A M OE B E

- FOR THE OCEAN

The AMOEBE *Plan*

Part 1: Overall plan
Part 2: Module descriptions

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

A 10-year multidiciplinary 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.

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Solenergi

Nutrients

Wind

Phytoplankton

Currents

The Amoebe Plan

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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 quantitative.*
- ■ *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, computer 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

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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 assessment of marine resources, including uncertainty estimates.
- Advanced operational information on the present and future state of the marine ecosystems.
- 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. Internation-ally 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 under-standing 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 Fisher-ies 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 suf-ficiently 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.
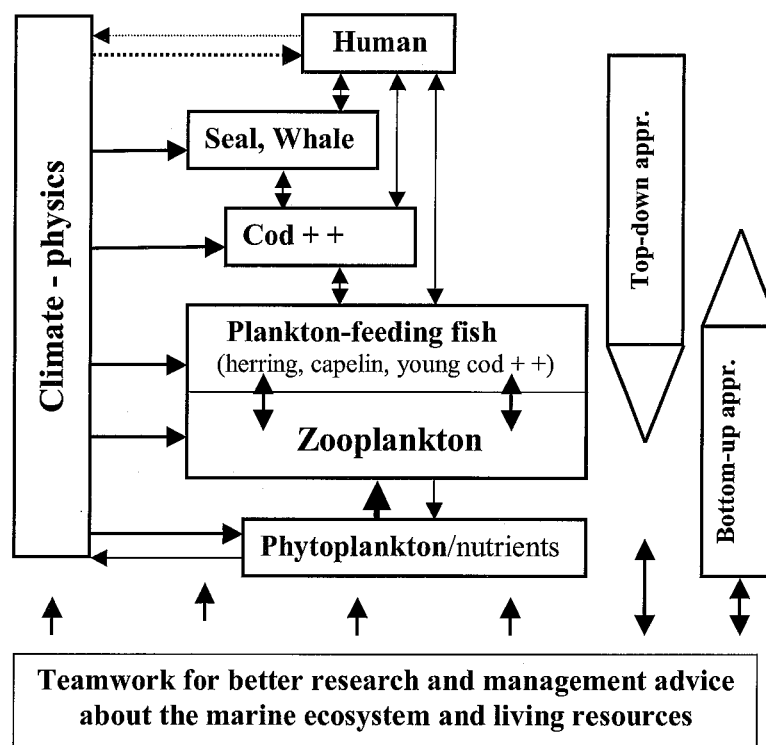
Figure 1. *Schematics of the marine ecosystem to be modelled*

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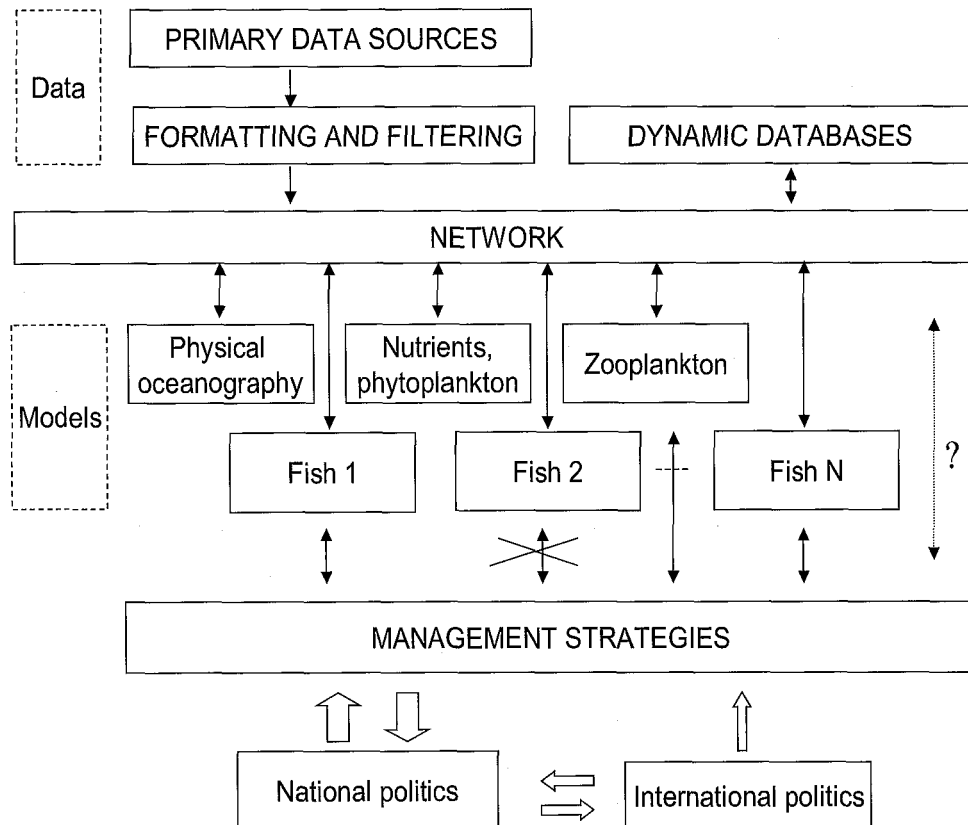
Figure 2. *First approach to the architecture of the AMOEBE reference model*

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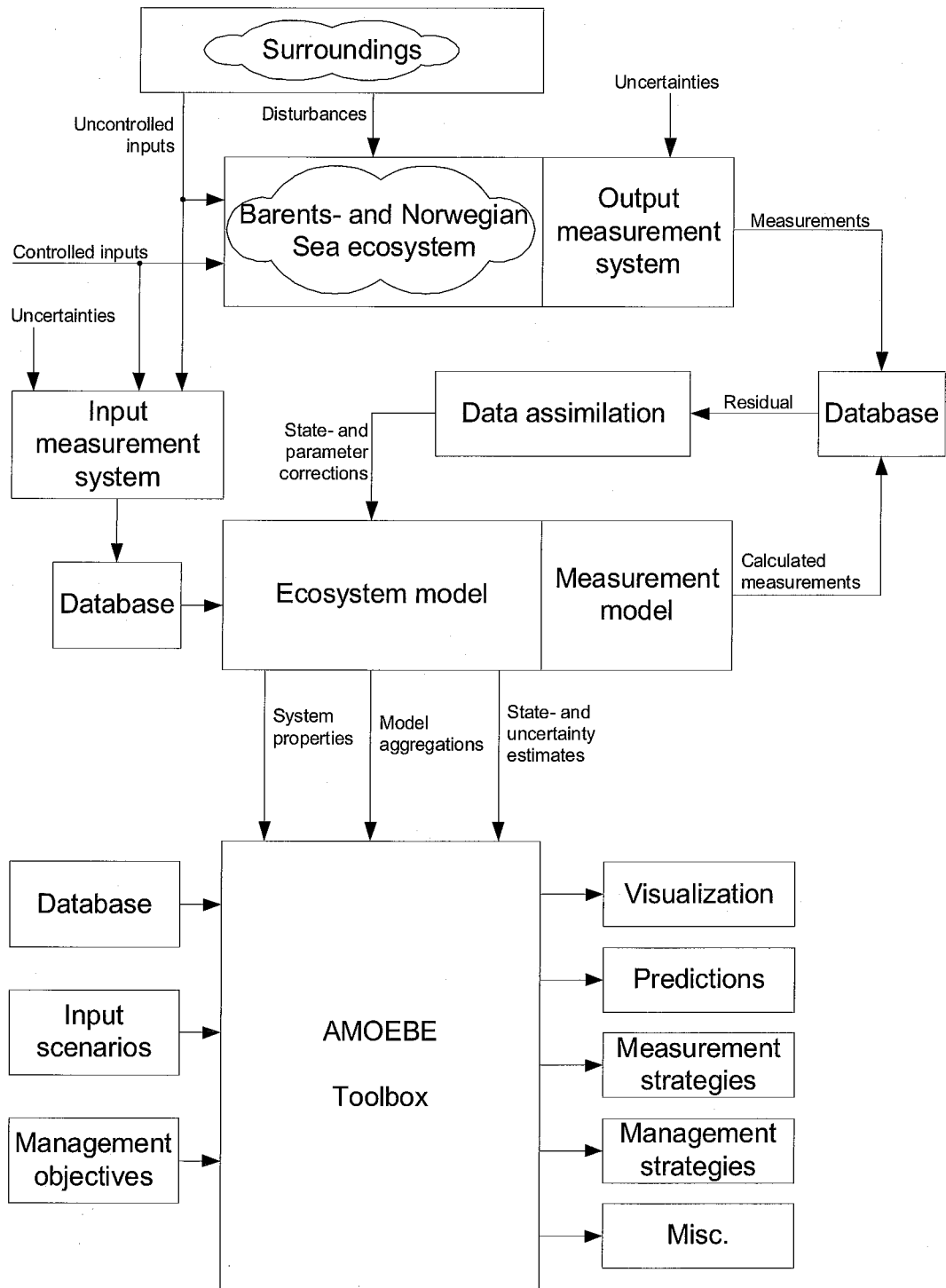
Figure 3. *Block diagram of the AMOEBE estimator structure.*

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.
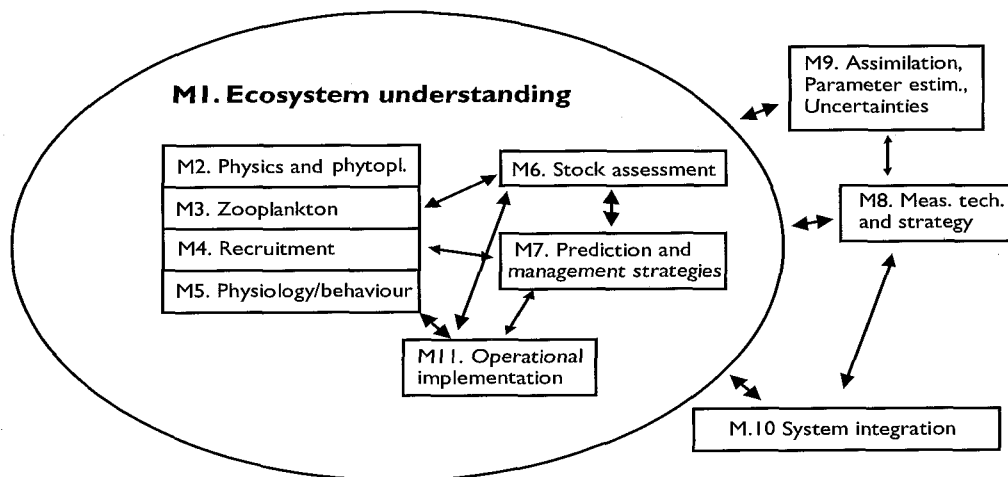
Figure 4. *Schematics of the AMOEBE module network*

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 identify-ing 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 uncertainties.
- 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 architecture 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 pro-
grammes: MARE, BeMatA, Monitoring (Overvåkning), RegClim, NoClim, Bjerknes Collabora-
tion, 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 "Precau-
tionary 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 model-
ling 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 manage-
ment 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 quantita tive 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:

30   The AMOEBE Plan - part I
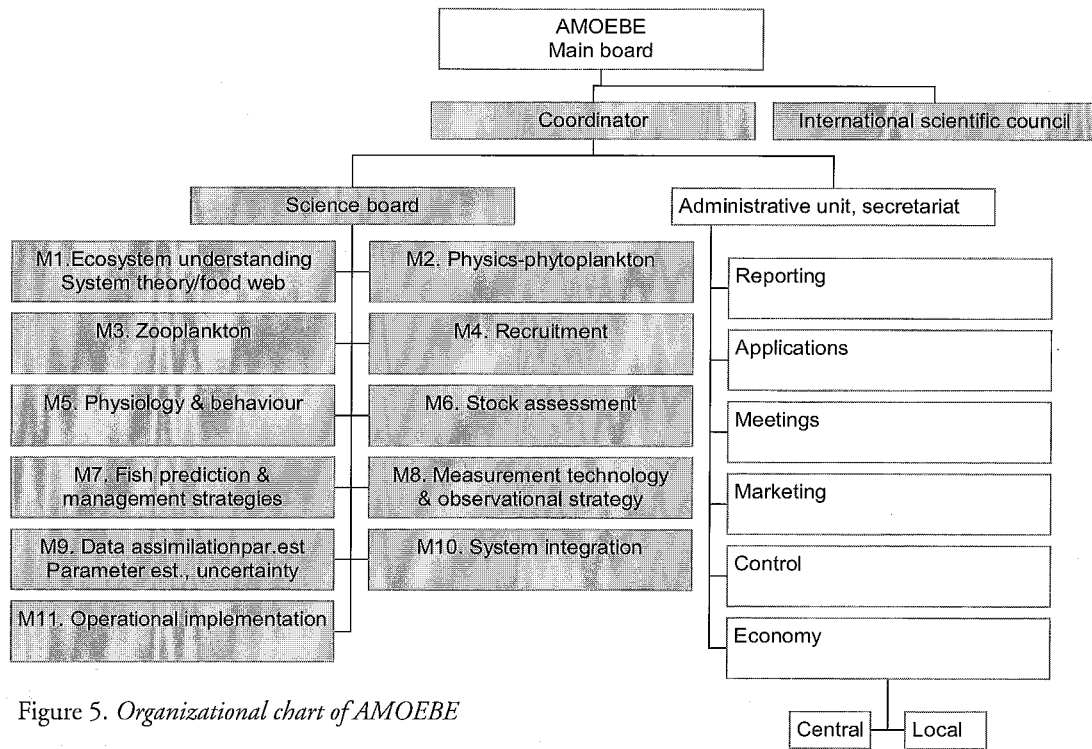
Figure 5. *Organizational chart of AMOEBE*

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 AMOEBE Plan - part I

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)

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The Amoebe Plan

Part 2:
Individual Module descriptions

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.

module 2

AMOEBE Module 2: Physics-Phytoplankton

Version 6.0, October 21, 2002

(Helge Drange (chairman), Geir Evensen, Tore Furevik, Lars Jørgen Natvik, Fransisco Rey, Asgeir Sorteberg, Einar Svendsen, Bjørn Ådlandsvik, Else Hegseth, Lars Petter Røed)

module 2

Content

1   Module summary

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

module 2 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 therodynamics, 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.

2   Objectives

The overall objective of Module 2 is to

> ***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 following three tasks have been defined:

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

Systematic and simultaneous analyses of physical, phytoplankton and biogeochemical (including nutrient) observations and a hierarchy of numerical models are required to describe the coupling between the marine climate and phytoplankton systems for past, present and possible future climate forcings, and for time scales ranging from days to decades. For the marine climate system, key parameters are the general ocean circulation, the distribution of temperature and salinity, the extent and thickness of sea ice, the characteristics and extent of the horizontal and vertical turbulence (including the depth of the upper mixed layer), and the light conditions. Similarly, the plankton system must address the major phytoplankton organisms, the nutrient distributions, and the interplay between the physical environment, the phytoplankton community, and the higher trophic levels. The latter component is manly the zooplankton component discussed in Module 3. Furthermore, the ocean circulation, mixing and thermodynamics have a bearing importance on, for instance, transport of fish eggs and larvae (Module 4), and transport and spreading of various pollutants. Therefore, Module 2 will provide appropriate numerical modules dealing with the physical driving forces of these processes as well.

3   Background

The climate system is characterized by various spatial-temporal variability modes, in addition to more long-term changes linked to low-frequency natural variability modes or to the human-induced increased greenhouse gas forcing of the atmosphere. Quantification, theoretical under-standing and numerical simulation of the climate variability modes and climate change are of paramount importance for the perceptions of the many earth systems, including understanding of the marine ecosystem.

The best known, and also the most profound of the natural climate variability modes is the El Niño-Southern Oscillation (ENSO). However, at mid to high northern latitudes, the North Atlantic Oscillation (NAO), commonly referred to as the Arctic Oscillation (AO) (Thompson and Wallace 1998), is the major climate variability mode. The NAO, which is a measure of the relative strengths of the Icelandic Low and the Azores High, and thus the strength of the westerlies, has been shown to influence water mass characteristics, volume fluxes and heat exchange in the Atlantic Ocean and the Nordic Seas (e.g. Kwok and Rothrock 1999; Häkkinen 1999; Stein 1999, Blindheim et al., 2001; Furevik 2001; Bentsen et al., 2002). In addition, it is known that the NAO effects, directly or in an indirect way, the marine ecosystems of the North Atlantic-Nordic Seas: It influences marine ecosystems on the level of primary production (Belgrano et al. 1999), on zooplankton production (e.g. Fromentin and Planque 1996; Planque and Fromentin 1996; Fromentin et al. 1998; Reid et al. 1998; Piontkovskii et al. 2000) and on the level of fish production, particularly cod (Rodionov 1995; Stein et al. 1998).

There are also indications of the influence of other large-scale climate indices at high northern

latitudes, for example the Euro-Siberian Oscillation (Kelly *et al.* 1999); and the Polar-Eurasian and Scandinavian Patterns (Barnston and Livezey 1987). Other indices of a more local character like the Barents Oscillation (Skeie 2000) can also have influence on the lower levels of a marine ecosystem as has been shown for the Barents Sea (Olsen *et al.* 2002).

module 2

The NAO/AO mode has a broad spectre of variations on inter-monthly to inter-decadal time-scales. More than 70% of the NAO/AO variance can be explained by short-term fluctuations having periods of less than 10 years. Still, decadal trends are clearly present in the instrumental records. The presence of these longer time trends have been discussed in recent literature since they may give rise to some predictability of long time changes in the NAO/AO (Stephensen *et al*, 2000). Suggested explanations for the low frequency trends or variability modes include long-term changes in the hydrography of the North Atlantic Ocean, external influence from e.g. global warming or stratospheric ozone depletion (Eichelberger and Holton, 2002; Hartmann, 2000), and natural stochastic variations (Wunsch, 1999). The physical mechanisms for the variability are, however, still unclear and may possibly involve tropical SST interactions (Hoerling *et al.*, 2001), changes in the propagation of planetary waves due to changes in the atmospheric temperatures (Eichelberger and Holton, 2002), changes in long-distance tele-connection patterns induced in the subtropical jet stream (Branstator, 2002), or feedback mechanisms from reduced sea ice or snow covers (Kvamstø *et al.* 2002; Cohen and Entekhabi, 1999).

Interestingly, the correlation between the NAO index and the advection of Atlantic Water into the Barents Sea varies with time and is stronger during the positive phase of NAO when storm tracks penetrate more directly into the Barents Sea (Dickson *et al.*, 2000). A recent study by Lu and Greatbatch (2002) shows that the correlation between NAO and a storm index has increased strongly since the mid seventies, which relates well with the increased correlation between the NAO index and the advection of Atlantic Water into the Barents Sea noted by Dickson *et al.* (2000).

The increased correlation between the storm activity mode and the NAO index over the last decades is related to the eastward shift of the NAO northern centre of action towards the Barents Sea. This shift is consistent with the increased NAO index seen for the last decades and hints at the special role played by the storm-tracks in the advection of Atlantic Water into the Barents Sea (Rogers and Mosley-Thompson, 1995). The last decade's eastward shift in the NAO centre of action is unprecedented in the instrumental records (Hilmer and Jung, 2000), and coupled GCM simulations (Ulbrich and Christoph, 1999; Sorteberg *et al*, 2002) have revealed that the eastward shift may be related to increased greenhouse forcing, indicating that external influences such as global warming may have an impact on the natural variability mode of the NAO. However, this does not rule out the possibility that the eastward shift is part of a natural, low frequency variability of the northern, high-latitude climate system.

A thorough description of the marine phytoplankton system depends critically on a proper description of the ocean circulation and thermodynamics. However, it is not only the ocean circulation, salinity and temperature distributions, and sea ice extent and properties that are of importance for the plankton system. Also horizontal and vertical turbulence, the surface and sub-surface light conditions, the availability of macro and micro nutrients, and the composition and concentration of the various plankton species determine the evolution of the system.

4   Structure of Module 2 and linkage to the other AMOEBE Modules

The marine climate system - its mean state, its fluctuations and possible long-term changes - is a key factor for the marine biota. Likewise, the phytoplankton system is the basic provider of biomass in the system. Module 2 is therefore tightly and directly linked to most of the modules in AMOEBE. Most of the deliverables are directed from Module 2 to the other modules, although tight collaboration and interaction with the different modules are a prerequisite for optimal use of the expertise and the various modelling tools in the module.

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.

Ocean circulation, mixing and temperature fields will be provided to the zooplankton and fish recruitment modules (Module 3 and 4) as these fields are needed for transport of individual particles and populations, plus eggs and larvae. The mentioned physical fields may also be important for the behavioural modelling in Module 5.

Furthermore, assessments of the degree of predictability the coupled physical-phytoplankton system is of direct value for the stock assessment (Module 6) and potentially also the prediction and management strategy (Module 7).

5   Innovation

The proposed model strategy is unique in that a consistent numerical modelling tool will provide information from global to very fine spatial scales. Preliminary analyses indicate that the modelling system is able to describe the main features of the circulation and thermodynamics in the Nordic and Barents Seas in a fairly realistic way.

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 therodynamics, 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.

Finally, thorough assessments of the degree of predictability of the physical system (i.e., the marine climate system) and the coupled physical-phytoplankton system are key activities in the module. The coupled atmosphere-sea ice-ocean model used in Module 2 is a new system showing promising results for the description of the present day climate state. This system will be extensively used in the predictability assessments. The predictability activities are expected to give new insight into the atmosphere-ocean coupling and the memory of the ocean system. Coupled to the phytoplankton modelling, these activities have the potential to significantlyy improve stock assessments and therefore be of direct value for management strategy.

6 Workplan

6.1 The physical system

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

The aim of this task is to explore and to quantify the atmospheric modes responsible for daily to decadal-timescale fluctuations in the regional to large-scale atmospheric forcings (like NAO/AO) that affects the Nordic and Barents Seas, and assess to which extent such fluctuations can be modified by changes in the human-induced greenhouse gas forcing. For this, historical observations, the latest observational datasets, a hierarchy of ocean only models and a state-of-the-art coupled ocean-atmosphere General Circulation Model (GCM) will be used.

The ocean-only model activity will probably include a truly global version of the Miami Isopycnic Coordinate Ocean Model (MICOM) with spatial resolution of 40 km in the Nordic Seas and forced with synoptic re-analyses fields for the last 50 years (e.g., Bentsen *et al.*, 2002, Furevik *et al.*, 2002b, Nilsen *et al.*, 2002); one-way nested, Nordic/Barents Seas versions of two of the best proven ocean circulation models (ROMS, MICOM, HYCOM, MI-POM) with spatial resolution of £10 km (e.g.Hatun *et al.*, in prog.); several high-resolution (i.e., 1-4 km), regional versions of the above models, forced and adjusted to the fields from the larger scale models at the lateral boundaries; and the Bergen Climate Model, a global fully coupled atmosphere-sea ice-ocean model system (Furevik *et al.*, 2002a; Bentsen *et al.*, 2002, Zhou *et al.*, 2002). The latter model system consists of the atmospheric model ARPEGE/IFS, developed jointly by Meteo France and the European Center for Medium Range Weather Forecast (ECMWF), and the global version of the above mentioned MICOM model.

Of crucial importance for both the validation and the continuous improvement and modifications of the models is the continuation of observational programs of key physical and biogeochemical parameters at selected areas in the Nordic Seas, particularly the Svinøy section and OWMS Mike for the Norwegian Sea, and the Fugløya-Bjørnøya section for the Barents Sea Opening. It is of pivotal importance for the modelling activities that these programs resolve the seasonal variability in an appropriate way.

The physical modelling activities described here, including data assimilation, will provide essential input to several of the AMOEBE modules. The current fields will be used to drive transport models for zooplankton in Module 3 and fish eggs and larvae in Module 4. They will also be important for the behavioural modelling in Module 5. In addition, almost all biological modelling activities rely on temperature and in addition may need other scalar fields such as salinity and turbulence.

The modelling activities in Module 2 will greatly benefit from the ongoing climate modelling studies in the Bjerknes Centre for Climate Research, a formal collaboration between the Institute of Marine Research, the University of Bergen and the Nansen Center. The Research Council

of Norway awarded the Bjerknes Centre for Climate Research status as a Centre of Excellence in Summer 2002.

Distribution and concentration of contaminants derived from simulated advective transport and dispersive mixing will be potential products based on the techniques developed in Module 2. **module 2** Together with other modules the pollution exposure time (dose) on plankton, fish, shellfish, macro algae and ocean farms can be simulated, and from this possible long and short time biological effects depending on basic dose-effect knowledge. This is not an integrated task in AMOEBE and will require some additional chemical experts and data and computer resources, but the cost will be relatively small since the framework will be developed within AMOEBE.

Work packages

    1.1 Analyses of observed circulation and hydrography over the last 50 years
    1.2 1950 to present hind-cast integrations with a 40 km global version of MICOM
    1.3 1950 to present hind-cast integrations with nested, £10 km version of the best proven model(s)
    1.4 Seasonal to multi-annual hind-cast and now-cast integrations with regional, 1-4 km versions of the best proven models
    1.5 Multi-centennial control climate and greenhouse warming scenario integrations with BCM

For all of the modelling work packages, integrated parts of the activity will be assessments of the simulated fields based on comparison with observations, and model improvement. In addition, ensemble integrations with a minimum of five members will be performed for each of the modelling activities to assess the uncertainty in the simulated fields. Both model validation and quantification of the spreading of the ensemble members are important since the output from Module 2 will directly or indirectly influence the physics-phytoplankton modelling and the modules pending on Module 2.

6.2 The coupled physical-phytoplankton system

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

The aim of this task is to identify, quantify and simulate key processes regarding the interaction between the physical environment and the marine phytoplankton system in the Nordic and Barents Seas.

Phytoplankton dynamics is closely connected to physical variability of the marine ecosystem. Present physical-biological coupled models reproduce adequately the response of the phytoplankton community to physical forcing in terms of biomass and productivity (bulk modelling) when growth has resumed in spring. Independently of the selected bio-physical model (e.g., Drange 1996, Slagstad and Wassmann 1996, Broström and Drange, 2000; Carmillet *et al.* 2001, or NORWECOM as described in Skogen *et al.* 1998,) there is a need to carry out a

confirmation/adaptation of the parameterisation of the model to the actual conditions in the different regions of the Nordic and Barents Seas, specially in the most northern areas where temperature conditions can be quite different from those in the southern areas.

module 2 An important aspect in the modelling work is phytoplankton species composition, and present models can with reasonable accuracy simulate succession. However, again there is a need of fine-tuning the parameterisation of the model to the actual regional conditions.

Another important, but often overlooked factor in phytoplankton dynamics is the bloom inoculum. South of the Arctic Circle algal cells may survive the winter in a vegetative stage, but in high latitude areas with a long, dark period there have to be other mechanisms for winter survival. Diatoms, the prime spring bloom phytoplankton group, spend the winter on the bottom as resting spores in northern shelf areas (Eilertsen *et al.* 1995, Hegseth *et al.* 1995).Winter convection creates vertical mixing down to the bottom in these relatively shallow (shelf) areas, providing the necessary mechanism for bringing the spores to the surface layers (Backhause *et al.* 1999). This is a key process for a spring bloom to initiate in high latitudes, and a possible change in climate influencing this process (change of surface heat flux and/or wind regime) could have significant effects on the marine ecosystem. Hence modelling and validation of the winter/early spring convection together with the resuspension of spores will be crucial in this task.

Probably the most important output of task 2 will be connected to the further transport of biological energy from the lower production levels to higher trophic levels (i.e., zooplankton). In this respect there are several aspects to be considered in the work of this task:

The timing of the spring phytoplankton bloom: An effective transfer of energy from primary producers to secondary consumers depends on a well-timed match between the spring bloom and zooplankton development. An early phytoplankton bloom not followed by zooplankton could result in substantial part of the bloom being exported out of the photic zone to deeper layers and not becoming available to the main zooplankton species in the Nordic Seas, *Calanus* spp. Although the sinking material can still be grazed in deeper layers, for instance by krill or other *Calanus* species or remineralized in the winter mixed layer before being deposited, it will nevertheless represent a less effective transfer. Such a phenomenon is likely to occur in regions where the formation of a surface mixed layer is mainly controlled by changes in salinity rather than temperature as in the marginal ice zone or in the oceanic front areas between the Atlantic Water and the fresher water carried by the Norwegian Coastal Current.

To resolve the spatial variability of the timing of the spring bloom, regional observations programs during the late winter and spring season should be carried out. Key observing parameters should include SST, irradiance and cloud conditions, wind force and direction, air temperature (wet and dry for latent heat flux), nutrient levels, depth of the upper mixed layer (from CTD profiles), depth of the critical depth (i.e., the Sverdrup depth) and phytoplankton biomass both as fluorescence and chlorophyll. Species composition of dominating algal groups must also be included. Furthermore, in order to assess the seasonal variability of these parameters, an observation program should be adapted at specific locations and transects in the Nordic and Barents Seas.

These observation programs together with the running of models will give us the opportunity of identifying key parameters and developing key proxies to be later on included in Task 3 work.

In general, the level of new production gives the harvesting potential of a marine ecosystem. New production, i.e., the production fuelled by winter nitrate, is considered to represent the fraction of the primary production that can be harvested by the system. Tracking the rate at which this new production is consumed from the spring bloom onwards provides also an idea of how effective the energy transfer to higher trophic levels is. To resolve this aspect it is necessary to rely on high frequency sampling programs (days or weeks) with main emphasis on nutrients for estimates of new production, and oxygen for estimates of the net community production (the integrated amount of carbon produced) at selected sites representing different dynamic relationships between the physical environment and the phytoplankton community. Model simulation of nutrient consumption will require, as in the above point, a fine-tuning of the parameterisation of the selected coupled physical-biological model.

module 2

The transfer of energy from primary producers to secondary consumers is highly dependent on the trophic interactions between these two components of the ecosystem. The reproductive period of *Calanus finmarchicus*, the main copepod in the Norwegian Sea is restricted to the location and the period of phytoplankton blooms and low reproductive activity is found when phytoplankton is scarce. However, it seems that maturation under food limitation enables *C. finmarchicus* females to a rapid response to sudden local food maxima because the corresponding metabolic pathways are already established. These facts reflect the close coupling between phytoplankton biomass and zooplankton development. As a rule, diatoms dominate the spring phytoplankton bloom in the Norwegian Sea, but from time to time the rapid development of other species not consuming silicate can retard diatom growth. Although there is still an ongoing discussion about the role of phytoplankton groups composition on both the reproductive ability of *C. finmarchicus* and its ability for selective grazing this is a high priority aspect to be elucidated through experimental work and model simulation. Looking at the nitrate to silicate ratios can assess the relative importance of the two main phytoplankton groups during the spring bloom.

Work packages

    2.1 Analyses of observed plant nutrient and phytoplankton biomass over the last 50 years
    2.2 Define, test and verify base line phytoplankton model for the region, coupled to the physical systems in Task 1
    2.3 Identify key *in situ* observation activities in the region
    2.4 Examine natural variability in the cycling of plant nutrients and primary biomass at different spatial resolutions

6.3 Predictability of the physical-phytoplankton system

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

The predictability activity will be split into two parts: An activity focussing on monthly/seasonal to longer time scales, and an activity dealing with daily and weekly time scales. This split is made

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since the first activity describes the major evolution of the marine climate system in the region, whereas the latter activity addresses marine forecast time scales of which operational systems already have been demonstrated (e.g. Brusdal *et al.* 2002, Natvik and Evensen 2002a,b), and with a coupled ocean-phytoplankton model (NORWECOM) being run operationally (for the North Sea) at the Norwegian meteorological institute.

For the monthly/seasonal and longer predictability assessment, systematic analysis of the outputs from the large scale sea ice-ocean model(s) will be conducted. The aim will be to identify the natural variability modes in the system, the lag relationships between different geographical areas, and key areas for the predictions of key oceanic parameters (e.g., mixed layer temperatures, mixed layer depths, transport of surface waters, sea ice cover) on time scales of days to seasons ahead. Such key areas should ideally be areas with extensive hydrographic (and preferably current) observations (e.g., the Faroe-Shetland inflowing region, the Svinøy-Gimsøy sections, and the Barents Opening region). In addition to hydrographic data based on *in situ* observations, indices based on satellite derived SST and ocean colour, and in the near future remotely sensed sea surface salinity, will be explored as possible predictors for the ocean climate and subsequently the primary biomass production.

Furthermore, output from century-scale control integrations with the coupled BCM will be examined in order to assess if 1) the relationships found from the ocean-only model are found in the fully coupled model as well, and 2) if they can be found in the coupled model forced with an increased amount of CO_2 in the atmosphere.

The more long-term predictability is based on the strong observational and modelling evidence that the variability of the large scale atmospheric forcing is governing the volume flux of the advection of Atlantic water masses into the Nordic and Barents Seas (e.g. Hansen & Østerhus 2000, Furevik 2001, Nilsen *et al.* 2002). However, the effect of large scale atmospheric forcing on the distribution of water masses within the Nordic and Barents Seas area is still unclear. Skeie (1999) identified the Barents Sea Oscillation (BO) as the second EOF principal component analysis of extratropical northern hemisphere winter SLP anomalies (NAO is the first) based on 40 years of reanalysed winter-time data, and by using SLP composites based on low and high Nordic Seas heat loss months after the removal of the NAO related variability. The BO index correlated to the Nordic Seas winter time heat loss with 0.76 over the 40-years period, indicating that the local effect of BO on Nordic Seas heat loss was much larger than the local effect of NAO. Recently Tremblay (2001) argues that the BO only represent a sudden eastward shift in the northern centre of action associated with the NAO observed in the mid seventies, and is as such not a physical property that can be separated from the NAO. The extent the NAO related large-scale atmospheric flow patterns is influencing the Nordic and Barents Seas region through its influence on the advection of North Atlantic Water or also through local winter time heat loss and wind associated with cold air outbreak is therefore unclear, and needs to be assessed.

The more short-term (days to weeks) predictability activity is critically dependent on describing an accurate initial state of the physical-nutrient-phytoplankton system. For this, remotely sensed ocean parameters are needed, in addition to the availability of in situ observations. The most frequently used remotely sensed fields for data assimilation of the marine climate system are sea surface temperature (SST), sea surface height (SSH) and the sea ice extent (Brusdal *et*

al., 2002). For prediction of the coupled physical-phytoplankton system, satellite SST has been successfully used as a proxy for estimating the depth of the upper mixed layer in areas with relative homogeneous salinity and where the warming of this layer mainly controls vertical stability. Also light conditions and key meteorological factors as wind force and direction can be derived from satellite-born sensors. In addition, ocean colour imagery provides a good estimation of phytoplankton biomass and probably also group composition. The rapid development of new techniques associated with new or improved sensors, and the steady increasing availability of the satellite data in (near) real-time, make remote sensing a powerful source for describing the initial state of the system. The data assimilation method to be applied will be based on the Ensemble Kalman approach, in which considerable expertise is found in Norway (e.g., Brusdal *et al.* 2002, Haugan and Evensen 2002, Natvik and Evensen 2002a), and to be further developed in Module 9.

Work packages

3.1 Analyses of natural variability modes in observations and 50 years of hind-cast simulation data
3.2 Analyses of natural variability modes, and the predictability of these modes, in BCM
3.3 Predictability of the marine climate system in the region of daily to weekly time scales
3.4 Predictability of the coupled physical-phytoplankton system in the region of daily to weekly time scales

7 Deliverables

Work package	Deliverable	Title
WP 1		**The physical system**
	D 1.1	Analyses of observed circulation and hydrography over the last 50 years
	D 1.2	1950 to present hind-cast integrations with a 40 km global version of MICOM
	D 1.3	1950 to present hind-cast integrations with nested, ≤10 km version of two of the best proven models
	D 1.4	Seasonal to multi-annual hind-cast and now-cast integrations with regional, 1-4 km versions of the best models
	D 1.5	Multi-centennial control climate and greenhouse warming scenario integrations with BCM
WP2		**The coupled physical-phytoplankton system**
	D 2.1	Analyses of observed plant nutrient and phytoplankton biomass over the last 50 years
	D 2.2	Define, test and verify base line phytoplankton model for the region, coupled to the physical systems in Task 1
	D 2.3	Identify key *in situ* observation activities in the region
	D 2.4	Examine natural variability in the cycling of plant nutrients and primary biomass at different spatial resolutions

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WP3		**Predictability of the physical-phytoplankton system**
	D 3.1	Analyses of natural variability modes in observations and 50 years of hind-cast simulation data
	D 3.2	Analyses of natural variability modes, and the predictability of these modes, in BCM
	D 3.3	Predictability of the marine climate system in the region of daily to weekly time scales
	D 3.4	Predictability of the coupled physical-phytoplankton system in the region of daily to weekly time scales

8 Timing

Table 1. Progress plan. Active work packages are indicated by x.

Work package	Year 1				Year 2				Year 3				Year 4				Year 5				Y 6	Y 7	Y 8	Y 9	Y 10
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP3					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

9 Budget for 5 years

The costs of module 2 will mainly be manpower, computing power and equipment mainly for deep water climate and phytoplankton in situ monitoring (ARGO+). Super computer costs are included in Module 11. The manpower will be distributed among senior scientists (30%), scientists (40%), and PhD students (30%). The total cost for the first 5 years will be about 67 million NOK, and the total cost over the ten year period is estimated to 110 mill. NOK. The cost of developing ARGO floats and possibly AUV's within fluorescence and oxygen sensors is included in Module 8, but 20 million NOK is included here to buy and deploy such equipment.

Work package	Yearly man months					Sum man	Man power	Equipment	Running	Total, 5Y
	Y1	Y2	Y3	Y4	Y5	months	Cost, 5Y	5 Year	cost, 5 Y	
WP0	12	6	6	6	6	36	2976	60	500	3536
WP1	36	36	36	36	36	180	15118	10000	2500	27618
WP2	18	36	36	36	36	162	13750	10000	2300	26050
WP3		24	24	24	24	96	8255	0	1400	9655
Sum	138	126	120	144	108	474	40099	20060	6700	66859

Table 2. Cost of module 5 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63. Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses.

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module 2

module 2

A Model based and data-driven Operational Ecological Biomass Estimator (AMOEBE)

MODULE 3 ZOOPLANKTON   module 3

Version 16. oct. 2002

(Kurt Tande (chairman), Dag Slagstad, Webjørn Melle, Øyvind Fiksen, Stein Kaartvedt, Olav Vadstein, Are Edvardsen, Ole-Petter Pedersen, Morten Skogen, Einar Svendsen)

Content

Module summary

The aim with the zooplankton module is to establish an integrated monitoring and modelling system that together with an assimilation procedure can estimate the biomass, internal structure (often size structure), and spatial distribution of selected groups of zooplankton species. In order to do this we will apply a variable spatially resolved hydro-dynamical model, to study confined areas on the coast and larger regions of the ocean with sufficient spatial resolution. The work includes existing data assimilation techniques and the development of new approaches to force the zooplankton models according to spatially and temporally resolved data inputs. One of the main challenges is to develop

new sampling technology (i.e. sensors, platforms) appropriate for the quantitative most important groups of zooplankton. This will lead to a new suite of routines for monitoring, data processing, and modelling, needed for ecologically based management of marine resources. The structure of the work plan is grouped into functional groups or state variables. These include copepods, krill and amphipods, gelatinous predators, microzooplankton. Since observation of animals in the size range of zooplankton is methodological difficult, a separate module is required for this effort. The necessary equipment development is described in Module 8.

