturation and conditioning factor).

One product will also be a set of recommendations regarding what type of measurements that should be acquired, and where and when monitoring activities should be carried out in order to obtain optimal AMOEBE-system performance.

In addition the system will form a basis for a similar approach necessary for estimating the threats to fisheries and ocean farming due to pollution and harmful algal blooms. The **potential products** of such a pollution module would be to estimate and predict the:

- Distribution and concentration of contaminants and harmful algae.
- Pollution exposure time (dose) on plankton, fish, shellfish, macro algae and ocean farms.
- Possible long and short term biological effects.

A potential development of a pollution module will require additional chemical experts and data and computer resources, but the additional investment cost will be much less since the framework will be laid in the AMOEBE project.

THE AMOEBE APPROACH AND WORKPLAN

The behaviour of marine ecosystems is too complex and dynamic to be understood and quantified by measurements alone, and the only way to tackle this problem is through mathematical models. This requires mathematical formulations representing the basic processes and the interactions between them. However, attempts to model the entire ecosystem "bottom-up" in one large and complex model system have failed. A combination of complex models based on and giving insight into the basic processes, and simpler models for management advice where knowledge extracted from the complex models can be included, is a more pragmatic approach with much better chances to succeed. These "bottom-up" and "top-down" approaches also need to be combined. In such a way the project will produce results that can be used in sustainable management advice through most of the project period. This approach is outlined in Figure 1.

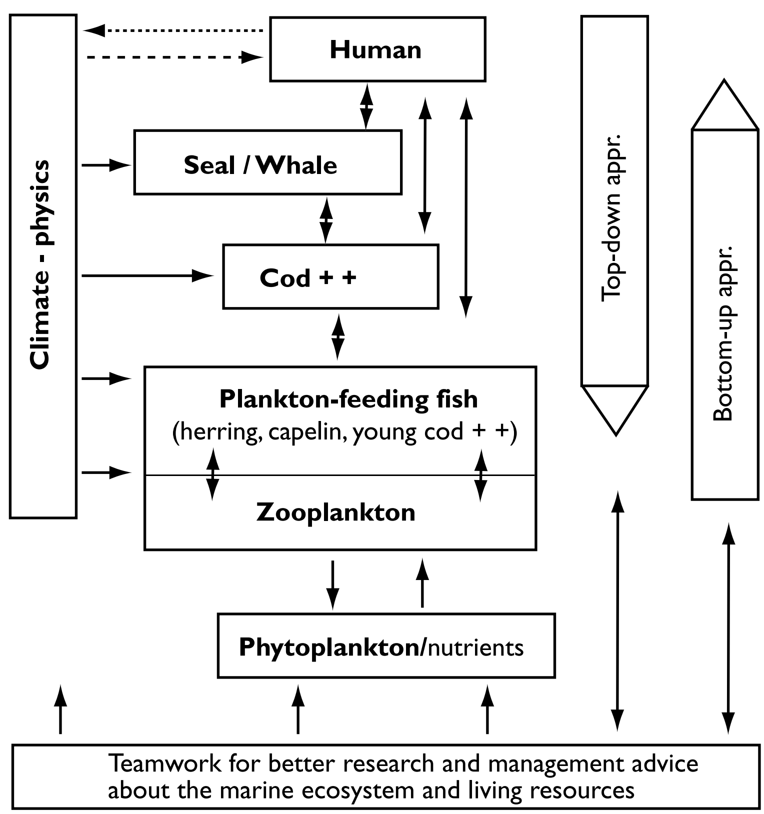

Figure 1. *Schematics of the marine ecosystem to be modelled*

Figure 1 shows that the trophic levels of zooplankton and plankton feeding fish (most fish are plankton feeders at the early stages) will be the main meeting place for the bottom-up and the top-down approaches. The bottom up approach will reach into the fish domain especially with respect to migration and plankton abundance, while the top-down approach reaches into the plankton domain with simple empirical relations in nature derived from long term monitoring.

The integration of the competence and capacity of a large part of the Norwegian marine scientific community towards a common product depends on recent advances in computing technology (large parallel computers), development of distributed system architectures and efficient communication networks. Rather than placing all data processing and computational activities in one centralized computer system, the load will be distributed over a number of communicating computers, where each computer is responsible for a definite part of the AMOEBE system. Figure 2 proposes a structure which can serve as a starting point for implementation of the system. It is obvious that design and implementation of the dynamic database or the establishment of a distributed data storage and management system where data can be distributed and retrieved from various (even heterogeneous) networked databases, represent a major challenge during the process of developing an operational AMOEBE-system.

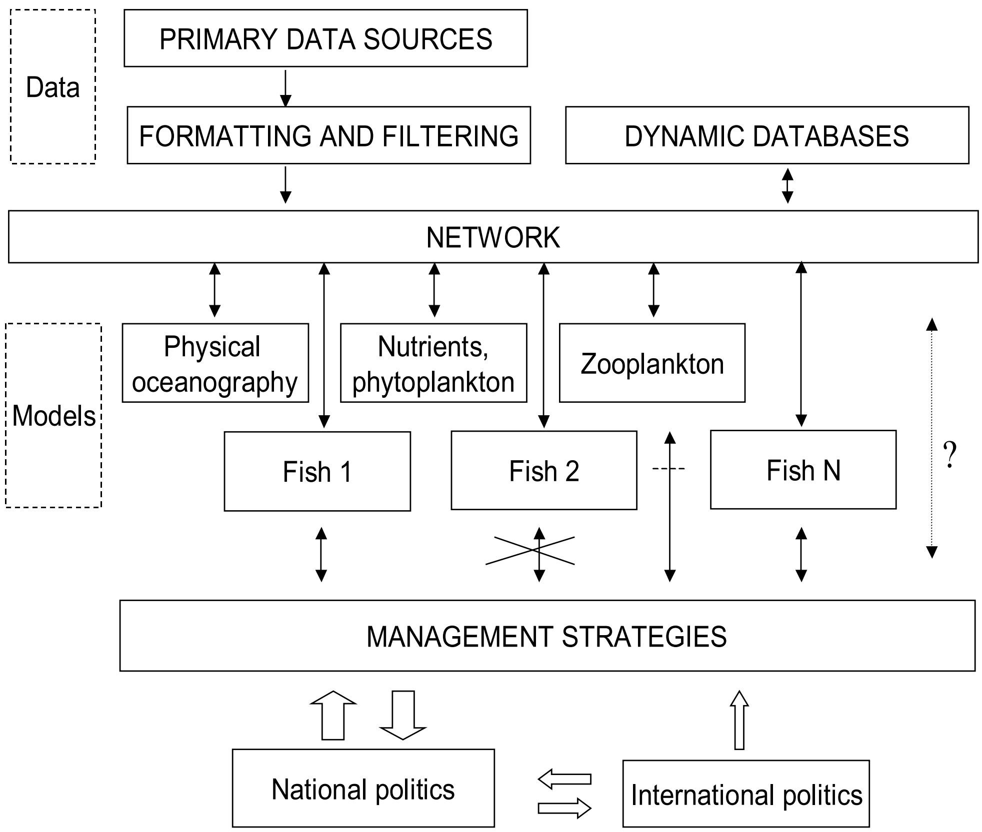

Figure 2. *First approach to the architecture of the AMOEBE reference model*

The realization of the actual model based and data-driven ecosystem state and uncertainty estimator, interacting with the database, external forces and management strategies are sketched in Figure 3. The state and uncertainty estimates will subsequently be used as a basis for routine resource assessment and forecasting purposes. Not visualized in the figure is the feedback from the estimator results via management of quota to the controlled inputs mainly being the fisheries mortality.

