Strategic plan for development of the NORWECOM.E2E model

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Vision

An operational state of the art marine end to end ecosystem model system.

Background

Models that include a fine scale representation of the physical features of the ecosystem as well as the biogeochemistry and the main components of the ecosystems are referred to as End to end models (E2E). The NORWECOM.E2E is under development to become an end to end model of the Norwegian Sea ecosystem.

Motivation

Do frontier research and dissemination in marine ecosystem research

The NORWECOM activities aim at advancements in our understanding on how natural and anthropogenic drivers affect marine ecosystems. We aim for a generic and modular modeling approach that can be applied for any part of the global ocean. Particular attention is given to applications, simulations and validations for an ocean area with long observational records; the Nordic Seas, the North Sea, the Barents Sea and the Norwegian coast. High quality is to be continuously ensured by dissemination of our methods and results in peer reviewed high quality scientific journals

Educate the next generation of researchers

Modeling and simulation of marine ecosystems require a knowledge base in biology, ecology as well as physical, chemical and biological oceanography. Furthermore, skills in mathematics and computer programming are a crucial requirement. The NORWECOM activities seek to establish a multidisciplinary learning and training environment for master students, PhD students and post docs.

Provide advice for ecosystem based management

The present fisheries management deals with single species and do not take the carrying capacity of ecosystems into account. This means that for example the management of herring takes place independent of how many competitors there are present. NORWECOM.E2E allows simulations to performed where the effects of different harvest control rules (HCR) on ecosystem dynamics are investigated. In this manner several single species HCRs can be tested and their effects on the ecosystem and each other can be investigated. - Geir

IBMs ideal for modeling higher trophic levels

A key limitation with expanding the traditional NPZD approach to the higher trophic levels is that behavioural repertoire increases and are becoming increasingly important. This flexibility needs to be included in ecosystem model DeYoung et al. 2004. IBMs are ideal for this as they are highly flexible for implementing behavioural and life history traits and are not Markovian and allows for example learning experiences to be carried over the life time. (DeANgelis and Gross 1992, Grimm & Railsback 2005). This makes the NORWECOM.E2E model well suited to simulate the dynamics of the higher trophic levels and to address the ecosystem consequences of different behavioural and life history traits.

Large benefits in developing an integrated operational multi purpose model system to serve several types of studies. There exists a lot of models for different trophic levels and species for Norwegian waters. But linking these models has been often done in an ad-hoc short-term manner without building structure for integrating ecosystem components. NORWECOM.E2E is a merger of two models, the NORWECOM model for the lower trophic levels and nutrient cycling (Aksnes et al. 1995, Skogen et al. 2007) and different individual based models developed initially for fish (Huse and Giske 1998, Strand et al. 2002, Huse et al. 2004, Huse and Ellingsen 2008) and zooplankton (Huse 2005, Samuelsen et al. 2009). These models are now being integrated into a fully coupled model system. - Geir

Effects of anthropogenic drivers on the ecosystem

Fisheries - Geir: Fisheries represents an important source of mortality to some fish stocks.
Acidification
Pollution
Eutrophication (nutrients) – Dag
The Norwegian Coastal Water (NCW) is transported by the Norwegian Coastal Current (NCC) from south to north and represents an important habitat for e.g. fish larvae of cod and herring. Some of the sources (Baltic Sea and the southern North Sea) of the NCW have undergone eutrophication processes the last century and some evidence suggest that such processes together with increased precipitation has affected e.g. the transparency of the NCW with pronounced ecosystem effects in some areas. There is also a rising concern that the increasing nutrient discharges from the fast growing salmon farming might affect habitat quality in coastal areas. The NORWECOM will be developed to more accurately describe the production and habitat characteristics of the NCW/NCC.

Usage areas

Understanding ecosystem dynamics
Climate change
Life history and behaviour
Spatial ecology
The recruitment problem
Improved efficiency of existing models that are not linked
Improved survey strategy
Estimating overlap and consumption by predator species
Eutrophication symptoms Dag
Eutrophication symptoms such as loss of kelp habitat and associated habitat destructio and reduced oxygen in some fjord basins have been observed along the coast of the southern Norway. It is expected that a NORWECOM model with increased resolution of NCW characteristics will be useful to analyze to what extent such changes can be related to e.g. long term changes in factors like temperature, light penetration and nutrients.

Feature list

Biogeochemistry

Current version:Except for atmospheric deposition of nitrogen, there are no internal sources for nutrients in the model, thus the initial field and the exchange across the open boundaries

detremines the total amount of nutrients in the domain. In the euphotic zone the phytoplankton consumes nutrients. Flagellates consumes nitrogen and phosphorus and in addition diatoms consumes silicate. There is leakage of nutrients from the phytoplankton and detritus are transformed to nutrients
Planned updates to the model:
Include river sources for nutrients.