Objectives and expected achievements

The aim with the zooplankton module is to construct a model and monitoring system that together with an assimilation procedure can estimate the biomass, internal structure (often size structure), and spatial distribution of selected groups of zooplankton species.
Specific objectives are:
- Identify the most appropriate model concepts which can simulate realistically and efficiently zooplankton dynamics in the ocean off Norway
- Establish data sets that for the targeted zooplankton groups that can be used for model validation.
- Clarify life cycle strategies and overwintering mechanisms.
- Establish autonomous and semi-autonomous devises that may be applied on various plat forms (bottom mounted, AUV, ships etc.) for monitoring targeted groups of zooplankters.
- Develop routines for data acquisition, processing and banking of data
- Develop routines for model updating based on primary data
- Develop routines for model prognosis for zooplankton and their impact on ecosystem understanding and management

Contribution to AMOEBE

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).

Structure and linkage to other AMOEBE modules

The structure of the zooplankton module is related to functional groups (i.e. state variables (Fig. 1). Development of models for the different groups is likely to take place at different institutions and coordination is necessary in order to ensure that the models can talk together. Since there is strong coupling between the components within this module and especially Module 2, testing and validation must be performed with an integrated system. Workpackage 7 will make the model integration internally to ensure that the coupling to other modules is done properly. Equipment development is a prerequisite for collecting the data necessary for model construction and validation as well as model updating. New development will be managed in Module 8, but testing of existing and new equipment is a task for Work package 6.
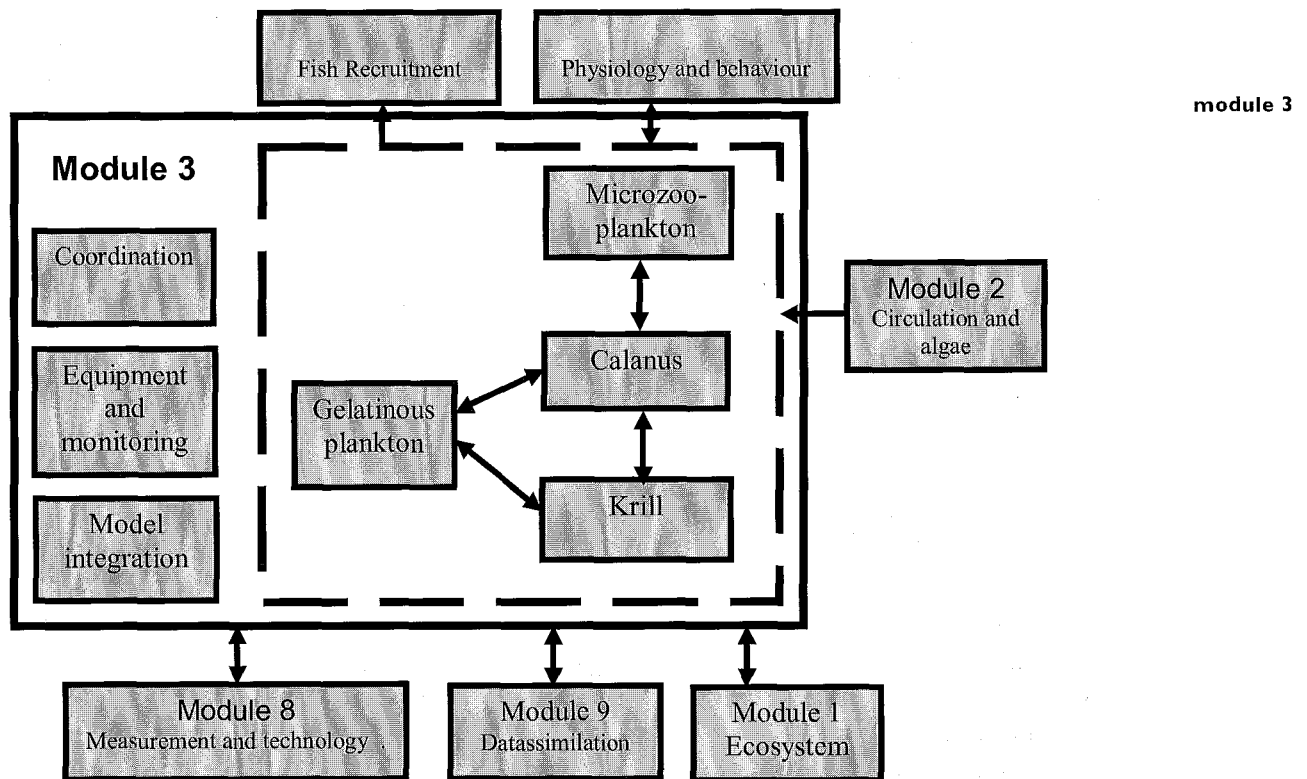
Figure 1. Structure of Module 3 and linkage to other AMOEBE modules.

Innovation

We will apply a variable spatially resolved hydro-dynamical model, which will enable us to study confined areas on the coast and larger regions of in the ocean with sufficient spatial resolution. The work includes existing data assimilation techniques and the development of new approaches to force the zooplankton models according to spatially and temporally resolved data inputs. One of the main challenges is to develop new sampling technology (i.e. sensors, platforms) appropriate for the quantitative most important groups of zooplankton. This will lead to a new suite of routines for monitoring, data processing, and modelling, needed for ecologically based management of marine resources.

Workplan

The zooplankton model that will be developed in AMOEBE must reflect these change in functional response as the structure age and/or size structure changes. These type of models are usually called structural models and includes either size (Slagstad et al. 2000) or developmental stage (Carlotti 1998). Most zooplankton models coupled to a 3D environmental models are not structured type of models, except for Slagstad et al. (2000). This is due to the heavy computational demands required for handling such models.

Two distinct model philosophies are often used in ecosystem modelling, individual based models (IBM) and Eulerian models. The IBM models look at a population as individuals (particles). Each particle may be given certain properties that can simulate the population structure. The Eulerian approach looks at the population as a concentration of animals (biomass or individuals) that is advected in the same manner as any scalar property such as temperature or salinity. Fish and mammals are likely to be represented by IBM models whereas phytoplankton is represented by the Eulerian approach. Zooplankton is somewhere in-between and which type of models that is most appropriate for meeting the requirements in a AMOEBE frame work must be in an early phase of the program.

The structure of the work plan is grouped into functional groups or state variables. This includes copepods, krill and amphipods, gelatinous predators, microzooplankton. Since observation of animals in the size range of zooplankton is methodological difficult, a separate module is required for this effort. The necessary equipment development is described in Module 8.

Copepods

Several integrated physical and biological plankton models are available, and there is a great need to increase the realism of these models by establishing automated sampling and updating procedures.

Our technological approach in zooplankton automated sampling is far behind compared to other closely related fields such as biological and physical oceanography. One of the main challenges in zooplankton is the mismatch between temporal and spatial variations and our ability to resolve this variability even by automatic sampling. The most important mechanisms affecting spatial distributions of zooplankton over time are ocean current patterns and physiological and population rates and their combined effects. For example, distribution of zooplankton in the California current was found to have a spatial decorrelation scale of 30-60 km with a corresponding temporal decorrelation scale of 3 days (Zhou 1998). This is a typical example, which demonstrate that our sampling programs need to be able to observe biomass with resolution of hours in time and hundreds of meters in space. The current state of this field in science does not allow us to meet this demand, and the question is therefore, at which level should our monitoring programs be detailed?

We suggest to use a three level approach to monitor the abundance and biomass changes in copepods:

i) 3-D large scale coverage once per year, preferable epipelagic distributions by use of ship-mounted devices

ii) 2-D monitoring of selected transects by use of ship-mounted devices

iii) 2-D continuously monitoring of selected "sensitive" sites by using anchored platforms

iv) 3-D large scale monitoring by using drifters (strategic investment)

In monitoring changes in numbers and biomass in size groups of copepods (see i-iii) above), there is two approaches which are currently available, either the use of ship-mounted automated optical or acoustic recorders or anchored platforms with automated optical/acoustic logging. The optical system (OPC) is available at a towed platform, and an acoustic hull-mounted broad-beam transducer trained to recognize groups of plankton (SCIFISH 2000) is about to be operative. These two systems will provide 3-D coverage of copepods and krill covering selected time windows and areas.

Krill

Krill form an important part of the diets of many commercially important fish species in the Barents and Norwegian Seas (Bogstad & Mehl 1997, Dalpadado *et al.* 2000). Decline in the capelin stock in the Barents Sea is often accompanied with increase in the large forms of zooplankton such as krill and amphipods. This indicates a clear predator-prey interrelationship between planktivorous capelin and krill in the Barents Sea and suggests that the krill populations are to a large extent controlled by predation (Dalpadado and Skjoldal 1996). Estimates of krill biomass based on sampling with traditional plankton nets such as WP 2 nets and the MOCNESS severely underestimate the biomass. Using traditional pelagic fish trawls, Dalpadado *et al.* (1998) estimated the total biomass of krill in a restricted area of the Norwegian Sea at 50 mill tons wet weight. Preliminary results with fine meshed plankton trawls indicated this was an underestimate by 60 % (Hassel & Melle 1999). Thus, biomass of krill in the Norwegian Sea may be 80 mill tons. Additional data indicate that total krill biomass of the whole Nordic Seas region (3.1 mill km2) is about 150 mill tons (Dommasnes *et al.* in prep.). This makes krill an important contributor to total zooplankton biomass and production.

Due to the size and swimming abilities of krill, representative catching and biomass estimation of these animals are challenging tasks. Krill tends to avoid even the largest zooplankton sampling systems (MOCNESS) and will be lost through the meshes of most pelagic trawls. To develop sampling devices that will give representative samples of the krill populations with respect to age and distribution will be an important task for AMOEBE. Not only sampling, but also abundance estimation and mapping of distribution on adequate temporal and spatial scales are presently not properly done. Acoustic and optical methods can be used to estimate abundance of krill, and especially acoustic methods are considered useful because of the larger size of krill compared to other zooplankton groups (Dalen *et al.* 2001). Acoustic surveys of krill can be conducted with hull mounted transducers when the krill are distributed within a few meters depth below the transducers. Acoustic measurements of krill will involve the use of an array of acoustic frequencies, ideally from 700 MHz to 38 kHz to be able to resolve most sizes of krill in the sea (Dalen *et al.* 2001). Due to the short operating range of high frequencies, the transducers have to be mounted on a towed body when the krill are distributed at greater depths, or perhaps on AUV's or profiling buoys. Development of acoustic methods for abundance estimation of krill should be included in AMOEBE.

In spite of the high abundances and great importance of krill in the northern ecosystems surprisingly little is known about their biology. The role of krill in the food chain is complicated since they feed both herbivorously and carnivorously (Båmstedt & Karlson 1998, Onsrud & Kaartvedt 1998). The trophic status of krill, however, is largely unknown. With a total biomass of ~150 mill tons the krill are the major predators on the herbivore copepods in the Nordic Seas ecosystem (Dommasnes *et al.* in prep.). Growth studies on krill are complicated because ageing is difficult and the specimens tend to shrink under unfavourable conditions. Longevity, mortality rate and reproductive biology remain largely indefinite (Siegel 2000). To explore the tropic position and vital rates of krill within the ecosystem is essential to model formulation and should be a task within AMOEBE.

The main task for this work package is:

Establish a dynamic model for the mai krill species based on existing knowledge and data. In an early phase one should point on important biological parameters for model construction that are missing. What details are needed for an operative krill model that can meet the requirements of the interacting species? Is it necessary to include a size distribution? Should the krill be treated as a single compartment or how many species do we need to include?

module 3

Determine life history parameters and vital rates of krill for inclusion in the biological model. Important data for model construction would be growth parameters, feeding rate, developmental rate, mortality rate, longevity, reproductive capacity and behaviour (e.g. vertical migration, swarming, feeding and anti-predator behaviour).

Data collection tools. Abundance of krill may easily be measured by multi-frequency echo sounders, but there is still work to be done until we can relay on the biomass estimates that arise from such measurement. Size distribution would probably be necessary data needed for updating of a krill model. Data are needed for model construction and data assimilation. The data requirements are not necessarily the same.

Monitoring. Data are needed for up-dating the model and data assimilation. This involves the construction of a monitoring system that can provide sufficient data to update the krill model. Due to the extended life cycle and lower rate of growth, mortality and development of krill compared to smaller zooplankton groups, the sampling frequency within of krill monitoring programs can be lower compared with other zooplankton monitoring programs. The program should include: One annual regional survey of the krill population within the Nordic Seas by research vessels. Quarterly sampling along four standard sections of the Norwegian and Barents Seas by research vessels. Continuous automated sampling by drifters. This monitoring system needs to be an integrated part of the AMOEBE surveillance system.

There are currently no models of the full life cycle of krill available in the literature, despite the accruing experimental and observational foundation for such models (Nicol 2000). This is surprising from the ecological importance of krill, and the progress that has been made recently both in population modelling in general (Tuljapulkar & Caswell 1997) and in other planktonic organisms, e.g. *Calanus finmarchicus* (e.g Slagstad *et al*. 2000). A few models of growth (Astheimer *et al*. 1985) and behavior (Tarling *et al*. 2000) have been presented, but not for the complete life cycle, and certainly not as a function of seasonal fluctuations in e.g. food supply. Theoretical models on life history strategies (energy allocation, longevity) are also warranted (Mangel & Nicol 2000), as are models acting as tools to extrapolate from experiments to natural situations (Nicol 2000). To improve our quantitative understanding of krill population biology, we should start the development of modelling tools for krill now.

Microzooplankton

In the context of AMOEBE this group includes protozoa, and in particular ciliates. Of the major functional groups of plankton, this is probably the one with lowest number of data available on taxonomy, distribution and dynamics, as both phyto- and zooplanktologists tradition-ally have omitted these organisms. Ciliates are an extremely diverse group that interacts with metazoan zooplankton in opposite ways. First, ciliates and metazoa compete for the same

food - phytoplankton - and ciliates may therefore strongly affect succession and production of herbivorous metazoa. In spite of large differences in size the two groups have partly overlapping size spectrum for food. When the whole life cycle of copepods is considered this overlap is considerable. Second, due to differences in size copepods and ciliates experience different mortality rates exerted by predators. The most notable difference is that the typical size of ciliates (10-40 µm) is well within the prey size range of copepods (Stoecker & Capuzzo 1990; Kleppel 1993; Hansen *et al.* 1994). Thus in these food webs we have an omnivorous system where copepods may exert a high selective mortality rate on their competitor the ciliates. Hence copepods may counteract competitive superiority of the ciliates by eating their competitor. When judging competitive ability between copepods and ciliates different measures apply to different context, and overall performance of a given species cannot be judged from a single parameter (Gismervik *et al.* 1996). Although the conceptual model for including ciliates in planktonic food web models is reasonably clarified, limited data makes parameterisation of this group difficult. Gismervik *et al.* (1996) have discussed these questions in detail, and their evaluation can be used to propose a minimum set of parameters for modelling purposes.

The first three tasks are closely linked and will be organised in an interactive manner. As there seems to be species-specific differences among copepods to which extent they selectively feed on ciliates, this information may have to be established for some key species as part of AMOEBE.

Gelatinous predators

Gelatinous plankton comprises a variety of species that use different life cycle strategies for utilising
the food resources. This group of plankton has the ability to reproduce fast and their main food is zooplankton. Gelatinous plankton is probably an important predator on fish larvae as well. The predatory impact on zooplankton probably depends on timing population growth and ontogenetic migration of their prey (e.g. *Calanus*). If plankton (*Calanus* and krill) is going to be exploited in the future, jellyfish is certainly going to cause problems both as a predator that reduce the available biomass and in the catch situation by clogging the nets
Not much modelling work has been done on this group of animals, therefore, basic modelling efforts is needed. This must go hand in hand with data collections to provide data sets for model validation. Laboratory work must also be performed in order to determine physiological parameters.
Quantitative observation of gelatinous plankton is difficult with the present sampling technology. It is therefore necessary to develop automatic equipment that is able to monitor the biomass and size structure of this predator group.

Equipment development and monitoring

Sampling of zooplankton with sufficient time and spatial resolution has always been difficult and expensive. The standard method has been nets of different types that produce a limited number of samples that is distributed either vertically or horizontally. Work up of the data (determining species composition and biomass) is expensive and time consuming. For krill, multi frequency echo sounder may be used to find biomass and size structure, but much work is still needed to verify this instrument. For smaller organisms (mesozooplankton), one needs to increase frequency, which means that the sampling range is decreased. This means that we have to bring

module 3

the instrument closer to the measuring target. What is needed is a general purpose, acoustic instrument that is able to measure particle distribution in a size range from less than 1 mm to about 10 mm. Since the detection range for physical reasons will be limited, it must be operated from different platforms (ship, bathfish, mored and drifting buoys and AUV). In the recent years Optical instruments (OPC and VPC) has been available for zooplankton sampling. OPC instruments are already in use and will be another tool that can bring increased knowledge of mesozooplankton distribution.

Progress plan

Tabell 1. Progress plan. Active work packages are indicated by x.

Work package	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
WP3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
WP4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x	x	x	
WP5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP7									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

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<div style="text-align: right;">module 3</div>

Deliverables

Table 1. List of deliverables.

Workpackage	Deliverable	Description
WP1	D1.1	Annual updated action plan.
	D1.1	Coordination of module 3
WP2	D2.1	Structured models of the most important Calanus species
	D2.2	Provide data sets based on existing and AMOEBE collected data that can be used for model validation and data assimilation.
	D2.3	Validated 1. generation of Calanus models and recommendations for further processes studies that need to be performed.
	D2.4	Recommend a monitoring program (based on system analysis) in order to increase the degree of observability of the Calanus system
WP3	D3.1	Provide data sets of Life history parameters and vital rates of krill for inclusion in the biological model.
	D3.2	Structured models of the most important krill species and recommendation for biological investigations in order to improve model performance.
	D3.3	Towed multi frequency acoustic and optic recording system, and automated krill identification and abundance estimation system with dbase storage
	D3.4	Procedure for assimilation of krill field data into a krill model
WP4	D4.1	A conceptual microzooplankton model especially designed for AMOEBE purpose
	D4.2	Field data for model validation
	D4.3	A validated model of the microzooplankton
WP5	D5.1	1. generation of gelatinous plankton model
	D5.2	Field data for model validation
	D5.3	Parameters to be used in the dynamic models based on laboratory experiments
WP6	D6.1	Scanfish sampling protocol
	D6.2	Neural network classifier for zooplankton groups
	D6.3	Real-time data acquisition for Scanfish carried instruments
WP5	D7.1	Recommendation for a zooplankton model structure
	D7.2	Evaluation of assimilation tools applied for zooplankton modul
	D7.3	Monitoring sites for zooplankton

Budget

The costs of Module 3 will mainly be equipment, manpower and computing. The manpower will be distributed among senior scientists (30%), scientists and post docs (30%) and PhD students (40%). The total cost of the first 5 years is about 60 million NOK. The total cost over 10 years is assumed to be about 110 million NOK.

Table 2. Cost of Module 3 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses.

Work package	Y1	Yearly man months Y2	Y3	Y4	Y5	Sum man months	Man power Cost, 5Y	Equipment 5 Year	Running cost, 5 Y	Total, 5Y
WP 1	12	6	6	6	6	30	2976		500	**3425**
WP 2	24	24	24	24	24	120	9906	3000	1800	**14706**
WP 3	12	24	24	24	24	108	9010	2000	1500	**12510**
WP 4	12	12	12			36	2826	500	500	**3826**
WP 5	12	18	24	24	24	102	8539	600	1500	**10639**
WP 6	12	24	30	30	30	126	10566	800	1800	**13168**
WP 7			6	12	12	30	2621	150	500	**3271**
Sum	**78**	**108**	**126**	**120**	**120**	**552**	**46446**	**7050**	**8100**	**61545**

Workpackages

WP1 Module coordination

Objectives
- To perform administrative tasks associated with Module 3.
- To develop action plan with annual update.

Description of work
The work of module 3 will require considerable coordination as it involves the co-ordination of many different individual researchers and institutions. An action plan will be developed in WP1 during the early stages of the project, and this will be updated annually in response to the developments in module 3 and AMOEBE as a whole.

Deliverables
D1.1 Annual updated action plan.D1.2 Coordination of module 3.

WP2 Copepods
(*C. finmarchicus and C. glacialis*)Responsible partners: NFH/HI (Kurt Tande, Webjørn Melle)

Objectives
- Establish a structured model for C. glacialis and C. hyperboreus.

- Validation of existing *Calanus* models using data already available
- Perform sensitivity tests and recommend monitoring programs in order to improve model performance.
- Quantify and understand mortality and advection processes during overwintering. What is the significance of overwintering on the shelf compared to oceanic overwintering?
- Determine the mortality processes (predation from fish, jellyfish etc.) during the growth season. What determines the overwintering stock?
- Understand the effect of interannual variability in climate on the *Calanus* production.
- Establish a monitoring system for *Calanus* based on System Analysis and existing and new instrumentation development.

module 3

Description of work

The Workpackage will focus on development of new *Calanus* models that are detailed enough to give an adequate description of the life cycle (i.e. must be structured and simulate ontogenetic behavior). The model structure is also determined from the demands of other parts of the ecosystem (fish, fish larvae etc.). Structured models of *C. finmarchicus* do already exist but more model validation is needed. The mortality processes in different phases of the *Calanus* life cycle is not understood. These processes can only be investigated using repeated cruises to selected locations measuring both the *Calanus* and the predator field. Effects of interannual variability climatic forcing on the *Calanus* production will be investigated using model simulations combined with historical data and data collected during the AMOEBE program.

Large scale field investigation and monitoring of small animals such as *Calanus* require advanced instrumentation. Such instrumentation is partly available (OPC, SCIFISH) but new development is necessary. Especially systems that can provide time series of biomass, size distribution and vertical migration.

Deliverables

D2.1 Structured models of the most important *Calanus* species

D2.2 Provide data sets based on existing and AMOEBE collected data that can be used for model validation and data assimilation.

D2.3 Validated 1. generation of *Calanus* models and recommendations for further proc esses studies that need to be performed.

D2.4 Recommend a monitoring program (based on system analysis) in order to increase the degree of observability of the *Calanus* system.

WP3 Krill (T. Inermis and M. norvegica)

Responsible partners: HI/UIB/UIO (Webjørn Melle, Øyvind Fiksen, Stein Kaartvedt)

Objectives

- determine life history parameters, trophic status and vital rates of krill
- establish a model
- for the most important krill species and amphipods and identify processes need special investigation (field and laboratory) in order to give a realistic model for use within the

AMOEBE program.

- develop routines for data acquisition, processing and banking of data·develop routines for model updating based on primary data

Description of work
Models of krill and amphipods that simulate the life history pattern, growth and reproduction are not available. There is a need for basic model development and it is likely that this will uncover processes that are not understood in a sufficient way to be modelled in a realistic way. By field, mesocosm and laboratory investigation life history parameters, trophic status and vital rates of krill will be determined. The biological krill parameters and abundance data will be used in the construction of the krill population model and data assimilation.The workpackage will develop a monitoring program for krill using towed platforms with multifrequency acoustics and optics, and automated krill identification and abundance estimation systems with dbase logging.

Deliverables
D3.1 Provide data sets of Life history parameters and vital rates of krill for inclusion in the biological model.
D3.2 Structured models of the most important krill species and recommendation for biological investigations in order to improve model performance.
D3.3 Towed multi frequency acoustic and optic recording system, and automated krill identification and abundance estimation system with dbase storage
D3.4 Procedure for assimilation of krill field data into a krill model

WP4 Microzooplankton
Responsible partner: NTNU (Olav Vadstein)

Objectives
- Establish a conceptual model for including ciliates in the general zooplankton model, determine a minimum set of parameters necessary, and implement this functional box in the general zooplankton model.
- Establish parameter values for ciliates based on literature data and a minimum set of physiological characterization experiments.
- Provide data sets from large scale surveys that can be used for model validation.
- Model validation against field data from different water masses (e.g. coastal,oceanic, Norwegian Sea, Barents Sea)

Description of work
Implementation of microzooplankton in ecosystem models depends on the specific objectives of the model (e.g. Baretta-Bekker *et al.* 1995; Slagstad *et al.* 1999). A simplified version of the microbial loop (Azam et. al. 1983) will be included in this submodel. For AMOEBE, there are necessary demands from other Modules as well as internal dynamics within the zooplankton module itself that will affect the choice of model structure. After selection of model structure, the model construction will be based on literature data. New short-term mesocosm experiments designed to both provide parameters for the model and for model validation. In our region, the mesozooplankton is often a dominating component of the zooplankton community and it

has been shown that microzooplankton is an important component of their diet. It is therefore to design both experimental setup and field surveys that may show the linkage between meso- and microzooplankton

Deliverables
    D4.1 A conceptual microzooplankton model especially designed for AMOEBE purpose

    D4.2 Field data for model validation

    D4.3 A validated model of the microzooplankton

module 3

WP5 Gelatinous plankton

Objectives
- Establish a model of the population dynamics of selected groups of gelatinous plankton
- Provide data sets from the field that can be used for model validation
  Perform laboratory experiments in order to find predator prey relationships and param eters for the gelatinous plankton model

Description of work
Based on literature, structured model of selected groups of gelatinous plankton will be estab- lished. This will uncover where knowledge is missing for building a reliable model and which field data that should be collected. In parallel equipment development will be developed an tested in order to make the field surveys effective.

Deliverables
    D5.1 1. generation of gelatinous plankton model

    D5.2 Field data for model validation

    D5.3 Parameters to be used in the dynamic models based on laboratory experiments

WP6 Equipment development and monitoring
Responsible partners: NFH/SINTEF/HI (Are Edvardsen, Dag Slagstad)

Objectives
- Establish standardized protocol for optical measurements of mesozooplankton abundance and size distribution.
- Develop methods for measurements and classification of zooplankton using broadband sonar frequency spectrum backscatter.
- Develop methods and tools for real-time processing and viewing of integrated physical (salinity, temperature and pressure) and biological (fluorescence and zooplankton) data.

Description of work
This workpackage will establish a protocol for automated sampling of integrated physical and biological data from a towed undulating instrument platform. Based on several years extencive use of this platform, an close to optimal way of sampling such data will be developed. Special emphasis will be put on the spatial distribution and dynamics of temperature, salinity and

fluorescence as well as abundance of meso-zooplankton. In parallel, neural network calssifiers will be built in order to infere zooplankton distribution from broadband sonar data. This can be aided by using zooplankton distribution data from the optical measurements. In order to assess the physical and biological features as they occur, a real-time data acquisition tool will be built in order to view the spatial features of data obtained from the towed platform.Long-term monitoring programs of the overwintering stocks will be established. It is also important to establish routes in the Norwegian and Barents Sea for the Continous Plankton Recording (CPR survey) in UK.

module 3

Deliverables

D6.1   Scanfish sampling protocol

D6.2   Neural network classifier for zooplankton as obtained from broadband sonar data.

D6.3   Real-time data acquisition tool for Scanfish carried instruments

WP7 Overall Zooplankton Model Integration

Responsible partners: SINTEF/NFH/HI (Dag Slagstad/Ole-Petter Pedersen/Morten Skogen)

Objectives

The objectives within this workpackage is to clarify which

- components is necessary to include in an AMOEBE zooplankton model
- data (temporal and spatial) are necessary to in order to make a proper data assimilation of the zooplankton models and ensure that the various submodels within the zooplankton module communicate and with other modules
- Estimate possible consequences of zooplankton harvest

Description of work

The zooplankton community is an ecosystem by itself connected to the primary producers at one end and nonplanktonic predators at the other end. There are numerous important players, but in the AMOEBE project we have to reduce the number of submodels as much as possible without loosing important dynamics and information for other parts of AMOEBE. An internal structure will be selected based on the requirements (e.g zooplankton species and size distribution of fish larvae and planktivorous fish) from other modules after extensive sensitivity testing. General assimilation tools for AMOEBE will be developed within Module 9. These tools will be tested and adapted for the zooplankton Module. Through numerical experiments, the data needed to update the model will be found. This will act as a guideline for the field measurements and development of new equipment for data collection.Since the submodels of zooplankton probably will be developed at different institutions, it is necessary to use strict rules for data communication within the module. Also, data communication with other modules will be ensured.The effect of future of zooplankton harvest on available prey for fish and fish larvae may only be assessed through model simulations. This issue has also a close link to Module 1.

Deliverables

D7.1   Recommendation of a zooplankton model structure

D7.2   Evaluation report from testing of the assimilation tool (developed in Module 9) applied for the zooplankton module

D7.3   Recommend where and when zooplankton data should be collected

A model based and data-driven Operational Ecological Biomassd Estimator (AMOEBE)

Module 4: Fish Recruitment

Version 24. sept. 2002

(Svein Sundby (chairman), Bjørn Ådlandsvik, Øyvind Fiksen, Arild Folkvord, Tara Marshall, and Torstein Pedersen)

Contents

module 4

1 MODULE SUMMARY

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:

- Recent studies of maturation and fecundity the spawning fish has given us *egg production models* that more realistically can estimate the number of eggs actually spawned in a f ish population.

- *Process studies* on larval and juvenile growth in laboratory and mesocosms have given us a large push forward in understanding and quantifying how environmental factors like temperature, light and turbulence influence the basic biological processes.

- A large advancement has occurred in developing *individual-based models* developed from first principles to utilise the knowledge achieved under the process studies above.

- More realistic *numerical ocean models* have been developed for the Nordic Seas and the coastal region of Norway. We are now at a stage of resolving the circulation dynamics on the relevant scale of larval and plankton distribution.

- *New field methods* have been developed which enable us to measure physical and biologi cal parameters on spatial and temporal scales of plankton patchiness. New methods have been developed to measure vital rates and state of larval fish from field sampling, particu larly methods on growth and condition estimation.

- *Improved computer technology* has made the integration of biological and physical proc esses in *coupled bio-physical models* feasible.

Our 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, 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 (Figure 1). 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 model 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").

module 4

During the first five-year period we will focus on the four species 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. The work in Module 4. consists of five work packages.

2 OBJECTIVES

The overall goal of the AMØBE Module 4. "Fish Recruitment" is:

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

These simulations will form input to improved stock assessment (Module 6) and prediction and management strategy (Module 7).

The work will be implemented by five components:

1. "Egg production models for marine fish"

2. "Process studies in laboratory and field"

3. "Individual-based models of larvae and early juveniles".

4. "Physical transport modelling of larvae and early juveniles".

5. "Integration of a coupled bio-physical model with data assimilation".

The overall goal of the study, the planned implementation by linking activities, and the objectives of the components are central in relation to the international IGBP programme GLOBEC (Global Ocean Ecosystem Dynamics) (Harris 1999). The projects will utilise the results of a number of national NFR-supported projects and strategic programmes. Moreover, we will build on and utilise the knowledge on first-principles, bio-physical modelling obtained during recent years in EU projects and other international projects, particularly the STEREO project and the US GLOBEC Georges Bank Study.

3 BACKGROUND

module 4

A predominant pattern of recruitment in marine fish is the large interannual fluctuations. These features were already focused by Hjort (1914) who hypothesised that these large fluctuations were caused by variability in mortality of the early larval stages induced by large variations in zooplankton food abundance. After nearly a century the hypothesis is still vigorously discussed, but it is remarkable that investigations to support or reject the hypothesis are scarce. It is also remarkable that we often have similar problems with subsequent and more specific recruitment hypotheses. There are several main reasons for this. Firstly, problems linked to the plankton biodynamics of the sea are multi-dimensional and demand for interdisciplinary approaches accounting for both biological and physical processes (Rothschild 1988). Secondly, the early larval fish go through a critical period when they are subjected to large spatial and temporal variability. Survival during this stage is poorly represented by average situations. Rather, the resulting survival of a larval population is the accumulated sum of critical single events of feeding and predation on the individual level. Testing of a specific recruitment hypothesis is often done by multivariate correlations between recruitment indices and environmental parameters. The parameters are then often highly aggregated and might not represent the critical factors in a proper way. Presently, we propose to develop a coupled integrated bio-physical model where critical biological and physical parameters are represented with a high temporal and spatial resolution. More specifically, we will model the growth and survival of the larvae and juveniles through the critical stage as they drift from the spawning grounds along the coast of Norway to the stage of 0-group when the juveniles are dispersed throughout the Barents Sea and the year-class strength is largely determined.

While we are now at the stage to model larval and juvenile feeding and growth by individual-based models, the problem of mortality is presently a more complex problem to approach by modelling. This is because of the general lack of identification of the predators on larval fish, and, hence, the lack of input data to the models. From northern Norwegian waters we know that herring schools may consume larger amounts of pelagic cod eggs (Melle 1986). On the other hand, we also know that small ctenophores are consumers of cod eggs and larvae (Båmstedt *et al.* 1994; Martinussen and Båmstedt 1999). We assume that small larvae in poor condition will have problems to avoid attack from these small ctenophores, while the bigger and well fit larvae will generally be more able to avoid them according to the hypothesis by Houde (1989) that bigger larvae has better survival. Our working hypothesis is that ctenophores and probably other small jelly plankton are important predators on the larval stages of fish off the coast of Norway in addition to krill and pelagic fish. To investigate this we need a dedicated field survey to identify the important predators on eggs and larvae and to quantify abundance and distribution of planktonic predators

A crucial step to improve the realism of existing spatial models is to improve the biological aspects of these models, which is usually the most sensitive parts (Heath and Gallego 1997). So far, no coupled bio-physical model with drift and environmentally determined growth of fish larvae have been developed for fish species in Norwegian waters. Among the recurrent enigmas in fishery science, the variability in recruitment and the spawner-recruitment relationship may be the most difficult and important (Hilborn and Walters 1992). Among the suggested causes of the high variability in recruitment of marine fishes (whether the relation to spawner biomass is evident or not) are changing environmental conditions, affecting growth and/or survival of eggs and larvae. To understand the role of environmental variability on the growth of larval fish, it is essential to investigate the processes linking growth to the physical- and biological properties of the natural habitat (Leggett and Deblois 1994). The integrated influence on these processes from several different environmental variables can only be adequately studied in numerical models (Houde 1997), while the reliability of the predictions from such models depends on our knowledge of single processes.

module 4

Reduced growth rate is critical to planktonic animals with high mortality rates, because it prolongs the time in the vulnerable condition. Among the most discussed external forces affecting larval growth rates are small-scale turbulence (Sundby and Fossum 1990, Sundby *et al.* 1994, MacKenzie *et al.* 1994), light (Blaxter 1986, Miner and Stein 1993, Suthers and Sundby 1996, Fiksen *et al.* 1998), turbidity (Chesney 1989, Fortier *et al.* 1996) and temperature (Houde 1989, 1997, Fiksen and Folkvord 1999). Each of these factors may cause recruitment variability irrespective of prey abundance; therefore it is important to develop fundamental, quantitative understanding of how they are connected to larval growth and survival (Fiksen and Folkvord 1999).

Several models on a wide array of the basic biology have been developed for cod (Laurence 1978, Ellertsen *et al.* 1981, Campana and Hurley 1989, Blom *et al.* 1991, Werner *et al.* 1996, Leising and Franks 1999). By merging several models, Fiksen *et al.* (1998) and Fiksen and Folkvord (1999) developed highly mechanistic models of prey encounter rates in herring larvae, accounting for development of visual ability, light conditions, small-scale turbulence, prey-catch probability (prey size/shape) and temperature. These models benefited from recent laboratory studies on temperature-dependent growth and the development of the nervous system (visual abilities) conducted at Institute of Fisheries and Marine Biology (DFM), University of Bergen. In addition, the models developed at DFM were the first individual-based models including all aspects of turbulence-generated ingestion success, both beneficial and inhibitory. Still, none of the existing models of larval cod growth listed above have incorporated the potentially negative effects from strong turbulence, nor have they developed the interaction between light and turbulence (see Fiksen *et al.* 1998, Fiksen and Folkvord 1999). This is likely to have major influence on predictions from trophodynamic models, like the state-of-the-art model by Werner *et al.* (1996) that predicted highest feeding rates in larvae near bottom of Georges Bank, at 100 m depth. Accounting for light in this model would invert the vertical profile of habitat profitability. Another deficiency in current models is the lack of state dynamics, particularly on the size of eggs and amount of yolk in the spawning products. Recent studies have found that these parameters can vary substantially between years, spawners and over the spawning season (e.g. Kjesbu *et al.* 1991, 1996, 1998, Solemdal 1997, Trippel *et al.* 1997).

Cod, haddock, herring and other fish stocks in Norwegian waters have particular long period of passive pelagic larval drift. During most of this drift phase, the eggs and larvae are totally

dependent on the environmental conditions encountered. Later the larvae may to some degree determine its environment by active vertical behaviour. Usually, the year class strength is determined during this period of pelagic drift (Sundby *et al.*, 1989). Increased knowledge on the processes affecting the drift phase is, therefore, central to the recruitment problem. Modelling is a method well suited for recruitment problems. Implementation of knowledge on different processes into a common model system can be used to produce quantitative connections. The Institute of Marine Research (IMR) have been using the combination of hydrodynamic current models and Lagrangian particle tracking models for different fish stocks. This particle approach is inherently "individual based" and therefore ideal for combination with individual-based biological models into coupled bio-physical models for recruitment. Such coupled bio-physical models has been used in other areas (Werner *et al.* 1996, Hinckley *et al.* 1996, Heath and Callego, 1998).

module 4

Earlier physical particle tracking modelling of Arcto-norwegian cod recruitment (Ådlandsvik and Sundby, 1994) and herring (Svendsen *et al.* 1995) show that the current variability induced by the large-scale wind system have considerable influence on the spatial distribution at the larval and early juvenile stages. The main physical limitation in these early works is also evident: a spatial resolution of 20 km is not sufficient to resolve the topographic and dynamic length scales of interest. IMR has experience with nesting finer models with resolution 4 km, both in Skagerrak (Svendsen *et al.* 1996) and on Svalbardbanken (Ådlandsvik and Hansen, 1998). More recently, a 4 km model along the coast of northern Norway has been developed (Vikebø 2000) with the specific goal to resolve the distribution pattern of cod eggs and larvae induced by the shelf topography. This model has substantially improved the details of transport and spreading of the offspring.

Both recruitment research and fisheries management have traditionally assumed that spawner biomass is directly proportional to total egg production. Recent studies have shown that the individual fecundity and egg quality are highly variable in long-lived species such as Atlantic cod (Kjesbu *et al.* 1998; Lambert and Dutil 2000). Scaling these individual-based data up to the stock level using the demographic information available from assessments and surveys has shown that spawner biomass is not proportional to total egg production (Marshall *et al.* 1998; Köster *et al.* 2001). Consequently, considerable research effort is now being directed to developing alternative measures of reproductive potential. Such measures can be developed through the incorporation of additional biological information into spawner biomass. Incorporating year-specific fecundity information converts biomass-based measures into estimates of total egg production. Egg quality can also be factored in to give estimates of total viable egg production (i.e., survival to hatching). For some stocks, information on distribution of spawners is being used to specify the spatial/temporal origin of eggs.