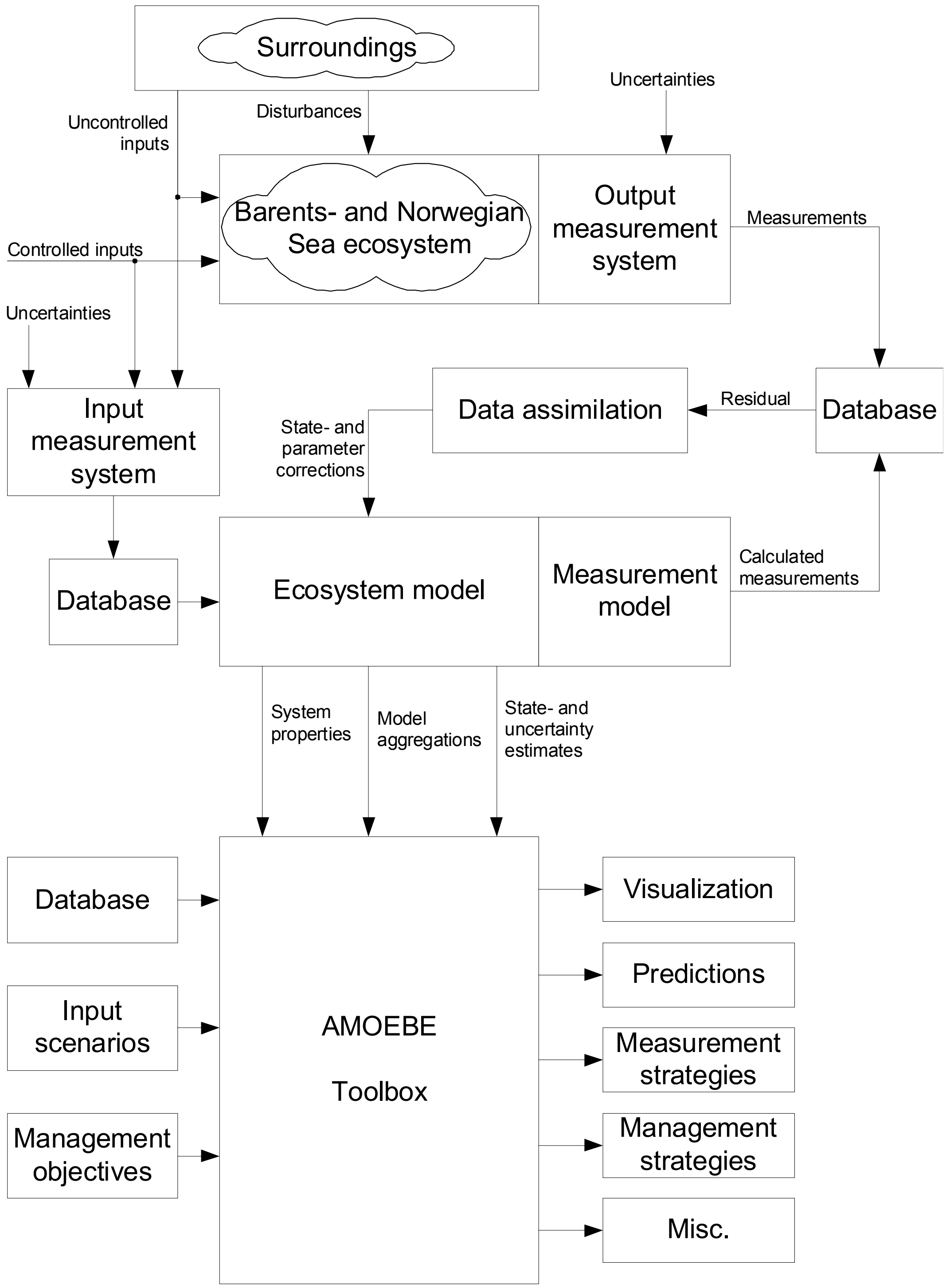

Figure 3. *Block diagram of the AMOEBE estimator structure.*

The success of the AMOEBE network based system occurs when all sub-systems succeeds and are working well together. AMOEBE will be designed as an integrated network of essentially autonomous modules. In this context, “autonomous” means that each module should work as independently of the other modules as possible, and aim at only input of key-data or key-functions from other modules. Note however, that proper key-data or key-functions are essential to the success of AMOEBE, and that old or average values have to be used if proper values or functions are missing. The reason for this approach is that a system consisting of large and tightly connected sub-systems will be difficult to develop, and difficult, not to say impossible, to maintain. A system dependent on the total success of each sub-system may end as a failure even if each of the sub-systems finally ends up as a success. It is very likely that some of the modules will strike a snag and will only partly succeed or not succeed at the proper time. A system-integration design that allows a slow transition from the current way of working to the AMOEBE way of working as each of the modules of the AMOEBE network reaches the proper level is therefore desirable. A schematics of the network needed to design, implement and operate the AMOEBE is given below.

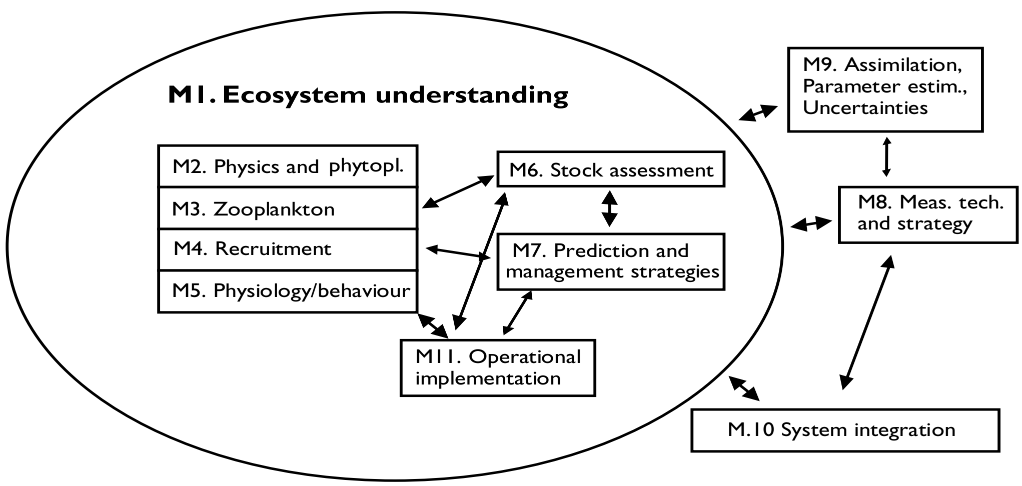

Figure 4. *Schematics of the AMOEBE module network*

Based on the view on modelling and observations outlined above, as well as the measurement problems discussed in Anon. (1999), the AMOEBE will consist of the following 11 modules. Here only objectives and a summary are given, and more detail descriptions are given in The AMOEBE Plan, Part 2, with description of work-packages, deliverables and budgets. It should be emphasized that at present the module descriptions are quite heterogeneous because of the large cultural diversity of the many scientific and management disciplines involved. One of the first challenges at the start of the project will be to homogenize these descriptions and the detailed action plans, especially to secure that the required interactions (inputs and outputs) between modules are being met. Unfortunately it has not been possible to produce a detailed description for Module 1 (an update of the basic ecosystem/food web understanding including system theory). This will still be an important part of the project.

MODULE 1: ECOSYSTEM UNDERSTANDING - SYSTEM THEORY/FOOD WEB

Objectives: *Describe the basic functioning of the Nordic and Barents seas ecosystems and the most important internal and external forces and processes needed to be considered within the AMOEBE framework.*

The main tasks in Module 1 is to:

1) Produce regular holistic updates of the qualitative and quantitative description of the functioning of the Nordic and Barents Seas ecosystems.
2) Secure necessary scientific integration and exchange of information between modules.
3) Give advice on processes, external forces and possible new state variables to be included at all levels of AMOEBE.

A major issue in ecology is how ecosystems are controlled or regulated from below (bottom-up) and from above (top-down) in the food webs. To the former category belong the effects of physical factors on phytoplankton production that are being transferred to higher trophic levels. How ecosystems are regulated have important implications for their management. If regulation from the top is not important, harvesting the living resources at higher trophic levels will have little effect on the basic functioning of the ecosystems. If, on the other hand, top-down regulation is important, harvesting can have severe effects on the system. We have realized that our northern marine ecosystems are significantly regulated both bottom-up and top-down. In addition, physics/climate has a direct effect on a variety of ecological processes on all trophic levels and on a variety of time scales. Examples from the Barents Sea demonstrate that thorough knowledge of the ecosystem dynamics is required before one can make a proper evaluation and prediction of the impact of fishing on a marine ecosystem. A fundamental challenge will be to separate the influence of nature from that of man.