Representation of key taxa

Phytoplankton

The phytoplankton in the model is divided in two functional groups, flagellates and diatoms. The two groups have different growth rates, light affinity, sinking speeds and the diatoms require silicate for growth. To mimic a rapid micro biological loop some nutrients are released as the phytoplankton dies and the rest becomes detritus, There is one detritus type for each nutrient with different regeneration time constants. The detritus that is not regenerated in the pelagic sink to the bottom, It may be resuspended or regenerated at the bottom, but some is also buried.

Microbial loop Dag

Currently the microbial loop of the NORWECOM model is parameterized as rates without specification of e.g. competition between bacteria and phytoplankton for nutrients. It is a need to investigate to what extent such simplification affects simulation results of e.g. the higher trophic levels but also of eutrophication symptoms, and the biogeochemistry.
Microzooplankton is at present a state variable in the NPZD module. This module includes also mesozooplankton and is modified from the ECOHAM4 model. The microzooplankton feeds on detritus and flagellates while they are eaten by the mesozooplankton. Fecal pellets production from microzooplankton is added to the detritus pool, while excretion (DON and NH4) is added to NIT.

Zooplankton

A full IBM module for Calanus finmarchicus has been implemented. The module includes feeding as functional response type 2, bioenergetics growth model, horizontal movement by currents and ontogeny and daily vertical migration in the vertical. Mortality is due to predation (pelagic, mesopelagic and tactile), starvation and spawning stress. Mature adults reproduce when above weight and fat threshold. Time step is 1 hour. Six life strategies traits (overwintering depth, wake up day, allocation to fat day, fat to soma ratio, and two parameters for vertical migration) are simulated using life history traits to control actions at key points. The module code is partly generic and partly species specific, i.e. it can be extended to other zooplankton species, for example C.helgolandicus, C. glacialis and hypoboreus, by modifying only the last set of routines.

Fish

Fish is one of the key trophic groups included in the model system. Presently the time span modeled is one year, but we plan to run the model over consecutive years and include the whole life cycle from larvae to adult fish. The time step for fish is one day, thereby ignoring any diel patterns is distribution and behavior. The essential processes in the model are movement, mortality and growth. The spatial resolution is 3D with a grid size of around 20 km horizontally and one meter vertically. Annual large scale migrations are either strict homing or modeled movement. The main focus of the model, the feeding period, is modeled while the spawning and overwintering migrations are straight homing to predefined locations. Modeled movement is a function of a directed speed and direction, random walk and advection due to currents. In the feeding period, fish will alter their migrations when encountering too cold water and good prey concentrations. Vertical movement is so far set to a minimum and is only changed between seasons (for instance between the spawning and feeding period). Mortality is a function of natural mortality, fishing mortality and predation from the higher trophic level if this is included. Until now, the mortality rate has been uniform over the entire model domain, but this can easily be changed in the future. Growth is modeled in a bioenergetics model, specific for each species included and is a function of prey availability of water temperature.

Planktivorous fish – interacting with zooplankton (Calanus and krill). The dominant species here is herring, mackerel and blue whiting, while capelin and a group of small mesopelagic fish will be included later. Feeding intensity is a determined with functional response where the half saturation constant is species specific. See the section "model validation" where this is described further. If there is not prey available for the fish, the fish will feed on "other prey" not explicit included in the model, to ensure a minimum feeding intensity.
Piscivore fish – model development on this issue is still in its infancy. These species will feed on a combination of planktivorous fish and zooplankton depending on own length and prey availability. They will also have a pool of "other prey" available that is not explicit included in the model. The migrations will be determined in the same manner as for planktivorous fish, but will depend more on following the prey species.

Mesopelagic fish

Evidence suggest that the current world estimate of mesopelagic fishes of 1 million tonnes might be severely underestimated and that this group of fishes need to be more accurately represented in ocean ecosystem models.

Jellyfish

In contrast to many zooplanktivorous fishes, most jellyfish are tactile zooplanktivores where feeding success is independent of light and optical properties of the water. Some evidence suggest that a long term darkening of the Norwegian Coastal Water tends to have favored jellyfish in some coastal areas. Because jellyfish is to a large extend considered a "dead end" of the food chain conditions that favor jellyfish will constrain the amount of biomass that are available to e.g. piscivore fishes. Thus jellyfish acts as a short circuit where biomass is transformed into the detritus and dissolved organic matter.

Larval fish

A module for calculating the feeding behavior, bioenergetics, and drift trajectories of larval fish has been implemented. The larval fish module can be easily modified to be applicable for any taxa (using #ifdef preprocessing directives), but is currently setup for cod. The module extends the generic zooplankton module and interacts directly with the Calanus module to estimate prey densities available for feeding. The feeding component of the module is mechanistic, meaning that all interactions between the larva and its prey and predators are estimated as functional responses determined by the physical and biological characteristics of the environment. For example, the feeding behavior is dependent on the current light conditions, the ocean temperature and turbulence, the developmental stage of the larva that determines the visual ability to perceive prey items, and the larval ability to attack and capture prey items. The larval fish module loops over each Calanus nauplii and copepodite stage to estimate the probabilities of successful attack and capture. The sum of ingested prey items per time step (1 hour) define the total ingested material provided to satisfy metabolism and growth.