4 STRUCTURE AND LINKAGE TO OTHER MODULES

The copepod *Calanus finmarchicus* is a key food item for larval fish in the Northeast Atlantic (Sundby 2000). The study on population dynamics of *C. finmarchicus* and other zooplankton species of importance as larval food will be the objective of Module 3. "Zooplankton". Module 3 will therefore provide key information on larval food abundance which will be used in the coupled bio-physical models developed under Module 4. The zooplankton data will initially be parameterised into the bio-physical larval models by an advection scheme of zooplankton from

the basin of the Norwegian Sea onto the Norwegian shelf. Module 4 needs from Module 3 geographical maps of copepods distributed in the naupliar and copepodites stages at time steps of each week from first-feeding larvae. In the next stage of module development we will fully integrate zooplankton production model with the bio-physical larval models. Abundance and distribution of medusae, krill will be other groups of zooplankton of particular relevance to the Module 4 as these species are suspected to be important predators on larval fish. Moreover, pelagic fishes, particularly herring is also assumed to be an important predator on pelagic eggs. Module 5." Physiology and behaviour" and Module 6. "Stock assessment" will provide the data on spawning stock biomass and conditions/liver indices as input to the egg production models. Module 2. "Ocean physics and algae" includes large-scale physical modelling and ocean climate. This module will provide the needed data on the physical boundary conditions into the regional-scale bio-physical models that takes care of the particle tracking.
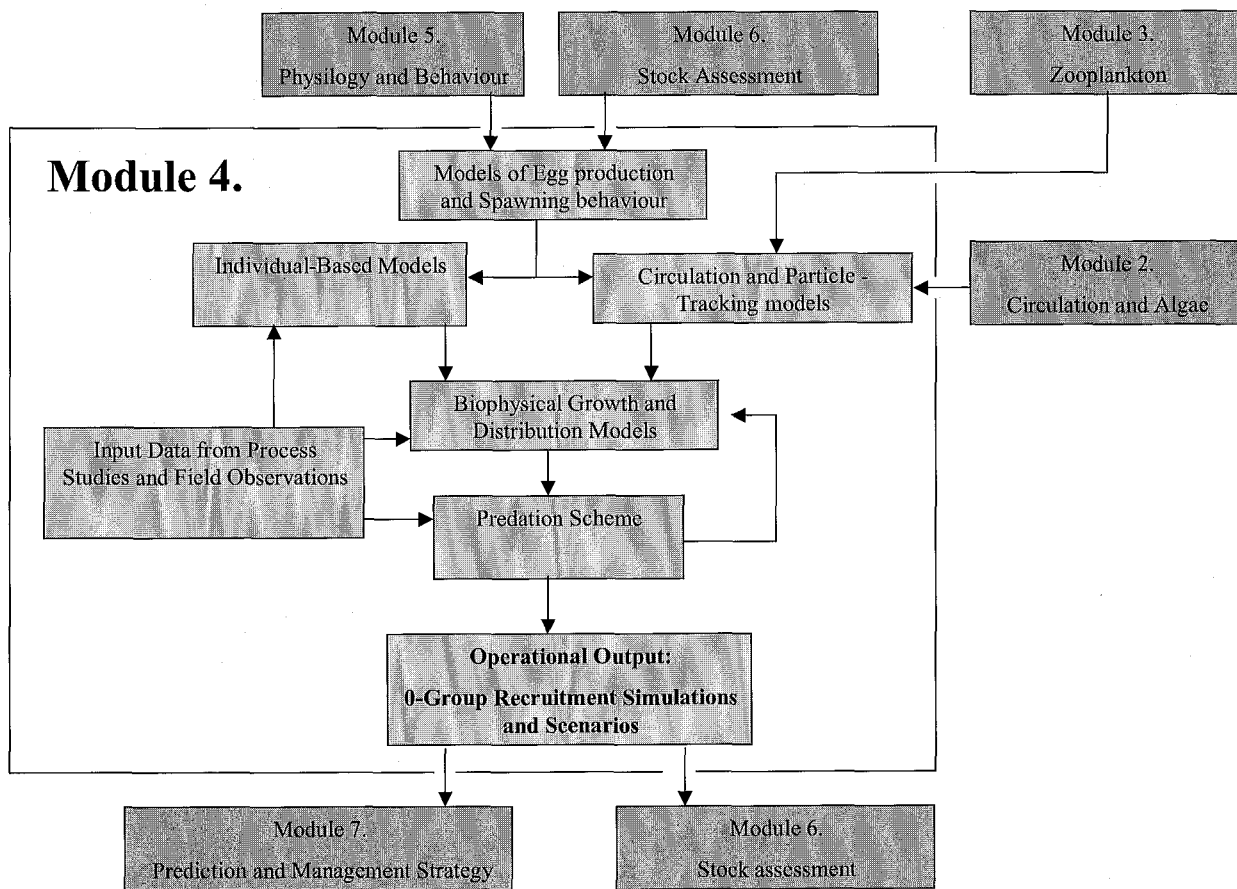
module 4

Figure 1. Structure of Module 4. "Recruitment" and linkage to other AMOEBE modules. The operational output of Module 4, i.e. the recruitment simulations and scenarios of the fish stocks, will be used by Module 6. "Stock Assessement" and Module 7. "Prediction and Management Strategy".

5 INNOVATION

The model concept of simulating larval growth from first principles integrating individual-based growth models with particle-tracking circulation model was put forward in the GLOBEC planning documents in the beginning of the 1990s. The first generation of this kind of integrated models was implemented for cod and haddock recruitment on Georges Bank (Werner *et al.* 1996). Similar kind of modelling has been planned for the Arcto-Norwegian cod in 1999 but has not yet been implemented. The present model concept is taking the first-generation integrated models several steps forward: We include an egg production model which enable us to simulate the recruitment in a more realistic way. We include light, another important physical parameter, in the individual-based larval model. We include a model for the vertical distribution the eggs that will give more realistic advection of the offspring. We introduce a new hydrodynamic circulation model with more flexible grid variation that also will improve the advection of the offspring. The use of data assimilation in individual-based models and coupled biophysical models is a novel aspect. Finally, the integration to the other AMØBE modules is a step forward.

6 WORKPLAN

6.0 SPECIFICATIONS AND PLANNING

The coordination of module 5 will require considerable administration as it involves many different individual researchers and institutions. An action plan will be developed in WP0 during the early stages of the project. The action plan for module 4 will be updated annually to allow flexibility in the developments of module 4 and AMOEBE as a whole.

6.1 EGG PRODUCTION MODELS FOR MARINE FISH

Egg production models are formulated in two different ways. Empirical data on maturity, weight and fecundity can be combined with demographic information from assessments to estimate total egg production on an absolute scale (e.g. Marshall *et al.* 1998; Köster *et al.* 2001). Such estimates can then be compared to recruitment indices obtained from surveys or assessments. Many stocks lack the data required to estimate total egg production on absolute scales. In such cases, egg production models can be conditioned using data and/or models from other stocks or time periods (e.g. Scott *et al.* 1999). Such egg production models are used in simulation analyses with the output being expressed on a relative scale (e.g. probability of survival to hatch).

6.1.1 Egg production model for Arcto-Norwegian cod and Arcto-Norwegian haddock

Total egg production for Arcto-Norwegian cod has been estimated on an absolute scale using a length-based approach. This allows them to be coupled with individual-based models representing size-dependent processes affecting egg quality, survival to hatching and/or dispersion. For example, egg mortality is higher for smaller, first-time spawners (Solemdal *et al.* 1995) or poor condition spawners (Kjesbu *et al.* 1998). Egg buoyancy varies as a function of spawner size (Kjesbu *et al.* 1992) and could affect subsequent dispersion.

The length-based nature of the total egg production estimates can also be used to enhance the spatial/temporal resolution of egg production. For cod the timing and duration of spawning is size-dependent (Marteinsdottir and Steinarsson 1996; Hutchings and Myers 1993), however, it is currently uncertain whether large cod spawn earlier than small cod for Arcto-Norwegian cod (Solemdal 1997). Over historical time scales the timing of peak spawning has shifted towards

later spawning (Pedersen 1984) which could reflect the size-dependency of spawning time given that the spawning stock has become increasingly dominated by smaller individuals (Nilssen *et al.* 1994).

Although the majority of the Arcto-Norwegian cod stock spawn in the Lofoten-Vesterålen region, coastal areas situated to the south (Møre, Helgeland) and north (Sørøy, off the Murman coast) (Bergstad *et al.* 1987) have been important in earlier time periods (Sundby and Godø 1994). Information could be compiled from several historical databases (e.g. landings information) to describe how changes in the spatial distribution of spawners interact with biological and temporal factors to impact the realized total egg production.

Initally, models on the length-based estimates of total egg production will be partitioned into the egg production at length for a given day in the spawning season using length-based models for batch number and batch fecundity (Kjesbu *et al.* 1996) and assuming a two day interval between batches. These length- and time- dependent egg production values will then be partitioned spatially using data from annual surveys of the distribution of spawning cod in Lofoten and the Barents Sea and/or by making assumptions about the proportion of eggs spawned in areas that are currently unsurveyed. Stock structural characteristics (e.g. condition and spawning experience) can then be used to prorate the eggs according to their probability of surviving to the hatching stage.

module 4

From this starting point the spawned eggs begin their developmental and survival trajectories. Temperature dependency of egg development and stage duration is well-established (Thompson and Riley 1981; Page and Frank 1989). Most cod stocks, including Arcto-Norwegian cod, spawn at temperatures ranging between 4 and 7°C (Sundby 2000). Models predicting time to hatch could be developed from existing data resources. Egg mortality rates are a classically difficult problem in fish population dynamics (Bunn *et al.* 2000). However, preliminary field estimates have been made for Arcto-Norwegian cod. These could be refined, possibly through the addition of knowledge about the dependency of egg mortality on characteristics of spawners (Makhotin and Solemdal 2001). Thus, the final output of the egg production model would be estimates of the number of hatched eggs.

Egg production model for Arcto-Norwegian haddock is not yet developed. Laboratory and field investigations will be performed similar to those for the cod. This is because the haddock, as a gadoid species, has many similar features to the cod with respect to reproduction, gonad and egg development.

6.1.2 Egg production model for Norwegian spring-spawning herring

Research is currently underway to estimate total egg production for the Norwegian spring-spawning herring stock on an absolute scale, as has been done for Arcto-Norwegian cod. This research combines the demographic information available from assessments with newly available fecundity data (Ma *et al.* 1998). For this stock, spawner condition has particularly strong effects on the intensity of atresia such that the available protein and lipid reserves in spawners regulate the realized fecundity (Kurita *et al.* 2000). Therefore, a long time series on spawner condition that has recently been compiled from industrial sources of information (Holst 1996) will be used to correct fecundity models for interannual variation in condition.

Timing of spawning in Norwegian spring-spawning herring is dependent on spawning experience such that repeat spawners spawn earlier than recruit spawners (Slotte *et al.* 2000). Thus, the dependency of the timing of spawning on stock structure is relatively easy to incorporate into the egg production model. Because the location of spawning varies considerably on both short-and

long-term scales (Slotte 1998) the spatial origin of eggs is not constant over time. Variation in spawning location can be factored into the egg production model either by using available survey data to partition the spawning stock among different spawning locations or by simulating a variety of possible scenarios.

6.1.3 Egg production model for Barents Sea capelin

Gjøsæter (1998) has reviewed the status on capelin maturation. The present maturity staging used for female capelin is based on histological studies by Forberg (1982;1983). He established a maturity scale with 10 stages. The capelin oocytes are classified in two growth phases, in which the first phase (oocyte diameter 5 - 190 mm) could be subdivided into three stages. It was defined as a resting stage and is found in capelin larger than 10 cm all through the year. The second growth phase (oocyte diameter 180 - 1020 mm) is divided into five stages. Spawning extends over a much longer period of time than for the cod and herring. The main spawning occurs during spring, but spawning might occurs onto late summer. Forberg and Tjelmeland (1985) modelled the maturation of capelin a monotonically increasing function of fish length, and 50 % of the stock matures at length 13.8 and 14.6 cm for females and males, respectively (Tjelmeland 1986). Huse and Gjøsæter (1997) found an average fecundity of about 11 500 eggs for a group of 70 female capelin. The oocyte diameter and fecundity increased with increasing length of the capelin and condition factor had an addition effect on the fecundity. The work by Huse and Gjøsæter (1997) will be used as the basis for an egg production model for the Barents Sea capelin.

6.2. PROCESS STUDIES IN THE LABORATORY AND FIELD

6.2.1. Experimental studies on growth of larval capelin

Few experimental studies have been carried out on the early life stages of the Barents Sea capelin stock, and most of these past studies were done during the embryonic stages or in outdoor enclosures with lesser degree of environmental control (e.g. Moksness 1982, Gjøsæter & Gjøsæter 1986, Moksness & Øiestad 1987). Basic relations needed for modelling the environmentally driven growth and survival dynamics in the larval and early juvenile stages are to a large extent missing. These relations include among others temperature and size dependent growth potential, and size specific functional growth response to varying food levels. Previous studies with Newfoundland capelin larvae have indicated that larval production is closely linked with the oceanographic and climatic conditions (e.g. Frank & Leggett 1981, 1982), and conditions for successfully combining physical models with biological models may therefore be in place. In order to model the larval production correctly, however, it is considered essential for the quality of the model output to provide and incorporate species specific, and if possible stock specific, estimates of essential parameters in the models.

New complementary controlled laboratory and field experiments are therefore needed for capelin larvae to provide necessary parameters for the modelling section of this module (see below). Basic temperature-growth relations will be investigated, enabling the link between ocean climate and larval growth. These studies on capelin will be combined with studies of growth and condition characterization (e.g. otolith microstructure and RNA:DNA analysis), for subsequent field validation of modelled condition and growth history. This approach will build on a recent RCN funded strategic programme "Theory and experiment based studies of recruitment in marine fishes" where similar studies were carried out with cod and herring larvae (Folkvord et al. 1998, Fiksen & Folkvord 1999, Otterlei et al. 1999). Supplementary studies establishing the relation

between ingestion and growth at different temperatures and larval sizes should also be carried out to account for the growth dynamics under varying feeding conditions (Kiørboe *et al.* 1987).

6.2.2. Field identification of larval predators
An investigation on identification of potential predators on larval fish will be conducted. Particular focus will be put on estimating the importance of small gelatinous plankton, krill and pelagic fish as predators. These organisms have already been confirmed to be predators on young fish larvae (Plotnikova 1961, Theilacker 1986, Huse & Toresen 2000) A pilot study using divers to observe and sample predation on cod eggs from jelly plankton was conducted in the former NFR project "Feeding conditions of fish larvae in tidally energetic regions". These results will form the input data to the bio-physical model to calculate predation pressure on the larval fish. We further plan to collaborate with Institute of Fisheries and Marine Biology; University of Bergen, to apply imuno-assay methods on identification of prey in the gut of predators using methods described in Theilacker *et al.* (1986). An alternative is the use of new molecular techniques in determining the DNA profile of stomach contents of selected predators (Rosel & Kocher 2002). The use of DNA profile for identifications is a particularly interesting methodology since it can be used simultaneously on a wide variety of predators with high degree of accuracy.

module 4

6.3 INDIVIDUAL-BASED MODELS FOR EGGS, LARVAE AND EARLY JUVENILES

To develop coupled biophysical models of recruitment processes in cod, haddock, herring and capelin, we need reliable biological sub models of growth and survival processes. The scientific challenge is to formulate models from first principles, and utilise the rich empirical foundation produced from process studies in lab and from surveys during the last two decades to parameterise and validate the model. It is reasonable to separate the modelling activity between egg-, larval growth- and development-, predation- and behavioural models.

6.3.1 Models on vertical distribution of eggs
Of the four target species only cod and haddock has pelagic fish eggs, i.e. eggs that are confined to the mixed layer with increasing concentrations towards the surface. The herring offspring becomes pelagic after hatching, since the eggs are attached to the bottom. Capelin eggs are to a certain extent less adhesive to the bottom than the herring eggs, and are partly transported along the bottom in the region off the coast of Finnmark (Sætre and Gjøsæter 1975). Buoyancy measurements of the eggs are necessary data input to model the vertical distribution (Sundby 1983; 1991). For the Arcto-Norwegian cod such data exists (Solemdal and Sundby 1981; Sundby 1983). Additional information on buoyancy is needed for capelin eggs, since they are partly observed free-drifting above the bottom. The vertical mixing and the density stratification of the water column are also necessary input parameters to models on the vertical distribution of fish eggs (Sundby 1991). For simulating the vertical distribution of cod eggs and capelin eggs we will use the numerical model developed Ådlandsvik (2002) which is developed as a tool box for Matlab. A demonstration of this model, both for the vertical distribution of eggs and larvae, has been done by Ådlandsvik *et al* (2001).

6.3.2 Individual-based models for cod, haddock and herring larvae
- Biological models of growth processes in larvae depending on environmental conditions

must be established. The models must synthesise the influences from e.g. temperature (Otterlei *et al.*, 1999, Fiksen and Folkvord 1999), prey size, -structure and -density (Munk 1995), light (Aksnes and Utne 1997), turbulence (Sundby and Fossum 1990, Kiørboe and MacKenzie 1995), visual ability (Fiksen *et al.* 1998) and size- and energy supply (yolk) at hatching (Kjesbu *et al.* 1998). They must be validated against independent observations that have recorded the relevant environmental forcing variables. Such data are available from ponds (Blom *et al.* 1991, 1994, Blom 1995, Folkvord *et al.* 1994, 1997, Munk 1992), plastic enclosures (Otterå 1993, van der Meeren and Næss 1993) and field surveys (Ellertsen *et al.* 1981, 1989, Sundby *et al.* 1994, Fossum and Moksness 1993). Also, some direct observations of larval behaviour may be used to evaluate the model (MacKenzie and Kiørboe 1995).

module 4

- A module of behaviour (e.g. vertical distribution) must be developed to include the ability of the larvae to respond to changes in the environment. The vertical positioning of the larvae may be important to the drift route predicted by a coupled biophysical model. Ideally, these models should be based on evolutionary reasoning (Giske *et al.* 1998), but other, more empirical implementations could also be useful. Field studies of vertical distribution of cod (e.g. Ellertsen *et al.* 1981, 1989) and herring (Heath *et al.* 1988) larvae along with environmental variables are available, and the models can be confronted with these data.

- The biological models must be integrated in physical circulation models, but may also be addressed to answer a number of interesting questions. Is the annual variability in temperature strong enough to cause significant changes in recruitment? How important is the overlap in time between larvae and their prey? Is it likely that an algal bloom will provide shelter from visual predators (and cannibals) or will it just reduce encounter rates with prey? These and similar questions can be addressed to clarify the sensitivities and predictions of the model.

- Since zooplankton may be particularly important to recruitment variability, and since the two classical hypotheses of recruitment ('the critical period' and 'the match-mismatch') focus on the role of food, it will be essential to couple an IBM of *Calanus finmarchicus* with the model of the fish larvae. Modern planktonic predator-prey theory suggests that the capture-success of planktivores will depend on small-scale hydrodynamic signals and the ability of prey to sense an approaching predator (Visser 2001). New models of larval fish feeding need to be specific on these small-scale processes. With a model specifying both predator and prey we will be able to ask new questions, such as: How do variations in the overwintering population of *Calanus* females affect recruitment success? At what level of zooplankton abundance should we expect the larvae to be food limited? When should we expect larval density to affect prey concentrations?

Module 4 will contribute to a coupled biological-physical model of the spatial and temporal fate of the spawning products. The IBMs will also be adapted and modified for integration with a 3D physical circulation model. The coupled model should bring us near the edge of what is possible with current computer technology, and open for questions like: How important is the distribution of spawning areas to recruitment success? Is retention of larvae within restricted areas a necessary condition for strong year classes? What are the characteristics of survivors?

6.3.3 Individual-based models for capelin larvae

Growth and foraging behaviour of capelin-larvae is less well known than in herring and cod larvae. Therefore, the development of new models on growth requires more experimental activity on this species. Basically, individual-based modelling of capelin follows the same scheme as for the other species. However, as there are presently no IBMs of capelin larvae, more emphasis on validation and model development is required.

6.3.4 Predation modelling

Predation is the most important reason for reduction in egg and larval abundance (Leggett and Deblois 1994). Predation on eggs, larvae and post-larvae represent different problems. Herring and capelin eggs are deposited on the sea floor, where numerous benthic- and epibenthic organisms consume as much as they can of these vulnerable delicacies. Various fish is also voraciously feeding on benthic deposits of fish eggs. The pelagic eggs of cod are smaller, and fall within the size range of many invertebrate predators. Larval fish are particularly vulnerable to predation, with their large size and low developmental level, which imply high encounter rates and low escape abilities with predators. The result is high mortality rates compared to other organisms of comparable size (McGurk 1986). In addition, many larval fish, e.g. cod, are cannibalistic, with larger larvae consuming smaller (Folkvord et al. 1994). Pepin et al. (2002) found that mortality in larval fish could be highly dependent (directly proportional to the abundance) on planktivorous fish. Capelin larvae are consumed by juvenile herring (Huse and Toresen 200), and may cause recruitment failure of capelin under given circumstances. Herring larvae drift through dense concentrations of krill, and although the efficiency of krill towards larval prey is unknown, this is potentially an important predator. The smaller cod larvae may be more vulnerable to invertebrate predators, but neither predator abundance nor the efficiency of invertebrate predators has been quantified yet.

module 4

The predation risk of larvae from fish is believed to be doom-shaped in relation to body size (Bailey and Houde 1989). The encounter rates with predators are likely to increase with size, as the reactive distance of the predator increase with prey size. However, as the larvae grow and develop, their ability to avoid attacks from predators also increase, and eventually dominate the outcome of the sequence. In addition, larger larvae alter their habitats (e.g. diel vertical migrations) such that encounters with efficient predators are reduced. In the juvenile stage, fish typically spend more time in refuges, such as schools or near benthic hiding-places.

The challenge to model variability in predation pressure on eggs-juvenile cod, herring and capelin can be divided in three components:

1) To express the sequence encounter-attack- capture mathematically, including the impact of relative size and spatial variability in the environment.

2) To assess the concentrations and distributions of the relevant predators during the actual time frame.

3) To couple the models of small-scale predator-prey interactions with large-scale exposure of eggs, larvae and juveniles to the predator-fields.

All these activities must be elaborated to improve our predictive capabilities on recruitment variability. A large scientific programme addressing these questions is likely to contribute considerably to the long-standing questions on fluctuations of fish stocks.

6.4   PHYSICAL TRANSPORT MODELLING OF LARVAE AND EARLY JUVENILES

The objective of this task is to describe the spatial distribution of fish eggs, larvae and early juveniles during this drift period. It will be done by physical transport modelling.

6.4.1 Transport model

There are two main classes of transport models, employing a particle-based (Lagrangian) or a field-based (Eulerian) framework. For transport of fish larvae the particle-based approach is most common and will be used in this task. The are several reasons for this choice. The particle approach is simple to implement, and is computationally effective. Numerically it avoids some of the problems with artificial diffusion and dispersion in Eulerian models. A useful feature is the "individuality" of the particles, making it possible to follow individual trajectories. This also allows for the coupling with individual based biological models, where a particle corresponds to an individual or better a super-individual in the sense of (Rose *et al.* 1993, Scheffer *et al.* 1995).

The technique of particle transport modelling is well developed and has been used for larval transport for many fish stocks in different areas. Internationally, for instance, this has been done for cod and haddock in the Georges bank area (Werner *et al* 1996) and the North Sea (Heath *et al.* 1999). There has also been work on North Sea Herring (Bartsch 1989).

A particle transport model, LADIM (Lagrangian Advection and Diffusion Model) has been developed at IMR. This model has been used in several species: for sandeel (Berntsen *et al.* 1994), cod (Ådlandsvik and Sundby, 1994), (Vikebø, 2000), herring (Svendsen *et al.* 1995), polar cod (Hansen and Ådlandsvik, 1996), capelin (Eriksrød and Ådlandsvik, 1997), blue whiting (Skogen *et al.* 1999) and Greenland halibut (Ådlandsvik *et al.*,1999), (Ådlandsvik, 2000). A similar model has been used at Norges Fiskerihøgskole for shrimp (Pedersen) and capelin (Slagstad unpublished).

The quality of the transport model itself is not a problem. The quality of the results therefore depends critically on the quality of the input. The main inputs are the initial condition and the forcing data, i.e. data on the abundance of eggs spawned at the various locations and the modelled current fields from a hydrodynamic circulation model. The transport also depends on the depth distribution of the eggs/larvae, from observations or a model of vertical behaviour. A physical model of vertical egg distributions balancing buoyancy and vertical mixing is available, (Sundby 1983; Sundby 1991; Ådlandsvik *et al.* 2001; Ådlandsvik 2002)

The physical modelling in AMOEBE will be done in Module 2. To be suitable for the transport modelling some requirements must be covered. The shelf area along the Norwegian coast from Stadt up to and including most of the Barents Sea must be covered. The domain must also include the Atlantic shelf edge current. For consistency, the same model fields must be used to transport zooplankton from the Norwegian Sea onto the shelf. This requires an extension of the domain into the deep Norwegian Sea. A larger scale model may be needed to provide boundary conditions for the regional model domain described above. Earlier experience, (Ådlandsvik and Sundby, 1994) and (Vikebø, 2000) shows that it is essential to cover finer details in the shelf topography, the resolution must not be coarser than 4 km.

The model must be driven with actual atmospheric fields. Special care must be taken to provide adequate wind conditions near the Lofoten mountains and other fjord/mountain areas. The driving forces must also include heat forcing in order to provide realistic temperature history

for the particle trajectories. For the representation of the Norwegian Coastal Current, realistic river run off data must also be included. The circulation model must include tidal forcing. This is important, both for the transport and to provide the trajectories with a realistic turbulence history. The latter also requires that the turbulence closure in the regional circulation model is able to provide the turbulent dissipation rates that influence larval feeding. To obtain the highest possible realism in the physical forcing fields, the regional circulation model must be part of a data assimilation system that includes all available information.

6.5 INTEGRATION OF A COUPLED BIO-PHYSICAL MODEL WITH DATA ASSIMILATION

<div style="text-align:right">module 4</div>

6.5.1 Validation of size, distribution and abundance of 0-group fish

The above problem definition and objectives lead to a combined study with 1) a model component on bio-physical modelling, 2) a field investigation component to provide input data on predation and to validate model results, and 3) a component to validate model results by historical time series on abundance and distribution of early juveniles and 0-group fish.

The individual-based model on larval growth will be implemented in the numerical particle-tracing model. The physical environmental input data (temperature, turbulence and light conditions) to the individual-based model will be taken from the hydrodynamic model and from the atmospheric forcing data for the hydrodynamic model. A revised version of a physical model on the vertical distribution of egg and larvae (Ådlandsvik *et al.* 2001; Ådlandsvik 2002) will be used to model the vertical behaviour of the larvae. The Arcto-Norwegian cod will be used as the model fish. Initial temporal distributions of cod eggs will be taken from field investigations on spawning period conducted in the 1970s and 1980s (Ellertsen *et al.* 1989). Initial horizontal distributions of eggs will be taken from egg surveys conducted in 1980s (Sundby and Bratland 1987). Input data on copepod prey will be parameterised from measured distributions of zooplankton. This is partly available from the TASC project (TransAtlantic Study on *Calanus finmarchicus*) and partly from time series on Russian zooplankton survey along the coast of northern Norway, in the northern Norwegian Sea and in the Barents Sea 1959-1990 (Nesterova 1990). The work on trophodynamic modelling on Georges Bank (Werner *et al.* 1996) will be used as framework for coupling of the individual-based models and the hydrodynamics model. We will hold an international workshop where we will invite experts on coupled models who have been working on similar problems on Georges Bank (Werner *et al.* 1996) and in the North Sea (Heath and Gallegio 1998).

Validation of the modelled abundance and distributions of early juveniles and 0-group fish will be done by pelagic juvenile surveys in June/July. Condition and growth of the sampled pelagic juveniles will be characterised by studying recent otolith growth (Suthers and Sundby 1993). Other potential methods to be applied in studying condition of the larvae will be RNA/DNA ratio (Clemmessen 1993) and lipid acid composition (Lochmann *et al.* 1995). The available time series on year-class abundances, distributions, and size compositions of early juveniles (30-50 mm) conducted each year in June/July for the period 1977 - 1991 and a similar time series on 0-group fish (60-80 mm) conducted each year in August/September for the period 1965 - present will also be used to validate the bio-physical model. When the bio-physical model is in operation an extensive sensitivity analysis will be conducted in order to explore the effects of variations in the climate parameters, the effects of maternal factor effects (age structure and condition of the spawning stock), the effects of spawning sites location, spatial and temporal overlap with prey

distribution, and the effects of vertical behaviour of the pelagic juvenile fish.

6.5.2 Data assimilation

To monitor the recruitment process both observations and modelling are needed. The purpose of data assimilation is to extract as much information as possible from models and data. Data assimilation in general within AMOEBE is covered in Module 9, but some aspects regarding recruitment will be mentioned here.

A coupled bio-physical model needs initial data. This means data on the spawning stock, such as total egg production and egg quality for each possible spawning area. Extensive forcing information is needed for the bio-physical model system. Physical inputs are currents, temperature, salinity, light, and turbulent dissipation. The most important biological input is food, in particular the distribution of *Calanus* nauplii. As predators of eggs and larvae are identified, information on their distribution is required as well. For reliability most of these initial and forcing data must be provided from models equipped with suitable data assimilation systems.

Data assimilation within the bio-physical recruitment model will use observations of the larval population. The most important data source is field observations from surveys on larvae, early juveniles and 0-group fish. In addition proxy data from sea birds can provide extra information. An important task is to determine at which time and from which area field data provides most information on the recruitment. Such problems can be addressed with data assimilation methods. The results will impact the design of the field program later in the AMOEBE project.

6.5.3 Operational management advice on fish recruitment

The individual-based model system will be in its first operational testing mode after 3 years. The operational mode will be improved as the needed additional input data to the egg production models (WP 1) are implemented, and the additional input data from the process studies (WP 2) to the individual-based models (WP 3) are implemented. As the individual-based models are evaluated towards 0-group field surveys we will expect to reveal the mechanistic links to the important recruitment processes. For example, what is the contribution to recruitment from the abundance and condition of the spawning stock, what is the importance of growth during the early larval stage, the distribution and abundance of *Calanus finmarchicus*, the advection by currents, the climate parameters, and the abundance of predators. Such relations will give the basis further predictions including predictions based on lags and cycles.

module 4

7 DELIVERABLES

Work package	Deliverable	Title
WP 0		**Planning and coordination**
	D 0.1	Produce action plan with annual updates
	D 0.2	Coordination of Module 4
WP 1		**Egg production models for marine fish**
	D 1.1	Egg production models for Arcto-Norwegian cod and Arcto-Norwegian haddock
	D 1.2	Egg production model for Norwegian Spring-Spawning herring
	D 1.3	Egg production model for Barents Sea capelin
WP 2		**Process studies in laboratory and field**
	D 2.1	Experimental studies on growth of larval capelin
	D 2.2	Field identification of larval predators
WP 3		**Individual-based models on fish larvae**
	D 3.1	Model on vertical distribution of eggs
	D 3.2	Individual-based model for cod and herring larvae
	D 3.3	Individual-based model for capelin larvae
	D 3.4	Predation modelling
WP 4		**Transport modelling of eggs, larvae and early juveniles**
	D 4.1	Vertical and horizontal particle tracking model
WP 5		**Implementation and validation of coupled bio-physical model**
	D 5.1	Validation of size, distribution and abundance of 0-group fish
	D 5.2	Data assimilation
	D 5.3	Operational management advice on fish recruitment

module 4

8 PROGRESS PLAN

The Gantt diagram below shows the anticipated timing relationship between the work packages defined in Module 04, with quarterly resolution of the first 5 years. WP1 and WP9 occupies the first half year with planning/product specification and the start on visualisation/communication of (semi)available products. Then successively the work on operationalizing results from WP2, 3, 4 and 5 will start and continue through the project. Each WP has a list of deliverables (Table 11.2), but it is premature to specify the timing (milestones) of these. This will be done at the start of WP0 and AMOEBE as a whole.

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y 6	Y 7	Y 8	Y 9	Y 10
WP0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
WP2					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
WP3			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
WP4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
WP5									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

9 BUDGET FOR 5 YEARS

The costs of module 5 will mainly be manpower and computing power. The manpower will be distributed among senior scientists (30%), scientists (30%), and PhD students (40%). The total cost of the first 5 years is about 60 million NOK. Since most of the WP's will end after 8 years, the total costs over the ten-year period is estimated to 100 mill. NOK.

Table 2. Cost of module 5 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63. Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses.

module 4

Work package	Yearly man months					Sum man months	Man power Cost, 5Y	Equipment 5 Year	Running cost, 5 Y	Total, 5Y
	Y1	Y2	Y3	Y4	Y5					
WP0	12	06	06	06	06	36	2952	0	500	3425
WP1	24	24	24	24	24	120	9900	1500	1800	13206
WP2		24	24	24	24	96	8114	3500	1500	13114
WP3	12	24	24	24	24	108	9010	900	1500	11410
WP4	12	12	12	24	24	84	7080	750	1200	9030
WP5			36	36	36	108	9347	400	1500	11247
Sum	60	90	120	138	138	546	46382	7050	8000	61432

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module 4

A Model based and data-driven Operational Ecological Biomass Estimator (AMOEBE)

Module 5 Physiology and behaviour

Version 18. Oct. 2002

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Contents

module 5

Module summary

This module contains a description of the implementation of physiology, ecology and behaviour of cod (*Gadus morhua*), herring (*Clupea harengus*), capelin (*Mallotus villosus*), shrimp (*Pandalus borealis*), harp seals (*Phoca groenlandica*) and minke whales (*Balaenoptera acutorostrata*) in the AMOEBE program. Individual-based modelling of movement behaviour, growth and maturation processes is used to simulate the dynamics of these target populations. To allow scaling from individuals to populations, we use an approach where "super-individuals" represent millions of identical individuals. Most importantly this level of aggregation allows realistic spatial distribution to be implemented, as well as a high resolution of the important physiological and ecological processes. The module consists of seven work packages including: Module coordination, scaling of individual-based models, movement behaviour, growth, maturation, process-based studies, and bookkeeping and forecasting.

module 5

Objectives and expected achievements

Module 5 regards physiology, ecology, and behaviour and of the major fish, shrimp, and marine mammal populations involved in AMOEBE. The objective of module 5 is to develop a framework for simulating the growth, mortality, reproduction and 3D movements of the target populations through mechanistic models, adaptation, and data assimilation. More specifically the objectives are:

- To develop method for bookkeeping of target populations in individual-based models.
- To provide a framework for estimating growth and predation resulting from interactions among target species.
- To establish species-specific models for 3D distribution of the target stocks based on adaptive models and data assimilation.
- To develop bioenergetics models for the target populations based on compilation of existing parameter values and generation of new values through experiments.
- To establish maturation of the target species as a function of size, age and condition.
- To provide population fecundity estimates for the target stocks.
- To undertake process-based studies to elucidate ecological aspects of target stocks.
- To keep track of target populations in real time by modelling and data assimilation.
- Perform routine forecasts of population developments.

Innovation

The chief challenge of module 5 will be to provide realistic predictions about spatial distribution of target stocks. This also represents the most innovative aspect of module 5. There now exist modelling approaches for simulating the spatial distribution of populations (Reed & Balchen 1982; Fiksen & al. 1995; Giske & al. 1998; Huse & Giske 1998; Huse & al. 1999; Huse 2001). In order to provide realistic predictions, the models need to be updated with observation on the distribution of the target populations. To achieve relevant knowledge about spatial processes it will be necessary to undertake studies to gather information about important processes involved in the interactions between predator and prey or social interactions within species. Modelling routines for data assimilation needs to be developed and systematic observations must be

established. Observations involve both data from scientific surveys, as well as commercial catch statistics, remote sensing, buoy data, and tagging data. The development of new observational platforms will be dealt with in module 8 of AMOEBE. The establishment of such an integrated modelling-data assimilation system will be highly innovative.

Progress plan

There will be an initial development phase followed by actual implementations and test runs of the model system before the final application with realistic forcing from the observation platforms. The general approach is to develop individual-based models (IBMs) for cod (*Gadus morhua*), herring (*Clupea harengus*), capelin (*Mallotus villosus*), shrimp (*Pandalus borealis*), harp seals (*Phoca groenlandica*) and minke whales (*Balaenoptera acutorostrata*). Within this individual-based structure, the entire populations will be represented, and processes related to growth, mortality and reproduction will be included. The predictions made by the models will be compared with observations from surveys, buoys, remote sensing, tagging data, and commercial fishing vessels. These discrepancies between predictions and observations will be used to correct the model results.

module 5

Table 1. Progress plan. Active work packages are indicated by x.

Work package	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	**x**
WP2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
WP3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
WP4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
WP5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									
WP6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
WP7													x	x	x	x	x	x	x	x	x	x	x	x	x

Module coordination

The coordination of module 5 will require considerable administration as it involves many different individual researchers and institutions. An action plan will be developed in WP1 during the early stages of the project. The action plan for module 5 will be updated annually to allow flexibility in the developments of module 5 and AMOEBE as a whole.

Scaling from individuals to populations

The basic modelling approach of module 5 will be individual-based modelling (Huston & al. 1988; DeAngelis & Gross 1992). Under this approach, individual characters can be specifies using an attribute vector A_i (Chambers 1993):

$$A_i = (a1_i, a2_i, a3_i, ..., am_i, x_i, y_i, z_i, t)$$

<div align="right">1</div>

where am_i is state m of individual i, x_i, y_i, z_i are the spatial co-ordinates of individual i at time t. The states include for example age, weight, sex, or maturity state. The greater the attribute vector, the more differences between individuals can be specified within the model. Essentially

this system allows any kind of aggregation of individual characters.

Even though the IBM structure is appealing, it is virtually impossible to simulate most fish stocks on a truly individual basis due to the great abundances involved. To allow the advantages of the individual-based approach and still be able to simulate large populations such as fish stocks, the super-individual approach was introduced (Scheffer & al. 1995). A super-individual represents many identical individuals, and the number of such identical siblings (ns) thus becomes an attribute of the super-individual. Mortality operates on the super-individual and number of siblings of each super-individual is thus decreased in proportion to the mortality rate (Scheffer & al. 1995). This is an efficient way of maintaining the individual-based structure, and still be able to simulate the great abundances of the target populations. Even though the approach is well documented, it has never been applied to large-scale simulation project such as AMOEBE. WP2 will therefore deliver a general method for representing such populations, with independent models for each target species. This will allow the different species to be represented by separate attribute vectors.

module 5

Many of the species involved in the AMOEBE program will interact with each other. These links must be included in a standardised manner. Module 5 will contain some major predator populations, and an important output of the module will be predation rates, both on species within and outside the module. Theory and routines for standardising how interactions between species should be taken into account will be developed.