In addition to the quite new science of coupled (physics, chemistry, biology) ecosystem modelling, Norway has two lines of tradition in marine research being of particular importance for reaching the goals of AMOEBE. One tradition is the fisheries investigations which has developed a high capability of studying and quantifying fish from a stock assessment point of view. This capability can now be turned to full use in marine ecology by allowing quantification of fish components of large marine ecosystems. The second tradition is the experience of conducting broad marine ecological research programmes. Two such programmes are Pro Mare (Program on Marine Arctic Ecology), which was a study of the Barents Sea ecosystem from 1984 to 1989, and Mare Cognitum, which was a study of the marine ecology of the Nordic Seas from 1993 to 2001 (a regional GLOBEC (Global Ocean Ecosystem Dynamics) programme). In particular, the work in this module and in the whole AMOEBE project will be based on the holistic ecosystem knowledge obtained from these programmes and presented in the "Proceeding of the Pro Mare Symposium on Polar Marine Ecology" (Eds. Sakshaug et al., 1991), the book "Økosystem Barentshavet" (Eds. Sakshaug et al., 1994, in Norwegian) and the book in preparation from the Mare Cognitum program (Eds. Skjoldal et al., 2003). In addition there is in preparation a relevant "Arctic Climate Impact Assessment report" (initiated by the Arctic Council) to be published in 2004.

Module 1 will have a strong advisory function towards the other modules in defining and ranking the most important processes and species to be included in AMOEBE. It will describe the effects of fisheries and climate on the marine ecosystem as a whole, including the evaluation of the importance of the bottom fauna and predation from birds. In addition to describing the present knowledge, the work in this module will follow and give advice to the development in the whole AMOEBE project and update/publish our new holistic and quantified ecosystem understanding.

Large variability in the living marine resources will continue to be part of the fisheries also in the future. In this respect Module 1 (in close cooperation with management) will suggest ecosystem quality objectives or functional objectives. This may e.g. be (based on the precautionary principles, socio-economics and through effective management) to dampen the large natural fluctuations in the resources rather than strengthen them as often been an unintentional result in the past. Management for stability will in general be an advantage for the fishing industry.

During the last 30 years the theoretical development in the ecological sciences have been strongly related to the field of *system theory* simply because ecology deals with the dynamics and interactions between large numbers of physical and biological processes. Theoretical descriptions of dynamical phenomena in general lead to the application of *differential equations*. Since the processes which are encountered in marine ecological systems to a great extent are distributed in a three-dimensional space, like flow of water and energy in the ocean, we are lead to describe such distributed systems by means of *partial differential equations*. This also applies to small particles and animals like algae and zoo plankton which may be regarded as purely distributed even though they are actually discrete by nature. Larger animals like fish and mammals, which definitely are discrete by nature, may also in some cases be regarded as distributed as an approximation or, as shall be seen (in Module 5), in some cases may be lumped together as large super-individuals representing a large number of identical individuals with similar behaviour.

MODULE 2: PHYSICS - PHYTOPLANKTON

Obectives: *Quantify, simulate and predict the natural state and variability, and possibly human-induced change of the marine climate system of the Nordic and Barents Seas on daily to decadal time scales, and the corresponding interactions between the physics and phytoplankton relevant for the marine production and biomass distribution in the region*

To fulfil the overall objective, the work will be structured according to:

1. Observational analyses and numerical simulation of the daily to decadal scale state and variability modes of the past, present and possible future marine climate system in the Nordic and Barents Seas
2. Exploration, quantification and simulation of the response of the marine phytoplankton system to the natural variability modes of, and changes in, the past, present and possible future marine climate system
3. Assessments of the predictability skills of ocean and coupled ocean-phytoplankton models on daily to decadal time scales

The interaction between the marine climate system and phytoplankton organisms is a key component of the marine food web. In order to adequately describe this interaction on local to basin spatial scales, and on time scales ranging from days to years (and possibly to decades), continuous high-precision observations of the coupled physical-plankton system, and state-of-the-art ocean general calculation models and coupled physical-phytoplankton models, are needed. Past and present activities in classical oceanography, marine biogeochemistry and numerical modelling open for substantial breakthrough when it comes to understanding the basic operation, the natural variability and the predictability of the coupled system. Module 2 will build on and bridge existing activities with the goal to quantify and simulate the near past and present coupled physical-plankton system, and to predict the coupled physical-plankton system on daily to (possibly) decadal time scales.

The three main objectivities of the module are:

Observational analyses and numerical simulation of the daily to decadal scale state and variability modes of the past, present and possible future marine climate system in the Nordic and Barents Seas;

Exploration, quantification and simulation of the response of the marine phytoplankton system to the natural variability modes of, and changes in, the past, present and possible future marine climate system; and

Assessments of the predictability skills of ocean and coupled ocean-phytoplankton models on daily to decadal time scales.

By combining existing observations (hydrography and current meters, nutrient and phytoplankton biomass concentrations and distributions) and state-of-the-art modelling tools, historical time series for both the ocean dynamics and thermodynamics, and plant nutrients and phytoplankton abundances, will be generated. Such time series are invaluable to the understanding of the recorded fluctuations of the higher trophic levels in the region.

The phytoplankton modelling in Module 2 requires input from the zooplankton module (Module 3) as the zooplankton organisms represent the major grazing factor on the phytoplankton biomass. Also input from the fish recruitment module (Module 4) might be needed to properly describe the closure on the phytoplankton system.

Particular focus will be put on simulating the mean state and variability of the ocean system in the Nordic and Barents Seas region. For this, global to high-resolution (down to 2 km grid spacing) numerical ocean general circulation models will be used, forced with realistic atmospheric forcing fields. In addition, the Bergen Climate Model, a fully coupled, global atmosphere-sea ice-ocean model will be used to examine the major natural variability modes in the region. Ocean circulation, mixing and temperature fields will be provided to the zooplankton and fish recruitment modules as these fields are needed for transport of individual particles and populations, plus egg and larvae.

For the predictability on daily to weekly time scales, advanced data assimilation methods based on the Ensemble Kalman filtering method will be used to obtain optimal initial conditions for the forecasts. Assessments of the degree of predictability of the coupled physical-phytoplankton system will be of direct value for the stock assessment, and consequently also for the prediction and management strategy in AMOEBE.

MODULE 3: ZOOPLANKTON (FOOD FOR FISH AND POSSIBLY FISH FARMS)

Objectives: *Construct a model and monitoring system that together with an assimilation procedure can estimate and predict the biomass, internal structure (often size structure), and spatial distribution of selected groups of zooplankton species.*

The work will be structured according to:

- Micro-zooplankton
- Copepods, with particular emphasis on the life cycle of Calanus finmarchicus.
- Krill
- Jellyfish
- Process-based studies

Most of the energy from the primary production to exploitable resources goes through zooplankton. This group of animals is key to understand the linkage between physics/phytoplankton and fish recruitment and growth migration behaviour. *C. finmarchicus* has a special position as the nauplii are the key prey item for larval fish in the Northeast Atlantic (Sundby 2000). A reliable estimate of the zooplankton state (biomass, structure and distribution) is of vital importance for input to Module 4 (Recruitment) and Module 5 (Physiology and behaviour). Models are available with respect to *C. finmarchicus*, but extensive validation and possibly improvements are needed. It is very possible that physics, phytoplankton and zooplankton modelling modules will be integrated into one operational system.

The main challenges are to:

- Identify the most appropriate model concepts which can simulate realistically and effi ciently zooplankton dynamics in the ocean off Norway.
- Establish data sets for the targeted zooplankton groups that can be used for model validation.
- Clarify life cycle strategies and over-wintering mechanisms.
- Establish autonomous and semi-autonomous devices that may be applied on various platforms (bottom mounted, AUV, ships etc.) for monitoring targeted groups of zooplank ton (to be developed in Module 8).
- Implement routines for data acquisition, processing and banking of data (to be developed in Module 10).
- Implement routines for model updating based on primary data (i.e. data assimilation, to be developed in Module 9).
- Develop routines for model prognosis for zooplankton and their impact on ecosystem understanding and management.

MODULE 4: RECRUITMENT

Objectives: *Develop an integrated operational model system, including data assimilation, to simulate and predict recruitment of cod, haddock, herring and capelin from the stage of egg production till the 0-group stage.*

The work will be structured according to:

- Egg production models.
- Feeding, growth and behaviour models for larvae and early juveniles.
- Physical transport modelling of larvae and early juveniles.
- Implementation and validation of coupled system.
- Process-based studies.

The larval and early juvenile stages in marine fish are critical phases for individual growth and survival and for the resulting abundances of the year classes. Since Hjort (1914) proposed the general hypothesis that variability in food abundance during the early larval stages is the major cause of the fluctuations in year class strength, a large effort has been put into laboratory and fieldwork to test Hjort´s hypothesis. This work has resulted in a number of new and more specific recruitment hypotheses that have the potential to be more easily tested. These efforts, in turn, have substantially increased our awareness to many key processes. However, when it comes to testing the hypotheses we are still often left with simple correlations between recruitment parameters and environmental factors in support (or rejection) of a certain recruitment hypothesis. The problem is multi-dimensional in time and space, and is far greater than can be considered in a single analysis. In order to cope with this problem, the critical recruitment processes need to be formulated in ways that make them quantitatively comparable. One way to achieve this is to aggregate the important processes from first principles in models. Even though various biological and physical numerical models already have been used for more than 20 years to study recruitment problems, we are now at a new stage where we can start to integrate the recruitment processes in a more realistic way.

The strategy for 1) quantitative testing of recruitment hypotheses, 2) simulation of larval/juvenile growth and survival, and 3) develop operational simulations of 0-group distributions and abundances, is to use the egg production models as a more realistic starting point for quantitatively estimating the recruitment. The recruitment processes will then be quantified by combining the individual-based models with a particle-tracking circulation model in an *integrated bio-physical model.* Revision of the input data and validation of the models will be done in the field and from process studies in the laboratory.

The time window to be modelled is from maturation of the egg-producing fish during winter till 0-group stage early in the following autumn when year-class strengths of many of the commercially important fishes are largely determined, a time frame of less than one year.
The activities within the present module will use input data on mature fish (Module 5. "Physiology and Behaviour" and Module 6. "Stock Assessment") to develop models of egg production and spawning behaviour. We will use input data on the ocean physics and zooplankton (Module 2. "Physics and Algae" and Module 3. "Zooplankton") in developing individual-based models and models for particle tracking. The resulting model simulations and recruitment scenarios on

0-group fish will provide an input to prediction and management strategy and to the stock assessment (Module 6. “Stock Assesment” and Module 7. “Prediction and Management Strategy”).

During the first five-year period we will focus on Arcto-Norwegian cod, Arcto-Norwegian haddock, Norwegian spring-spawning herring and Barents Sea capelin as model fish stocks. Particularly for the cod, there is a large amount of already existing input data for the models from process studies in laboratory, mesocosm and field. Historical data as well as data from new experimental work in the laboratory and the field will be assimilated into the models. For capelin additional process studies and experimental laboratory studies need to be conducted in order to achieve the necessary input data to the individual-based models.

MODULE 5: PHYSIOLOGY AND BEHAVIOUR

Objectives: *Develop a framework for simulating the growth, mortality, reproduction and 3D movement of the target populations through mechanistic models, adaptation, and data assimilation.*

The work will be structured according to:
- Scaling of individuals to populations
- Migration patterns
- Growth
- Maturation and fecundity
- Process-based studies

The interactions between species and cannibalism affect all the main population dynamics processes (growth, maturation, recruitment, mortality, migration). The mathematical description of these processes can be formulated based on historical data on fish and environmental variables, and from studies in laboratories and from fish farming. Just a few environmental variables will be used (circulation, temperature, turbulence, light, plankton abundance/distribution, larval drift), for which predictions can be derived from the complex oceanography/plankton models. Predictions for overlap between species are needed in order to quantify species interactions. This will be derived from the migration models. The migration modelling requires “continuous” information of the forcing fields (primarily plankton concentration, temperature, light and circulation) from module 2 and 3, and utilization of data from research vessels and the fishing fleet. The environmental conditions may give direct input to the fish growth and the mortality on the early life stages, and also give feedback to the plankton mortality. It is very important to quantify the uncertainty associated with the predictions in order to comply with the precautionary approach.

MODULE 6: STOCK ESTIMATION

Objectives: *Obtain unbiased estimates of present and historical stock abundance of the main stocks of fish, shrimp and marine mammals, with associated uncertainty estimates.*

The work will be structured according to the target species and:
- Implementation of appropriate structure/complexity of models with respect to population

dynamics (recruitment, growth, maturation, predation, migration).
- Fitting models to data.
- Quantifying uncertainty.
- Linking stock assessment models to oceanography/plankton models/information
- Improve observation models for the data used.

Estimation of the present and historical stock size of fish and marine mammals is a discipline, which has developed rapidly over the last decades. This is due to major advances both in the observation (survey) methodology, better understanding of the mathematical and statistical aspects of stock assessment models, and faster computers. However, there has been relatively little progress in including more biological knowledge in the assessment models.

The main topics in this module are:
- Including more biological realism in assessment models. This includes linking to zooplankton/oceanography models.
- Mathematical/statistical issues concerning choice of models and how to fit models to data.
- Quantifying uncertainty in results.

The main innovation in this module in the AMOEBE context will be to focus the research on biology, measurement methods, mathematics/statistics and modeling so that results from such research are formulated in a way, which can be implemented in assessment models.

MODULE 7: FISH PREDICTION AND MANAGEMENT STRATEGIES

Objectives: *Develop methods and tools for computation and evaluation of optimal harvesting control rules coupled to predictive capabilities on fish stock abundance, migration/ distribution and growth.*

The work will be structured according to the target species and:
- Construction of CARE (Catch Rule Evaluator).
- Interfacing population dynamics models to CARE.
- Develop and implement reduced order prediction models.
- Develop a system for model based predictive control.
- Harvesting control rules.
- Implement operationality with interface to managers.

When estimating present stock sizes from observations, environmental variables like plankton and temperature are not very crucial, although relations between temperature and survey catch-ability do influence stock estimates to some extent. For prediction purposes, however, both multi-species interactions and environmental processes need to be taken into account. The interactions between cod, herring and capelin, as well as the environmental influence on these stocks, are quite strong (Hamre, 1994). The usual way of finding an optimal harvest strategy is by stochastic simulations. During runs into the future the yearly varying parameters describing the biological processes (particularly recruitment) are drawn at random from the time series of historically estimated parameters. However, there are clear indications that e.g. the recruitment is partly deterministic in relation to climate, so prediction of the recruitment will have a significant impact on the long-term management strategies. Many such runs are done for each harvest strategy in order to find the optimal one. The simplest approach is to optimise the total yield in biomass, but the economic value of the harvest may also be taken into account. When exploring harvest strategies in a multispecies context, values (e.g. prices) have to be assigned to each of the species harvested in order to have a quantity to optimise.

MODULE 8: MEASUREMENT TECHNOLOGY AND OBSERVA TIONAL STRATEGY

Objectives: Provide technological and strategic solutions to the diversity of measurement problems that will arise during the AMOEBE project. Specify the constraints inherent to the measurement systems and implement the resulting optimal meas urement strategy for the maximum benefits to the AMOEBE system.

The work will be structured according to the requirements from the individual modules 2-6:

- Measurement technology for meteorology, physical oceanography and primary produc tion.
- Measurement technology for abundance and spatial distribution of target zooplankton species.
- Measurement technology for abundance (including benthos and aquatic mammals), spa tial distribution and migration of target populations of fish.
- Measurement technology for observation of various aspects of the physiological state and the population dynamics for target fish species, represented by growth, maturation, reproduction potential, distribution and densities of fish larvae/0-group, mortality risk, and food-web interactions (predation pattern).