Migration patterns

One of the advantages of the individual-based approach is that it allows the implementation of spatial detail (Huston & al. 1988). Since AMOEBE is a spatially resolved program, the inclusion of movement behaviour in the nektonic populations is essential. A work package (WP3) is therefore devoted to the inclusion of spatial distribution of the target species. This work package involves finding the best way of implementing 3D movement dynamics of the individuals. The inclusion of vertical distribution necessitates a fine temporal resolution since important vertical dynamics takes place within the diel cycle. In order to provide realistic predictions, the models needs to be developed with a basic distribution model that is then complemented by data assimilation. The basic models needs to be able to include individual responses to the physical environment which includes temperature, prey abundance, light, and abundance of conspecifics, as well as the internal states of individuals (Fig. 1). The latter provides the motivation for example for homing migrations and other behavioural actions that are not immediate environmental responses. A general approach for implementing movement behaviour is to use adaptive models based on genetic algorithms and neural networks which has been applied to this type of problem earlier (Giske & al. 1998; Huse & Giske 1998; Huse & al. 1999; Strand & al. 2002). In addition to possessing states, real individuals have adaptive traits, such as life history and behavioural strategies that specify how they should live their life. Adaptive traits can be modelled by introducing a strategy vector S_i that specifies the adaptive traits, such as life history traits or behaviour, of an individual:

$$S_i = (b1_i, b2_i, b3_i, ..., bm_i) \qquad 2$$

where bm_i is the adaptive trait m of individual $_i$. A similar approach is described in Balchen (1979) and Balchen (2000). The strategy vector may be considered as analogous to a biological

chromosome as in the genetic algorithm (Holland 1992), but S_i may also be updated during the individual's life as a way to simulate learning. The combination of attribute vectors and strategy vectors thus enables most relevant characteristics of individuals to be implemented in IBMs. Movements of the target populations will be calculated using the neural networks based on information about the external environment and internal states (Fig. 1). The real time distribution and forecasts of population movements will be a combined result of simulated migrations and data assimilation.
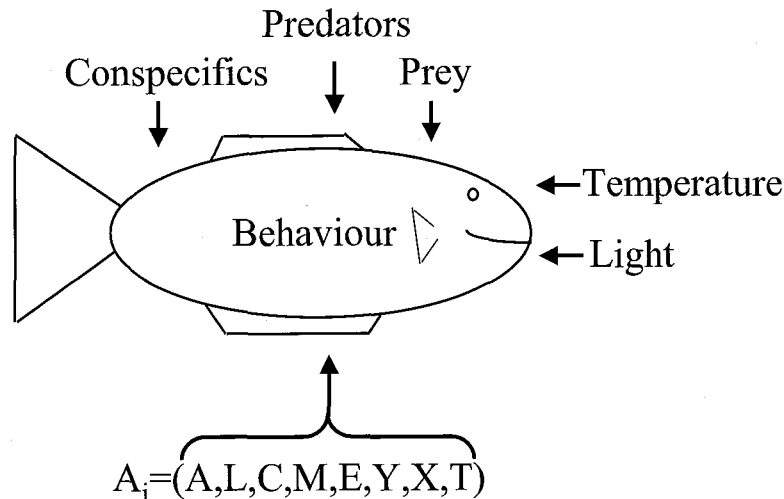
module 5

Figure 1. The main factors influencing fish migrations including environmental factors and internal states (A_i) such as age, length, condition, maturity state, energetic state, and spatial co-ordinates.

Growth

Growth results from a sequence of processes which include prey search, attack, and eventual ingestion and assimilation of energy. WP4 will address these processes. The essential models will be encounter models based on visual range of the predators, and presence of prey (Gerritsen & Strickler 1977), and bioenergetics models. For cod and herring, bioenergetics models are readily available (Hewett & Johnson 1992; Hansson & al. 1996), while for capelin such a model is being developed. Similar information is available for shrimp (Bergstrøm 1992) and the marine mammals as well (Renough & al. 1993; Haug & al. 1995; Hedd & al. 1997; Hindell & Lea 1998).

Maturation

Maturation is an important process because it affects the future recruitment to the population. Also it affects the individual growth pattern and migration pattern, which again influences the population dynamics. WP5 will therefore be devoted to developing a quantitative description of the maturation process to be fitted into IBMs of the target populations. This will allow the probability of maturation to be specified as a function of age, size, and condition. An important output of WP5 will be to estimate the fecundity of individuals. This can again be used to provide population fecundity (Serebryakov 1990) of the relevant populations which will be used in the

recruitment module (4) of AMOEBE.

Process-based studies

As mentioned above the prediction of realistic spatial distribution remains the chief challenge in module 5. In order to achieve this there is need for detailed understanding of the spatial dynamics of the target populations. In many cases such information is missing. For example the effect of interactions among conspecifics in herring schools on spatial dynamics may be great (Fernö & al. 1998; Huse & al. 2002). Similarly the effect predators have on the distribution of prey and vice versa (Brown & al. 1999), needs to be better understood. There is also a need for better understanding the orientation mechanisms involved in migration of the target species. We therefore devote WP6 to address these kinds of issue to have a firmer basis for the spatial modelling. The initial work in this work package will be to establish a list of particular mechanisms that needs to be elucidated through detailed process-based studies. Process studies will be undertaken using field observations, data storage tags, and experiments.

module 5

Bookkeeping and forecasting

The conceptual developments will eventually be put together in WP7, which will perform real time bookkeeping of the target populations as well as forecasts of their developments. The module requires high temporal and spatial resolution in the data. This includes harvest data from fishing operations as well as survey data and data from acoustic buoys. Real time acoustics data at selected positions will be gathered routinely as part of the bookkeeping and forecasting procedure. The costs associated with this data acquisition are covered by WP7.

Input data

Three different observational platforms are included in module 5: scientific surveys, fisheries data, and acoustic buoys. The target stocks should be monitored at least twice a year to allow accurate real time description and forecasts of population and spatial dynamics. A lot of these measurements can be taken from currently existing surveys. Harvest data should be gathered in with only a slight time delay and high spatial precision. Additional data needed are acoustic buoys that will provide real time information about fish abundance at selected positions. These data will be assimilated into WP7 when now casting and forecasting population and spatial dynamics. Module 8 will perform the necessary developments of hardware needed for real time measurements using acoustics. Furthermore temperature fields from module 2, and zooplankton data from module 3 will routinely be used as input to module 5 both in the movement routines and as impacting on growth and maturation.

Work package network

Figure 2 shows how the different work packages in module 5 are linked together. The end product will be WP7 where the results of the WP2-6 will be used to keep track of the target populations and provide forecasts. These data will be will used for fisheries assessment purposes (module 6).
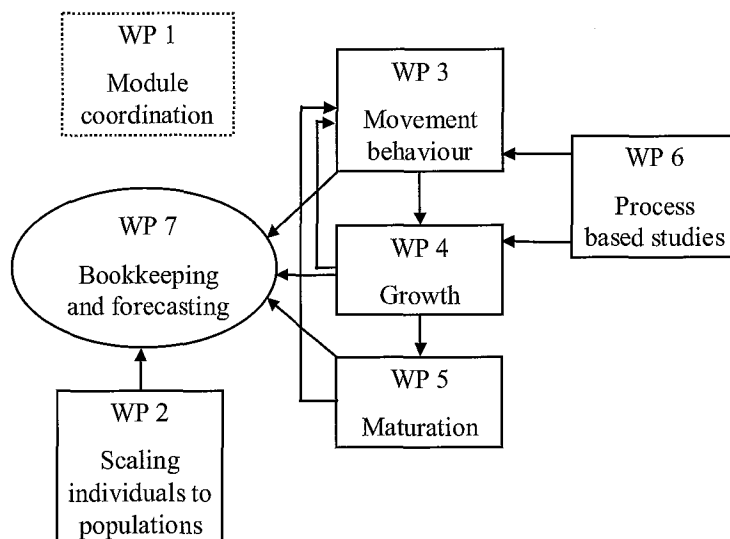
Figure 2. Work package network of module 5.

Budget

The costs of module 5 will mainly be manpower and computing power. The manpower will be distributed among senior scientists (30%), scientists (30%), and PhD students (40%). The total cost for the first 5 years will be about 61 million NOK, and the total cost over the ten year period is estimated to 90 mill. NOK. In addition, the module depends upon real time acoustics observations and these costs are included in WP7. The cost of development and deployment of new instrumentation is included in Module 8.

Table 2. Cost of module 5 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63. Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses.

Work package	Yearly man months					Manpower	Equipment	Running	Total, 5Y
	Y1	Y2	Y3	Y4	Y5	months	Cost, 5Y	5 Year	cost, 5 Y	
WP1	12	6	6	6	6	36	2925	60	500	3485
WP2	48	48	24	24	0	144	11402	250	2000	13652
WP3	24	24	24	24	24	120	9906	250	1800	11956
WP4	24	24	24	24	24	120	9906	250	1800	11956
WP5	24	12	12	12	0	60	4760	200	900	5860
WP6	6	6	24	24	24	84	7150	500	1200	8850
WP7	0	0	0	24	24	48	4255	1000	700	5955
Sum	138	126	120	144	108	612	50304	2510	8900	61714

WP1 Module coordination

Objectives
- To perform administrative tasks associated with module 5.
- To develop action plan with annual update.

Description of work
The coordination of module 5 will require considerable coordination as it involves the co-ordination of many different individual researchers and institutions. An action plan will be developed in WP1 during the early stages of the project, and this will be updated annually in response to the developments in module 5 and AMOEBE as a whole.

Deliverables
D1.1 Annual updated action plan.
D1.2 Coordination of module 5.

module 5

WP2 Scaling from individuals to populations

Objectives
- To develop computer code for bookkeeping of abundant populations in individual-based models.
- To establish species-specific attribute vectors.
- To develop general framework for including interactions among species within AMOEBE.
- To develop routines for assimilating data into the attribute vectors.

Description of work
The best way of simulating the target populations as a function of their composite individuals will be established. Although the super-individual approach is established it has never been applied to large-scale simulation project such as AMOEBE. This work package will therefore deliver a method for representing each of the target populations with the necessary aggregation of characters. Thus the model could be resolved by age as well as by length, weight and maturity state. These characters should be specified independently for each population using the attribute vector concept. Ecological differences between for example minke whales and capelin may lead to differences in the attribute vectors needed to specify these populations. This work package will be initiated at an early stage since the other work packages in module 5 relies heavily on the way this is specified. Many of the species involved in the AMOEBE program will interact with each other. These links must be included in a standardised manner. Module 5 will contain some major predators, and an important output of the module will be predation rates, both on species within and outside the module. The current project will develop theory and routines for standardising how interactions between species should be taken into account. This is to ensure that when individuals of a target stock are eaten by a target predator, the prey is removed along with the predator is being added energy. Links to WP4 will be important for the predator populations.

Deliverables
    D2.1 Procedure for keeping track of the abundant target populations.
    D2.2 Species specific implementation of individual-based models.
    D2.3 A general framework for linking predator-prey dynamics.
    D2.4 Routine for data assimilation into attribute vectors.

WP3 Movement behaviour

Objectives
- To develop adaptive models for simulating movement behaviour of target stocks.
- To validate model output with observations in hind cast analysis.
- To extract individual rules for movement of target stocks based on a combination of adaptive models and observations.
- To produce method for forecasting of horizontal distribution of target populations.

module 5

Description of work
IBMs of movement behaviour will be developed for the target stocks using adaptive models based on neural networks and genetic algorithms. Thus good behavioural strategies are adapted through simulation of evolution by natural selection. The criteria for selecting "good" behaviours are growth and survival as in nature. While the states of an individual will be kept track of in the attribute vector, the adaptive traits of an individual will be stored in the strategy vector. By using this approach, behaviour can be simulated as a combined response to environmental factors and to changes in the internal states such as condition and maturity status. Physics and zooplankton data from modules 2 and 3 will be important input here. The model will be developed through hind cast analysis with the aim of extracting general rules for each target stock. This will be done by a simulating the environment of the populations and let them move about in it. The genetic algorithm will then be used to sort out the best strategies for movement. In order to provide a link to the observed distributions, a second criterion for evaluating the migration strategies will be fit to observations. General migration patterns will be established in WP6. The migration rules will then be used in the eventual forecasting model in WP7. Furthermore there is a need for assimilation of data into the model. The fish and shrimp populations should be covered twice a year while yearly observations of abundance and distribution are needed for the marine mammals. In addition new observation platforms such as buoys fitted with acoustic transducers will complement the routine surveys. Routines for the data assimilation will be developed.

Deliverables
    D3.1 Development of model for moving individuals about.
    D3.2 Species specific implementation of movement routines.
    D3.3 Assimilation of data into the movement routines.

WP4 Growth

Objectives
- To establish concept for estimating encounters between predators and their respective prey.
- To develop a bioenergetics models for all target species based on literature surveys and experiments.

Description of work
Models for encounters between predators and prey will be developed from existing models of visual feeding. There will be need for some experimental work to establish relations such as visual range for some of the predators. Bioenergetics models will be established for the target species based on compilation of existing information and new experimental work to estimate missing variables. For cod and herring there exists bioenergetics models, and a similar model is currently being developed for capelin. Similar models will be established for marine mammals and shrimp.

Deliverables
    D4.1 Concept for calculating encounters between predators and prey.
    D4.2 Bioenergetics models for all target species.

WP5 Maturation

Objectives
- To develop quantitative description of the maturation process to be fitted into individual-based models of target populations.
- To produce forecasts of population fecundity to enter the recruitment module (4).

Description of work
Empirically based models for maturation of the target species will be developed. This includes size, condition and age dependent maturation probability functions as well as fecundity estimates. The output of WP5 will be used in WP2 since the maturity status has a great impact on individual distribution, including the partaking in spawning migrations. Another important output of WP5 is population fecundity estimates which will be used in the recruitment module (4) of AMOEBE.

Deliverables
    D5.1 Maturity probability curves as a function of relevant state variables.
    D5.2 Fecundity at size and state for the target species.
    D5.3 Population fecundity estimates of target species.

WP6 Process-based studies

Objectives
- To recognise important problems related to spatial ecology of target species.
- To elucidate predator prey interactions through experimental work and observations.
- To improve our understanding of social interactions within species through experimental work and observations.
- To provide quantitative descriptions of the relevant mechanisms.

Description of work
Important spatial processes will be investigated through detailed experimental-, and field work. Such processes include the interactions between predators and prey, social interaction among the member of schools and populations, orientation mechanisms during migration. A range of

different observational platforms will be used to elucidate these processes including acoustics during survey activity, data storage tags, buoys fitted with acoustics, and remote sensing. This will allow specific areas of special importance to module 5 being elucidated. The exact nature of these interactions is at present not entirely clear, and the first task of the work package will be to recognise mechanisms that are particularly relevant for AMOEBE. The end results of these studies will be mechanistic and quantitative descriptions of the key processes.

Deliverables
> D6.1 Ranked list of problems related to spatial ecology of target species.
> D6.2 Mechanistic and quantitative descriptions of the most important processes.

WP7 Bookkeeping and forecasting

Objectives

module 5

- To develop method for forecasting population abundance and distribution.
- To perform real time bookkeeping of populations.
- To provide short- and long term forecasts of population developments.

Description of work
The conceptual developments will eventually be put together in WP7, which will perform real time bookkeeping of the target populations as well as forecasts of their developments. The module requires high temporal and spatial resolution in the data. This includes harvest data from fishing operations as well as survey data. The target populations should be monitored at least twice a year to allow an accurate description of population and spatial dynamics of the stocks. Furthermore temperature fields from module 2, and zooplankton data from module 3 will be used as continuous input to module 5. Observations of the target populations will be assimilated into the bookkeeping system.

Deliverables
> D7.1 A procedure for forecasting population abundance and distribution.
> D7.2 Real time bookkeeping of target populations.
> D7.3 Short term (months) and long term (years) forecasts about population developments.

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module 5

module 5

A Model based and data-driven Operational Ecological
Biomass Estimator (AMOEBE)

Module 6 Stock estimation

Version: 18.10.02
(Bjarte Bogstad (chairman), Sigurd Tjelmeland)

Contents

module 6

1 Module summary

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.

2 Objectives and expected achievements

The objective of module 6 is to obtain unbiased estimates of present and historical stock abundance of the main stocks of fish, shrimp and marine mammals, with associated uncertainty estimates. The stock estimates will be made using mathematical models based on the following data sources: surveys (trawl, acoustic, sightings), commercial catch data, tagging data and stomach content data. Oceanography and plankton models and data will also be included whenever appropriate.

3 Background

3.1 Models

module 6   This module is based on a top-down modelling philosophy without reference to 'first principles'.

A stock assessment model consists of a mathematical model of the population dynamics of the stock together with a method for fitting the model to the observations. Most models of the population dynamics used for assessment purposes today use a very coarse description of the stock dynamics, although there is a trend towards including more biological detail in the models.

The state variables are usually number of individuals (and individual weight), which may be given by age/length/maturity/sex/area. The time steps are long (month/quarter/year), and usually the area resolution is very coarse. The model time step must be in accordance with data resolution in space and time. The annual cycle in the biology of the species in question must be accounted for in the models. The models calculate present as well as historical abundance of the stocks, so that the perception of the stock size in a given year will change as time passes. Some existing single-species models used for stock assessment are:

1- VPA-type models (XSA (Shepherd, 1999), used for Northeast arctic cod and haddock, SeaStar (ICES, 2002b), used for Norwegian-Spring Spawning herring
2- Statistical catch-at-age models (ICA (Patterson and Melvin, 1996), Fleksibest (Frøysa et al., 2002), used for Northeast arctic cod in addition to XSA)

Multi-species models
Such models are often used more for research purposes and for answering what-if questions than for stock assessment. An exception to this is the Bifrost model (Gjøsæter *et al.*, 2002) which is used for assessment of Barents Sea capelin.

Among the most used multispecies models are MULTSPEC/BORMICON/Gadget (Bogstad et al., 1997; Stefansson and Palsson, 1997, 1998, Anon., 2002a) and MSVPA (Gislason and Helgason, 1985; Sparre, 1991).

3.2 Data sources

Commercial catch data

For the fish and shrimp stocks, data on commercial catch in tonnes, and samples of the age/length/sex composition of the commercial catches by different fleet categories (e.g. gear types, countries) are available on a fairly coarse area and time resolution (ICES 2002a, b). Work on quantifying the uncertainty in the estimated age composition of such data is ongoing; see e.g. Aanes and Pennington (2001) and Hirst et al. (2001).

For marine mammals, the catch is reported in numbers, and some age data exist.

For some stocks, data on catch per unit effort (CPUE) in the commercial fishery can also be used for assessment purposes.

Scientific survey data

Trawl and acoustic estimates are based on line-transect surveys carried out by research vessels, and the stomach content data are also sampled during such surveys. Generally these survey estimates are treated as indices of abundance, but the acoustic estimate of capelin is treated as an estimate of absolute abundance. Usually a stock is surveyed by one or two surveys per year, which each cover the entire stock, or only parts of the distribution area. The surveys are often international.

module 6

The problems with the survey methodology available today are discussed in Anon. (1999). Among these are gear avoidance, acoustic dead zone near the bottom, and many others. 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. It is important that resources are set aside for implementing new research results in the computer programs used for calculation of abundance indices, and that historical time series are updated taking new knowledge and technology into account (see e.g. Aglen and Nakken, 1997).

Acoustic values are available on fairly fine scale (1nm, 10 m depth channels). The trawl hauls are typically 20-30 nm apart. For some species, trawl abundance estimates are used, while for other species, total acoustic abundance estimates (i.e. back scattering area) are combined with information on species and size distribution from trawl hauls and information from the pattern of acoustic registrations to obtain abundance estimates. Below, these two methods are denoted acoustic and trawl, respectively.

Overviews of current survey methodology for the various fish species can be found in the papers cited below:

Capelin (acoustic): Gjøsæter et al., 1998, Toresen et al., 1998

Herring (acoustic): Toresen et al., 1998, Holst et al., 2000

Cod and haddock (bottom trawl and acoustic): Jakobsen et al., 1997; Lepesevich and Shevelev, 1997, Korsbrekke, 1997 (acoustic only)

Greenland halibut (bottom trawl) : See overview of surveys in ICES (2002a)

Redfish (bottom trawl and acoustic) See overview in ICES (2002a)

Polar cod (acoustic): Gjøsæter and Ushakov, 1997

Saithe (acoustic): See ICES (2002a)

0-group (all fish species in the Barents Sea, pelagic trawl): Anon., 1983, ICES, 1996

Shrimp (bottom trawl): Aschan and Sunnanå 1997, Aschan et al. 1996, Harbitz et al. 1998

For marine mammals, abundance estimates from sightings surveys of minke whales (Schweder et al., 1997) and aerial surveys of pup production of harp seals at the breeding grounds (ICES, 2001) are available. Also, the geographical overlap between harp seals and capelin is monitored using aerial surveys (Anon., 2002b).

Tagging data

Data from tagging experiments are also available for some stocks, e.g. Norwegian spring-spawning herring (ICES, 2002b). Data from data storage tags for cod (Godø and Michalsen, 2000) and satellite tracking of marine mammals (ref.) could also be used. In addition to estimates of survival rates, these data give information on migration patterns.

Stomach content data

Data on stomach content (species and size composition, by weight) are available for several of the most important predator species. These data need to be combined with a stomach evacuation rate model or a bioenergetics model in order to calculate the amount consumed.

For cod, an overview of the sampling methodology is given by Mehl and Yaragina (1992), while the method for consumption calculation currently used is described in Bogstad and Mehl (1997).For harp seal and minke whale the methods for calculating the consumption, as well as the data used in such calculations, are described by Nilssen et al., (2000) and Folkow et al., (2000), respectively. An overview of the knowledge about the consumption by other predators is given by Bogstad et al. (2000).

4 Innovation

The main topics in further development of stock assessment models are:
- Including more biological reali sm in assessment models. This includes linking to zooplankton/oceanography models
- Fitting models to data
- Quantifying uncertainty

Today, the research in these areas (particularly the first one) is not very well coordinated and focused on achieving a common goal of improving stock assessment. 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. Today, there are a lot of research results which are not very far from being applicable in stock assessment models, but bringing such results into actual management use is generally not given high priority by researchers not doing assessments.

5 Work packages

The following division in WPs is suggested:

WP 0 Module coordination

WP 1 Include more knowledge on fish population dynamics (recruitment, growth, maturation, predation, migration) in stock assessment models

WP 2 Fitting models to data

WP 3 Quantifying uncertainty

WP 4 Linking stock assessment models to oceanography/plankton models

In **WP 0** the initial work will be to write a detailed action plan. This plan will be updated annually. WP 0 will take care of the coordination of the work within Module 6 and secure the communication to other relevant modules.

In **WP 1**, the biological sub-models used by assessment models for processes as growth, mortality, maturation, recruitment will be improved by including knowledge about the stock in question and its relation to other stocks as well as the environment. An example of how this can be done is the work done by Gjøsæter and Bogstad (1998) on influence of herring on capelin recruitment, and by Bogstad and Gjøsæter (2001) on predation by capelin on cod. These results are now used by the capelin assessment model Bifrost (Gjøsæter et al., 2002). This will draw on modules 4 and 5, which should be able to deliver sub-models for use in modules 6 and 7.

module 6

In **WP 2**, issues concerning fitting models to data will be addressed. These include assumptions about the underlying distribution of the data, choice of likelihood functions, weighting of different data sources, choice of observation models for catch, survey, stomach and tagging data, the level of detail which comparisons between observations and model results should be made, search algorithms in parameter space, and many other issues. Recent work in this field include: Cadigan and Myers, 2001; Patterson, 1999, Patterson et al., 2001. This module will draw on the competence in module 9.

In **WP 3**, methods for calculating the uncertainty in stock estimates based on knowledge about uncertainties in the input data will be developed. The end product of this will be the uncertainty associated with the management advice based on the results from module 7, which depend heavily on the stock estimates made by module 6. In the case of NEA cod the simulation of catch at age would include simulating catch at age in different fleet categories in different area and time periods. The simulation procedures will be based on statistical models for the data generating processes, such as described in Hirst et al. (2001) and Berg et al. (2001). Age reading error will also be included (Aanes and Pennington, 2001). The uncertainty in trawl-acoustic survey estimates has previously been modelled for Norwegian-spring spawning herring (Høst et al., 2002) and for Barents Sea capelin (Tjelmeland, 2002). Bottom trawl surveys could be modelled e.g. as done for Icelandic cod by Hrafnkellson and Stefansson (2002), which is based on the analysis of Icelandic cod bottom trawl survey data made by Stefansson (1996). In both cases (trawl-acoustic and acoustic surveys) one should also include the uncertainty in age readings (Aanes and Pennington, 2001).

WP 4 A top-down approach for linking multispecies models and models for oceanography/ plankton. Here one will start from scratch, so the development is described step-wise:

Step 1

a)　　Construct a multispecies model for fish, marine mammals and shrimp of the MULTSPEC/ BORMICON/Gadget type. This will be a model with a coarse resolution in space and time (typical figures: 1 month time step, 7 areas in the Barents Sea). The various biological processes in this model will be functions of the state variables for the individual stocks, as well as of zooplankton abundance and temperature. There will not be any internal model dynamics in the development of zooplankton and temperature, but these entities vary in time and space on an annual cycle according to historical data. They are constant from year to year. This also applies to the migration which is implemented as migration matrices for each stock/age group/maturity stage/sex etc. The model is fit to the data by parameter estimation. An explanation of why this is an appropriate framework for multispecies models for Arctic-boreal systems is given by Stefánsson and Pálsson (1998).

b) Construct a linked physics-phytoplankton-zooplankton model. This model will have a fine resolution in space (e. g. 10x10 km) and time. The mortality of zooplankton will vary in time and space on an annual cycle, but will be constant from year to year. The model will be validated by data assimilation. This is done in Module 2 and 3.

Step 2

Link models given in 1 a) and b) in the following way: Since the models operate on a different temporal and spatial scale, one solution is that the models communicate via files. The models described under a) write the predator fields to files, while the models given under b) write the temperature-, zooplankton- and possibly current-fields to files. The models will then fit these data to the appropriate resolution in time and space by integrating to a coarser grid the data from models given under b) for use in the models mentioned under a), while for the models given in b) a uniform distribution in space and constant development in time within the coarse grid for the models in a) is assumed in order to transform the variables to the grid given in b). The growth of plankton feeders and the drift of larvae is now dependent of the input from the models of zooplankton and current fields, while the temperature affects many of the processes. The migration is still constant from year to year. The mortality of zooplankton is now made dependent of the abundance of plankton feeders. Perform new parameter estimation (fish models) and data assimilation (plankton models).

Step 3

Develop simple migration models for fish/marine mammals/shrimp of the kind
　　　Element in migration matrix (species, age, size, fromarea, toarea, time) =
　　　standard pattern (species, age, size, fromarea, toarea, timeofyear) +
　　　f(species, age, size, temperature(fromarea, toarea, time)+
　　　g(food abundance(species, age, size, fromarea, toarea, time))

in order to model yearly variation in the migration pattern. These equations should be based on results from module 5. Perform new parameter estimation and data assimilation. Then more refined migration models can be tried.

We envision that models of type a), but with a coarser resolution in space, time and biological

structure (e.g. yearly time step, one area, only age structure in population) for use in Module 7. However, species interactions are more important for prognosis models than for assessment models.

It should be noted that WP 1 and 2 also will make use of environmental data, by including environmental information e.g. in calculation of ambient temperature used for calculation of consumption, which is very important in predation/mortality modeling. Also, environmental data are relevant in observation models for surveys.

6 Relation to other modules

From Modules 2 and 3, one would, via Module 11, obtain operational data/model results for the physical environment. From Modules 4 and 5, one would obtain sub-models (equations, parameters) for recruitment, growth, maturation, predation mortality and migration, to improve the biological realism of assessment and prediction models. Module 8 would provide (via Module 10) observations (with uncertainty measures) used by Module 6, while Module 9 would provide estimation techniques for use in Module 6.

Module 6 would deliver to Module 3, 4 and 5 historical absolute abundance estimates of the total stock size for use in analyses. To module 7 it would deliver input data for short-and medium term predictions, as well as population parameters for use in long-term predictions. It will also deliver to Module 8 the effect of changing the observation strategy on the precision of the assessment. Module 10 will secure the smooth integration and flow of information between modules.

module 6

The models in modules 6 and 7 should be compatible, more biological detail is needed in module 7 than in module 6, in order to make good short-and medium-term predictions.

7 Deliverables

Work package	Deliverable	Title
WP 0		**Administrative tasks and action plan with annual updates**
WP 1		**Include more knowledge on fish population dynamics in stock assessment models**
	D 1.1	Inclusion of recruitment models
	D 1.2	Inclusion of growth and maturation models
	D 1.3	Inclusion of predation models
	D 1.4	Inclusion of migration models
WP 2		**Fitting models to data**
	D 2.1	Likelihood functions
	D 2.2	Observation models
	D 2.3	Search algorithms
WP 3		**Quantifying uncertainty**
	D 3.1	Model for uncertainty in trawl estimates
	D 3.2	Model for uncertainty in acoustic estimates
	D 3.3	Model for uncertainty in catch data
	D 3.4	Quantifying uncertainty in results from assessment models
WP 4		**Linking stock assessment models to oceanography/plankton models**
	D 4.1	Linked model with constant migration from year to year
	D 4.2	Linked model with variable migration from year to year

8 Budget

Table 6.1. Progress plan (Gantt diagram). Module level. Active work packages are indicated by "x".

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP1	x	x	x	x	x x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2	x	x	x	x	x	x	x	x	x	x	x	x x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP4					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

The costs of module 6 will mainly be manpower, with some equipment and computing power. The total cost for the first 5 years will be about 61 million NOK, and the total cost over the ten year period is estimated to 90 mill. NOK. The cost of development, deployment and drift of new instrumentation for length/weight measurements of fish from the commersial fisheries, and sampling of stomach data from the harp seal is 15 million NOK over 5 years, which is included in the budget of Module 8.

module 6

Table 6.2. Cost of Module 6 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses. The personnel distribution is assumed to be: 30% on Cat.1, 40% on Cat.2 and 30% on Cat.3, giving an average man month cost of 76.000 NOK

Work package	Yearly man months					Sum man months	Man power Cost, 5Y	Equipment 5Y	Running cost, 5Y	Total 5Y
	Y1	Y2	Y3	Y4	Y5					
WP 0	12	6	6	6	6	36	2976	60	500	3536
WP 1	36	36	36	36	36	180	15118	300	2500	17918
WP 2	24	24	24	24	24	120	10079	250	1800	12129
WP 3	24	24	24	24	24	120	10079	250	1800	12129
WP 4		24	24	24	24	96	8255	200	1500	9955
Sum	96	120	120	120	120	552	46506	1060	8100	55666

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module 6

module 6

A Model based and data-driven Operational Ecological Biomass Estimator (AMOEBE)

Module 7 - Management strategies and prediction

Version October 17, 2002

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1   Module summary

Present-day management consists of two processes, that most often are distinct stages in the assessment process or may be performed in one operation: 1) establishing the perceived stock history and 2) making short and medium term prognoses to evaluate the consequences of proposed future catches.

In this process, catches are at present proposed according to reference points that take no account of what is the best management in the long run. It is the task of Module 7 to integrate knowledge established in AMOEBE not only to improve short and medium term prognoses with respect to accuracy and biological relevance, but also to use present and new knowledge to establish 3) harvesting control rules.

Prognoses conditional on future catches are of no value in management unless there is some understanding of which future development of the living resources is preferred. Module 7 aims at providing this important link between prognoses and management.

Analyses based on observations are subject to uncertainty and in order to comply with the precautionary approach the uncertainty shall be taken into account in management. Thus, predictive simulations must reflect the uncertainty in the models and the data and the proposed quota must take into account both the prognostic uncertainty and the uncertainty in the harvesting

module 7   control rules in a way that appropriately reduces the quota when the uncertainty is high.

The management of the most important fish stocks in Norwegian waters is international and quotas are determined jointly by the coastal states using advice from the International Council for the exploration of the Sea (ICES). During the development and subsequent implementation of AMOEBE close contact should be made to managers and scientists in the ICES countries with which Norway shares fish quotas. Of special significance is Russia with which Norway shares quotas of capelin and demersal species in the Barents Sea. It is a task of special significance for Module 7 to establish and maintain these contacts, since - from a management point of view - the end product of AMOEBE is Module 7.

Long-term harvesting control rules

The most important consideration behind long-term harvesting control rules is the value of the mature part of the stock for future generations of fish or sea mammals. Optimal long-term harvesting control rules will be found by long-term simulations using two alternative but complementary approaches:

The simulations can be based on predictive simulations of the climate and relations between climate and the population dynamics established in other modules. These simulations will be limited in scope by the time horizon over which the climate can be realistically predicted.

Alternatively, long-term harvesting control rules can be viewed as functions of the modelled relations between spawning stock and recruitment, between growth and abundance, and other modelled relations where the parameters can be estimated on historic data, as well as functions of

socio-economic nature proposed by the managers. The most common method used at present for evaluating long-term harvesting control rules is long-term (30-100 years) repeated probabilistic projections. These runs are not considered having any predictive value, rather they will reveal the relation between the stock dynamics and the catch rule strategies and can only be interpreted in a statistical sense.

Medium-term harvesting control rules

An important aspect in management is medium-term probabilistic prognoses, which have proved valuable in establishing a sound harvesting control rule for Norwegian spring spawning herring and would probably play the same role for other species (for instance, North-east arctic cod). The current age structure of the stock enables medium-term prognoses with some reliability. Also a realistic model for the environment might provide reasonable prognoses for a limited period into the future. The metric from a harvesting control rule (an optimal spawning stock, for instance) may be achieved in many different ways: the catch may be allocated differently between different segments of the fleet, the goal may be reached in the coarse of different periods of time etc. Finding the optimal catch allocations given a multidimensional objective function and taking into account uncertainty requires the solution of a non-trivial optimisation problem.

Population dynamics models

The task undertaken by Module 7 of evaluating management strategies and running predictions is based on mathematical models for the dynamics of the fish stocks, i.e. quantification of how recruitment, mortality and growth relate to stock abundance, the abundance of predators and to the environment. The most important of these models will be a part of Module 6, but the Module 6 models may need to be augmented with relations that are not necessary for historic assessments, and for which the basic material is taken from other modules. Amendments of the models in order to make the necessary predictive runs and probabilistic long-term projections may be done in Module 7. Also, the general framework CARE (Catch Rule Evaluator) for testing management strategies may use population dynamics models that not necessarily are parts of AMOEBE.

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Evaluation of management strategies

Management strategies, whether they are long-term strategies or medium-term strategies, shall be tested by simulations. The techniques and scientific basis for such testing is well established (Sainsbury et al, 2000) and consists of implementing the management strategy in an "operational" or "scenario" model. The biological part of the model should be as rich or richer in biological content as the biological models used for estimating parameters in proposed harvesting control rules and the management system as a whole should be simulated, i.e. simulating management decisions is a part of the process. This importance of this approach has been acknowledged by ICES, who has started a process in that direction (ICES 2001);

2 Introduction

AMOEBE is a large-scale effort to integrate existing knowledge and to establish new knowledge of marine ecosystems in the North-east Atlantic in order to promote better management of marine living resources. In present-day management species interactions and relations between living resources and the environment are considered only fragmentarily and in rare cases. AMOEBE seeks to improve the present knowledge base by establishing new knowledge of species migration, production and impact of the environment and to make the knowledge relevant to management of living resources.

The management of fish in the North-east Atlantic is largely centered at keeping a spawning stock next year high enough that the recruitment will not be severely hampered, with no or little consideration of what is good management in the long run. In Module 7 present knowledge and new knowledge established during the lifetime of AMOEBE will be integrated with the purpose of establishing long-term harvesting control rules. Such rules involves considerations made by managers of a socio-economic nature and AMOEBE aims at developing a tool for managers in which the managers can define harvesting control rules and analyse their effects using state-of-the-art population dynamics models.

Management of fish has concentrated on the top-down effects of fishing while considerations to the bottom-up effects of the environment have not been much in focus. The challenge is to pay due attention to both sides, adjusting fishery to changes in environmental conditions (Larkin, 1996).

module 7

The advice on management from ICES to member countries is based on scientific work made in the ICES working groups. In order for ICES to take due account of the fish-fish , fish-marine mammals and fish-environment relations revealed during the AMOEBE work results from AMOEBE should be implemented in those working groups and made a part of their toolboxes. In this way AMOEBE could also influence ICES towards providing multidisciplinary advice.

The work in ICES is driven by consensus; it is simply assumed that the scientists in the working groups agree on the perception of the state of the stock and on methods for its assessment. To reach such agreement when AMOEBE is introduced as a tool for management the work should be followed by scientists in other countries that work in the relevant ICES working groups. Preferably, these scientists should take part in the work in Module 7, where work done in other modules is integrated into a form useful for managers. Since management advice that involves consideration of species interactions and interactions between fish/marine mammals species and their environment is most likely to be first realised for the Barents Sea, researchers from Russia should be attracted to the AMOEBA work at an early stage.

For the credibility of the management advice it is important to achieve transparency in all parts of the process leading up to the advice. Therefore, the computer programs developed in Module 7 should be made accessible for running over the Internet, and the source code should be available for all participants in the project.

Definition of terms

Note on usage of terms: participants in the AMOEBE project come from widely different milieus, which is part of the strength of the project. However, terms may have different meanings in different fields. For clarity, the meaning of some important terms as used in the present document is given below:

Predictive simulation: A simulation into the future that is supposed to actually predict the stock development, i.e. it is assumed that the actual stock will not differ very much from the predicted.

Probabilistic projections: Simulations into the future where it is not understood that the stock development will be predicted by any trajectory. Such simulations are most often done in order to display the model behaviour in a large number of possible futures that all comply with knowledge obtained by fitting the population dynamics model to historic data.

Medium-term prognoses: Simulations into the future from when the stocks are dependent only on the initial conditions (present state, which may be uncertain) to when the stock only depends on estimated relations. Such simulations are invariably probabilistic.

Short-term prognoses: Simulations into the future over a time period when the stock largely is determined by the initial conditions. Short-term prognoses are predictive simulations. The reason for running short-term prognoses is to set the quota next year or for a few years.

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Reference points, or biological reference points: Numbers calculated from historic stock data that serve as aids during the management process. Such reference points may be Fmax, the fishing pressure which balances future growth against future loss due to natural mortality optimally, Blim, the spawning stock biomass below which the danger of poor recruitment is high, and others. Biological reference points may in many cases be viewed as extremely simple harvesting control rules.

Harvesting control rule: The harvesting control rule is a rule that gives the catch next year (or for some years in succession) when the yearly assessment has been performed. As opposed to biological reference points harvesting control rules can contain socio-economic elements. Also, the harvesting control rule may divide the catch between different segments of the fishing fleet.

Assessment: The yearly process of implementing new data in the analysis of fish and sea mammal stocks. The assessment gives the perceived stock history. It is a part of an assessment to calculate biological reference points and make short-term and medium-term projections.

Metric: A measurable quantity that may serve as a guideline in management. This term is borrowed from concepts developed in connection with recent developments in ecosystem management theory.

3 Objectives

The objective of Module 7 is to develop methods and tools for computation of optimal harvesting control rules based on multiple objectives and for evaluating these proposed harvesting control rules (CARE - Catch Rule Evaluator) for use in assessment and management of fish and marine mammal stocks. This tool consists of the following parts:

1. A computer program that enables repeated prognostic runs with single- or multi-species models using proposed single and multi-species harvesting control rules and the evaluation of the performance of the rules against proposed multiple objective functions.
2. A computer program for computation of optimised harvesting control strategy based on selected multiple objective functions and predictive population dynamics models.
3. Statistical methodology to interpret the results in a precautionary approach context
4. Web-based presentation developed in Module 7 and integrated with similar presentations for other parts of AMOEBE in the general networking web-based interface developed in Module 10. Interactive learning environments (similar to flight simulators).

CARE provides a standardised interface to population dynamics models and can run on all models that comply with the interface. CARE will host both programs for complex medium-term predictive control runs and for long-term probabilistic projections with simpler population dynamics models.

module 7

Implementation in management

In addition to delivering the harvesting control rule evaluation tool CARE Module 7 is also responsible for implementing the tool in the management process. For a successful implementation not only must appropriate presentation tools be developed, but the end users must be integrated in the development process to ensure that the developed tools are adequate for the questions being asked and to ensure that the developed tools find their place in the managers' toolboxes.

Multi-dimensional objective functions

Harvesting control rules in a multi-species context necessarily involves multi-dimensional objective functions where socio-economic elements are important. It is not possible to define beforehand which elements should be entered into a harvesting control rule. Therefore, part of Module 7 will be a tool for managers with which they can design test rules based on the parts of the ecosystem addressed by the available population dynamics models. A wide range of techniques exist for dealing with multi-dimensional objective functions (Marler and Arora 2001, Mardle and Pascoe 1999).