Module 8 is a preparatory plan for the activities related to research, development, implementation and operationalisation of measurement technologies and observational strategies (the monitoring system) that are necessary to generate the information flow required to keep the AMOEBE estimator updated and sufficiently close to the true ecosystem state. The work starts by identifying critical factors based on a review of the technological status in marine environmental- and resource monitoring and an assessment of the actual monitoring requirements that ensue from the AMOEBE approach. It includes technological issues relating to the monitoring tasks present at various levels of the marine ecosystem, from low-level physical processes to complex fish- and mammalian population dynamics and behaviour. It also addresses the question of finding optimal observational strategies based on methodical analysis of system properties. Quantification and systematic handling of measurement uncertainties, cost efficient measurement technology, and adoption of intelligent observational strategies are proposed as the three principal objectives for the design of the AMOEBE monitoring framework:

- Thorough reviews of the state-of-the-art in marine resource- and environmental monitor ing in context of the AMOEBE concept (what do we have, and what do we need?).
- Innovation and utilisation of modern technology at all stages of the measurement process, from the selection of sensing principles and instrument carriers to deployment strategies and the actual transmission of data to the respective AMOEBE database node.
- Cost effective monitoring systems, e.g. by reduced human intervention, increased use of automatic, self-sustained and multi-purpose measurement platforms and remote sen

sing principles.
- Intelligent design of monitoring strategies, e.g. by maximising observability and using model predictions.
- Accurate and formal descriptions of the measurement principles involved (measurement models) including remedies for quantification and proper handling of measurement uncer tainties.
- National and international cooperation on observational tasks between the stakeholders in the Norwegian- and Barents Sea regions (coast guard, fishery fleet, etc.).

Measurement technology for ocean currents, climate and plankton abundance need to be improved. The needs and deficiencies with today's monitoring have to be evaluated and necessary actions taken in order to obtain optimal AMOEBE-system performance. Assimilation techniques for scattered field data are still under development.

The methods in question for abundance measurements of shrimp, fish and marine mammals are trawl surveys, acoustic surveys, tagging, aerial surveys (for seals) and sightings surveys (for whales). The problems with the survey methodology available today are discussed in Anon. (1999). It should be noted that although absolute abundance estimates are preferable, precise indices of relative abundance are also of high value for use in the population models. New methods for better quantification of abundance and uncertainty estimates must be developed and implemented, and historical time series updated taking new knowledge and technology into account (see e.g. Aglen and Nakken, 1997).

The needs and potential development and use of new concepts will be continuously assessed.

MODULE 9: DATA ASSIMILATION, PARAMETER ESTIMATION, AND UNCERTAINTIES

Objectives: *Develop and secure the implementation of suitable parameter estimation and data assimilation tools for the suite of models in modules 2-6, in order to improve the quality of model outputs with reduced and quantified uncertainties, including uncertainties of predictions and related management strategies.*

The work will be structured according to the challenges and observational possibilities within the individual modules 2-6.
- Advanced assimilation tools (with large amounts of observations).
- Assimilation of very sparse data in large scale models.
- Validation of assimilation tools.
- Parameter estimation in large scale models.
- Coupled data assimilation system.
- Quantification of specific and total uncertainties.

Module 9 will to a certain extent act as a service module for some of the other modules, where specific problems arising in connection with those modules are solved in conjunction with tools and methods developed in this module. Issues of more general character found in the module are (1) development and validation of data assimilation tools in AMOEBE, (2) parameter estimation utilising many different techniques (an important part in many of the modules), and (3) uncertainties, viz. how these can be represented and their influence calculated (an integral part of stock assessments).

MODULE 10: SYSTEM INTEGRATION

Objectives: *1. Establish and maintain the AMOEBE architecture that promotes and supports the integration of the modules of the AMOEBE network.*
2. Design a database model for the AMOEBE network.
3. Realize the integration of the components according to the AMOEBE architec ture by the means of available technology.
4. Describe the mechanisms and processes that support the maintenance of the AMOEBE architecture.

The work will be structured according to:

- Establishing of reference model and common concepts.
- Design of data flow and establishment of functional specifications.
- Design the AMOEBE database and communication.
- Realization of the integration of the AMOEBE modules.
- Maintenance of the AMOEBE architecture.
- Implementation of a suitable GIS system for AMOEBE.

The System Integration Module provides the framework that the modules should work within, and a set of tools that will ease the integration of the modules. This includes the establishment of a system architecture as well as the specification of general user interfaces strategies and the development of some general procedures and tools (APIs and development tools) that shall be used in the integration process.

Detailed decisions about how to establish the system architecture have to be taken during the work. Common concepts, integration and interoperability will be focused. However, issues dealing with logic and system component internal to only one of the other modules are not a part of the architecture. Special attention will be given to the experience obtained during the development of The European Regional Seas Ecosystem Model system (ERSEM) applied on the North Sea (Baretta et al., 1995, Blackford and Radford, 1995, Ruardij, 1995).

During the lifetime of AMOEBE, new knowledge about marine species and dependencies is likely to emerge. New technologies, as well as new software and hardware platforms will also become available. Thus, effort should be put into the establishment of a system architecture that as far as possible arrange for such changes. Advanced software development tools that provide mechanisms for model based software development (automatically software development from models) should be deployed. Thus, changes in specifications can be exported to systems components in an efficient way.

The module is also responsible for the realization of the integration, i.e. to assure that each of the other modules are integrated in the AMOEBE architecture. The tools developed are used in module 11 in order to develop and maintain a set of “Operational products”, which are used to

provide required information products that are accessible to users routinely, reliably, in suitable forms and within required time limits.
The system shall also provide for a more freely created "Experimental" system, which for example can be used to create "What if" scenarios where certain physical situations can be simulated in known models, or new models can be tested in a greater context.

MODULE 11: OPERATIONAL IMPLEMENTATION

Objectives: *Turn all existing and new knowledge related to the northern ecosystem dynamics into operational products, and secure through maximum inter-disiplinary use that the products are refined into higher-level products useful for improving environ mental and fisheries management advice. It is expected that the scientific com munity also outside the AMOEBE project will do basic research on the new operational products helping to improve our forecasting capabilities with respect to climate and fisheries.*

The work will be structured according to the operational needs and challenges within the individual modules 2-7. The module describes the plan for implementing the total operationality of the AMOEBE concept. It is based on the full range of products anticipated during the planning of the project, and on the operational requirements for producing and disseminating these products at the right time in a suitable form. New information sources and user products will obviously be invented during the course of the project and must be included in the operational system. The public outreach will be a major challenge in this module, and it is of particular concern that the information be made understandable for ecosystem managers, politicians and the general public. This implies that information be made available through user-friendly GIS systems linked to Internet, in addition to regular ecosystem status reports and participation in relevant scientific and management advisory fora. This module will also develop plans for the operationality of the system after the termination of the AMOEBE project.

Specifically this module has to secure the operationality of the monitoring systems, the database, network and communication, and suitable Geographical Information System. The data used by the models as well as individual or coupled model results will be gathered in a joint (or partly distributed) dynamic database, accessible over Internet to support the work done in all other modules. In addition, useful products can be delivered already at an early stage of the development of AMOEBE, and such products needs to be made operational. The Department of Marine Resources at IMR is operational in the sense of routinely estimating (within the ICES system) the annual stock sizes and advice on quota. However, the environmental (physics-plankton), migration/distribution etc. information can be turned into regular products not only for the project and management advice, but also for other scientific and industrial use, and for the public interest.