Use in yearly management

A different but related objective is enabling the tool to be used in practical management of fish stocks and could be clearly stated: Provide a suggestion for the quota next year, given the present year's assessment and a given harvesting control rule. Due account should be taken of

the uncertainties in both the assessment and the harvesting control rule, as well as the managers' willingness to accept risks.

A danger here is that a focus on predictions of next year's quotas and next year's stocks could distract decision makers away from the more elaborate tradeoffs that underlie a proper strategy. Brekke and Moxnes (forthcoming) show that while predictions can be useful, they are not sufficient to correct systematic biases in quota setting.

Compatibility with Module 6

The population dynamics models used in Module 7 must be compatible with the population dynamics models used in Module 6. Ideally, the population dynamics models used in Module 7 should integrate the models used in Module 6, possibly augmented with interaction sub-models. The population dynamics models will be gradually enriched in content from the models actually used in management today until more comprehensive models incorporating the environment and several interacting fish species by the end of the project period.

Openness

The management of fish is perceived by the general public and NGO's as a closed process. There may be good reasons for keeping the final political step in the process closed for the public, since it involves negotiations between the countries, but the scientific foundation and the political priorities underlying the harvesting strategies should be open for the public. The consequences of different possible harvesting strategies emphasising different aspects of the societal economy should be part of the public discussion about management of fish stocks. A valuable aid in this process is to make experimenting with harvesting control rules open for the public, which will be a concern in Module 7.

Involving Russia

The management of the majority of fish stocks in Norwegian waters is based on consensus between several nations based on advice from ICES. The tool should therefore be implemented also in ICES as well as in other countries that play a role in the management. The most important of these countries is Russia, and Russian researchers and managers should therefore be a part of the project from the beginning. Also, in Russia data exist that would be valuable for the improvement of the underlying population dynamics models and a co-operation with Russia would facilitate the use of such data.

Beyond the fact that Russian scientists can contribute both to modelling and data, it is also of vital importance to involve Russian scientists in the modelling project to strengthen the diffusion and acceptance of the knowledge produced.

Influence from the environment

Despite a hundred years worth of research on the relations between fish stocks and the environment little or no consideration to such relations is made during the yearly assessments of fish

stocks in the North-east Atlantic. This is in striking contrast to the fact that in boreal systems the impact from the environment on fish stocks is large and of comparable magnitude to the fishery (Livingston and Tjelmeland, 2000). Simulation studies show, however, that there may be a gain from incorporating environmental effects provided they could be well predicted in the short term (Basson, 1999).

New quantitative knowledge regarding the impact of the environment on the population dynamics of fish is supposed to grow in modules 1-5. It is expected that such knowledge will help to clearer reveal the marginal effect of the spawning stock (possibly qualified with age, maturation, sex distribution or other entities) on the recruitment and thereby improve the estimation of recruitment-based harvesting control rules. In the tactical implementation of harvesting control rules using medium term predictive simulation the quantification of environmental effects may help optimise the managemental response to fish stocks deviating from their desired states.

Besides predicting short-term environmental fluctuations of significance to the development of fish stocks where the AMOEBE work aims at extending the present time horizon of less than a year to possibly a few years, the study of slowly moving large scale anomalies can possibly enable useful predictions well into the medium-term (5-10 years).

Uncertainty

module 7

In order for management to comply with the precautionary approach it is essential that the uncertainty be properly handled. The basic uncertainty in the historic perception of the stock is quantified in Module 6, for instance in the form of replicate assessments using either Bayesian Markov Chain Monte Carlo or bootstrapping (Patterson et al, 2001).

The uncertainty connected to management strategies must be tested with simulations where the management strategies are used on simulated stocks in an underlying scenario or operational model. Basic techniques have been tried in practice (Butterworth and Punt, 1999, Hagen et al, 1998), but the possible complexities - especially due to modelling the influence from the environment - in the new AMOEBE models makes this as especially technical and conceptual challenging task, for which the basic methodology is expected to be developed in Module 9.

All models and modelling approaches relating to Module 7 shall handle the uncertainty properly and deliver results in the form of distributions of the interesting entities, rather than as point estimates or single trajectories.

4   Contribution to AMOEBE, relation to other modules

Module 7 is an end product in the sense that the results obtained in this module is of limited relevance as input to other AMOEBE modules. Module 7 draws heavily on the other modules, though. The population dynamics models used in Module 7 are the same as those used in Module 6, or aggregated versions of those. Module 6 models as well as data used for those models are channelled to Module 7 through the networking interface provided by Module 10. Part of the output from Modules 1 - 5 is used in Module 6 and will be used in Module 7 in the same form as in Module 6 or in an aggregated form. However, Module 7 will also require input that not

necessarily is relevant in Module 6.

It is not possible at the present stage to foresee the development in the challenging and knowledge-generating Modules 1 - 5. It is also not possible to accurately foresee the general technical development (stronger computers, more effective web-technologies) and the conceptual developments in Module 7 that will enable the utilisation of results from Modules 1 - 5 during the lifetime of AMOEBE. However, based on present-day understanding, available techniques and technical development some basic ideas may be sketched. However, a thorough revision of AMOEBE plans should be made every few years.

The inputs from Modules 1 - 5 must be operational in Module 7, i.e. relations between inputs needed in Module 7 and variables endogenous in Module 7 population dynamics models must be found. Models used on historic data in Modules 1 - 5 cannot be expected to run prognostically in a meaningful way for a long enough period to be interesting for Module 7 if they rely on variables that can be measured historically but not prognosed for a time period of many years (e.g. temperature). Therefore, statistical relationships must be built based on outputs from Modules 1 - 5, which is considered a task for Module 7.

A typical problem when constructing aggregate models for planning purposes is that needed information is lacking or is in a form that is not very useful. One reason for this is that the specialists working with the details have goals for their work that are not always compatible with the goals and purposes of the aggregate modelling needed in management. Thus much time is used on tasks that could have been performed better by others. A strength of AMOEBE is that it is organized such that the goals and needs of the modellers at the aggregate level is distributed to the specialists working with details. Hence, the work in Module 7 should provide important input to the other modules regarding purposes, goals and deliverables.

module 7

Input to Module 7 from Module 1

Direct input from Module 1 to Module 7 will be limited. However, an increased knowledge of ecosystem functioning made available from Module 1 might benefit Module 7 through Modules 2, 3 and 4.

Input to module 7 from Module 2

Module 2 has a large indirect impact to Module 7 because the physical model provides input to migration models developed in Module 5. To the extent the climate can be predicted in Module 2 the medium-term prognostic simulations made in Module 7 will be improved. Also, Module 2 is expected to provide grounds for more accurate estimates of yearly ambient temperature of fish when connected to the migration models.

In Module 2, research that is relevant and important in its own right will be conducted in addition to developing and running large-scale oceanographic models. Such research could be empirical relations between environmental conditions and recruitment success, which would be important input to Module 7, either directly or through Module 4.

Input to Module 7 from Module 3

Relationships between plankton, sea mammals and fish will be part of the long-term prognostic models in Module 7. From the combined effort of Module 3 and Module 5 statistical relationships between fish and sea mammal abundance on the one hand and plankton abundance and growth on the other hand will be evaluated and used in Module 7 models.

Input to Module 7 from Module 4

The recruitment relations are crucial to the evaluation of harvesting control rules using long-time prognostic simulations. Recruitment relations that more clearly show the dependence of recruitment on the spawning stock are supposed to be found by connecting the recruitment not only to the size and structure of the spawning stock, but also to other variables that can be endogenous or exogenous to the prognostic population dynamics model. Explanatory variables that cannot be prognosed will still be valuable in revealing the marginal value of the spawning stock. However, in that case distribution functions for use in the prognostic runs must be provided

Input to Module 7 from Module 5

Since species interactions are of crucial importance in Module 7 the most important result from Module 5 will be the simulated consumption per predator fields and the associated geographical distribution fields of species during the year and over the time range relevant for the assessment models. For use with Module 7 the consumptions must be given in a spatial aggregated form. For some fish stocks (cod and herring are examples) the present-day management is conducted assuming natural mortalities that are only poorly founded on data and the relation between yearly consumptions estimated in Module 5 (with uncertainty) and (spatially aggregated) predator species can be used more or less directly. For other species (capelin) part of the natural mortality is estimated from data at present, for other parts one has to rely on modelling. Here, the natural mortality needs to be partitioned by month and divided on sex and degree of maturation. Also for capelin such quantification of the relation between the mortality and (spatially aggregated) predator species can be used directly in Module 7 models.

It should be noted that in order to transform consumption estimated in Module 5 to natural mortalities the absolute stock abundances must be known. This is a task for Module 6 and effective ways of co-operation between Modules 5 and 6 in this respect must be found.

It is of crucial importance that the mortalities be estimated with a quantification of the uncertainty, which will consist of two parts: 1) the uncertainty in the estimated geographically distributed mortalities and 2) the uncertainty generated by the aggregation over space and time.

Based on the quality and amount of available data and based on a ranking of importance to the management the order in which consumption per predator fields estimated in Module 5 can be implemented in Module 7 is assumed to be:

1. Cod preying on prespawning (October - March) capelin in the Barents Sea
2. Cod preying on immature capelin, cod, haddock, herring and shrimp in the Barents Sea

3. Herring preying on capelin larvae in the Barents Sea
4. Harp seal preying on fish stocks in the Barents Sea
5. Minke whales preying on fish stocks in the Barents Sea
6. Competition between herring, blue whiting and mackerel in the Norwegian Sea

It should be noted that even if the estimation of migration in Module 5 can rely on measured distribution of fish there will be complications if the migration depends on the absolute abundance of fish through grazing of plankton if the plankton abundance is of significance in the migration model. Then an iterative relation to Module 6 may arise. It should be made experiments in Module 5 whether this is an important consideration or whether it could be ignored.

To the extent uncertain parameters are involved in the migration and predation simulation in Module 5 it is expected that the results be delivered in the form of stochastic replicates.

The relations between the individual growth and maturation on the one hand and the consumption and environmental factors (ambient temperature, energy expenditures) on the other hand are important for Module 7 models and is expected to be evaluated on historic data in Module 5. Again, these relationships must be evaluated based on variables that are operational in Module 7, i.e. area-distributed quantities must be aggregated and for environmental variables statistical relationships must be found.

One of the important contributions from Module 7 will be to move management away from the present-day rather narrow focusing on the spawning stock biomass as the decisive factor for recruitment (apart from environmental conditions). Fecundity, age distribution and sex distribution may be important qualifiers and will be affected by how the fishery is regulated. The basic material for utilising knowledge between these variables and recruitment in Module 7 must stem from work conducted in Module 6. Again, results should be delivered on an area-aggregated basis and the uncertainty expressed in the form of stochastic replicates.

module 7

Input to Module 7 from Module 6

There must be compatibility between the population dynamics models used in Module 6 and the population dynamics models used in Module 7, the models used in Module 7 being a subset of the models used in Module 6, i.e. Module 6 models must be properly aggregated.

The input from Module 6 is thus the structure of each model used. The models are properly aggregated in Module 7, either by directly running Module 6 models in an aggregated mode provided by the modellers or by constructing new models using equations from the Module 6 models. The choice of strategy will be made at a later stage, and may differ for different species.

The level of aggregation will also differ from species to species, and for some species the population dynamics in Modules 6 and 7 may be the same.

Input to Module 7 from Module 9

Module 9 is a service module providing advice on statistical methods. However, finding a statistically correct confidence distribution for the quota may require active research in statistical methods for inference.

Input to Module 7 from Module 10

Module 10 is the major provider of input to Module 7. From Module 10 Module 7 will get all the input data, including replicate files of historic stock abundances from Module 6. Aggregating the data to the level required by Module 7 is a task in Module 7.

Input to Module 10 from Module 7

It is more effective that the aggregation of models and data necessary for the use of results from other modules is done within Module 7. However, aggregated time series are of a wider interest than just for use in the simulation models in Module 7 and should be available over the network provided by Module 10. Therefore, aggregating tools developed in Module 7 will be implemented in Module 10.

The web presentation of tools developed in Module 7 is a task for Module 7. However, it will be integrated into the AMOEBE web presentation developed in Module 10.

module 7

5   Innovation

New knowledge will concerning the ecosystems will be developed in other modules. However the integration, analysing and web presentation will call for innovations in web technology and presentation techniques. Also, this process calls for new and improved human interactions between science and management, which in itself constitutes important innovations.

Statistical methodology

Fish stock assessments are complex from a statistical point of view. No satisfactory methods exist today by which the uncertainty in models and estimated parameters can be used in a statistical meaningful way in the final decision process. New methods must be developed and advances must be made in inferential statistics.

Web-based interactive presentation

In Module 7 integration of science and management is an important task and the meeting place is the evaluation of multi-dimensional harvesting control rules. The Internet will be used actively in promoting this integration and new presentation techniques as well as innovative web solutions have to be found.

Species interactions and impact from the environment

Although species interactions and the impact from the environment on marine living resources is more at focus in other modules the statistical relations built from knowledge generated in Modules 2 - 5 and used in module 7 for long-term projective runs are a scientific innovation that will be beneficial not only in Module 7 but also of interest for biological modellers on a world wide scale.

Model based predictive control

Development and implementation of MPC (Model based Predictive Control) algorithms (Rawlings 2000, Biegler 1998) for computing optimal medium-term harvesting control strategies based on stochastic predictive models and multi-criteria objective functions. This is a technique developed for industrial systems and might constitute a major innovation in fishery systems.

6   Workplan

Methodology and approach

The basic building blocks in Module 7 are population dynamics models. These could be single- or multispecies models of various complexities. One set of models of special importance is the models currently in use in routine assessments. These models will continuously be in focus and gradually improved over the life span of AMOEBE. However, it is of great value for illustrative and pedagogical purposes to also analyse simpler models.

module 7

Module 7 will provide a general framework for computing and analysing harvesting control rules using different underlying population dynamics models. Different research groups and management agencies may want to explore different models and Module 7 will provide a standardised and net-based framework for doing so. Population dynamics models to be analysed could either reside on the user's site or be uploaded to the standard AMOEBE server.

The AMOEBE catch rule evaluator - CARE

The essence of Module 7 is to compute catch rules and to evaluate the proposed catch rules or harvesting strategies. CARE consists of a net-based computer program that systematically runs model based predictive optimisation based on population dynamics models and evaluates the proposed harvesting control strategies. The statistical methodology applied enables the determination of a yearly quota that fulfils the goals for the fishery with a given probability.

Basing a proposed quota on a harvesting control rule based on historical assessments leads to problems in inferential statistics that are not yet solved. In this respect Module 7 expects to draw heavily on statistical work in Module 9.

Economical and socio-economical considerations made by the managers will be important elements in harvesting control rules and CARE must provide facilities for implementation of

different considerations important in management th   - 13 -at goes beyond a simple catch maximisation.

The definition and implementation of this part of CARE should be done in close co-operation with managers. For technical aspects in the definition and implementation of CARE it may be necessary to draw on technical expertise outside of the AMOEBE group.

Interfacing population dynamics models to CARE

The managers' perception of the ecosystem in which he wants to manage the fishing activity is defined by mathematical models that describe the relations between different elements in the ecosystem. These models - referred to as population dynamics models - describe growth, recruitment and how the different species influence each other, as well as how the fishery and the climate influences the different species.

module 7

Population dynamics models used for management are developed in the ICES working groups that make the yearly assessment. In most cases the models at present are very simple, but there are also cases where the present-day management is based on more involved models that describe species interactions (capelin-cod in management of capelin). Crucial to the use of population dynamics models in assessment is the estimation of the parameters that define the quantitative relations between its elements. The estimation procedure is always quite complex and poses severe statistical problems, most of which not having a satisfactory solution at present.

The models used in management should be interfaced to CARE as early as possible, but no models can be interfaced unless there exists a recruitment relation. Establishing recruitment relations should thus be a first priority for many fish stocks (i.e. herring, cod), and this work should be done in the relevant ICES working groups with aid based on knowledge established in AMOEBE. The reason for the lack of recruitment relations and hence the lack of long term harvesting control rules is primarily that the perceived stochastic impact from the environment is so large that it has precluded meaningful estimations of the spawning stock - recruitment relationship. Thus, the marginal effect of the spawning stock for future recruitment has not been revealed. It is a primary task of the work in modules 4 with input from modules 1-3 and 5 to quantify the relations between recruitment and climate

The population dynamics models used in assessment will be gradually developed. With the establishment of AMOEBE the development is expected to go faster and more elements of vital ecological importance can be incorporated. It is expected that other modules will deliver material for the improvement of underlying population dynamics models or deliver full-fledged models to be analysed in Module 7. However, also population dynamics models developed outside of the AMOEBE project may be used of evaluating harvesting control rules with CARE.

Underlying population dynamics models

Simple models
Even if the main focus in Module 7 is on the population dynamics models used for management at any time, simpler models may have a value serving as a conceptual bridge to the management

models. Such models should also be interfaced to CARE for the purpose of education and for studying harvesting control rules in a simpler environment where the statistical problems connected to the assessments could be temporarily looked away from.

Models used for management

In the beginning of AMOEBE the models actually used in management today will be used in Module 7. These models are:

Capelin
Today, the capelin is managed using the population dynamics model Bifrost, which has a strong multispecies element in that the predation by cod on prespawning capelin is modelled. The model will be used for evaluating harvesting control rules for capelin. Bifrost can readily be integrated into CARE.

Cod
The historic perception of the cod stock is evaluated with the models Fleksibest and XSA, where the latter is supposed to be phased out. Fleksibest is length-structured and code compatible with the general-purpose simulator for boreal ecosystems - Bormicon. Fleksibest can be integrated into CARE by constructing a small program that runs it one year at a time. For long-term prognostic purposes Fleksibest could be aggregated over length.

Herring
The herring is today assessed with the assessment program SeaStar, which provides both the perception of the historic stock and long-term runs. Also, the uncertainty is delivered in the form of bootstrap replicates. SeaStar can readily be integrated into CARE.

module 7

Other commercial fish species
The most interesting fish species aside from the ones mentioned above seem to be Greenland halibut, polar cod, blue whiting, mackerel and Northeast arctic saithe.

Shrimp

Harp seal
A logical start is to use the present-day population dynamics model that is used for the regular stock assessment of harp seal. The model could be interfaced to CARE directly, in which case a separate model for the interaction between harp seal and fish has to be written. An alternative is to incorporate the harp seal population dynamics model into a multi-species model (for instance, Bifrost).

Minke whales
The same model philosophy as for harp seal may also apply for minke whales.

Other sea mammals
Other sea mammals may also have an important role in the ecological system and it may be necessary or advantageous to address the interaction between these sea mammal species and fish when evaluating harvesting control rules. Such species could be humpback whales and dolphins

Plankton

Plankton may serve as an important mediator of interactions between commercial fish and mammal species. For that reason, but also because a directed plankton catch could become a reality, the interactions between plankton, fish and sea mammals could be addressed when harvesting control rules are evaluated.

Geographical overlap

The geographical overlap between species is decisive for the interaction. Based on the historical analysis made in Module 5 the effect of the geographical overlap can be separated from other effects (size dependency, maximum consumption per individual). However, for long-term prognostic simulations with models not having geographical structure the overlap needs to be aggregated over area, i.e. an overlap index must be defined and quantified on historical data or on historical geographically distributed simulations.

Interactions

Most of the assessments made to day are single-species assessments. In Module 7 the respective models can be interfaced to CARE and harvesting control rules can be analysed on a single-species basis. Also, a multi-species analysis can be made by running two or several single-species models and connecting them with an interaction module. After having proved valuable this set of models could be integrated to one multi-species model.

module 7

Workpackages

WP0 Module coordination

Objectives
• To perform administrative tasks associated with Module 7
• To develop action plan with annual updates

Description of work
The coordination of module 7 will involve several different individual researchers (and in particular people from Russia) and results from several modules. An action plan will be developed in WP0 during the early stages of the project, and this will be updated annually in response to the developments in module 7 and AMOEBE as a whole.

Deliverables
• D0.1 Annual updated action plan
• D0.2 Coordination of Module 7

WP1 Care - Catch rule valuator

Objectives
- Develop a generic computer program that can evaluate proposed harvest control rules for a variety of species
- Implement the program for running over Internet
- Enable users to understand and use the program, and to contribute to the development of the program

Description of work
CARE is a computer programme for running one or several population dynamics models for a long-term prognostic simulation is constructed as a set of rules for sequential running of processes and collection of information for updating the objective function. The programme must also provide possibilities for optimisation using repeated runs and a good web-based interface.Besides running long-term prognostic simulation for evaluating harvesting control rules, CARE will also provide a workbench for running medium-term predictive simulations. These simulations will serve as supportive information in the yearly management but also as material for evaluating medium-term harvesting control rules.CARE analyses the information that can be provided by the population dynamics models and lets the user (manager) define a harvesting control rule based on information available in the model and auxiliary information provided by Module 10 (for instance, price relations, price elasticities, cost of fishing operations). The rule is then evaluated by CARE.Crucial to success is a good interface to users and users should take active part in designing the interface. A first version should be established as soon as possible, so that users can take part in the continued refinement by using the product.

module 7

Deliverables·
D1.1 The logical interface between CARE and population dynamics models·
D1.2 The computer program CARE·
D1.3 Implementation of CARE in national research institutions·
D1.4 Implementation of CARE in ICES working groups·
D1.5 Implementation of CARE in national management agencies

WP2 Interfacing population dynamics models to CARE

Objectives
- Interface existing population dynamics models to CARE

Description of work
Any population dynamics model should be allowed to interface to CARE, both simple single-species models and multi-species models with a high degree of complexity. It is not a direct task in Module 7 to improve population dynamics models, rather to put models constructed or improved in other modules or elsewhere into a management context. However, connecting different models together and connecting models to CARE is a consideration for module 7.

Deliverables
- D2.1 Interface single species models for cod and herring to CARE
- D2.2 Interface a cod-herring-capelin model to CARE
- D2.3 Interface an ecosystem model for the Barents Sea to CARE

WP3 Reduced order models

Objectives
- Development of reduced order population dynamics models for prediction of future states and associated predictive uncertainty.

Description of work

Prognostic models that have predictive capability because they can with some degree of accuracy predict the climatic driving forces behind the development of living resources can be very complex. In order for those models to be statistically tractable they may have to be reduced in complexity. Different reduced order models need to be developed for different time spans (prediction horizons). It is important to start off with existing models with different degrees of complexity. Observability and controllability characteristics and requirements of the reduced order models shall be analysed.

module 7

Deliverables
- D3.1 A set of reduced order models suitable for use in for predictive simulation and optimal control harvesting computations.
- D3.2 Computer realisation of the models on a form suitable for use in prediction and optimisation.

WP4 System for model based predictive control

Objectives
- Develop a system for model based predictive control

Description of work

Developing a system for Modelbased Predictive Control for computing optimal harvesting strategies based on given multicriteria objectives. As a basis for such an optimisation, it is assumed that predictive models for single or multispecies population dynamics and environmental models are used, as well as associated uncertainty models which computes en estimate of prediction uncertainties or statistics. The latter is important in order to find safe solution (max yield for worst case).Since the performance of the system depends on predictive models the progress will depend on the progress in modules that will establish these models.

Deliverables
- D4.1 Appropriate multiobjective criteria for optimisation
- D4.2 Optimisation algorithms based on multicriteria objectives suitable for computing optimal harvesting strategies, reduced order models and associated statistical prediction

uncertainty.
- D4.3 Computer implementation of the algorithms for operational use in CARE.
- D4.4 Interface for the optimiser to the online estimation system, including the computation of reduced order state estimates.
- D4.5 User interface for operation and decision support.

WP5 Harvesting control rules

Objectives
· Developing long-time harvesting control rules
· Developing medium-term harvesting control rules

Description of work
Harvesting control rules are the driving force behind management of living resources. Long-term harvesting control rules give the general guidelines for the management, and are established by repeated long-term simulations. Medium-term harvesting control rules use in addition to the long-term general guidelines knowledge about future states of the ecosystem that can be inferred from present-day observations. In both cases are interaction with managers of vital importance for defining socio-economic elements.

Deliverables
- D5.1 Make general socio-economic objectives for management operational in harvesting control rules
- D5.1 Estimate long-term harvesting control rules in CARE
- D5.3 Implement harvesting control rules in systems for model based predictive control in the medium term

module 7

7 List of deliverables

Work package	Deliverable	Title
WP1		CARE –catch rule evaluator
	D1.1	The logical interface between CARE and population dynamics models
	D1.2	The computer program CARE
	D1.3	Implementation of CARE in national research institution
	D1.4	Implementation of CARE in ICES working groups
	D1.5	Implementation of CARE in national management agencies
WP2		Interfacing population dynamics models to CARE
	D2.1	Interface single species models for cod and herring to CARE

module 7

	D2.2	Interface a cod-capelin-herring model to CARE
	D2.3	Interface an ecosystem model for the Barents Sea to CARE
WP3		Reduced order models
	D3.1 A set of reduced order models suitable for use in for predictive simulation and optimal control harvesting computations.	
	D3.2 Computer realisation of the models on a form suitable for use in prediction and optimisation.	
WP4		System for model based predictive control
	D4.1 Appropriate multiobjective criteria for optimisation	
	D4.2 Optimisation algorithms based on multicriteria objectives suitable for computing optimal harvesting strategies, reduced order models and associated statistical prediction uncertainty.	
	D4.3 Computer implementation of the algorithms for operational use in CARE.	
	D4.4 Interface for the optimiser to the online estimation system, including the computation of reduced order state estimates.	
	D4.5 User interface for operation and decision support.	
WP5		Harvesting control rules
	D5.1	Make general socio-economic objectives for management operational in harvesting control rules
	D5.2	Estimate long-term harvesting control rules in CARE
	D5.3	Implement harvesting control rules in systems for model based predictive control in the medium term

8   Progress plan

Table 1. Progress plan (Gantt diagram). Module level. Active work packages are indicated by "x".

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2						x	x		x	x	x												x	x	x
WP3													x	x	x	x	x	x	x	x	x	x			
WP4		x	x	x	x	x	x	x	x	x	x	x	x	x											
WP5													x	x	x	x	x	x	x	x	x	x	x	x	x

9   Budget

The costs of module 7 will mainly be manpower, internet communication/interaction with Russia and computing power. The total cost for the first 5 years will be near 67 million NOK, and the total cost over the ten-year period is estimated to 120 mill. NOK.

Table 2. Cost of Module 7 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses. The personnel distribution is assumed to be: 30% on Cat.1, 40% on Cat.2 and 30% on Cat.3, giving an average man month cost of 76.000 NOK

module 7

Work package	Yearly man months					Sum man months	Manpower Cost, 5Y	Equipment 5 Year	Running cost, 5 Y	Total, 5Y
	Y1	Y2	Y3	Y4	Y5					
WP 0	12	6	6	6	6	36	2976	60	500	3536
WP 1	36	36	36	36	36	180	17704	5000	3000	25704
WP 2	12	12	12	0	0	36	2508	500	500	3508
WP 3	0	0	0	36	36	72	5056	3000	2000	10056
WP 4	36	36	36	36	36	180	12640	3000	2000	17640
WP 5	0	0	0	24	24	48	4376	0	2000	6376
Sum	84	84	84	132	132	552	45260	11560	10000	66820

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module 7

A Model based and data-driven Operational Ecological
Biomass Estimator (AMOEBE)

Module 8
Measurement technology and observational strategy

Version: Oct.18. 2002
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module 8

Module summary

This document presents a preparatory plan for the activities related to research, development, implementation and operationalisation of measurement technologies and observational strategies for AMOEBE. The module is divided into seven work packages, each focusing on different tasks and parts of the system. Work package 1 serves as an administrative unit, identifying critical project factors, and working out a detailed module plan 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. Work packages 2 to 6 are devoted to 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. Work package 7 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. The document also includes a preliminary time plan and budget.

Key words: *Measurement technology, Observational strategy, Measurement uncertainty, Marine environmental monitoring, Marine resource monitoring, Cost efficiency, Sensing principles, Instrument platforms, Automation, Remote sensing.*

Objectives

module 8

Module 8 is responsible for activities related to research, development, implementation and operationalisation of the 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 (e.g. Pitcher et al., 1998). This means that Module 8 will take the role as a provider of technological and strategical solutions to the diversity of measurement problems that will arise during the AMOEBE project. Following the AMOEBE module organisation, the objectives of this module is therefore to specify the constraints inherent to the measurement system and to implement the resulting optimal measurement strategy. These objectives can partly be met by employing existing technology and systems, while other require extensive research and development of new solutions. The solutions will be based on:

- Thorough reviews of the state-of-the-art in marine resource- and environmental monitoring 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 sensing 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 uncertainties
  •   National and international cooperation on observational tasks between the stakeholders in
the Norwegian- and Barents Sea regions (coast guard, fishery fleet, etc.)

Contribution to AMOEBE

Clearly, module 8 constitutes a large and fundamental part of the total AMOEBE project. It will
be very demanding with respect to consumption of man-hours and heavy investments in costly
equipment, and it can potentially (and will probably) surpass any of the other modules on the
budgetary plans. However, advanced technology cannot substitute lack of insight in fundamental
environmental and ecological processes and module 8 activities should therefore be grounded in
careful examinations of the various ecosystem properties conducted in other AMOEBE modules.

Relation to other modules

The part of the AMOEBE responsible for estimating the current state of the ecosystem (the
estimator) can be regarded as a system consisting of three interacting components:
  •   the mathematical models representing/simulating the environmental and biological proc
      esses
  •   the measurement system providing real-world observations of process variables
  •   and the data-assimilation procedure that combines the model computations and observa
      tions into a filtered state estimate.

The block diagram in Figure 1 shows the structure of the estimator. It is evident that this module
has relations to almost all other modules in the project. Of particular importance are its relations
to the modelling modules, module 1-6, which are of decisive influence with respect to process
knowledge and identification of variables that are important to observe. Considerable input is
required from these modules in order to determine the measurement needs as regards what,
where, and when measurements should be acquired. This will be reflected in the work package
descriptions.

module 8

The data-assimilation module, module 9, has a close relation to module 8 in the matter of
designing optimal measurement strategies. A reasonable criteria in that respect would be to
demand maximum information yield from the resources invested in monitoring activities, that
is, to find a set of measurements and a measurement schedule that give the best estimator
performance.
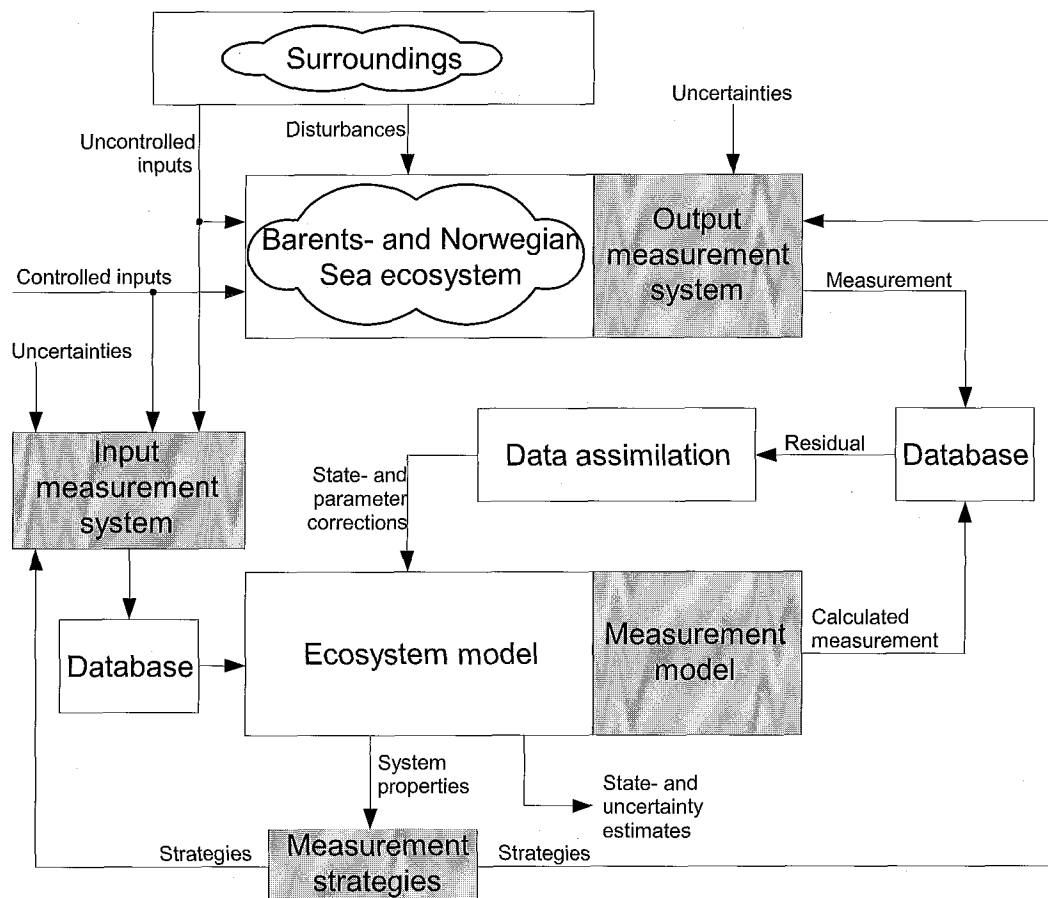
Figure 1: Block diagram of the AMOEBE estimator structure. Blocks covered by Module 8 indicated as grey boxes.

module 8

Module 8's relation to module 10, system integration, concerns particularly the specification of the interface between the AMOEBE databases and the communication infrastructure in general. Careful engineering will be required in order to avoid bottlenecks in the data path from the in-situ sensing elements to the respective AMOEBE database nodes. Finally, module 11 is related to module 8 as a receiver of "finished" measurement solutions. At a certain stage in the development process a particular measurement solution will become ready for incorporation into the operational AMOEBE monitoring system. This type of transaction requires close collaboration between the problem owners in the two modules and should be formalized through documentation standards and integration procedures.

Innovation

The main challenge concerning existing systems relates to their adaptation to the AMOEBE infrastructure and preparation for routine operation (operationalisation). This requires considerable innovation. Moreover, the distributed nature of the AMOEBE monitoring system puts high demands on the development of the underlying communication systems, in particular in the context of near real time data processing and transmission. Modern telecommunication systems will therefore be an important component of the operational part of AMOEBE.

The main innovation associated with module 8 activities pertains to the research, development and implementation of new sensing principles and incorporation of these on existing and new

instrument carriers. Considering the processes that need to be observed, the large span of temporal and spatial scales involved, and the great demand for data, high technological ingenuity and engineering skills are required for fulfilment of the AMOEBE mission. At this point it is not clearly set out what kind of sensing principles and technology that will become available in the course of the project, but it is up to the project to identify the needs and to investigate possible solutions, including consideration of:

- Satellite based remote sensing principles for wide area coverage
- Airborne instrument carriers for LIDAR surveys and instrument deployment
- Autonomous instrument platforms such as AUVs, smart Lagrangian drifters, gliders and static samplers
- Ships-of-opportunity carrying automatic measurement systems
- Further development of high-frequency and multi-frequency acoustic principles
- Stereo-camera and holographical techniques for species recognition and size measurement
- Biotelemetry and tagging

WORKPLAN

Methodology and approach

Introduction

The AMOEBE approach aims to integrate mathematical models and simulation tools with systematic observations through advanced data-assimilation techniques in terms of a dynamic estimator structure generating routine quantified estimates of the ecosystem states and corresponding uncertainties (see Figure 1).

module 8

To achieve this goal the collaboration between the design of the monitoring systems and the modelling work need to be strong, since consistent estimator performance depends on how well the information acquired by the monitoring systems correspond to model properties such as the composition of the state space and the dynamics of the processes involved. In other words, technological advances in the monitoring systems need to be based on knowledge and insight in the fundamental biological and environmental processes of the target region. A review of the state-of-the-art in marine resource and environmental monitoring seen in context with the modelling work performed in modules 1 to 6 and the systems theoretical considerations made in module 9 will therefore provide the premises that are required in order to make detailed specifications of this module.

The inherent complexity of the ecosystem processes and the variety of temporal and spatial scales involved put considerable demands on the characteristics of the underlying measurement systems as regards accuracy, capacity, cost efficiency and applicability. Obviously, the AMOEBE measurement domain will appear as highly heterogeneous with respect to the type of measurements, measurement procedures, temporal and spatial sampling frequencies, etc. As an illustration, measurements will range from highly complicated but operational remote sensing observations, via simple XBT temperature readings to sophisticated stock abundance surveys performed by highly sophisticated instrument platforms, while sampling strategy will range from several readings a day to once or twice a year, and from point measurements to hundreds of kilometre-wide satellite sweeps.

Study of existing technology

It is important to take into account the history and the state-of-the-art in marine resource and environmental monitoring, and the work in module 8 should therefore commence through a review of the technological status. Conclusions from this study in addition to inputs from the modelling and data-assimilation modules should provide the information required for detailed specification of the module action plan. Furthermore, measurement systems identified through the initial study, either existing or potential, should be arranged into the following categories or modes:
- Operational - measurement systems delivering routine observations for operational use
- Pre-operational - functional measurement technology ready for integration into the AMOEBE framework
- Emerging - working sensing principles which is robust and reliable requiring limited modifications for operational use
- Research mode - new developing sensing principles undertaken in scientific studies

This will help judging a particular measurement principle's "distance" from being operational and will provide useful information as regards identification of critical components in the monitoring system and it will give an indication of the time and resources needed to bring them to the AMOEBE operational mode. Note that there will also be a need for some research and development dealing with sensing principles targeted for pure scientific investigations of basic ecosystem mechanisms and processes, that is, measurements not intended primarily for operational use. These should be identified in cooperation with the respective modelling modules as soon as possible, and whether a sensing principle subsequently should be brought forward to the operational stage or not should be decided in each particular case.

module 8
Partitioning of problem

In order to overcome the proportions of the measurement problem, it is recommended that it is reduced into several isolated and clearly defined sub-tasks. Essentially, this partitioning has already been done through the AMOEBE module organisation, where the modules denote relatively isolated measurement systems targeting different levels and processes in the ecosystem. The following items indicate the partitioning:
- Measurement technology for meteorology, physical oceanography and primary production
- Measurement technology for abundance and spatial distribution of target zooplankton species
- Measurement technology for abundance (including benthos and aquatic mammals), spatial 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)

These items will be reflected in the work package definitions. In addition, there will be an important work package that targets the measurement strategy problems both on a general basis and, more specifically, for each of the listed measurement systems.

It will also be important to quantify the external forces acting on the system, termed as inputs in Figure 1. The inputs may be divided in two categories - uncontrolled inputs and controlled inputs. Uncontrolled inputs include atmospheric forcing, geophysical and biochemical processes, and conditions at the AMOEBE domain boundaries. In contrast, controlled inputs represent influences subject to human control. The fisheries represent the most important inputs of this type. As indicated in Figure 1, observations of both types of input need to be obtained on a regular basis, either from direct measurements or as output from other model systems, e.g. an operational meteorological model. Special action must be taken by module 8 in order to identify system inputs (actually specified by the modelling modules) and to establish an input measurement system capable of reproducing the predominant external forcing with sufficient accuracy.