In several modules we have included the activity of basic scientific research on critical ecosystem processes. In order to improve/formulate models for population dynamics (including stock interactions) for plankton and fish, better (mathematically formulated) understanding of the energy flow through the ecosystem and some of the basic population dynamics processes

(growth, maturation, spawning, recruitment, mortality, migration) is still needed. Much work has been done on understanding these processes, but the work has seldom been carried forward to a point where it is ready for use in population models.
The education and training of new scientific personnel within the AMOEBE concept has not been clearly stated here, but it is implicit in most of the module description in Part 2 of The AMOEBE Plan.
The estimated duration of the project is ten years. It is important to realize that the potential for scientific and technological progress during this period is great, making it difficult in detail to specify how the AMOEBE estimator (the monitoring and modelling system) will appear at the end of the project. To assure that AMOEBE keeps up with the rapid technological evolution, the project action plan (including the budget) needs to adopt an iterative and flexible strategy where new ideas and technological solutions are evaluated annually throughout the project.
We have been careful with the involvement of industry until a clear go signal is given for AMOEBE, however several small to medium (and large) sized enterprises have indicated their interest. We have so far not tried to organise the assumed spin-off product from AMOEBE.

BUDGET

It is not possible to realistically plan and budget every detail in all years in a 10-year research and development project. The AMOEBE Plan together with detailed action plans will therefore be updated annually, including the use of resources. While it has been possible to somewhat realistically develop a distributed budget for the first five years, we foresee that the distribution of resources will more be dependent on scientific applications to the Scientific Board.

The total budget for the first five years of more than 700 million Norwegian kroner) is estimated based on the needs (related to the modules and additional challenges described above) from the 11 research modules (see details in individual module descriptions in Part 2 of The AMOEBE Plan), giving an average of about 100 people each year. The estimated total cost of the full ten year period is more than 1.3 billion kroner.
In this budget (in 1000 NOK) the cost of existing regular surveys by research vessels (being of the same order of magnitude), the actual cost of earth observations from space, and collection of fisheries statistics is not included. (7.5 NOK = 1 Euro, Oct. 02).

Workpackage	Man months 5 years	Man cost 5 years	Equipment 5 years	Running cost 5 years	Sum 5 years	Total 10 years
Coord.Adm.	300	25080	1000	10000	35.080	70.000
Module 1	276	23133	460	4100	27.693	60.000
Module 2	474	40099	20060	6700	66.859	110.000
Module 3	552	46446	7050	8100	61.545	110.000
Module 4	546	46382	7050	8000	61.432	100.000
Module 5	636	53244	2510	4200	59.954	100.000
Module 6	552	46506	1060	8100	55.666	90.000
Module 7	552	45260	11560	10000	66.820	120.000
Module 8	703	59621	55000	10000	124.621	250.000
Module 9	486	39912	960	7000	47.872	80.000
Module 10	621	51750	3500	9100	64.350	100.000
Module 11	447	38517	27200	6700	72.417	160.000
SUM	6145	515.950	137.410	92.000	**744.309**	**1350.000**

Matching activities are found within parts of the ongoing Norwegian Research Council programmes: MARE, BeMatA, Monitoring (Overvåkning), RegClim, NoClim, Bjerknes Collaboration, and a few SIP and SUP programs. Of clear relevance is also the up-starting research programs: Polar Climate, Climate Effects and KlimaProg. In addition the projects "Precautionary management of fish stocks" (including Fleksibest), "Absolute abundance estimates", BASECOEX and "Use of plankton in feeding fish in aquaculture" are quite relevant. Also the IMR has some relevant funding from the Ministry of Fisheries related to fish population modelling and data quality assurance. As mentioned earlier, there are also a few ongoing international EU projects being relevant, and hopefully some relevant initiatives towards the 6th Framework Program will be funded.

These matching activities have a funding of about 20-30 MNOK per year, and when most of these projects are terminated from the start of AMOEBE or after a few more years, hopefully the experts will be available to AMOEBE. Assuming part of the ongoing relevant activities can be steered into the framework of the project, maybe the annual cost of the first few years can be reduced by 10-20 %. In addition the involvement of "permanently funded" personnel may reduce the overall costs by about 20 %.

BACKGROUND AND RELEVANT ACTIVITIES

The Norwegian fishing industry is the second largest export industry in Norway. The management of these resources is based on scientific advice provided through the International Council for the Exploration of the Sea (ICES). Inappropriate methods and neglecting uncertainty in the data cause the management to be sub-optimal, and several stocks are at present over-exploited. The Barents Sea and the Norwegian Sea are the most important areas for the Norwegian fisheries. Initiatives for improving the management advice for the fish stocks in these areas will have to come from Norway, as we can not expect major research programmes for these areas to be launched by Russia or the other countries fishing there.
Several large research programmes, aiming to improve the understanding of the ecosystems and the management of the marine resources in the Barents and Norwegian Seas, have been conducted during the last 25 years.
On the modelling side, the main programmes have been HAVBIOMODELLER (1975-1983) (Balchen, 1981; 2000), the Multispecies Management program (1990-1994) (Rødseth, 1998), Marine Ressurser og Miljø (MAREMI, 1995-1999), Marin ressursforvaltning (MARRES, 1995-1999) and Marine ressurser, miljø og forvaltning (MARE, 2000-2004). The programmes Pro Mare and Mare Cognitum were aiming to improve the basic knowledge and understanding of the Barents Sea and Norwegian Sea ecosystems, and MARICULT has improved our basic knowledge of the lowest trophic levels of the ecosystem (nutrients, virus, bacteria, algae, zooplankton). Quite relevant activities are also found in the climate programmes RegClim, NoClim and the Bjerknes Collaboration, and in the Monitoring (Overvåkning) and BeMatA programmes, and within the up-starting climate and climate effect programmes.

Internationally several EU projects are more or less relevant, but the most relevant ecosystem modelling work seems to be the GLOBEC activity at the Georges Bank on the east coast of the USA (http://globec.whoi.edu/). Large field and modelling resources have been put into this program, with which we already have very good connections. Another very relevant source of modelling expertise and information comes from the international Trans-Atlantic Study of *Calanus finmarchicus*, TASC (http://calanus.nfh.uit.no/TASC.HTML).

The direct improvement in the management of the fish stocks from the research funded by these programs has been limited. One of the reasons for this is that improvement of the assessment and management of fish stocks was not (or did not turn out to be) the focus of these research programs. It was assumed that better understanding of the ecosystem and better models for various parts of the ecosystem automatically would lead to better management. This was not the reality. We thus feel it is time for a new research and development program where the improvement of assessment of and management advice for fish stocks is in focus.
During the last 25 years, several important factors have changed making the chances of success much higher today:

- The knowledge of several basic ecosystem processes is much higher and more quantitative today.
- The numerical modelling tools, knowledge and competence are now available at several Norwegian universities and research institutes.
- The capacity of computers per unit cost has increased by a factor of 10 000 and will continue to increase.
- The availability of the Internet makes it possible to use jointly distributed databases, computer systems and models.

A significant part of the stock assessment problems are identified as large uncertainties in the current monitoring and data acquisition procedures (see e.g. Anon, 1999 (p.14-16). These problems are being studied under the research program “Absolute Stock Estimates” at the Institute of Marine Research (IMR), and AMOEBE will contribute to optimise the measurement strategy. It is apparent that a substantial part of the problems can be ascribed to improper modelling practices and especially the neglecting of basic ecosystem processes. In the executive summary it is stated that “Substantial investments in new technological and modelling development is needed to elevate the quality of existing assessment enough to match the present high exploitation pressure on most stocks”…”*In the long-term there will be an increasing demand for precise assessments not only of the commercially exploited species, but also of the entire ecosystem. Investments in developing methodologies today will in the future pay off by fulfilling requirements set by international conventions*”. This is one of the major challenges set by AMOEBE, which will operate as a platform for our national expertise in this area.

“Bottom-up” approaches for simulating parts of the ecosystem (from physics to plankton) are underway at several institutes. The SINMOD at SINTEF (Slagstad and Tande, 1996), the NORWECOM (Søyland and Skogen, 2000, Skogen and Søyland, 1998) at IMR (run operationally at the meteorological institute) and the “ECOMICOM” at the Nansen Environment and Remote Sensing Centre (Drange, 1996, Bostrøm and Drange 2000) are being run for different purposes for different ocean areas with different resolution and with different and partly unknown accuracies. At the Institute for Fisheries and Marine Biology, University of Bergen, several approaches for plankton and fish migration modelling have been published (e.g. Fiksen, 2000, Giske et al., 1998), but also Balchen (1979) at the Norwegian University of Science and Technology have laid the basis for this type of modelling.

The main problem with these models is the lack of proper validation or uncertainty estimates and proper data for assimilation (updating). In addition to more advanced sampling strategies and use of our own existing data, this will improve with the growing Global Ocean Observing System (GOOS and EuroGOOS) in addition to already ongoing international exchange of oceanographic data. Of special interest for marine climate prediction (necessary for both the bottom-up and top-down approach) is the global ARGO program where 3000 profiling buoys are planned to be deployed within 2005, and the Global Ocean Data Assimilation Experiment (GODAE) being a modelling program with the purpose of operational assimilation of the ARGO and other near real time data. Unfortunately the Norwegian Sea is at present just slightly a part of the ARGO program, but it is anticipated that this can be an extension handled through the AMOEBE project. So far empirically based "top-down" approaches for assessment of the fish stocks in the Barents and Norwegian Seas have mostly been done using standard VPA (Virtual Population Analysis)-based models adopted by ICES. Capelin has, however, always been assessed using population dynamics models developed at IMR, and the model CAPTOOL is now used (ICES, 2002b). At present, population dynamics models for herring and cod are under development at the IMR. The SeaStar model (ICES, 2002b) is used for the assessment of Norwegian Spring-spawning herring. For cod, the FLEKSIBEST model (Frøysa et al., 2002; ICES, 2002a) has been used as a supplementary model in the assessments made in 1999-2002. CAPTOOL is a multi-species model, which takes into effect the influence of cod and herring on capelin, while the other two are single-species models.

These models are used for estimating the present and historical stock size (including uncertainty estimates), based on survey data and commercial catch data. There are still many statistical and mathematical questions that need to be solved, concerning how to fit data and models in the best possible way. Models for the other commercially important species are also needed.

Much of the work done with the MULTSPEC model (Tjelmeland and Bogstad, 1998; Bogstad et al., 1997) can be utilised in AMOEBE. MULTSPEC is a multispecies model containing the species cod, capelin, herring, harp seal and minke whale. Much quantitative knowledge about predation, feeding ratios and mortality is already available. A major source of information here is the joint Norwegian-Russian stomach content database (Mehl and Yaragina, 1992), which contains information on stomach content of more than 150 000 individual fish, mainly cod. This data collection started in 1984 and is still in operation. Russian scientists have collected large amounts of qualitative stomach content data for the entire post-war period, and work is in progress to make such data computerised so that they can be made available for more detailed analyses.

In order to advise on what the catch level in the next year(s) should be, a harvest strategy is needed in addition to the stock estimate. Several such models already exist: AGGMULT (Tjelmeland and Bogstad, 1998), SYSTMOD (Hamre and Hatlebakk, 1998, Hamre, 2000) and Scenario Barents Sea (Hagen et al., 1998). All these models focus on the cod, herring and capelin interactions. In addition, plankton is included in AGGMULT, the impact of climate is emphasised in SYSTMOD, while Scenario Barents Sea emphasises the management procedure and the performance measures of a model more than the biological performance.

MANAGEMENT AND PARTNERS

Two important key words in AMOEBE are Integration and Cooperation. Lots of good knowledge about parts of the ecosystems, data and observational systems, modelling tools, and expert knowledge on producing management advice, are spread all over Norway and internationally. A main challenge is therefore through a unique AMOEBE cooperation to integrate all these resources, knowledge and competence. In this way we will produce better and useful information to the society significantly better than today and thereby reducing the risk of management failure.

ORGANISATION AND LEADERSHIP

The work on splitting tasks and responsibilities in this large integrated cooperation to develop a new generation of knowledge and management tool has already reached an advanced stage. It is necessary to establish a well functioning organisational structure to secure the planned progress and reaching of the overall goals of AMOEBE, and to control the use of resources.

This organisational structure shall through the coordinator, science board and administrative unit:

- Function as a communication network between AMOEBE and the funding authorities.
- Secure the necessary national and international cooperation and coordination.
- Secure the fulfilment of the AMOEBE deliverables, milestones and goals, including publications in international review journals.
- Establish standards for the modules on reporting, presentations etc.
- Evaluate applications from the scientific community and supply resources.
- Evaluate and respond to progress reports.
- All other functions necessary for the technical coordination.

The **module leaders** shall:

- Coordinate the different work-packages and tasks within their individual modules.
- Secure the fulfilment of milestones, deliverables and goals within their modules.
- Make decisions on methodology and approach and use of given resources to reach the AMOEBE goals.
- Control and evaluate the work.
- Report to the coordinator and the scientific board.

Schematics of the organisational structure in AMOEBE:

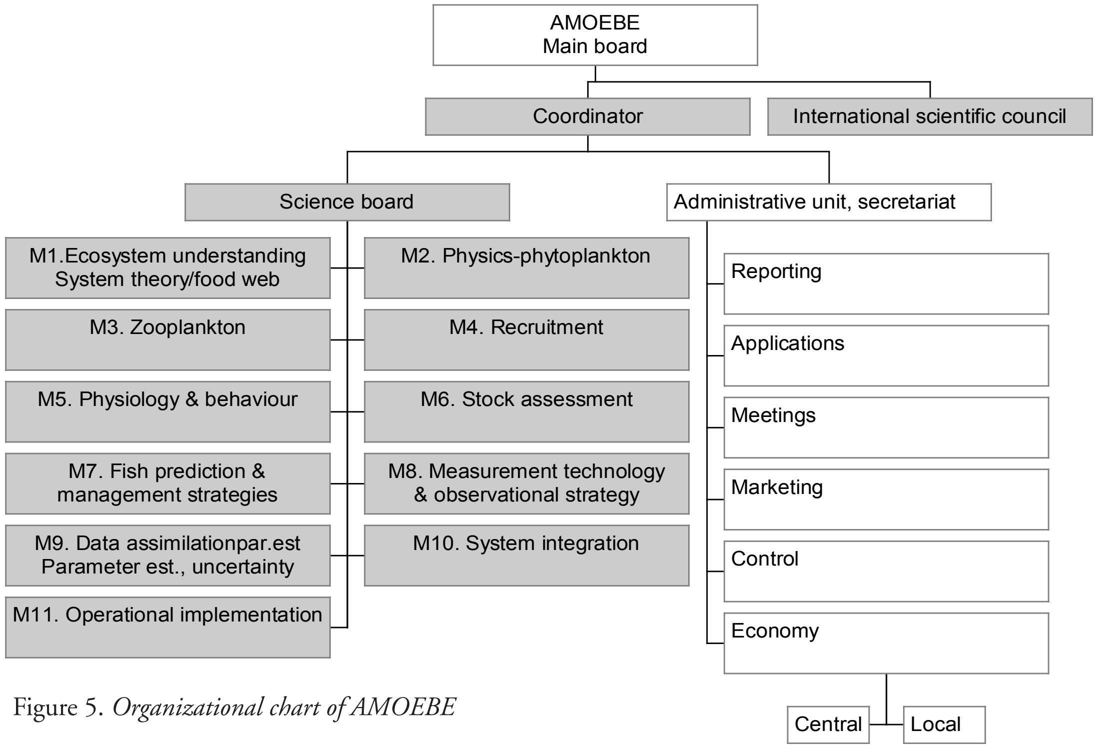

Figure 5. *Organizational chart of AMOEBE*

The M1 to M11 are Module 1 to Module 11 being the scientific modules in AMOEBE. Each module typically consists of 5-10 Work Packages with leaders. The major part of the **science board** will consist of the module leaders (also acting as a scientific secretariat). By having module leaders coming from all the main research centres in Norway (Tromsø, Trondheim, Oslo and Bergen), we have secured a distributed secretariat to maximise the local float of information. The main board may primarily consist of the directors of the main institutions involved, representatives from the most relevant Norwegian ministries (Fishery, Education, Environment and Industry) and from the Norwegian Research Council who also will be represented in the **Science board**. It will be important to obtain a strong **international scientific council** with links to both marine ecosystem research and management.