General design guidelines

Although many of the measurement and strategy problems pertinent to AMOEBE are yet to be specified, a substantial body of knowledge exist regarding which challenges are likely to occur and recommendations on how future marine monitoring systems should be designed. Some key design guidelines that applies to all levels of the monitoring hierarchy should be given high priority regarding the measurement technologies and observational strategies adopted by the AMOEBE system:

Quantification and proper handling of measurement uncertainty. The error by which a variable is measured is as important as the measured value itself, and consequently, all systems generating data for AMOEBE must supply information about the uncertainty associated with the data.

Cost efficiency. The great spatial scales involved, the severe weather conditions often encoun-
tered at sea, and the fact that most phenomena of interest are concealed by the visually impenetrable sea surface, put special requirements on the type of sensing principles and instru-
ment platforms employed in marine monitoring systems. As a consequence, marine resource and environment monitoring is traditionally a very expensive business. Optimum application and benefit of remote sensing observations is therefore a must. Considering the extensive amount of information needed by AMOEBE, it is obvious that focus on cost effective measurement principles need to be encouraged.

module 8

Design of strategies based on system properties. A fundamental question and associated task is what kind of measurements is required and where and when should they be collected? The answers to these questions are closely related to the system properties of the ecosystem itself and should be approached on the basis of the knowledge embedded in the models. An interesting issue in this respect, which should be investigated in cooperation with the data assimilation module, is optimization of monitoring strategy based on maximization of system properties such as observability and identifiability, i.e. conducting ocean system simulation experiments (OSSE). Additionally, utilisation of model predictions can give valuable information as regards where and when measurements should be acquired. It is likely that the overall monitoring strategy will consist of a combination of routine measurements and a more sophisticated model-based approach where the measurements are acquired on the basis of desired estimator performance

and expected system behaviour.

Work packages

As a preliminary disposition, the research activity in module 8 is divided into seven work packages (WPs) which are interrelated as shown in Figure 2.
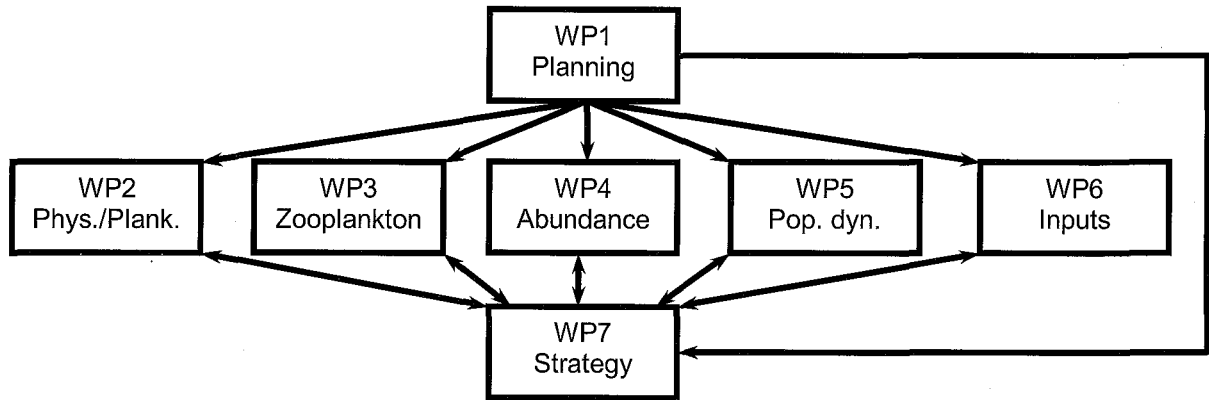
Figure 2: Work package network.

It should be noticed that WP1 is committed to a thorough review of the state-of-the-art in marine resource and environmental monitoring in context of the measurement requirements of AMOEBE (as identified by the modelling modules). Necessarily, this preparatory work must be completed before any serious action can be taken in the other WPs since the module organisation may become altered during this process. At this stage of the planning process it is neither advisable nor possible to make a detailed description of all WPs. The information supplied in the subsequent WPs (2-7) should therefore merely serve as input to the more elaborate planning work scheduled for WP1. It is the outcome of WP1 that will determine the final organisation of module 8 and provide precise descriptions of the corresponding WPs - including a detailed list of objectives and deliverables for each WP. The subsequent Gantt diagram and the budgetary plans should be interpreted with this information in mind.

module 8

Work package 1

Title:
Review of the state-of-the-art in marine resource and environmental monitoring and preparation of a detailed module action plan

Objectives:
- Finding out: What do we have, and what do we need?
- Cooperate with the modelling modules to identify measurement needs and specify the corresponding observational approach
- Evaluate the applicability of various measurement principles for the AMOEBE measurement system

- Writing a detailed action plan for module 8 specifying target areas and estimates of time and resource requirements

Short description:
A reasonable starting point for the work in WP1 will be a review of recent and on-going studies of marine monitoring systems, such as the GLOBEC project, the Godø-report (from The Research Council of Norway) and similar reports on marine environmental monitoring including the large number of publications under the EuroGOOS series as well as its recent release on Operational Oceanography (Tziavos and Flemming 1998, Anon. 1999, Halpern 2000, EuroGOOS 2001, Koblinsky and Smith 2001, Flemming et al. 2002, www.globec.org, www.eurogoos.org). These will serve as valuable input when assessing, in the light of AMOEBE requirements, the state-of-the-art and future perspectives in marine resource and environmental monitoring. The question concerning how AMOEBE should be interfaced with ongoing monitoring activities at various ecosystem levels should be emphasised.

Existing measurement technology for each of the ecosystem components, from physics to mammals, should be discussed and their applicability to the AMOEBE operational measurement framework evaluated. Each of the candidate measurement technologies should be classified based on its level of development as outlined above (from operational to research mode), and estimates should be made as regards the time and research effort needed to bring them to a stage where they can accomplish routine generation of data for assimilation and real time execution of the estimator system. This should be integrated in a comprehensive table that includes all types of processes (and variables) described by the AMOEBE model system along with their corresponding measurement needs and the availability of technology for each process. Necessarily, this investigation must be synchronised with the modelling work performed in module 1 to 6. In addition complementing effort should be put in planning and description of the communication network that will be responsible for the information transfer from the measurement platforms to the database nodes.

module 8

Detailed work package descriptions, with a possibility for reorganisation of the current work package structure, will follow from these investigations.

Deliverables:
- Annually updated module action plans including organisation of work, detailed work package descriptions and realistic estimates of time consumption and financial needs

The following work package descriptions are just suggestions and should serve as input to the discussion scheduled for WP1.

Work package 2

Title:
Environmental and primary production processes

Objectives:

- Establish an operational system for measurement of the environmental and primary pro
duction processes relevant to AMOEBE
- Conduct a feasibility study on existing and potential technology
- Integrate existing operational techniques into AMOEBE
- Initiate research projects

Short description:

The premises for the activity in this work package will be to find the optimum technological solu-
tions to the measurement needs given by the modelling and systems theoretical considerations
made in module 2. Of particular interest here is the assessment and integration of satellite remote
sensing principles which currently supplies regular and calibrated environmental and biological
data on surface parameters such as sea surface temperature (SST), cloud cover, near surface
wind, waves, ocean surface topography (sea currents) and ocean colour (chlorophyll). The fact
that observations from space generally cover very large spatial and temporal scales make them
highly attractive in view of the immense measurement requirements faced in the AMOEBE
project. Moreover, observations from airborne instruments, although operating at lower spatial
and temporal scales, share many of the characteristics possessed by satellite observations and
needs to be assessed, especially with respect to carrying of bio-optical sensors. Data from
satellites and airborne platforms must also be complemented by appropriate in-situ high accuracy
point measurements for ground truthing and calibration purposes.

For the numerous subsurface processes other techniques must be investigated. Most of the state
variables that will appear in the physical (oceanographic) and primary production domains of
the AMOEBE model system are readily measurable employing existing technology. The problem
is rather to find instrument platforms and measurement procedures that are able to cover the
vast regions in question in a cost effective manner. In this matter, development and utilization of

module 8   autonomous and expandable buoys and drifters (e.g. ARGO) will be of great interest (Tziavos and
Flemming 1998, Anon. 1998, argo.jcommops.org). In addition to the dedicated research vessels,
the fleets of military/coast guard, rescue, fishery and voluntary observing ships (VOS) represent
a valuable resource of potential instrument carriers/deployment platforms that constantly covers
large areas of the "AMOEBE oceans" as e.g. Nielsen and Jaccard (1999). Better utilization of
these resources should be addressed. The possibility of including aircrafts normally engaged
in routine surveillance activity in the area of interest (fisheries surveillance etc.) should be
considered in a similar manner.

Deliverables:

- Operational monitoring system for environmental variables and magnitude and distribu
tion of primary production

Work package 3

Title:
Abundance and spatial distribution of zooplankton

Objectives:
- Establish an operational system for identification of zooplankton species and measurement of zooplankton abundance and distribution
- Conduct a feasibility study for existing and emerging technology
- Integrate existing operational techniques into AMOEBE
- Initiate research projects

Short description:
The premises for the activity in this work package will be given by the modelling and systems theoretical considerations made in module 3. Based on the resulting structure and extent of the models describing the abundance and spatial distribution of relevant zooplankton species, it will be the responsibility of this work package to find technological solutions to the specific measurement requirements and need.

Technology for measuring variables such as biomass, spatial distribution, patchiness, size structure and taxonomic origin will be essential in the zooplankton monitoring system. Traditional sampling methods such as plankton nets and pumps will be important for species recognition and instrument calibration, but other more advanced and cost efficient methods are required in order to generate the bulk zooplankton data for the estimator. In this respect, a technological solution based on a combination of optical and broadbanded acoustical sensing elements carried by new advanced instrument platforms that are capable of covering large space and time scales will be more useful (Holliday, 1977, Holliday et al., 1989, Herman, 1992, Benfield, et al., 1998, Anon. 2002b). The AMOEBE project should identify typical zooplankton measurement scenarios and stimulate development of instruments that are capable of producing useful data for these situations (e.g. to provide a reasonable measure for the influx of *C. finmarchicus* to the Barents Sea).

Deliverables: module 8
- Operational measurement system for observation of zooplankton abundance and distribution

Work package 4

Title:
Abundance, distribution and behaviour (migration) of target populations of fish and abundance of benthos and marine mammals.

Objectives:
- Establish an operational system for measurement of abundance, including size and age group composition, of target fish species
- Establish an operational system for measurement of spatial distribution and migration of target fish species
- Establish an operational system for abundance measurement of benthos (including shrimp) and marine mammals
- Conduct a feasibility study on existing and emerging technology
- ntegrate existing operational techniques into AMOEBE

- Initiate research projects

Short description:
The premises for the activity in this work package will be given by the modelling and systems theoretical considerations made in module 5 and 6. Based on the resulting structure and extent of the models describing the target populations of fish, it will be the responsibility of this work package to find technological solutions to the actual measurement needs as some associated challenges are described by Fréon and Misund (1999). Technology for monitoring the abundance and distribution of fish is currently well established and several of the methods employed are operational today as are those of some whale species (e.g. Øien, 1991). Much of the work is therefore related to evaluation of existing technology as regards the measurement needs and adaptation and integration of these techniques into the operational AMOEBE measurement framework. Nevertheless, the new requirements put forward by AMOEBE should also stimulate innovation, new developments and improvement of the methods applied in this area today. One of the major objectives will be to provide considerable support to activities that aim to remedy the shortcomings trawl and acoustic survey methods experience today (e.g. MacLennan and Simmonds, 1992). Trawl performance, trawl standardisation, and the complex fish-trawl interaction effects together with the difficulties arising from the presence of the survey vessel itself relative to fish behaviour should be addressed. Concerning acoustic surveys, methods for resolving acoustic blind zones near the sea surface and the sea floor need to be addressed. New observing platforms such as autonomous drifters, AUVs (overviews: e.g. Anon. 2002a, Anon. 2002c) and towed bodies equipped with sonars (overview: e.g. Dalen et al., 2000) and advanced imaging capabilities (machine vision) could prove valuable both as a remedy for resolving the blind zones and for calibration and "ground truthing" of acoustic techniques. Incorporation of multi-frequency techniques combined with advanced pattern recognition algorithms for automatic size and species identification is also an important area of research that could increase the efficiency of the measurement task. In any case, proper quantification of measurement uncertainty should be emphasised.

Concerning monitoring of fish behaviour (migration), i.e. tracking the movements of individual fish or groups of fish, some experience and technology are available for this measurement task today (e.g. Fernø and Olsen, 1994). While tracking of individual fish may not be particularly important relative to the operational part of AMOEBE, it plays an important role as a tool for uncovering important migration mechanisms that need to be accounted for in the models (Cury, 1994).

Additionally, new (and old) ideas that in some way can contribute to a more efficient measurement system, in terms of increased data quality and data quantity and reduced costs, should be explored. Some topics are listed here:

Lidar (light direction and ranging) - analysis of scattering from pulsed laser light can be used for detection and calculation of biomass of fish schools dwelling in the upper ocean. The instrument can be carried by e.g. an aircraft (Churnside et al., 2001).

Silent approach - developing advanced AUVs and autonomous drifters that are capable of monitoring fish without inflicting any disturbances on their natural behaviour. Operating independ-

ently or in cooperation with a research vessel (e.g. Anon. 2002a).

Ships-of-opportunity - developing automated measurement equipment and procedures making it possible to employ fishery fleet and coast guard in monitoring tasks (e.g. Dalen and Totland, 2002). Automated use of fisheries data.

Tagging techniques - developing inexpensive transponder tags for large scale tagging (overview: Anon 2002d).

Deliverables:
- Operational measurement system for abundance, spatial distribution, size and age group composition of target fish species
- Operational measurement system for abundance and spatial distribution shrimp and benthos

Work package 5

Title:
Physiology and population dynamics of target fish species

Objectives:
- Establish an operational system for measurement of physiological variables related to the bioenergetic state of fish
- Establish an operational system for measurement of variables related to recruitment and mortality of target fish species
- Conduct a feasibility study on existing and potential technology
- Integrate existing operational techniques into AMOEBE
- Initiate research projects

module 8

Short description:
The premises for the activity in this work package will be given by the modelling and systems theoretical considerations made in module 1, 4, 5 and 6. Based on the resulting structure and extent of the models describing the population dynamics and the physiological state of the target populations of fish, it will be the responsibility of this work package to find technological solutions to the particular measurement needs. Population dynamics (recruitment and mortality) is closely related to the physiological state of the individuals that constitute the population. Aspects of the measurement systems that target these two areas are therefore treated collectively.

Processes related to recruitment, mortality and migration (in/out) determine the population dynamics of a certain fish species. If the system can be regarded as closed, only recruitment and mortality affect the population dynamics. While abundance observations, as presented in WP 4, focus on determination of the actual size of a population, observation of recruitment and mortality will provide information on the rate of change of the population size. It should be realized that knowing the exact size of a population at a given time does not say anything about the future development of the population. Consequently, gaining accurate observations of these processes will be very important regarding the quality of the AMOEBE population predictors, that is, the system's ability to predict how the fish populations will evolve in the future. Mortality is normally divided in natural mortality and fishing mortality. Natural mortality is

difficult to observe directly and considerable innovation is needed in this area. Some useful information may be obtained by careful studies of the effects of predator-prey overlaps, which can be measured acoustically and by trawl samplings (and tracking/spotting of marine mammals). Likewise, establishment of stomach content databases will give valuable information on prey mortality, relative prey preference and to some degree prey availability. Accurate quantification of fishing mortality (fisheries data) represents a research area of fundamental importance and will be treated separately in WP 6, external forcing.

In order to determine the recruitment success it will be critical to obtain quality observations in the time window spanning from winter, when the mature egg producing fish enter the spawning grounds, to early autumn when the 0-group stage is established. The recruitment potential (fecundity) of the year classes that constitute the spawning stock can be determined by regular abundance surveys and field sampling of mature fish conducted by research vessels and ships-of-opportunity (fishing vessels). This can be complemented by direct observations of larval density and distribution on the spawning grounds. Detection and sampling of larval fish are largely subject to similar technological challenges as detection and sampling of and planktonic organisms, which suggest that research efforts in this area should be coordinated with WP 3 (OPCs, multi-frequency acoustics, sampling trawl technology etc.). Larvae and juvenile fish are subject to considerable mortality as a result of predation, starvation and various environmental effects. Methodology for estimating quality and fitness of juvenile samples should therefore be emphasized. To determine the actual year class strength it is necessary to measure the frequency of 0-group stage fish that have reached the "nursery areas" in early autumn (Randa, 1981).

0-group surveys are well established in present-day marine resource monitoring and should be continued within AMOEBE. To achieve maximum yield, these surveys need to be assisted by particle transport simulations based on hydrodynamic ocean models.

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Concerning physiological state, observations are largely based on direct sampling and analysis of individual fish with respect to variables such as size at age, growth history, condition factor, fat content, liver index, maturity, fecundity etc. For the species and age classes subject to fisheries, fish samples can readily be gathered from the fishing fleet. Age classes and species not represented in the fisheries need to be collected through research surveys. Sampling and analysis of individual fish are labour intensive tasks and need to be made more efficient. This field has room for considerable innovation. Fish growth depends on the availability of food and measurements of predator-prey overlaps (cod-capelin, cod-herring, larval fish-*Calanus* etc.) may provide useful information on the growth potential and mortality of various age classes and populations of fish. Methodologies for observing predator-prey encounters have much in common with the abundance and distribution measurements addressed in WP 4 (and should therefore be coordinated).

Deliverables:
- Operational measurement system for key variables affecting the population dynamics of the target fish species

Work package 6

Title:
External forcing

Objectives:

- Get an overview of the external forces acting on the system (controlled and uncontrolled inputs), including boundary conditions
- Determine what inputs can be obtained from other types of monitoring systems and what must be measured directly by AMOEBE
- Establish the input measurement system

Short description:

The work in the modelling modules will result in a clear definition of the AMOEBE system boundaries including a description of the external driving forces, referred to as the system inputs. Obviously, models can only give a sufficiently accurate representation of reality if they are subject to the same forcing as the real-world system. Consequently, the relevant inputs need to be properly quantified, and this will be the responsibility of the input measurement system. It is premature, of obvious reasons, to give a detailed account of the input measurement system, but some important input sources may be mentioned.

Concerning environmental forcing, outputs from already existing operational meteorological systems can probably supply a major part of the required data (e.g. Svendsen et al., 1995, Stenseth et al., 2002). Interfacing AMOEBE with these systems will therefore make up an important activity when establishing the input measurement system. In a spatially distributed system like AMOEBE, acquisition of observations along the system boundary (boundary conditions) should be given special attention (e.g. precise measurements of the Atlantic inflow).

The most important system input on the biological side is the fisheries, which in many situations represent the prime fish mortality factor. Reliable fisheries data are therefore as important for AMOEBE as it is for any other resource assessment tool. Today, fisheries data are comprised of catch statistics, fishing effort data, and biological data obtained from samples of the landed fish. Despite the fact that fisheries data potentially represent a highly valuable source of information, a long range of problems are associated with their use in resource assessment, mostly as a consequence of large uncertainties and unreliable acquisition procedures. Obtaining high quality fisheries data is of utmost importance and AMOEBE should support ongoing activities in this area. To mention some, introduction of modern communication and information technology in the reporting system will help to secure data integrity and timeliness, while replacement of manual sampling procedures (weight, length) with dedicated automated equipment will increase the sampling rate and remove data inaccuracy introduced by human operators.

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Deliverables:

- Operational input measurement system

Work package 7

Title:
Observational strategy

Objectives:
To find optimal observational strategies based on analysis of system properties

Short description:
Finding out where and when measurements should be acquired (the observational strategy) are just as important questions as finding out what kinds of measurements are required and how they should be realized (the measurement technology). With respect to AMOEBE, WP 2 - 6 in this module together with the work conducted in the modelling modules will focus on the latter question, while this WP addresses the former. As long as the time and resources available for monitoring are limited, there will always be an issue on the matter of how the measurement system should be managed in order to achieve maximum information yield and make sure that the estimator works properly. Essentially, this is a problem rooted in systems theory and optimisation.

Generally, the observational strategy must be based on thorough knowledge of the structural and dynamic properties of the systems involved. In AMOEBE, this knowledge will be contained in the set of mathematical models representing various parts of the ecosystem, which will provide a natural basis for a methodical analysis and specification of the observational strategy in several respects. For instance, in order to secure proper representation of the system's true behaviour in sampled time series, temporal and spatial sampling rates need to be determined on the basis of an analysis of the dynamic modes, or time constants, and the spatial variability of the system. Likewise, the measurements should be collected over a period sufficiently long (sampling duration), or over an area sufficiently wide, that most significant features of the process are contained in the data. Both sampling rate and sampling duration are important absolute parameters associated with the observational strategy that have significant impact on the extent and complexity of the underlying monitoring system. Consequently, establishing proper methods based on sound mathematical analysis for exact determination of these parameters may result in considerable cost savings and performance gains as opposed to an ad hoc approach which is susceptible to unfavourable over- and under sampling effects.

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Investigation of important system properties such as observability - the ability to determine the model states based on information made available by the measurements - and identifiability - the ability to determine the model parameters based on the information made available by the measurements and the input excitation pattern - need to be properly addressed. In general, the observability and identifiability concepts provide a methodical approach to the problem of finding optimal observational strategies, and the design of state- and parameter estimators rely heavily on these properties. The degree of observability depends on structural and parametric properties of the model and the configuration of the measurement system. Since the structure of a model usually is fixed for a given process, the main problem will be to find a feasible configuration of the measurement system and an observational strategy that maximise observability and the likelihood of finding a realizable state estimator. Similarly, analysis of identifiability in relation to parameter identification will give useful input with respect to the configuration of the measurement system. When examining the degree of identifiability it will also be necessary to take into account the persistency of excitation and the type of identification algorithm used.
In large spatially distributed systems it is evident that only a relatively small portion of the system can be covered by the monitoring system at a time (which is particularly true for the large number of variables and processes that are impossible to observe from space). With limited monitoring resources it is a natural to ask: When and where in the system should measurements be acquired in order to keep the estimator adequately updated? - which is, in many respects, similar to asking:

When and where are the most significant "changes" taking place in the system? Provided that the models yield a reasonable correct representation of the system, it is a good idea to use the a priori information that is embedded in the models to make predictions (numerical simulations) of future system behaviour that can be utilised in the observational planning. In this way measurement resources can be put where they are most needed. Observational planning by use of expected system behaviour may be termed model-based guidance of observational strategy. However, it should be noted that since the models are far from perfect it will also be necessary to conduct some routine observations that are independent of model predictions.

Mathematical analysis of system properties and numerical simulation and assessment of the effect of different observational strategies are computationally demanding, and should therefore be assisted by suitable software tools. Development of such tools will be a key factor for a cost effective measurement system and it is probable the quality of the results obtained in this WP will be decisive for the feasibility of the project as a whole. Note that the WP's strong dependence on various system/model properties suggests that start-up should await the results from the modelling modules.

Deliverables:
- A computer-based framework for optimal design of observational strategy for all segments of the measurement system

Project timing

The Gantt-chart below shows the preliminary timing relationship between the work packages defined in module 8 for the first six years. As can be seen, WP1 occupies (exclusively) the first three quarters of the first year. This period is purposed for preparation of the detailed module action plan in close co-operation with the modelling modules. An annual revision of the module plan is also included. WPs 2 - 6, which are fairly independent, are scheduled immediately after completion of the module plan. Work on WP7 should start in parallel with WPs 2 - 6 since there will be mutual dependencies between the technological solutions and strategical decisions in the final monitoring framework. Each task has a number of milestones (deliverables) connected to its timeline, but it would be premature to specify these at this point. Exact scheduling of milestones is left to the detailed module planning covered by WP1.

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Table 8.1. Progress plan (Gantt diagram). Module level. Active work packages are indicated by "x".

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP1	x	x	x					x				x				x				x	x	x	x	x	x
WP2				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP3				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP4				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP5				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP6				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP7					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Participants

Researchers from both the main marine research institutions and the universities will be responsible for the work in this module. The need for basic research and a strategy for national AMOEBE competence build-up suggest that a number of doctorate students should be linked to fundamental research areas that are relevant to the module. Moreover, the module's strong focus on technology requires close cooperation with industrial partners. International cooperation will be encouraged.

Preliminary budget

The costs of Module 8 will represent a substantial part of the total budget of AMOEBE because it will be responsible for development and integration of measurement solutions for a long range of variables, as specified in the modeling modules. The module will be resource consuming both with respect to manpower and investments in costly equipment. The manpower consists of special task groups including personnel of three categories: Cat. 1 - Senior scientists, Cat. 2 - Scientists, Cat. 3 - Technicians/Engineers/PhD students/Others. The composition of personnel categories will vary from task to task according to the character of the problems. In module 8, cooperation with industrial partners that have commercial interests in particular measurement systems or instruments will be important. It is hence assumed that significant parts of the budget can be financed by contributions (labour/development costs) from industrial partners. The preliminary budget indicates that the effort of equipping AMOEBE with the required technological ability has an estimated cost of ~250 mill. NOK over ten years.

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Table 8.2. Cost of Module 8 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Cost per man year is increased yearly by 5 %. Running cost includes: Travel expenses, minor operation costs, consumables and ordinary computing expenses. The personnel distribution is assumed to be: 30% on Cat.1, 40% on Cat.2 and 30% on Cat.3, giving an average man month cost in 2004 of 76.000 NOK

	Yearly man months					Sum man	Man power	Equipment	Running	Total
Work package	Y1	Y2	Y3	Y4	Y5	months	Cost, 5Y	5Y	cost, 5Y	5Y
WP 1	45	5	5	5	5	65	5140	0	500	5640
WP 2	6	24	24	24	24	102	8711	10000	1500	20211
WP 3	6	24	24	24	24	102	8711	10000	1500	20211
WP 4	8	30	30	30	30	128	10926	15000	2000	27926
WP 5	6	24	24	24	24	102	8711	10000	1500	20211
WP 6	6	24	24	24	24	102	8711	10000	1500	20211
WP 7	6	24	24	24	24	102	8711	0	1500	10211
Sum	83	155	155	155	155	703	59621	55000	10000	124621

Main deliverables list

Work package	Deliverables	Description
WP1	D1.1	Annually updated module action plan including organisation of work, detailed work package descriptions and realistic estimates of time consumption and financial needs
WP2	D2.1	Operational monitoring system for environmental variables and magnitude and distribution of primary production
WP3	D3.1	Operational measurement system for observation of zooplankton abundance and distribution
WP4	D4.1	Operational measurement system for abundance, spatial distribution, size and age group composition of target fish species
	D4.2	Operational measurement system for abundance and spatial distribution shrimp and benthos
WP5	D5.1	Operational measurement system for key variables affecting the population dynamics of the target fish species
WP6	D6.1	Operational input measurement system
WP7	D7.1	A computer-based framework for optimal design of observational strategy for all segments of the measurement system

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module 8

module 8

AMOEBE
A Model based and data driven Operational Ecological Biomass Estimator

Module 9 - Data Assimilation, Parameter Estimation, and Uncertainties

Version 15.sept.02
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Module Summary

*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). Several specific work packages are described in more detail.*

Objectives

AMOEBE will include the development and use of several dynamical mathematical models, possessing different degrees of complexity and uncertainty. Examples of such are dynamical physical models, ecological models, sea-ice models, fish-stock assessment models, etc. and, of course, the interaction between those models. One imporant objective of AMOEBE is to develop advanced parameter esimation and data assimilation tools for the models in order to improve the quality of model outputs and thereby achieving better management strategies for the fish stocks.

The history of modern fish stock assessment goes back to Fournier and Archibald (1982) who were the first to cast the assessment problems as a parameter estimation problem (current stock size would usually be the most important variable which could be obtained from this). They constructed a likelihood function that integrated a population dynamic model with all available sources of data (acoustic and trawl survey data, catch data, line transect data, mark-recapture data, and genetic data.). Numerical optimisation techniques were used to maximise the likelihood function with respect to the unknown parameters in the model. This approach has become widely used within the ICES (International Council for the Exploration of the Sea) system, and one particular example is the FLEKSIBEST model (Frøysa et al., 2002) which has been developed at the IMR (Institute of Marine Research, Bergen).

The problem with the approach by Fournier and Archibald (1982) is that the number of parameters that may have to be estimated can be very large. As an alternative for such situations, methods based on the Kalman filtering techniques (Gudmundsson, 1994) or Markov Chain Monte Carlo methods (Meyer and Millar, 1999) have been suggested. These approaches can be very computer intensive, but may provide better handling of problems with many unknown parameters.

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Module 9 is focused on three topics, viz. (1) data assimilation, i.e., the utilisation (integration) of measurements and observations in dynamic models for the purpose of improving a model's ability to estimate present (filtering), future (prediction), and past (smoothing) values of model variables, (2) parameter estimation, i.e., the use of available data (in the form of measurements, observations, and known inputs) to estimate unknown parameters in dynamic models, and (3) uncertainties, i.e., how uncertainties in the inputs can be represented, how uncertainties in the inputs and the model will influence the variables in the model, and how uncertainties in the model variables can be represented.

Data assimilation will in AMOEBE mean utilisation of a large variety of measurements and observations, which can be categorised in many different fashions, e.g. (i) physical, chemical, biological, (ii) pointwise, linewise, spacially distributed, (iii) rapid (high sampling frequency), slow (low sampling frequency), (iv) automatic, conventional, spontaneous, etc. Moreover, the types of observations are very different and will include remote sensing data (altimeter data, sea surface temperature data, colour spectral data, wave spectral data), buoy data (e.g., pressure meaurements, flow measurements, temperature measurements), chemical data, catch data, survey data, tagging data, etc. And, the methods being used for assimilation of these data in a model (also called updating) can be based on different techniques, e.g., Kalman filtering and related techniques (extended Kalman filter (EKF), second order nonlinear filters), techniques based

upon Monte Carlo methods (viz. the ensemble Kalman filter (EnKF)), and variational inverse approaches.

Parameter estimation is part of the field of interest called system identification (in control engineering), i.e., determination of an unknown system's structure and parameters. Usually the structure of the underlying system is determined beforehand using physical, chemical, biological, behavioural etc. knowledge about the system, an approach which generally leads to models containing unknown parameters. The methods can be categorised in different ways, one being nonparametric and parametric, where the former means methods with no upper bound on the number of parameters (transient analysis, frequency analysis, correlation analysis, spectral analysis), whereas the latter means methods with a limited (model dependent, however) number of parameters, e.g. prediction error (PE) methods (including maximum likelihood), augmented Kalman filter, least squares (LS) methods, instrumental variable (IV) methods, subspace identification methods, and inverse methods. The parametric methods may further be categorised as nonrecursive (batchwise) or recursive. Parameter estimation will in AMOEBE mean to find the most suitable parameter estimation methods for each submodel, and to utilise these methods in finding the unknown parameters.

Uncertainties in the data model variables and parameters are represented in the form of probability distributions. These probability distributions should reflect sampling effort and measurement errors of the input data and mirror the underlying model uncertainties, e.g., stochastic inputs, spurious inputs, unmodeled dynamics (neglected processes), simplifications, chaotic dynamics, etc. The development of the model uncertainties is a dynamic process which can be computed utilising the mathematical model and the observation data. Uncertainties will in AMOEBE be very important in assessments and predictions of fish stock, shrimp, seals, mink whales, etc.

Contributions

Data assimilation, or model updating, has been widely used in engineering applications since the early sixties, and has more recently been subject to growing attention in the field of oceanography. Some national oceanographic centres have taken this approach in use, e.g., the Nansen Environmental and Remote Sensing Centre (NERSC) in Bergen, which has developed a data assimilation technique suitable for use in an operational ocean monotoring and forecasting system for the North Atlantic Ocean. The different data assimilation techniques developed for integrating observation data into the models, e.g, Kalman filtering and related algorithms or techniques based upon Monte Carlo methods, have conceptually no problem in handling the fact that the observation data may be very different (coming from very different sources), may be synchronous or asynchronous, may be automatic or "manual", may be sparse or abundent, etc. It is believed, however, that use of the observation data must be model oriented in the sense that the different submodels make use of just a subset of the available data. For example, catch data for a certain fish population will most certainly have no meaning in an ocean general circulation model, but may be very important for another fish population. Important research should in this context be focused on

- What observation data should be used for data assimilation in each submodel, and what data can be neglected?
- How can the different observation data be assimilated (i.e, integrated in a specific model) in an optimal fashion?

module 9

It turns out that the extended Kalman filter (EKF) may give unsatisfactory results for systems having strong nonlinearities, a problem which has led to other filtering algorithms, e.g., the ensemble Kalman filter (EnKF), Evensen (1994), which among others utilises Monte Carlo methods, see also Bølviken et al. (2001). The main improvement of the latter compared with the former is that certain terms originating from the model nonlinearities are retained, resulting in more accurate predictions and assimilation of data. It is a fact, however, that a major part of the influence of the nonlinearities in many cases can be retained utilising one of the so-called second order nonlinear filters (truncated or Gaussian), see Jazwinski (1970) and Henriksen (1982). To what extent that is true can be an interesting study in AMOEBE.

Typically, within AMOEBE, large scale models will be used to assimilate very few, sparse observations. In these circumstances, a very effective approach for data assimilation is the representer form of variational inverse (Bennett, 1992; Chua and Bennett, 2001). In such a scheme, computational effort is not wasted on the null space - that part of the state space which is not observable (i.e., not invertible). Representer inverse methodology will be implemented and made available to the various modelling components within AMOEBE to complement the Kalman filter approaches for problems in which observations are sparse.

Many of the submodels of AMOEBE will be large scale models, and typical examples of this will be models obtained from partial differential equations by spatial discretisation (e.g., ocean general circulation models). How all kinds of observations can be assimilated in such models is not clear, e.g., how spatially sparse measurements can be utilised both alone and in conjunction with spatially abundent measurements, and a detailed study must involve both structuring of the model (e.g., hierarchical vs. non-hierarchical) and model aggregation. A very important research study should therefore be

- Assimilation of sparsely distributed in situ data in large scale models

module 9

Parameter estimation can in AMOEBE to a large extent probably be carried out utilising prediction error (PE) methods, of which the maximum likelihood (ML) method is one, in some form. These methods, which are based upon the innovation process, i.e, the difference between the observation (measurement etc.) and the one-step model predicted observation, are very general and can be applied to any type of model (state-space, ARMAX, etc.). PE methods can under certain assumptions be shown to be efficient, i.e., to satisfy the Cramér-Rao lower bound, but the computational effort may be very demanding, and simplifications most certainly will be required for many of the submodels. The augmented Kalman filter (AKF) is an attractive recursive estimator (of both states and parameters) for certain state-space models, but the accuracy may not always be satisfactory as opposed to methods derived from the PEM concept. The underlying algorithms for PEM or AKF can be based upon any of the previously described estimators, i.e., EKF, EnKF or second order nonlinear filters. Parameter estimation in conjunction with data assimilation is an integral part of model building, and will be very important in AMOEBE.

An additional aspect is the following. Data carrying information about biological parameters typically have both a spatial and a temporal dimension. Thus, methods from the field of spatial statistics (Cressie, 1993) can be important in Module 9. A conceptually appealing way of modelling correlation patterns is through the use of latent stochastic variables. This class of models includes for instance Bayesian models (Punt and Hilborn, 1997). Recent advances in computing algorithms and power allow latent variable models to be fit to real data. Examples of new computation methods are Markov Chain Monte Carlo algorithms (Besag et al., 1995) and automatic differentiation (Skaug, 2001).

Uncertainties in modeled quantities may stem from input data, from model choice or from estimates of model parameters. The quantification of uncertainty is done through the specification of a probability distribution for the quantity of interest. This probability distribution may be obtained analytically or through the use of computer simulations. An important activity of this module is to identify the main sources of uncertainty and quantify these statistically. This is necessary for assessment of sensitivity on model output and management options.

One of the primary sources of uncertainty is the input data. The input data may be obtained from dedicated surveys, from surface buoys, remote sensing devices or from additional sources (such as fish catch statistics). Each of these data sources and modes of observation has its own sampling properties, which will give rise to a unique statistical model for the given data source. The quantification of uncertainty in the various data sources will be important for designing and revising surveys, as well as for monitoring and sampling programs.

Another source of uncertainties will also be the models themselves, i.e., to what extent do the models reflect the dynamics of the underlying system, and what might the influence and sensitivity of, say, unmodelled dynamics be.

Adhering to a precautionary approach to fisheries management, the uncertainties should be reflected in the management procedures. Thus, uncertainties have to be accounted for at the observation level, and these uncertainties have to be propagated through the relevant model/ models to the management level.

Innovation

A main challenge in Module 9 will be the proper handling and assimilation of the many different kinds of observations in the form of remote sensing data, catch data, buoy data, tagging data, etc., etc. Although the nature of the data may be very different, and to a great extent asynchronous, that does conceptually not have to be a problem, but the way the data are being utilised will still be a challenge. Many of the observations are quite abundent both in time and space, e.g., remote sensing data, whereas other observations may be very sparse, e.g., data from buoys or surveys of marine populations. The information content in these input data will be affected by spatial-temporal dependencies (or correlations) in the processes being measured. How these observations can be combined in an optimal manner (e.g., to yield optimal predictions) is an unsolved problem which has to be addressed. Another challenge will be the use of the different data in parameter estimation. Although this also may seem to be no problem, conceptually speaking, it should be quite clear from the outset that the practical problems which will be encountered demand a lot of refinements in the methods before the problems can be solved satisfactorily, at least with regard to the size of the problems. Many of the submodels in AMOEBE will be large scale models with potentially large sets of unknown parameters, and to overcome just that will at least computationally be a very tough challenge. A further challenge is to provide quantitative guidance on effort allocation for future surveys. Collection data on marine populations is costly, and a detailed uncertainty analysis will be useful in quantifying the effects of alternative data collection strategies on the uncertainty in the variables of interest.

The challenges encountered in Module 9 will in most cases probably be best handled in conjunction with the more specific type of models and problems described in the other modules, i.e., handling of the topics focused upon in Module 9 will to a large extent have to be model and problem oriented, and not just a special case of some general solution.

module 9

Workplan

The following work packages are described in more details later on:
    WP1: Action plan for Module 9
    WP2: Development of advanced data assimilation tools
    WP3: Assimilation of very sparse in situ data in large scale models
    WP4: Validation of assimilation tools
    WP5: Parameter estimation in large scale models
    WP6: Uncertainties in observations, models and model predictions
    WP7: Linearisation and sensitivity analysis
    WP8: Synthesis of an optimal observation system

Gannt Chart

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y 6	Y 7	Y 8	Y 9	Y10
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2					x	x	x	x	x	x	x	x	x	x											
WP3							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP4											x	x	x	x	x	x									
WP5							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP6							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X
WP7							x	x	x	x	x	x	x	x	x	x									
WP8							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Figure 1. Time table for the projects in Module 9 for the initial 5 years.

module 9

Work Package Network
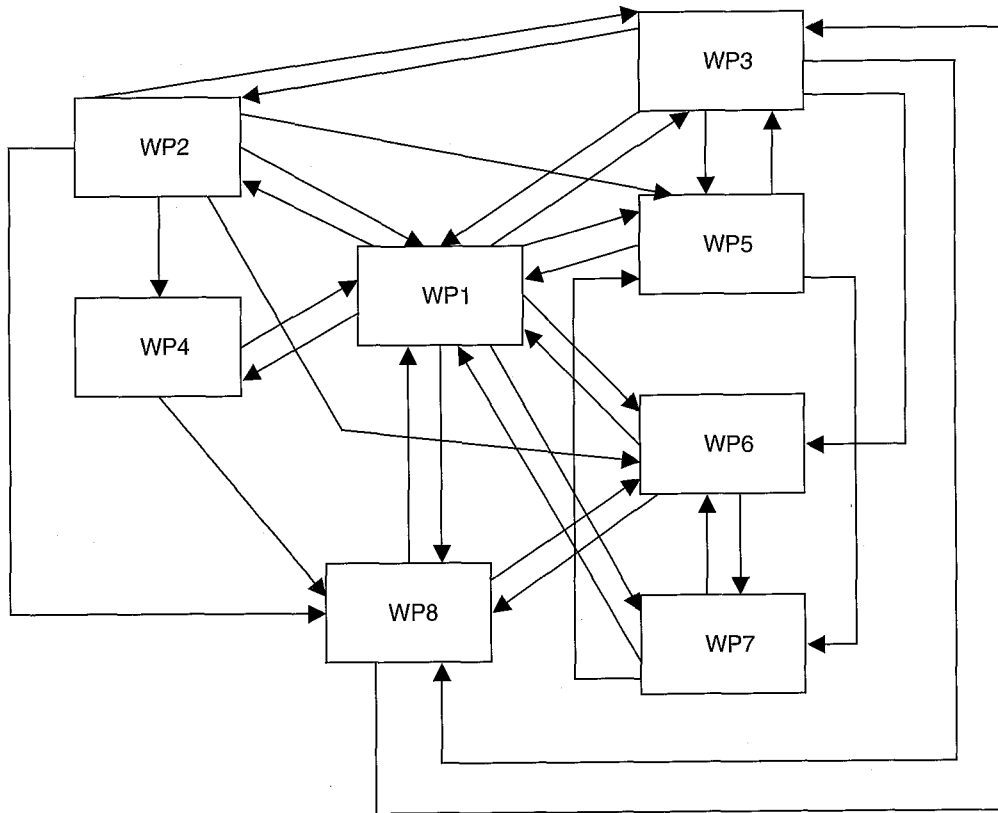
Figure 2. Links between the work packages of Module 9.

Deliverables

module 9

Work Package	Deliverables	Description
WP1	D1.1 D1.2	Development of an action plan for Module 9, to be reviewed and, if necessary, revised every year
WP2	D2.1 D2.2 D2.3 D2.4	Development of data assimilation tools and interface for physical ocean model Development of data assimilation tools and interface for ecosystem model Development of data assimilation tools and interface for sea-ice model Development of data assimilation tools and interface for fishstock model
WP3	D3.1 D3.2	Development of suitable model structures for assimilation of sparse *in situ* observation methods for combined use of *in situ*, remote sensing, and other observation data Development of suitable assimilation methods for combined use of *in situ*, remote sensing, and other observation data
WP4	D4.1 D4.2 D4.3 D4.4	Validated data assimilation tools for physical ocean model Validated data assimilation tools for ecosystem model Validated data assimilation tools for sea-ice model Validated data assimilation tools for fishstock model
WP5	D5.1 D5.2	A system for parameter estimation in large scale physical ocean models

WP6	D6.1 D6.2	A system for computing uncertainties in past, present, and future assessment of fish stocks
WP7	D7.1 D7.2	A system for sensitivity analysis of parameters based upon linearisation
WP8	D8.1 D8.2	An observation system which combines all measurement devices (and data) in an optimal, or near-optimal, fashion

Table 1. List of deliverables by work package for Module 9.

Budget

The costs for Module 9 are given in NOK 1000 in the following table:

| Work Package | Yearly man months | | | | | Sum man months | Man power costs, 5 Y | Equipment costs, 5 Y | Running costs, 5 Y | Total costs, 5 5 Y |
	Y1	Y2	Y3	Y4	Y5					
WP1	12	6	6	6	6	36	2848	50	500	3398
WP2		24	24	12		60	4769	80	900	5749
WP3		12	24	24	24	84	6985	200	1200	8385
WP4			12	24		36	2984	50	500	3534
WP5		12	24	24	24	84	6985	200	1200	8385
WP6		12	24	24	24	84	6985	200	1200	8385
WP7		12	24	24		60	4863	80	900	5843
WP8		6	12	12	12	42	3493	100	600	4193
Sum	12	80	146	146	62	486	39912	960	7000	47872

Table 2. Costs by work package for the first 5 years.

Average costs per man month are set to (2004 rates): Category 1 (senior scientist): 89,000; Category 2 (scientist): 67,000; Category 3 (technicians/engineers/PhD students etc.): 63,000. Costs per man are increased yearly by 5 %. Running costs include travel expences, minor operational costs, consumables, and computing expences. The avarage costs per man month (power only) are calculated in accordance with the following weights: category 1: 25 %, category 2: 25 %, category 3: 50 %.

Total costs after 5 years is 48 million NOK, and estimated total cost for the whole 10 year period is 80 million NOK.

Work Packages

WP1: Action plan for Module 9

Description of work
A review of the state-of-art in the different workpackages of Module 9, including annual updating and, if necessary, change of focus when needed.

Time scedule
2004 - 2008 (12 months + 2 months + 2 months + 2 months + 2 months)

Deliverables
- Plans, annually updated, for the workpackages in Module 9

WP2: Development of advanced data assimilation tools

Description of work
An early effort in this module will be put on developing and implementing advanced data assimilation tools for the dynamical models considered, where different and specialised assimilation and estimation methods are chosen to suit the specific application. It is most important that the assimilation tools are made appropriate for each component of the system and that the resulting assimilation system is practical for operational purposes. Moreover, all available observation data (except for, naturally, those that will have no significance) should be utilised in the system, either for assimilation, parameter estimation or for validation of the results. Different data types are, or can be, available for these purposes; here we mention a few, e.g., remote sensing data of sea surface height (SSH), sea surface temperature (SST), sea surface salinity (SSS), sea level anomalies (SAL), ocean colour data, ice concentration, ice extent, wave spectra, acoustic and trawl survey data, line transect data, mark-recapture data, and genetic data.[1]

Time schedule
2005 - 2007 (30 months)

Deliverables
- Development of data assimilation tools and interface for physical ocean model
- Development of data assimilation tools and interface for ecosystem model
- Development of data assimilation tools and interface for sea-ice model
- Development of data assimilation tools and interface for fishstock prediction

module 9

WP3: Assimilation of very sparse in situ data in large scale models

Description of workIn situ measurements obtained from buoys (pressure, flow, salinity, etc.) can provide valuable information of the internal ocean state, especially in coastal areas where additional information is needed in addition to the remote sensing data because of difficult topography. Moreover, higher resolution is usually needed. How data like that, most often sparsely distributed in space, can be used effectively in large scale physical ocean models (as typically obtained by spatial discretisation of distributed parameter models) is probably yet an open question, and research is needed to find out how these data can be assimilated and utilised in

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[1]Data like these have been used extensively by NERSC (Nansen Environmental and Remote Sensing Center) in various projects, e.g., in the EC-funded DIADEM project where NERSC has developed a real time ocean monitoring and forecasting system based upon the EnKF. In the DIADEM project the EnKF has been employed with the ocean general circulation model MICOM and the ecological FDM model. Remote sensing data such as SLA, SST and ocean colour data have been assimilated weekly, and the model system has been forced with atmospheric data from ECMWF. Currently improvements of the DIADEM system is carried out in the EC-funded TOPAZ project where, e.g., the MICOM model has been substituted with the hybrid model HYCOM. Further description of these projects and systems can be found in the pertinent references.

conjunction with remote sensing data in order to obtain the best result. It is anticipated that ideas and knowledge developed in the DIADEM and TOPAZ projects, see the foregoing footnote, to a large extent can be utilised in the AMOEBE project.

Time schedule
2005 - 2007 (30 months)

Deliverables
- Development of suitable model structures for assimilation of sparse in situ observations
- Development of suitable assimilation methods for combined use of in situ, remote sens ing, and other observation data

WP4: Validation of assimilation tools

Description of work
The data assimilation tools first has to be tested using synthetic data, i.e., data generated by the the numerical model being considered (data from simulation experiments). In this context the reference solution from the model represents the "true" state, and the impact of assimilating data can therefore be studied thoroughly. When considering real measurement data the impact of data assimilation will be investigated using independent data resources, i.e., available data that are not assimilated. Finally, statistics for the sequence of innovations (differences between observations assimilated and the corresponding model output data) can be calculated. These statistics provide, for instance, estimates of possible biases (e.g., unmodelled or incorrectly modelled dynamics) in the models, and the impact of the data assimilation on these biases.

Time scedule
2006 - 2007 (18 months)

module 9

Deliverables
- Validated data assimilation tools for physical models
- Validated data assimilation tools for ecosystem models
- Validated data assimilation tools for sea-ice models
- Validated data assimilation tools for fish stock models

WP5: Parameter estimation in large scale models

Description of work
The use of conceptually well-known parameter estimation methods, e.g., PE methods or inversion methods, in large scale models may, at least because of the size and complexity of the models, require use of quite a few system theoretic concepts in order to simplify and facilitate the computational effort involved, e.g., choice of model structure, aggregation, partitioning of the model, information exchange between submodels, etc.For the fish stock models it is important that all relevant observations like catch data, estimates and observations of fish stock, seal and minke whale populations, etc. are assimilated and utilised in a meaningful manner for parameter

estimation and model validation, a task which subsequently must lead to better estimates of fish stock and better assessment of uncertainties.

Time scedule
2005 - 2008 (42 months)

Deliverables
* A system for parameter estimation in large scale oceanographic models.

WP6: Uncertainties in observations, models, and model predictions

Description of work
It is natural to focus much of the attention on the observed data, since these data form the basis for the models and the subsequent decisions to be made. There are several sources of data in the AMOEBE system, all with unique statistical properties. The initial phase of the project will be to identify the most important data sources for further work.Data from surveys of marine populations are characterized by imcomplete coverage in space-time. If the population is stationary during the survey period, then the temporal aspect may be neglected, and there is only spatial uncertainty in the data. Models for spatial data are described in Cressie (1993), and applications to fish stock estimation are given by Rivoirard et al. (2000). Non-Gaussian situations are still a research field, but spatial hierarchical models (Diggle et al., 1998) may be promising candidates for complex observational schemes. In some situations there may be significant dynamics during the survey period. In these case the non-synoptic nature of the collected data must be taken into account, and a joint space-time model must be specified. Statistical space-time modeling is still an emerging field, and there is presently no state-of-the-art. Some interesting approaches include Bayesian hierarchical models, see Wikle et al. (1998), and the space-time Kalman filtering approach of Wikle and Cressie (1999).Data of caught fish may often have very complex sampling properties. Detailed estimation of uncertainty in commercial catch data may be outside the main scope of AMOEBE, but the effect of such uncertainties on population parameters and model output is important. Thus, statistical models for catch data, in terms of total amount and age-length distribution of caught fish, will be important for uncertainty assessment. The uncertainty in this case comes from potential mis-reporting and incomplete observations across gears, vessel types, and in the space-time domain.For a given model, the parameter uncertainty may be assessed directly from the probability distribution of parameter estimates. This may be done analytically or through simulations. Combining uncertainty in input data with parameter uncertainty, one may estimate uncertainty in model output by simulations. Bootstrapping and Monte Carlo techniques will be useful for these purposes.Such a procedure may be repeated for alternative models in order to display uncertainty in the model choice. The alternative models will be obtained through appropriate AMOEBE modules. For uncertainty assessment it is preferable that alternative models are conceptually simple and computationally fast.Thus, the assessment of total uncertainty includes simulating the uncertainty in input data, propagating the uncertainty through a range of plausible models to generate a random sample of the quantity of interest. Such a random sample could be a scenario for the future development of an ecosystem, a collection of populations or a single stock. This will form the basis for the final

module 9

essessment of uncertainty and input to the study of management procedures in Module 7.

Time schedule
2005-2008 (42 months)

Deliverables
- A system for computing uncertainties in past, present, and future fish stock assessments

WP7: Linearisation and sensitivity analysis

Description of work
Most models used in, e.g., stock assessment can be considered a mix of a deterministic part and a stochastic part. The deterministic part will contain unknown parameters that either must be assigend a priori values, or be estimated based on data, or both (Bayesian analysis). The stochastic part is related to the statistical properties of the parameter estimates. A sensitivity analysis in this context is synonymous with an analysis of how sensitive the output (e.g., prediction of stock abundance next year) is with respect to the different para-meters. This sensitivity is dependent on the deterministic as well as the stochastic part of the model, and the sensitivity with respect to each parameter should be analysed on an appropriate parameter scale corresponding to the variance of the parameter estimator. Such analysis methods are well known and widely applied in a range of other fields, e.g., probabilistic fracture mechanics and snow avalanche hazard analysis. In practice, a sensitivity analysis is often done ad hoc by changing one parameter at a time due to the complexity and nonlinear properties of the model. This should in principle be easily overcome, however, by linearising the actual model with respect to the unknown parameters, with the parameter estimate as the linearisation point. By a transformation from the parameter estimator space to a space with iid $N(0,1)$-variables, e.g., by use of a Rosenblatt transformation, sensitivity factors could be provided in a rather straightforward fashion within the general framework applied in other fields. A great advantage of the above approach is to efficiently learn how the different parameters influence the model output on an appropriate parameter scale, possibly identifying bottlenecks where more data are needed. Even though the sensitivity of several parameters might change rather dramatically with a small change in input assumptions, some improtant parameters might appear to retain their importance.

module 9

Time schedule
2005 - 2007 (30 months)

Deliverables
- A system for sensitivity analysis of model parameters based upon linearisation.

WP8: Design of optimal observation system

Description of work
An important and difficult task will be to find out what kind of observations that are needed and where to carry out the observations. This is believed to depend strongly upon which module that

is considered and what technology that is available. To combine these tasks to an optimal, or near-optimal, observation/measurement system is the focus of this work package.

Time scedule
2005 - 2008 (42 months)

Deliverables
- An observation system which combines all relevant measurement devices (and data) in an optimal, or near-optimal, fashion.

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A Model based and data-driven Operational Ecological Biomass Estimator (AMOEBE)

Module 10: System Integration

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Contents

General comments to integration of AMOEBE modules

AMOEBE will be designed as an integrated network of essentially autonomous modules; the success of this network occurs when all sub-systems succeed and are working well together. (In this context, "autonomous" means that each module should work as independently of the other modules as possible, and aim only at input of key-data or key-functions from other modules.) The reason for the modular approach in AMOEBE 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. Some sub-systems may also be periodically inoperative.

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The system integration approach is to 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. Proper key-data and key-functions are essential to the success of AMOEBE,

thus good replacement values (like old or average values) have to be used if proper values or functions are missing.

1. Module summary

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 specfication 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 a 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 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.

2. Objectives and expected achievements

The main objectives of the System Integration Module of AMOEBE are to
1. Establish and maintain the AMOEBE system architecture that promotes and supports the integration of the modules of the AMOEBE network.
2. Design the database models for the AMOEBE network.
3. Realize the integration of the components according to the AMOEBE architecture by the means of available technology.
4. Describe mechanisms and processes that support the maintenance of the AMOEBE architecture.

Several (partly overlapping) aspects of the resulting AMOEBE network will be specified:
• A user interface style guide, i.e. a general design of the user interface of the components.

- Overall concepts like a marine reference model, roles, etc.
- The functionality provided to the users as well as the functionality provided by system components (primary data sources, data repositories, mathematical models, etc.), overall data flow included.
- The data and information used by the components of the AMOEBE network and the format these data should have.
- Interactions between the AMOEBE network components (Data exchange, sequencing and synchronizing)
- General tools (API) for integration and data exchange
- Realization of the integration by the means of available technology (representation of information, protocols, communication bearers, hardware and software platforms, etc.)

3. Innovation

This module will provide a framework to make it possible for the autonomous modules of the AMOEBE network to work together. To achieve this, this module will:
- Establish common concepts (terminology, definitions, measurement units, relations)
- Establish a marine information specification
- Definition of user interfaces
- Definition of interfaces towards system components
- Maintenance of the system architecture

Establishment of common concepts

The AMOEBE modules that are to be integrated represent activities that up till recently has developed more or less autonomously. Thus, separate terminologies and specifications have developed. However, in AMOEBE all the modules shall operate as an integrated system with common data repositories and information exchange as the basis for the processing. Thus, the need for common concepts is emphasized, and the establishment of such concepts is crucial to the success of AMOEBE. This is also stressed by the fact that a large number of actors, professions and systems shall work together over a long period of time, and the systems will be developed by different organizations at different times, and put into operation at different times.

The common concepts can be denoted by the means of
- A common terminology that names the concepts
- Definitions and specifications denoting the meaning of the concepts as well as the relationships and dependencies among the them (semantics)
- Specifications of concept values (syntax, unit of measurement, possible values, etc.)

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The overall concepts should as far as possible remain unchanged throughout technological changes. However, concepts at a more detailed level may be revised due to new knowledge about the ecological model. Thus methods supporting changes must be defined.

Several activities will contribute to the establishment of the common concepts:
- The establishment of a reference model and the definition of roles will define overall concepts
- The establishment of the functional specifications will define concepts denoting defined functionality and overall data flows.
- The establishment of a information specification (a conceptual data model or metadata

model for the marin domain) will define concepts denoting information objects common to two or more AMOEBE modules as well as the relations between these information objects. The necessity of such concepts is stressed by the fact that the AMOEBE network must supply an extensive set of common historical as well as measured data, both for operational and experimental processes. Mechanisms supporting the recording of infor mation about how the data is established (e.g. measured/processed/refined, estimated or based upon historical values), error estimates etc. should also be a part of the informa-tion specification.

Definitions of user interfaces

A standardized Graphical User Interfaces (GUI) has to be specified. Most of the man-machine interfaces (i.e. the windows) will be made under each module, but a general user interface style is desirable in order to give the GUIs of the different modules a common look, and thus make the use of different modules easier for the users. Other interfaces like program input and output (presentation of results in maps, tables, graphs, animations etc.) also have to be specified in a general manner. General tools (APIs) will be developed.

Definitions of interfaces towards system components

Interfaces between system components have to be specified in a general manner as well as a specific matter for each interface. As new knowledge about marine species and dependencies will emerge during the lifetime of AMOEBE, parts of the system architecture may change. However, the defined interfaces towards system components shall not be influenced (this may cause inconsistency). If new functionality should be supported, new interfaces have to be defined and realized.

Information exchange through access to common databases and exchange of data sets is the preferred way of communication between the AMOEBE modules, since this allows the modules to be essentially autonomous.

- The content and the format of the information exchanged shall be defined (standardized exchange formats) by means of the common concepts denoted in the information specifi-cation.
- A common set of data communication procedures (APIs) shall be provided.

Maintenance of the system architecture

Knowledge and experience gained in the project period have to be incorporated into the system architecture (addition of new concepts, new relationships, re-design, etc.). Changes that are required by one AMOEBE module should ideally not have negative consequences for others. Thus, after an initial phase on the initial establishment of the system architecture, amendments must be done according to predefined procedures in such a way that negative consequences can be avoided or handled in a sufficient way. However, the maintenance process should not be too bureaucratic or too time-consuming. The design of the different modules, and the data exchange between them, shall consider the dynamic system architecture, so that changes that might have impact on several modules, are handled and tested in each of these modules. In such cases, compatibility with old programs and data sets has to be taken into consideration.

4. Workplan

Methodology and approach
With respect to the research methodology, the activities in this module are not considered to
be within the main research fields of AMOEBE. However, the establishment of the system
architecture is crucial, and the system architecture must be tested and verified in trials. An
example of software engineering methods, description of iterative development and the system
architecture content are described in detail in Annex A. Final decisions about how to establish
the architecture have to be taken during the work. Common concepts, integration and interoper-
ability should be focused. However, issues dealing with internal logic and realization of system
component developed by the other modules are not a part of the system architecture.
The establishment of a system architecture will consist of the following specifications:
1. Reference model defining the overall focus domains as well as other overall concepts
   like roles
2. Functional specifications specifying functionality and overall workflow. The deployment of
   the functionality in work processes should also be described.
3. Information specification defining the common information types, their attributes, data
   types, allowed values, etc.
4. Communication specification specifying the required interaction types, data sets to be
   exchanged, sequencing and synchronizing requirements.
5. Component specification specifying software components and their interfaces and APIs.
6. Implementations specification specifying how the integration should be realized by means
   of the best available technologies, software and hardware platforms.

Work within different AMOEBE modules may be at different stages. Logical work on specifica-
tions denoting the common concepts (point 1, 2 and 3 above) for one area may for example go
on in parallel with technical work on realizing integration of system components within other
modules. The stage will be depending on the maturity of the respective areas. Thus, an iterative
approach shall be followed. Experiences gained within one area shall benefit future work within
other areas. Improved solutions or deployment of new technology should spread to other areas
and benefit new versions of the solutions.
The work on system integration is divided into phases, one phase for each year. Prior to each
phase detailed plans should be made denoting objectives, time schedule, activities, collaboration
and co-ordination with other AMOEBE modules, working methodology, etc. If necessary, overall
plans should be adjusted.   **module 10**
Relationships between the tasks
The diagram below shows the relationship between the WPs in the System Integration Module
and the other modules. The Other AMOEBE Modules will dependent on the maturity of their
focus areas provide input of requirements, knowledge and comments to the work in WP2, WP3,
WP4, WP5, WP6 and WP7 (Establish system architecture specifications). These WPs coordinate
their work by exchanging specifications. Preliminary specifications are issued to Other AMOEBE
Modules so that they can be commented upon. Whenever WP2, WP3, WP4, WP5, WP6 and WP7
are satisfied with their work, draft specifications are issued.
WP10 (Maintenance of the AMOEBE System Architecture) receives draft specifications. They
are checked, approved and distributed to Other AMOEBE Modules. Other AMOEBE Modules
and WP10 as well as WP8 (System Integration Realization) and WP9 (Graphical user interface

and GIS) may request updates of the specifications. WP10 or the WPs establishing the specifications (WP2, WP3, WP4, WP5, WP6 and WP7) will depending on the status of the specifications (aproved or draft), consider the necessity of the updates.

WP8 (System Integration Realization) integrates subsystems based on the specifications. The databases are designed and realized under extensive communication with the other modules WP1 (System Integration Management and Coordination) considers plans received from Other AMOEBE Modules. Detailed plans for the system architecture work are made, and the WPs are managed according to these plans.
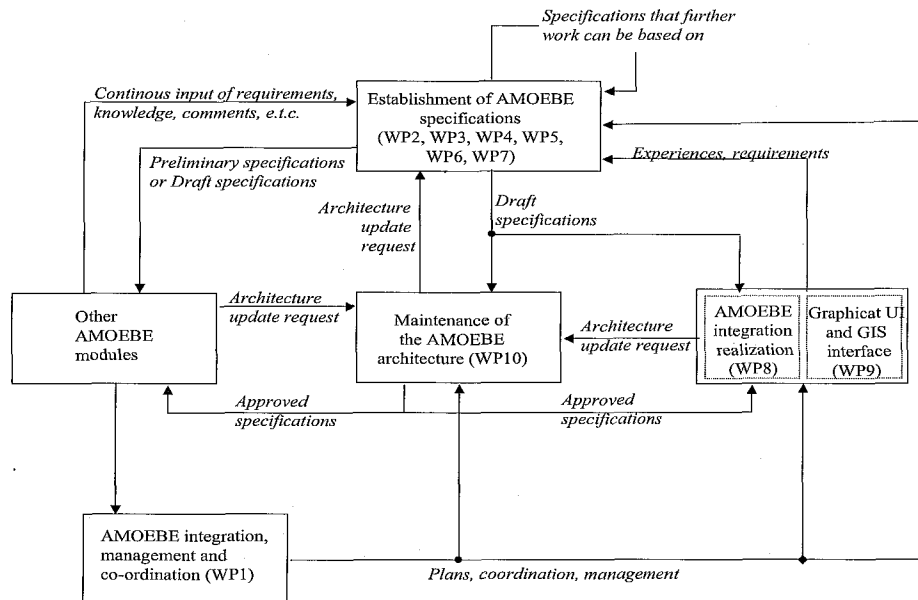

Figure 1 Relationships between the tasks.

5. Time schedule

Table 2 Time schedule for the work packages of module 10.

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Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y6	Y7	Y8	Y9	Y10
WP10.1 System Integration Management and Co-ordination	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.2 Reference Model and overall concepts	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.3 Functional specifications		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.4 Marine information specification		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.5 Data exchange					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.6 Data storage					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.7 Process interaction					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP10.8 Integration and GUI tools	to be planned when specifications are ready																								
WP10.9 Visualization of results		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
WP10.10 Realization of integration					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
WP 10.11 Maintenance of the AMOEBE architecture					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x

6. Deliverables

Many of the deliverables will be repetitive. New versions of the specifications will be issued every year. Some deliverables are dependent on the progress in other modules. Milestones for the deliverables will be set up when WP1 is initiated.

Table 10.1. List of deliverables.

Workpackage	Deliverable	Description
WP1	D.10.1.1	Detailed plan for year 1 - N
	D.10.1.11	Plan for use of software engineering methodology and tools, and working procedures with respect to how specification and realization should be done
WP2	D.10.2.1	The reference model and overall concepts
WP3	D.10.3.1	The functional specifications
WP4	D.10.4.1	The marine information specification
	D.10.4.2	Procedures for deployment of the information specification
WP5	D.10.5.1	Description of data flow.
	D.10.5.2	Description of data collection.
	D.10.5.3	A common API for data and metadata input/output.
WP6	D.10.6.1	The database and data storage model.
	D.10.6.2	Software and hardware platforms discussed and selected.
WP7	D.10.7.1	A framework for specification of process synchronization between modules.
	D.10.7.2	A tool that enables synchronizing and sequencing of processes.
	D.10.7.3	A tool that enables regular, synchronized and timely execution of the different modules within the operational systems.
WP8	D.10.8.1	Specification of format and contents in configuration files for the different modules.
	D.10.8.2	APIs for handling configuration files.
	D.10.8.3	General strategies for user interface and visualization
	D.10.8.4	APIs for common graphical environment
	D.10.8.5	A graphical integration tool.
WP9	D.10.9.1	General strategies for visualization
	D.10.9.2	Evaluate, test and adapt different visualization software to be used by scientists and developers.
	D.10.9.3	Develop reporting and visualization tools for end users.
	D.10.9.4	Integrate the visualization tools with a GIS.
WP10	D.10.10.1	Requirements and recommendations concerning hardware and software platforms.
	D.10.10.2	Test procedures to be used when integrating each module, containing a set of well defined operations concerning data input and output, GUI and result visualization, links between modules, and synchronization.
	D.10.10.3	The test procedures described above are applied to a test-module, to verify that APIs and other common solutions are conformant with the specification.
	D.10.10.4	The different modules are integrated with AMOEBE
	D.10.10.5	The AMOEBE network system give realistic results
	D.10.10.6	Evaluation plans
	D.10.10.7	Experience gained - input to the respective WPs of the System Integration Module
WP11	D.10.11.1	General procedures for maintenance of the system architecture
	D.10.11.2	Procedure for handling specific changes (new information elements in the information specification, database changes, etc.

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7. Budget

Co-ordination and collaboration with the other modules is a necessity. Thus, the management of the module requires significant resources.

The use of software engineering tools will influence on how the work will disperse across the WP's. Advanced tools will simplify the realization and arrange for a more flexible system architecture that will tolerate more changes. Simpler tools will cause more re-designs and a lot of manual implementation. The total amount of work within this module also depends on the distribution of implementation workload between the modules. More detailed budgets have to be made as a part of the work in WP1.

Table 10.2. Cost of Module 10 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist/siv.eng.): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Cost per man year is increased yearly by 5 %. Running cost includes: Travel expences, minor operation costs, consumables and ordinary computing expences. The personnel distribution is assumed to be: 30% on Cat.1, 40% on Cat.2 and 30% on Cat.3, giving an average manmonth cost in 2004 of 76.000 NOK

Work package	Yearly man months					Sum man months	Man power Cost, 5Y	Equipment 5 Year	Running cost, 5 Y	Total, 5Y
	Y1	Y2	Y3	Y4	Y5					
WP 1	18	6	6	6	6	42	3432	1000	600	5032
WP 2	3	1	1	1	1	7	572	50	100	722
WP 3	24	24	6	6	6	66	5324	200	1000	6524
WP 4	12	24	24	12	12	84	7002	300	1200	8502
WP 5	12	12	12	6	6	48	3957	200	700	4857
WP 6	6	18	18	12	12	66	5565	200	1000	6865
WP 7	6	18	18	12	12	66	5565	200	1000	6765
WP 8	12	12	12	12	12	60	5039	200	900	6139
WP 9	12	24	36	24	12	108	9064	500	1500	11064
WP 10	12	12	18	12	12	66	5542	500	1000	7042
WP 11	0	2	2	2	2	8	688	50	100	838
Sum	117	153	153	105	93	621	51750	3500	9100	64350

The budget for the first 5 years for Module 10 is 64 million NOK. We assume that the cost of Module 10 for the last half period of AMOEBE will be about half of the first period, giving the total cost for the 10 year period of Module 10 to be about 100 million NOK.

module 10 ## 8. Work packages

WP1 System integration management and coordination

Objectives
- To manage the activities within the System Integration Module
- To establish detailed work plans for the module·   Do decide upon the use of software engineering methodology and tools, and to establish working procedures with respect to how specification and realization should be done.
- To co-ordinate the planning and the work with plans for and work in the other Modules

Description of work

The system integration module has to be managed and administrated. The work is very depending on input and collaboration with the other modules. The work for one year ahead will be planned in details. The maturity of the work within the other modules will influence on the time schedule. E.g. for some areas the work may be on functional specifications for two year, for other areas implementation specifications can be made much sooner. Decitions about use of software engineering methodology and tools have to be taken, and the working procedures conserning the development of the system architecture must be specified. Advansed software engineering tools that support model based software development should be used in such a way that software components to some extent can be generated automatically, and so that the solutions as far as possible are flexible with respect to changes.

Deliverables:

D10.1.1   Detailed plan for year N (N is 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10)

D10.1.11   Plan for use of software engineering methodology and tools, and working proce dures with respect to how specification and realization should be done

WP2 Reference model and overall concepts

Objectives

- To establish the reference model
- To specify the overall concept (roles, terminology, meaning of, overall relationships, syntax, unit of measurement, etc.)The concepts should as far as possible remain unchained throughout technological changes.

Description of work

The Reference Model will be established in co-operation with the other modules. The roles (possessed by the actors) are defined in a generic way to prepare for structural and organizational changes. Other overall concepts and the relations between them must also be specified.

Deliverables

D10.2.1 The reference model and overall concepts

module 10

WP3 Functional specifications

Objectives

- To capture user requirements and other requirements that are essential to the success
- To specify the disired functionality that the AMOEBE network shall provide and support. Both user functionality and functionality supporting professional requiremets are focused.
- To identify the overall data flows.

Description of work

Aspects such as functionality and working procedures will be specified in co-operation with marin actors and the other AMOEBE modules by means of use cases with scenarios describing

how users will interact with the systems. Also functionality supporting professional requiremets as well as system requirements are focused. Functionality, interactions, achievements, fault situations, etc. is denoted. A description of the working procedures will provide a common understanding of how input is generated, how and by whom the functionality will be used, etc. It is also important to describe how achieved results in turn leads to new knowledge that are used to design improved survey strategies and to recommend improvements to instrument manufacturers, ship designers, and designers of other observing platforms. Administrative working procedures for management of the systems and information exchange must also be specified.The overall data flows between functional components will be identified to prepare for further specifications in the component and communication specifications (WP 5 and 6).

Deliverables
>D10.2.1 Functional specification

WP4 Marine information specification

Objectives
- To design a conceptual information model that encompasses all information used by two or more AMOEBE modules.
- To establish general routines and mechanisms that support deployment of the specification when physical databases are designed and established (how to handle heritage, how to keep historical data, how to add error estimates, etc.)

Description of work
Information objects and relations between objects that are common to two or more AMOEBE module are specified. The work will be done in co-operation with the other AMOEBE modules. The process will be iterative as the AMOEBE modules may give input at different times. The objects will be specified by the means of UML class diagrams and may in addition to definitions of information elements (attributes) also contain operations. However, these will be specified in WP 5. The specification is a conceptual model. General procedure supporting such deployment of the information specification will be specified, e.g. deployment in design of physical databases and sàecification of standardised data sets by means of elements form the information specifica-tion. The software engineering tools used for the specifications shall also provide support for database design that is based on the information specification as well as support for the establish-ment of databases (WP8), or it must be able to use the specification as input to such design.

module 10

Deliverables
>D10.4.1 The marin information specification
>D10.4.2 Procedures for deployment of the information specification

WP5 Data exchange and distribution architecture

Objectives
- To identify the different types of information exchange within the AMOEBE network,

i.e. communication between modules, programs and command lines (land -> observing-platform -> land).
- To specify requirements and functionality supporting data collection, administration, data formats, metadata and data processing.
- To specify a framework and develop tools for data and metadata exchange between modules.
- To design, implement and verify a data platform suitable for the data exchange needs for the overall AMOEBE system.

Description of work:
The AMOEBE system components shall interact and exchange information. Requirements with respect to presentation of information will be specified as well as requirements and functionality supporting data collection, administration, and data processing.These interactions should be realized as equally as possible. A limited set of required interaction types must be identified, and the overall aspect about the realization of the interactions (e.g. exchange sequences) must be specified. The information blocks that are exchanged also have to be specified both with respect to content and format by mans of elements from the information specification (established in WP4). The specifications should be at a logical level and independent of the communication technology and the protocols used. These may vary during the lifetime of the project, and it should also be possible to use the same logical specifications even though the technology changes. It should also be possible to use the same specifications for different communication strategiesCommon procedures for communication with the database and other kinds of data sets, for the interpretation of data formats and metadata will be developed. The interface to these procedures shall be transparent to the selected communication strategy.Fig. C1 shows the current data flow at IMR. Fig. C2 show the data flow thought to be close to the ideal for IMR. Elements from Fig. C2 are recognized in Fig. C1.

Deliverables
D.10.5.1   Description of data flow.
D.10.5.2   Description of data collection.
D.10.5.3   A common API for data and metadata input/output.

WP6 Distributed data storage

module 10

Objectivs
- To design a database and data storage model to be used by the AMOEBE network
- Select the best available hardware and software platforms for database solutions·
  To specify a data distribution strategy suitable for the AMOEBA needs
- To specify an efficient management and maintenance strategy for data and information in the distributed storage system.

Description of work:
The design of the data model is based on current data with a relatively known structure.The requirements that are based on the marine information specification (WP4) must be added in the model.The data model shall also include metadata; describing information about the

stored/retrieved data Any software engineering tools used in the model specification should provide support (or input to tools) for database design and establishment.Establishing a distributed data storage and management system where data can be distributed and retrieved from various (even heterogeneous) networked databases forces an open and modular design of the system - which will able the system to scale with increasing AMOEBE needs.

Deliverables

D.10.6.1   The database and data storage model.

D.10.6.2   Software and hardware platforms discussed and selected.

WP7 Process interaction

Objectives

- To enable a reliable and timely execution of the different processes within AMOEBE

Description of work:

Both operational and experimental systems rely on a sequential (and possibly iterative) execution of programs in different AMOEBE modules. The synchronization needs between the programs must be specified, and tools that fulfil these needs must be found.

Deliverables

D.10.7.1   A framework for specification of process synchronization between modules.

D.10.7.2   A tool that enables synchronizing and sequencing of processes.

D.10.7.3   A tool that enables regular, synchronized and timely execution of the different modules within the operational systems.

WP8 Integration and GUI tools

Objectives

- To define a standardized way to specify program configuration, i.e. setting up parameters for data sets, time intervals, geographical restrictions etc.
- To establish common strategies with respect to user interfaces and define a graphical environment common to all modules.
- To develop a graphical tool for defining a composite calculation model, with defined requirements with respect to starting point (input data/configuration) and result (output)
- The tool shall be applied in Module 11 to generate "Operational products"

module 10

Description of work:

The requirements for each module with respect to configuration shall be examined, and standardized formats and procedures shall, as far as possible, be described.Specify the needs and define a common graphical interface. Develop APIs that shall be used to enable a unified appearance and user dialogue that can be used by other modules.Develop a graphical integration tool.

Deliverables

D.10.8.1   Specification of format and contents in configuration files for the different mod

ules.

D.10.8.2 APIs for handling configuration files.

D.10.8.3 General strategies for user interface and visualization

D.10.8.4 APIs for common graphical environment

D.10.8.5 A graphical integration tool.

WP9 Visualization of results

Objectives

- To establish common strategies with respect to visualization
- To provide tools for result visualization for two different user groups: Scientists/developers on one side, and management/other end users on the other.

Description of work:

Scientists/developers will need various visualization tools in order to present the results according to their actual needs. As far as possible, standardized software, based on standard formats, should be usedFor management and other end users, there might be a need to develop more specialized reports and graphical representation of the results.Interface with a Geographical Information System (GIS) shall be developed

Deliverables

D.10.9.1 General strategies for visualization

D.10.9.2 Evaluate, test and adapt different visualization software to be used by scientists and developers.

D.10.9.3 Develop reporting and visualization tools for end users.

D.10.9.4 Integrate the visualization tools with a GIS.

WP10 Realization of the integration

Objectives

- Select best technology and practice with respect to hardware and software platforms, communication solutions, etc.
- Realize the integration of the AMOEBE modules in cooperation with the other modules.
- To test the upcoming versions of the AMOEBE network system.
- To evaluate the upcoming versions of the AMOEBE network system
- To provide feedback to the respective WPs of the System Integration Module
- Make a first functional version of the AMOEBE network system.

module 10

Description of work:

The choice of hardware and software platforms for the different modules must support a balanced growth in capacity, so that no modules will be stuck with old technology, and thus represent a bottleneck in the processing chain.The integration will be realized in cooperation with the other AMOEBE modules. The integration of the different modules can be done separately, given that sufficient test data and environment exist. The System Integration Module must provide ways to

establish test-data and environment. Mutual influence will ensure the quality. In addition, quality assurance of software engineering and software realization accomplished by the other modules will be performed.Test and evaluation plans for the integration will be made, and integrations will be tested and evaluated according to these plans.Feedback concerning the system architecture specifications, especially the implementation specifications, will be given to the respective WPs of the System Integration Module. Thus, experience gained on realization in one part of the system can benefit other parts of the system (adjustments can be done and approved solutions can be re-used). The first and forthcoming tests will be used as feedback to all modules. The modules of the AMOEBE network, and the integrated network will have to be adjusted during the process.There are at the moment no requirements with respect to hardware or software platforms. In an ideally distributed system, the modules could be considered as components in a network, where there are no considerations neither to hardware nor software platforms, given that the architectural technology is supported. AMOEBE might require a closer connection between the modules, implying that the platforms cannot be selected freely. This issue is of great importance for the implementation of the different modules, and for the total integration. An expected growth in processing capacity will enable us to handle more complex models during the lifetime of AMOEBE.

Deliverables

D.10.10.1   Requirements and recommendations concerning hardware and software platforms.

D.10.10.2   Test procedures to be used when integrating each module, containing a set of well defined operations concerning data input and output, GUI and result visuali zation, links between modules, and synchronization.

D.10.10.3   The test procedures described above are applied to a test-module, to verify that APIs and other common solutions are conformant with the specification.

D.10.10.4   The different modules are integrated with AMOEBE

D.10.10.5   The AMOEBE network system give realistic results

D.10.10.6   Evaluation plans

D.10.10.7   Experience gained - input to the respective WPs of the System Integration Module

WP11 Maintenance of the AMOEBE architecture

Objectives

module 10

- To design realistic procedures to maintain the AMOEBE architecture.
- To describe procedures to analyse consequences to any module caused by changes in one AMOEBE module.