Meetings

A series of plenary meetings is planned, among others Annual Scientific Conferences (ASC). To discuss and organise the work within the project, workshop-like meetings will be organised. The scientific board will meet twice a year, one meeting to coincide with the AMOEBE ASC from where an annual conference report will be disseminated to the consortium and the relevant ministries.

The **Coordinator** shall:

- be responsible for the overall project management, including financial, administrative and technical aspects.
- act as a communication point for everyone associated with AMOEBE.
- review and integrate financial and administrative data from the modules.
- prepare and submit the progress reports.

The Coordinator acts as chairman of the Scientific Board.

The **administrative unit/secretariat** (with close links to the Norwegian Research Council) will have the following tasks:

- Keep track of the economy and report to the Coordinator, Module leaders and Work Package leaders.
- Keep track of reporting according to milestones and deliverables and report to relevant leaders.
- Organise meetings.
- Organise practical arrangements with applications.
- Support marketing.
- All other practical arrangement.

International cooperation

AMOEBE shall and must include a close international cooperation to reach the anticipated goals. Here the ongoing extensive cooperation within ICES will be central. Work is also in progress to introduce the AMOEBE ideas within the EU's 6th Framework Programme, and positioning within a few larger project initiatives. Since Russia is one of the closest scientific "partners" in the search for ecosystem understanding and at the same time the main "competitor" of the fisheries resources of the northern regions, it is of special importance that they become an active partner in AMOEBE planning groups.

The following **core group** are the main responsible for the overall planning of AMOEBE:

Kurt Tande (NFH, UiT)
Dag Slagstad (Sintef)
Johnny Johannessen (Kari Brusdal), (NERSC)
Jo Arve Alfredsen, Jens G. Balchen (ITK, NTNU)
(Nils Christian Stenseth, Geir Ottersen), (Bio, UiO)
Bjarte Bogstad, (Arne Bjørge, Are Dommasnes), (IMR-marine resources)
Morten Skogen (IMR, scientific secretary)
Einar Svendsen (IMR-marine environment, leader)

REFERENCES AND BILIOGRAPHY

A major part of relevant bibliography are found in the specific module descriptions in The AMOEBE Plan, Part 2, Modules: 2-11.

Aglen, A. and Nakken, O. 1997. Improving time series of abundance indices applying new knowledge. Fisheries Research 30: 17-26.

Anon. 1999. Methods for Fishery Resources Assessment. Status and Potentials of Main Resource and Environment Monitoring. Norges forskningsråd, Bioproduksjon og foredling. ISBN 82-12-01208-5, 75 pp.

Balchen, J.G. 1979. 'Modelling, prediction and control of fish behavior', in *Control and Dynamic Systems*, ed. Leondes, C. T., Academic Press Inc.

Balchen, J.G. 1981. 'Mathematical and numerical modelling of physical and biological processes in the Barents Sea', in Quantitative Population Dynamics, eds. Chapman D.G. & Gallucci V. F., International Co-operative Publishing House.

Balchen, J.G. 2000. Thirty years of research on the application of cybernetic methods in fisheries and aquaculture technology, *Modelling, Identification and Control*, vol.21, no.1, pp. 3-64.

Bogstad, B., Hiis Hauge, K. and Ulltang, Ø. 1997. MULTSPEC - A Multi-species Model for Fish and Marine Mammals in the Barents Sea. J. Northw. Atl. Fish. Sci., 22: 317-341.

Brostrøm, G. and Drange, H. 2000. On the mathematical formulation and parameter estimation of the Norwegian Sea plankton system. Sarsia 85, 211-225.

Drange, H. 1996. A 3-D isopycnic coordinate model of the seasonal cycling of carbon and nitrogen in the Atlantic Ocean. Physics and Chemistry of the Earth, 21, 503-509.

Fiksen, Ø., 2000. The adaptive timing of phenology - a search for evolutionary robust strategies in *Calanus finmarchicus*. ICES Journal of Marine Science, XXX:000-000.

Frøysa, K.G., Bogstad, B. and Skagen, D.W. 2001. Fleksibest - an age-length structured fish stock assessment. Fisheries esearch (accepted).

Giske, J., Huse, G. and Fiksen, Ø. 1998. Modelling spatial dynamics of fish. Reviews in Fish Biology and Fisheries 8, 57-91.

Hagen, G., Hatlebakk, E. and Schweder, T. 1998. Scenario Barents Sea: A Tool for Evaluating Fisheries Management Regimes. Pp. 173-226 In: Rødseth, T. (Ed.) Models for Multispecies Management. ISBN 3-7908-1001-0. Physica-Verlag, Heidelberg- New York.

Hamre, J. 1994. Biodiversity and exploitation of the main fish stocks in the Norwegian Sea - Barents Sea ecosystem. Biodiversity and Conservation, 3: 273-292.

Hamre, J. 2000. Effects of climate and stocks interactions on the yield of north-east arctic cod. Results from multispecies model run. ICES CM 2000/V:04, pp.12. Theme session on Medium-Term Forecasts in Decision-Making.

Hamre, J. and Hatlebakk, E. 1998. System Modell (Systmod) for the Norwegian Sea and the Barents Sea. Pp. 93-115. *In*: Rødseth, T. (Ed.) Models for Multispecies Management. ISBN 3-7908-1001-0. Physica-Verlag, Heidelberg, New York.

ICES, 2000. Report of the Northern Pelagic and Blue Whiting Fisheries Working Group, Copenhagen 27 April - 5 May 1999. ICES C.M. 2000/ACFM:16, 278 pp.

ICES, 2001. Report of the Arctic Fisheries Working Group, Copenhagen 22-31 August 2000. ICES C.M. 2001/ACFM:2, 340 pp.

Mehl, S. and Yaragina, N.A. 1992. Methods and results in the joint PINRO-IMR stomach sampling program. In B. Bogstad and S. Tjelmeland (editors). Interrelations between fish populations in the Barents Sea, pp. 5-16. Proceed ings of the fifth PINRO-IMR Symposium, Murmansk, 12-16 August 1991. Institute of Marine Research, Bergen, Norway.

Reed M, Balchen JG. 1982. A multidimensional continuum model of fish population dynamics and behaviour: Applica tion to the Barents Sea capelin *(Mallotus villosus). Modelling, Identification and Control* 3:65-110.

Rødseth, T. (Ed.) 1998. Models for Multispecies Management. ISBN 3-7908-1001-0. Physica-Verlag, Heidelberg- New York.

Sakshaug, E., C.C.E. Hopkins and N.A. Øritsland (eds.), 1991. Proceedings of the Pro Mare Symposium on Polar Marine Ecology, Trondheim, Norway, 12-16 May 1990. Polar Research, Vol. 10 No. 1 & 2.

Sakshaug, E., A. Bjørge, B. Gulliksen, H. Loeng og F. Mehlum (eds.), 1994 Økosystem Barentshavet. Norges forskning sråd, Universitetsforlaget AS. ISBN 82-00-03963-3.

Skjoldal, H.R., T.T. Noji, J. Giske, J.H. Fosså, J. Blindheim and S. Sundby, 1993. MARE COGNITUM Science Plan for research on Marine Ecology of the Nordic Seas (Greenland, Norwegian, Iceland Seas), 1993-2000, A regional GLOBEC Program with contributions also to WOCE and JGOFS. Institute of Marine Research, P.O.Box 19870 Nordnes, N-5024 Bergen, Norway.

Skogen, M.D. and Søiland, H. 1998. A user´s guide to NORWECOM V2. The Norwegian Ecological Model System. Fisken og havet nr.18-1998.

Slagstad, D. and Tande, K. 1996. The importance of seasonal vertical migration in across shelf transport of *Calanus finmarchicus.* Ophelia 44: 189-205.

Søiland, H. and Skogen, M. D. 2000. Validation of a three-dimensional biophysical model using nutrient observations in the North Sea. ICES Journal of Marine Science, 57: 816-823

Tjelmeland, S. and Bogstad, B. 1998. Biological Modelling. Pp. 69-91 In: Rødseth, T. (Ed.) Models for Multispecies Management. ISBN 3-7908-1001-0 Physica-Verlag, Heidelberg, New York.