Description of work:

This work package deals with the "ever lasting" maintenance of the established parts of the system architecture. Processes for management and processing of request for architecture updates and amendments will be defined.The maintenance process activity cannot start until an initial AMOEBE architecture is defined and deployed. The work will be done according to the defined processes in collaboration with the work packages dealing with the respective specifications.

Deliverables

D.10.11.1   General procedures for maintenance of the system architecture

D.10.11.2   Procedure for handling specific changes (new information elements in the infor mation specification, database changes, etc.

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module 10

Annex A. Methodology and approach

A1. Software engineering methodologies

The software engineering is done by the means of:
- Architecture definition frameworks giving directions on how to establish the architecture (specification process, what should be specified, etc.). A number of such frameworks are available. A customization of the following, partly overlapping, frameworks can be used:
  - ISO RM-ODP (ISO/IEC DIS 10746 Reference Model for Open Distributed Processing) - comprehensive and generic framework for software development
  - Magma - a handbook for developers of off-the-self software handling that both the underpinning technology and the user demands are in constant movement

- Techniques and notations for specification of systems. There are several approved software engineering methods and techniques. The main approaches are:
  - The object oriented approach for IKT system modeling[1]. The whole problem domain is specified as a set of collaborating objects.
  - The structured analysis based methods. The software is seen as a hierarchy of functions operating on common data.

The work will mainly follow the object-oriented approach. UML (Unified Modeling Language[2]) will be used. However, to support the establishment of common concepts, elements from structured analyses based methods may also be used to give a more top-down picture of the main functionality.

A2. Iterative development

Work within different AMOEBE modules may be at different stages. Logical work on specifications denoting the common concepts for one area may for example go on in parallel with technical work on realizing integration of system components within other modules. The stage will be depending on the maturity of the respective areas. The work on system integration is divided into phases, one phase for each year. Prior to each phase detailed plans should be made denoting objectives, time schedule, activities, collaboration and co-ordination with other AMOEBE modules, working methodology, etc. If necessary, overall plans should be adjusted.

module 10

A3. A framework used for design and maintenance of dynamic systems

Figure A1 shows the first approach to what should be specified by the System Integration Module. Knowledge gained during the execution of the projects may detect new requirements. Thus, the approach should be re-considered whenever detailed plans are established prior to each programme phase.

The overall conceptual aspects will depict the AMOEBE system in an overall and generic way. The relations between the main concepts, including actors and their roles as well as the main control domains are described. The result will be a *reference model emphasizing*:

Simplicity: The reference model shall contribute to the establishment of a common and simple conceptual specification of the whole AMOEBE domain in the minds of involved actors of all types (end users, the general public, biologists, technicians, etc.). It should be possible to relate

activities, functionality, roles and solutions to the reference model in such a way that it makes sense for most actors.

Stability: The reference model shall last through changes in user needs, user requirements, marine knowledge and technology changes.

Flexibility: The reference model shall not put constraints to the realization of the AMOEBE system components
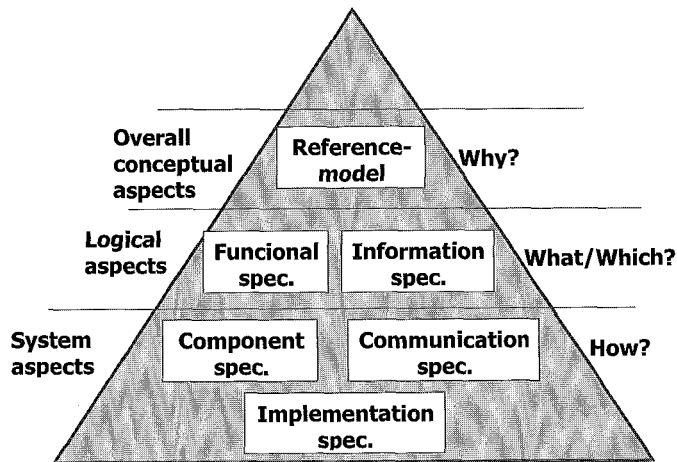

Figure A1 System architecture aspects and specifications

The *logical aspects* will also contribute to the establishment of concepts, but at a much more detailed level than for the level above. The AMOEBE domain will be depicted in a way that defines and describes functionality, information exchange, working procedures, etc. Focus is on "what functionality is to be supported, which working procedures are involved, what information is necessary, what information is exchanged, etc.

Functional specifications specify the purpose, scope and policies of the system. This is functionality or services provided to the actors, working processes or activities that are involved, and overall information flows. This can be specified by the means of the Use Case methodology and UML activity diagrams. (Enterprise viewpoint in ISO RM-ODP, Business Model in Magma).

Information specifications specify the information objects and information processing. Such specifications will contribute to the establishment of common concepts with respect to information (terminology, syntax, semantic). UML class diagrams can be used. (Information viewpoint in ISO RM-ODP, Business Object Model in Magma). In the AMOEBE system integration module   **module 10** the main focus will be on the information. The identification and specification of the information processing (operations) will, however, to a large extent be done within the other AMOEBE modules. However, co-ordination must ensure exchange of interests and plans, to promote re-use of operations across the modules.

The *system aspects* describe how the system denoted by the logical aspects should be realized. To some extent this can be described in a technology independent way, and this should be emphasized. However, the final realization by the means of the prevailing technology also has to be specified.

---

[1]The terms modelling and model are referring to **IKT** system modelling and models that specify the **IKT** solutions and systems. These are *not* mathematical models (differential equation etc.), but graphical representations of system functionality and components and relations between functions and components.

[2]A graphical notation

Component specifications specify how the information objects should be grouped into software components. (Computational viewpoint in ISO RM-ODP, Component Model in Magma) Interfaces towards the system components should also be specified. Once an interface has been defined, it cannot be changed or deleted (new interfaces may be added to cope with new requirements). It is however, possible to change the implementation behind the interface. Use cases can be used to describe the services provided by the interface, and UML class diagrams can be used to specify the information and operations. (Component Interface Model in Magma).

Communication specifications specify interactions and information exchanged between system components and interfaces. The content of the information messages or packages that are exchanged must be composed and described by the means of attributes from the information specifications. In addition to textual descriptions, UML sequence diagrams can be used to specify the interactions. (System viewpoint in ISO RM-ODP)

Implementation specifications specify how the system components are to be realized and set into operation. That is the use of hardware and software platforms, requirements with respect to capacity, etc. The realization of the communication is also to be specified. This includes the technology used to represent the information that is transferred, communication protocols, etc. In addition to textual descriptions, exchange information specifications (e.g. XML schemas), physical database schemas (in case common databases should be used), UML collaboration diagrams and UML deployment diagrams can be used to specify the implementation. (Technology and Engineering viewpoint in ISO RM-ODP, System Distribution Model and Implementation Model in Magma).

module 10

Annex B. First approach to the AMOEBE reference model

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 desirable. Figure B1 shows a first approach to the AMOEBE reference model. Such a model should not change during the AMOEBE project except for the non-connected arrows (marked with an x). Measurements, mathematical models and management strategies are connected to the measured data via a network (mainly a data communication or telecom networks, but parts of it, e.g. the management strategies, could be human communication networks). Note that the management strategies are on single stocks, not on the ecosystem (i.e. the network) in total. There may be a desire to manage the total ecosystem in the future. Note also that political instructions from the national government have a strong influence on the management strategies, but there is also information from the scientists that should have a strong influence on the politics. In addition, international politics, that is lack of international agreements, indirectly may have an influence on the management strategies as a consequence of local regulations on common stocks.
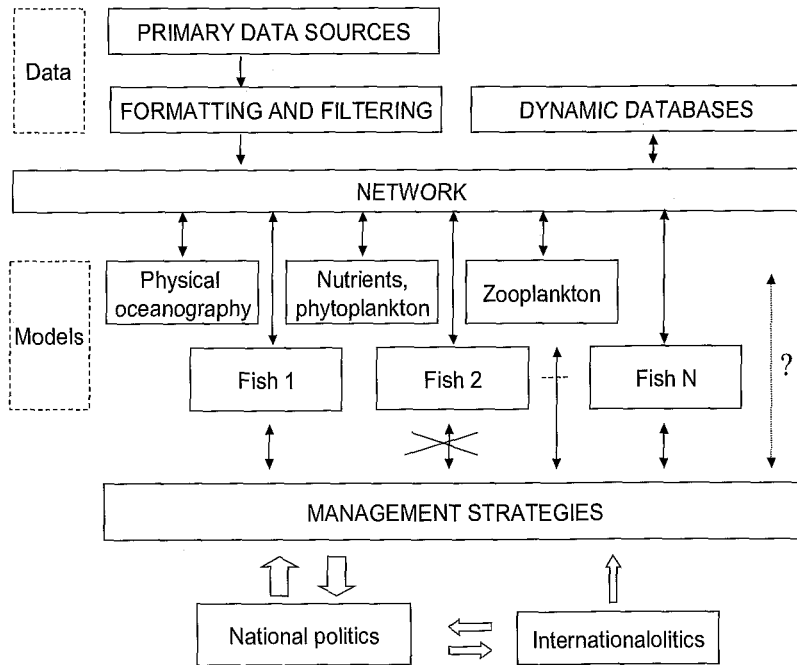
Figure B1 First approach to the AMOEBE reference model

module 10

Annex C. Estimation of fish abundance through the Bergen method and a current description of idealized data flow at the Institute of Marine Research
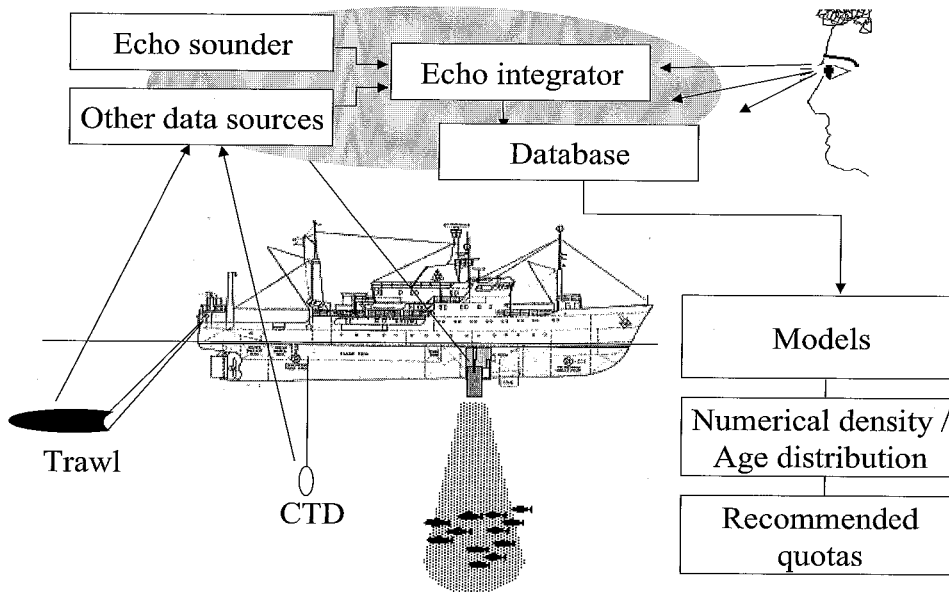

Figure C1. An example: acoustic data flow though the systems for abundance estimation of fish (The Bergen method).

Figure C2 shows idealized data flow between land and the observing platform as the Institute of Marine Research (IMR) are reaching for in 2001. Elements from *Figure B1* are recognized, but data processing and more detailed functionality are emphasized. The figure is meant to be general, but more specific than *Figure B1*, and it is likely to be adjusted during the project. Even though *Figure C2* does not show the interconnections between the different modules, it emphasizes the need for administration functionality supporting information exchange administration. *Figure C1* shows the data flow through a network where fish abundance is estimated from acoustic and biological data.
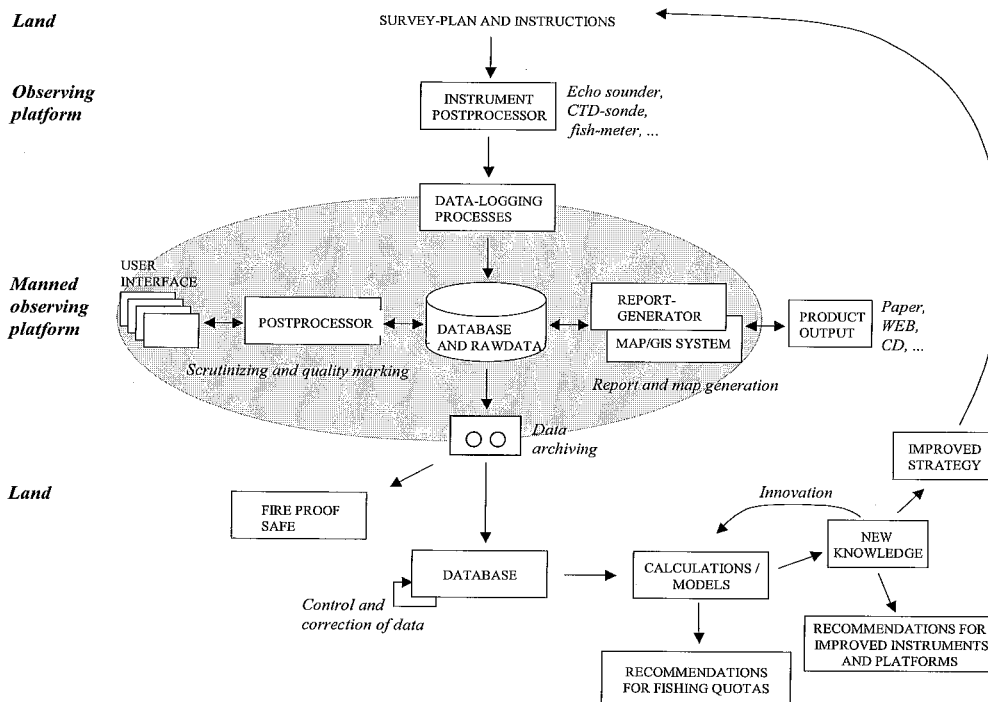
module 10

A Model based and data-driven Operational Ecological Biomass Estimator (AMOEBE)

Module 11   Operational implementation

Version 20.Sept.02
Einar Svendsen (chairman), Bruce Hackett, Kjell Røang, Bjørn Ådlandsvik, Roald Sætre, Vinjar Wærenskjold

Content

module II

Module summary

This 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.

Objectives and expected achievements

The main objectives of this module are 1) to turn all existing and new knowledge related to the northern ecosystem dynamics into operational products, 2) to secure reliable operational access to quality assured data and products, and 3) to ensure through maximum interdisciplinary use, that the products are refined into higher level products useful for improving environmental and fisheries management advice.

The expected achievements:
- 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 services in the development and operation of the AMOEBE system (Telenor, ABB, CMR, Oceanor, Kongsberg Maritime, Simrad, Scanmar, Aanderaa Instruments, Predictor as, Triad, etc.)
- The knowledge and operationality of AMOEBE offers a global market for Norwegian services.
- Information of significant interest to a number of offices within the Norwegian state administration

It is expected that the scientific community also outside the AMOEBE project will do basic research on the new operational products, thereby helping to improve our forecasting capabilities with respect to climate and fisheries. In addition, feedback from non-scientific users (fisheries managers, general public, commercial enterprises) will be invaluable for advancing the capabilities of the system

module II

Innovation

Several international organisations (GOOS, EuroGOOS, BOOS, NOOS, ICES) are working towards developing operational information systems for the oceans. For some aspects such as

traditional fisheries assessment, ocean circulation modelling and real time global marine climate observation within the ARGO program, such operationality are in place (together with the observations and information coming through the operational meteorological organizations). However, operational availability of the integrated dynamics of most part of the marine ecosystem has never earlier been developed and is therefore highly innovative. The further operational coupling of information on marine climate and different levels of the food chain into useful fisheries multi-species management issues (also called "an ecological approach to fisheries management", being internationally accepted as a major goal), has to our knowledge never been developed, at least not in a total modelling concept as planned for in AMOEBE (see other module descriptions).

Work plan

Operationality
It is planned from the beginning of the project to make existing information/results/products operationally available for the user community, and to implement new products as they are developed in the different modules. "Operational availability" is here taken to mean that required information products are accessible to users routinely, reliably, in suitable forms and within required time limits. Timeliness is a critical issue, and the system must accommodate a range of uses, which depend on the time scale of the process and user requirements. For example, an estimate of last month's algae production and herring migration, a forecast of larval drift the next five days, the cod stock size in 3 years and a decadal trend for mean water temperature are user products that place very different demands on the timely access to data, production time and delivery time.

The main needs from marine ecosystem management are basically realistic predictions of the natural development coupled with "what-if" scenario predictions of impacts from possible management actions. Such predictions are based on some type of model, either on bottom-up "first principles" models of the ecosystem, simplified population dynamics models, top-down empirical/statistical models, or a combination of these models, together with available observations. The different prediction modelling approaches need and can produce different kinds of operational products, but a common and important task is production of the best updated state of the ecosystem at present, often called a nowcast, for use in routine monitoring. This means running the models up to the present with assimilation of all available and useful data. Again, related to the definition of "present" (today, this month, this year), the frequency of information and product formats will depend on the different users.

For fisheries management purposes, it is initially planned to perform regular monthly nowcasts (where possible) with special attention to the requirements of the different ICES working groups. This type of nowcast requires access to observations and model simulations over the past months (a hindcast); delivery of management information may be required within a few days.

For special short term events, such as support to field investigations, pollution incidents, harmful algal blooms, etc., a daily "weather-forecasting" mode is necessary. In this case, the focus is on producing forecast for the next days to weeks (known as "short- to medium-range forecasting"), using numerical models that assimilate available observations up to the present and are driven by forecast atmospheric data into the near future. Forecasting on this time scale requires near-real

module 11

time access to observations and regular (at least daily) runs of the forecast models. During special events, user information is required within hours. In addition, daily monitoring of forecasts can give an indication of impending significant changes in the state of the ecosystem.

Nowcasting and forecasting skill may be improved by learning from the past. Thus, an important aspect of operationality is the capability to perform hindcast simulations for longer (say 50 years) or shorter periods of the past "on demand". This requires access to considerable computing resources, and not least, ready access to archived observations for assimilation and validation.

Operational products

The definition of new products is part of the project. However, the following products based on 3D numerical models with high time resolution constitute an initial short-list of products that may be implemented early in the project:

Daily (or weekly, monthly) distributions (maps/ animations) at many depths of:
- Ocean circulation, turbulence, temperature and salinity
- Diatom and flagellate concentration and production and light intensity
- Zooplankton stage/age, concentration and production

When developed somewhat later in the project, we suggest producing similar distributions (in space and time) for the individual target fish species:
- total number/biomass at age and size
- growth at age and size
- natural mortality
- fisheries mortality (if fishing data can be made available in near real time from the fishing fleet)

These variables will be averaged in time and space to be compared with or as input to other more statistical or population dynamics or management models already existing or developed/improved within AMOEBE. The relatively new initiatives of quantifying the impact of climate change/variability on the processes of the higher trophic levels of total populations will be made operational.

There are many poorly known parameters in the equations to be used for estimating many of the above state variables, and for some even the equations are not well formulated. Therefore, estimation of several of these state variables will strongly depend on measurements (from research vessels, ships of opportunity, drifting or anchored buoys, AUVs, satellites, aircraft). It is therefore essential that the data flow and quality assurance from the measurement platform to the modeller is made as efficient as possible. For numerical models in forecast mode, there is a need for near-real time access to assimilatable observations. This, in turn, places heavy demands on the performance of the database and data transfer elements of AMOEBE, and may require revision of data handling systems by individual data providers (see Module 10).

module 11

There are also uncertainties (often large) in the observations to be assimilated in the models, and therefore it is essential that AMOEBE operationality includes routine evaluation of the data

usefulness and quality.

There might seem to be an overlap between Module 10 and 11, however while the technical development and related realization of the prototype system is developed in Module 10, Module 11 utilizes the results from Module 10 to implement all aspects of an operational system and specify further development if necessary

WP1: Specifications and planning

Specification of operational products, necessary and available input data and operational require-ments for timely production and dissemination. An initial specification will be written early in the project, based on the most readily available products at present. This is part of a detailed action plan with annual revision according to product development progresses in Modules 2-9 and new user requirements. This WP also includes the module coordination, meeting arrangements and the cost of travels.

WP2: Physics and phytoplankton

Operationalize physics and primary production simulations from 3D numerical models.
- daily forecasting mode
- nowcasting monthly means and status
- produce 50 year time series
- ensure that all relevant data are operationally and readily available for the modellers
- ensure that longer term climate prediction (seasons to decades) are made relevant to predict ocean production.

WP3: Zooplankton

Operationalize numerical zooplankton simulations.
- daily forecasting mode
- nowcasting monthly status
- produce time series for several years
- ensure that all relevant data are operationally and readily available for the modellers
- Set up routines for contaminant exposure simulations

WP4: Recruitment (fish eggs and larvae)

Operationalize drift/growth/mortality simulations of fish eggs and larvae.
- daily forecasting mode
- nowcasting monthly status
- produce time series for several years
- ensure that all relevant data are operationally and readily available for the modellers
- set up routines for contaminant exposure simulations

module 11

WP5: Fish migration/distribution/growth/mortality

Operationalize numerical fish migration/distribution/growth/mortality simulations
- daily forecasting mode
- nowcasting monthly status
- produce time series for several years
- ensure that all relevant data are operationally and readily available for the modellers

WP6: Stock estimation

Module 6, Stock estimation, is considered by itself an operational module for hindcasting and nowcasting the individual stock sizes with age, length and weight distributions. In Module 11 we will ensure that all relevant ecosystem information from models and observations related to Modules 2-5 is timely available in a format useful for the population dynamic models. In addition this information will have to be operationally communicated with the user community (ICES working groups, fisheries managers etc.)

WP7: Prediction/management strategies

Module 7, Prediction/management strategies, is considered by itself an operational module for predictions of stocks. As for WP6, we will here ensure that all relevant ecosystem information from models and observations related to Modules 2-6 is timely available in a format useful for the predictive population dynamic models, or simpler statistical models. In addition this information will have to be operationally communicated with the user community (ICES working groups, fisheries managers etc.).

WP8: Operational monitoring system

Ongoing and new measurement routines and strategies will be adapted to the AMOEBE infra-structure and prepared for routine operation in Module 8, 9 and 10. From there on Module 11 will develop procedures for keeping the regularity in the flow of data from the diverse national and international observing platforms (ships, satellites, buoys, aircraft) to the operational AMOEBE databases, including initial data quality assurance. This also includes results from individual AMOEBE models and possibly other relevant operational models.

WP9: Database/Network/Communication

The operational databases (including modelling products), network and communication have to be maintained and operated according to the general needs and the requirements and specifica-tions from the other modules. The technical development is done in Module 10, but the daily operation, quality assurance and value added services to the whole AMOEBE and other user community has to be professionally operated through a web based system. A set of standard graphical plots/maps and tables will be defined and distributed on a web based GIS system.

module 11

This work package will ensure a close contact with the user community, and a user group will be set up including representatives from the main ministries (fisheries, environment, education, industry), national fisheries organisation(s) and NGO's. The international communication will at first be through the ICES system and related EU projects.

Progress plan

The Gantt diagram below shows the anticipated timing relationship between the work packages defined in Module 11, with quarterly resolution of the first 5 years. WP1 and WP9 occupies the first half year with planning/product specification and the start on visualisation/communication of (semi)available products. Then successively the work on operationalizing results from WP2, 3, 4 and 5 will start and continue through the project. Each WP has a list of deliverables (Table 11.2), but it is premature to specify the timing (milestones) of these. This will be done at the start of WP1 and AMOEBE as a whole.

Table 11.1 Progress plan (Gantt diagram).

Workpackage	Year 1				Year 2				Year 3				Year 4				Year 5				Y 6	Y 7	Y 8	Y 9	Y 10
WP1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP2			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP3						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP4						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP5									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP6					x			x				x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP7					x			x			x		x	x	x	x	x	x	x	x	x	x	x	x	x
WP8			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WP9	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Work package network

All the WP's depend on the input from WP1 with respect to defining the operational products and securing the operational information flow between the WP's, especially from 2 to 3 to 4 to 5, 6 and 7, but also from 6 to 5 and from 5 and 6 to 3 and 4. All the major operational results or value added products will be communicated through WP9, although "stand alone" products from individual WP's can be communicated directly to users, especially from WP6 and 7.

Figure 11.1. Work package network of Module 11
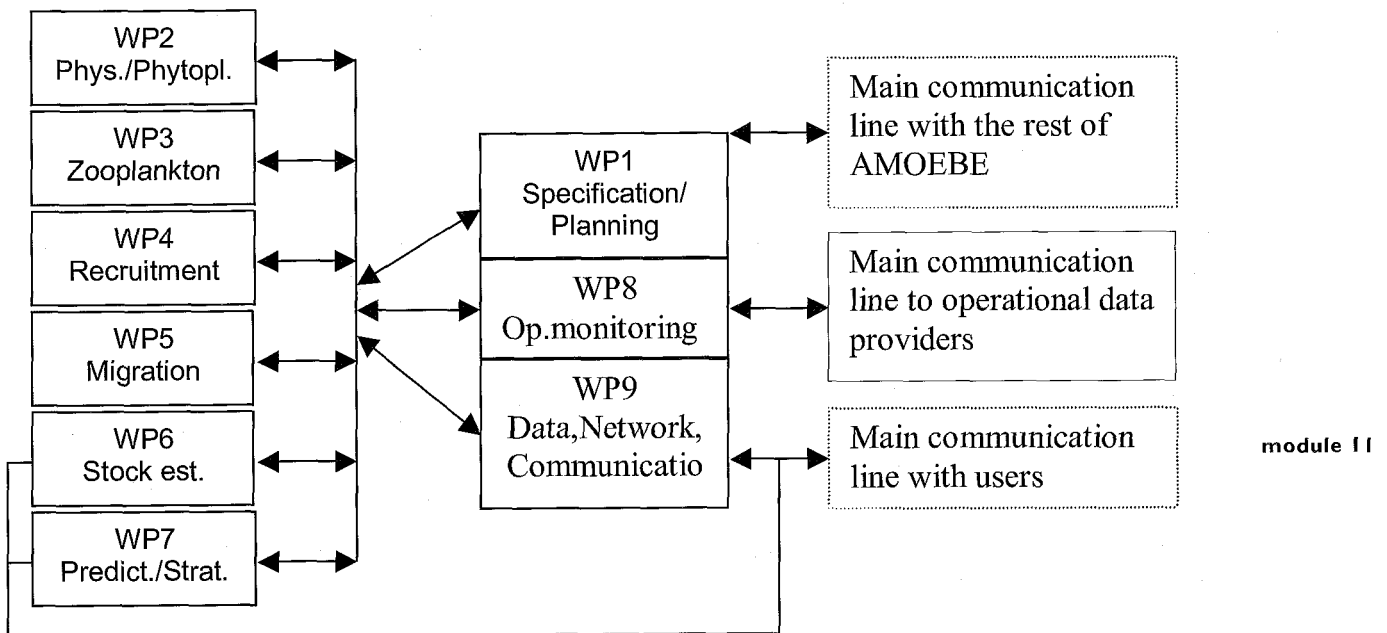
module 11

Deliverables

Table 11.2: List of deliverables by work package for Module 11

Workpackage	Deliverable	Description
WP1	D11.1.1 D11.1.2 D11.1.3 D11.1.4	Specification of operational products Specification of input data Specification of timing and dissimination Annually revised action plan
WP2	D11.2.1 D11.2.2 D11.2.3	Daily forecast of physics and prim.prod Monthly mean nowcast of physics and prim.prod Annual updates of 50 year time series of physics and prim.prod
WP3	D11.3.1 D11.3.2 D11.3.3	Daily forecast of zooplankton distribution Monthly mean nowcast of zooplankton distribution Annual updates of 20 year time series of zooplankton distribution
WP4	D11.4.1 D11.4.2 D11.4.3	Daily forecast of fish eggs and larvae distributions Monthly mean nowcast of fish eggs and larvae distributions Annual updates of 20 year time series of fish eggs and larvae distributions
WP5	D11.5.1 D11.5.2 D11.5.3	Daily forecast of fish stock distribution Monthly mean nowcast of fish stock distribution Annual updates of 20 year time series of fish stock distribution
WP6	D11.6.1	Deliverables from WP1-5 in suitable form and time for Module 6 and other users (eg. ICES)
WP7	D.11.7.1	Deliverables from WP1-5 in suitable form and time for Module 7 and other users (eg. ICES)
WP8	D.11.8.1	Procedure and necessary actions for regularity of dataflow from originator to database
WP9	D.11.9.1	Procedure and necessary actions for regularity in value added end products and communication with users

Budget

A large amount of the work within this module is the communication with the other modules and the user community. Special attention is required to make present "non-operational" data operational and easily available to the modellers. The costs are in 1000 NOK, and the man-power costs are split in three categories; Senior scientists, Scientists and others (PhD students, technicians, engineers, adm). Most of the equipment is related to super-computing (for all modules gathered in this module), GIS related systems and (technical) arrangements for operationalizing data . High running costs are associated with extensive travelling due to the strong focus on communication with users.

Table 11.3. Cost of Module 11 by work packages the first 5 years. Costs in NOK 1000. Average costs per man month is set to (2004 rates): Category 1 (senior scientist): 89. Category 2 (scientist/siv.eng.): 76. Category 3 (Technicians/engineers/PhD students, others): 63; Cost per man year is increased yearly by 5 %. Running cost includes: Travel expences, minor operation costs, consumables and ordinary computing expences. The personnel distribution is assumed to be: 30% on Cat.1, 40% on Cat.2 and 30% on Cat.3, giving an average manmonth cost in 2004 of 76.000 NOK

	Yearly man months					Sum man	Man power	Equipment	Running	Total, 5Y
Work package	Y1	Y2	Y3	Y4	Y5	months	Cost, 5Y	5 Year	cost, 5 Y	
WP 1	12	6	6	6	6	36	2976	200	500	3676
WP 2	06	12	12	12	12	54	4583	5000	800	10383
WP 3		12	12	12	12	48	4127	4000	700	8827
WP 4		09	12	12	12	45	3888	3000	700	7588
WP 5			24	24	24	72	6340	5000	1100	12440
WP 6		06	06	09	09	30	2605	1000	500	4105
WP 7		06	06	12	12	36	3146	1000	500	4646
WP 8		06	12	24	24	66	5813	1000	1000	7813
WP 9	12	12	12	12	12	60	5039	7000	900	12939
Sum	30	75	108	129	129	447	38517	27200	6700	**72417**

The budget for the first 5 years for Module 5 is about 72 million NOK. The operational tasks will increase through the last 5 years of the project as new products are developed. However, we assume this will be compensated by an increasing skill of the operational operators of the system. Assuming the manpower continues as in year 4 and 5, the total cost for the 10 year period of Module 11 will be about 160 mill. NOK.

Work packages

WP1: Specification

Description of work
Specification of operational products, necessary and available input data and operational requirements for timely production and dissemination. An initial specification will be written early in the project, based on the most readily available products at present. This is part of a detailed action plan with annual revision according to product development progresses in Modules 2-9 and new user requirements. Coordination of Module 11 (in close cooperation with other modules. Meeting and travel arrangements.

Time schedule
First year + annual updates

module 11

Deliverables
- Specification of operational products
- Specification of input data
- Specification of timing and dissimination

• Annually revised action plan

WP2: Physics and phytoplankton

Description of work
The daily forecasting of the circulation, hydrography and algae will be based on present operational skills and infrastructure for every day functioning. The challenge is to assimilate "daily" operational data into such a system.Nowcasting monthly means and status will be based on longer term (several months-year) hindcast to nowcast simulations including data which has not been readily available for the daily operations.Production of 50 year time series is a major job both on the modelling and data assimilation side. The best validated circulation model will be used. A key issue is to store and make available information most relevant for biological production and in particular fish distribution and recruitment.To ensure that all relevant data (from ships, satellites, buoys) are operationally and readily available for the modellers is a challenge, including the preparation of huge amount of historic data. To get hold of some of these data involves direct expenses in addition to manpower.In addition we have make sure that longer term climate predictions (seasons-decades) are "down-scaled" to be relevant for predicting the ocean production similar to the issue above on 50 year hindcast. This requires finer scale models to be forced with results from a coupled atmosphere-sea ice- ocean model (e.g. the Bergen Climate Model)

Time schedule
The whole project minus the first 6 months

Deliverables
• Daily forecast of physics and prim.prod.
• Monthly mean nowcast of physics and prim.prod.
• Annual updates of 50 year time series of physics and prim.prod.
• Long term down-scaled ocean climate predictions.

WP3: Zooplankton

Description of work
This WP is based on WP2.The daily forecasting mode will be based on present operational skills and infrastructure for every day functioning. There will be no, or very few, daily operational data available for such a system, but it will be based on the below challenge:Nowcasting monthly means and status will be based on longer term (several months-year) hindcast to nowcast simulations including assimilation of recent data.Production of 20 year time series is a major job both on the modelling and data assimilation side. The best validated model system (integrated with WP2) will be used. A key issue is to store and present information most relevant for fish- recruitment, growth and migration.To ensure that all relevant data (from ships and future buoys) are semi-operationally and readily available for the modellers is a challenge, including the preparation of huge amount of historic zooplankton data especially from Russia and the Continous Plankton Recorder. To get hold of some of these data involves direct expenses in

addition to manpower.

Time schedule
The whole project minus the first year

Deliverables
- Daily forecast of zooplankton distribution
- Monthly mean nowcast of zooplankton distribution
- Annual updates of 20 year time series of zooplankton distribution

WP4: Recruitment (eggs and larvae)

Description of work
This WP is based on WP2 and WP3The daily forecasting mode will be based on present operational skills and infrastructure for every day functioning. There will be no, or very few, daily operational data available for such a system, but it will be based on the below challenge:Nowcasting monthly means and status will be based on longer term (several months-year) hindcast to nowcast simulations including assimilation of recent data.Production of 20 year time series is a major job both on the modelling and data assimilation side. The best validated model system (integrated with WP2, 3, 5 and 6) will be used. A key issue is to store and present information most relevant for fish survival, growth, mortality and migration.To ensure that all relevant data (from ships and future buoys) are semi-operationally and readily available for the modellers is a challenge, including the preparation of historic national and international data. To get hold of some of these data involves direct expenses in addition to manpower.

Time schedule
The whole project minus the first 1.5 year

Deliverables
- Daily forecast of fish eggs and larvae distributions
- Monthly mean nowcast of fish eggs and larvae distributions
- Annual updates of 20 year time series of fish eggs and larvae distributions

WP5: Fish migration

Description of workThis WP is based on WP2, WP3 and WP4The daily forecasting mode will be based on present operational skills and infrastructure for every day functioning. There will be no, or very few, daily operational data available for such a system, but it will be based on the below challenge:Nowcasting monthly means and status will be based on longer term (several months-year) hindcast to nowcast simulations including assimilation of recent data. Data from surveys and the fishing fleet must be made rapidly available directly from the field.Production of 20 year time series is a major job both on the modelling and data assimilation side. The best validated model system (integrated with WP2, 3, 4 and 6) will be used. A key issue is to store and present information most relevant for species interaction (and thereby mortality and growth)

module II

and recident time in different international zones To ensure that all relevant data (from ships and future buoys) are semi-operationally and readily available for the modellers is a challenge, including the preparation of historic national and international data. To get hold of some of these data may involve direct expenses in addition to manpower.

Time schedule
The whole project minus the first 1.5 year

Deliverables
- Daily forecast of fish stock distribution
- Monthly mean nowcast of fish stock distribution
- Annual updates of 20 year time series of fish stock distribution

WP6: Stock estimation

Description of work
Ensure that all relevant ecosystem information from models and observations related to Modules 2-5 is timely available in a format useful for the population dynamic models in Module 6. In addition this information will have to be operationally communicated with the user community (ICES working groups, fisheries managers etc.)

Time schedule
The whole project minus the first 0.5 year

Deliverables
Deliverables from WP1-5 in suitable form and time for Module 6 and other users (eg. ICES)

WP7: Prediction/management strategies

Description of work
Ensure that all relevant ecosystem information from models and observations related to Modules 2-6 is timely available in a format useful for the predictive population dynamic models, or simpler statistical models. In addition this information will have to be operationally communicated with the user community (ICES working groups, fisheries managers etc.).

Time schedule
The whole project minus the first year

Deliverables
Deliverables from WP1-5 in suitable form and time for Module 7 and other users (eg. ICES)

module II

WP8: Operational monitoring system

Description of work
Develop procedures for keeping the regularity in the flow of data from the diverse national and international observing platforms (ships, satellites, buoys, aircraft) to the operational AMOEBE database, including initial data quality assurance. This also includes results from individual AMOEBE models and possibly other relevant operational models.

Time schedule
The whole project period

Deliverables
Procedure and necessary actions for regularity of dataflow from originator to database

WP9: Database/Network/Communication

Description of work
Maintenance and daily operation of the operational databases (including modelling products and quality assurance), network and communication according to the general needs and the requirements and specifications from the other modules. Value added services to the whole AMOEBE and other user community will be operated through a web based system. A set of standard graphical plots/maps and tables will be defined and distributed on a web based GIS system. Ensure close contact with the user community. Set up and maintenance of user group.

Time schedule
The whole project period

Deliverables
Procedure and necessary actions for regularity in value added end products and communication with users

module 11

References

Examples on operational systems to be consulted (with references to relevant literature) can be found on the following web-pages:

www.coriolis.eu.org/coriolis/
www.argo.jcommops.org/
www.jcommops.org/sot
www.eurogoos.org
www.ices.dk
www.ioc.unesco.org/goos/
www.boos.org
www.ioc.unesco.org/goos/eurogoos.htm
www.imr.no/~morten/nocomments/ ⇨ products ⇨ here
www.topaz.nersc.no/
www.mercator.com.fr/
www.meteo.gov.uk/research/ocean
www.cineca.it/mfspp
www.jason.oceanobs.com/
www.cdc.noaa.gov/cdc/data.ncep.reanalysis.html
www.coaps.fsu.edu/scatterometry/Qscat/gridded.html

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KNOWLEDGE

Marine ecosystems are complex. With present knowledge it is difficult to predict the future development of the fish stocks and the marine environment, under highly varying pressure from climate, fisheries and pollution. To improve our knowledge of the dynamics of the ecosystems, it is necessary to develop knowledge-based models within a range of areas.

The Norwegian marine research communities (with international contributions) have agreed to cooperate to develop the necessary knowledge and modelling tools within the research initiative AMOEBE. We will increase the level of knowledge and develop and apply new technology which can contribute to reach the goal of a manifold increase in added value of the products from marine living resources.

AMOEBE shall:

- Give us necessary improved knowledge about our large marine ecosystems. Optimal exploitation of the marine living resources based on sustainability and precautionary principles can only be achieved by a multi-disciplinary holistic view on the ocean dynamics.
- Integrate the knowledge from and secure the recruitment to a range of disciplines: oceanography, meteorology, fishery and marine biology, mathematics, system theory, instrumentation technology, and information and communication technology. This will open possibilities for export of Norwegian know-how.
- Combine complex mathematical models, giving quantitative insight into basic processes, with simpler models for management advice. This will give a method to solve the future demands for an ecological approach to fisheries management.
- Cooperate significantly with relevant international activities.
  Contribute to reach the national goal of increased export of fish products.

AMOEBE