Marine mammals

For the Norwegian sea, five different species of whales should be considered for inclusion in the model: Killer whales, Sperm Whales, Humpback whales, Minke whales and Fin whales. All groups except the killer whale migrate out of the area during winter, and need to be "kept" somewhere for that period. All changes to the individuals/groups in that period (fatter, thinner, less individuals, more adults/juveniles etc.) should be updated before letting them into the model domain in the spring. As they consume roughly 3% of their bodyweight each day (not much information about this), their presence is important for krill, squid and various fish species (capelin, herring, polar cod, blue whiting, haddock, mackerel, saithe, redfish, this varies for the different groups).
Seals: One -two groups that should be considered (maybe more?-coastal species?): Hooded and harp seals, which enter the model domain. The same as for the whales: they will leave the model domain for periods of the year; hence this information needs to be updated before they enter. Need to take into consideration their interaction with snow/ice thickness and concentration. Diet and where they dive throughout the day is important for several of the fish species included in the model (capelin, polar cod(?), herring, cod, saithe, haddock ++). What to do with them during moulting and breeding on ice? And need to define either their migration patters (not much information about this), or other kinds of moving in the model domain (predator-prey?).

Seabirds (Frode/Cecilie)

Co-variation betweeen larval fish and seabirds population dynamics will be studied by the use of individual-based models of ichthyoplankton and individual geolocation data loggers fitted to selected seabird species from selected colonies. Of particular interest is the effect of climate variability cascading up through tropic layers affecting seabirds by modifying spatio-temporal prey availability. While bottom-up control is apparent it is of interest to also study whether seabird may substantially affect larval survival e.g. when spawning stock biomass is low and the offspring is concentrated in time and space. In the waters off the coast of Norway and in the Barents Sea there are about 26 million individual seabirds and field data are collected at several locations, e.g. Hornøya and Røst, for several decades. Together with observed and modeled spatiotemporal distribution of early stages of fish this constitute a unique possibility to study co-variation in a shifting climate.

Need to consider how to include the seabirds – which species should be the used for parameterization; a mix between several, the most common or the one in focus? Information can be difficult to obtain – depending on which parameters is needed in the model (depth of diving, number of chicks, hatching, distribution and seasonal patterns etc.). Some of the species migrate in different seasons (winter migration southward, summer migration northward), hence the number of birds within the model domain will vary somewhat throughout the year.

Behaviour and life history features

Different methods for implementation of behavior and life history traits. Geir: The ability to include behavioural and life history traits is a particular strength in IBMs. At present there are rather simple strcutures for including these elements and there is mainly a direct representation of the genotype in the phenotype.
Emergent ecosystems – experiments on different structure from initial conditions. Geir

Implementation of anthropogenic pressures

Fishing mortality: Currently, fishing mortality (F) is implemented as constant yearly rates for the respective fish species. However, a more generic application should also include optional fishing mortality for lower trophic levels (e.g. euphausides in the Antarctic). Also, variation in F over seasons and space is likely to affect the model dynamics. This can be implemented in several ways, either by applying specific temporal (season, month, week, day) and geographically defined rates, or by adding fishing through individual agents in a separate IMB module. There are ca. 5000 fishing vessels operating in the Norwegian EEZ, and inclusion of these will unlikely add much to model runtime. By adding such detail to harvest induced mortality, specific management issues (e.g. total quotas, individual quotas, seasonal constraints, area closures etc) can (in principle) be addressed with higher accuracy.
Acidification: An acidification submodule is available taken from ERSEM and using Haltafall. The module use three prognostic variables (detC, DIC and DOC), while a diagnostic routine is redistributing DIC to CO2, CO_3^{2-} and HCO_3^- and calculating pH, pCO2(water). Omega(aragonite) and Omega(calcite) taking atmospheric pressure of CO2 and the alkalinity as inputs. Finally the module calculates the air-sea flux of CO2.
Warming: Physical effects of global warming are implemented via input from the hydrological model. Also, phytoplankton, zooplankton and fish larvae have physiological characteristics dependent on ambient temperatures. In turn, these characteristics mediate important processes such as growth rates, bloom timing as well as stage specific mortality. However, temperature effects on higher trophic levels (fish and up) are primarily forced from below. It has been suggested that temperature has direct influence on spawning ground distribution, but also indirect through the effect on offspring fitness and individual state. Implementing these effects will either require specific parameterization of preferred temperature ranges for spawning (statistic), or spawning "decisions" could be coupled to the fish larvae module and internal state (mechanistic).
Nutrients: At present river nutrients is not included in NORWECOM.E2E. Data from the hydrological model E-HYPE (that also includes N and P) is available and routines to include this will be implemented. Freshwater is assumed taken care of in the physical model. A simple formulation for atmospheric N is included distinguishing between coastal and open sea cells and using gross estimates from EMEP.
Ongoing NFR-projects (Pribase and Symbioses) aim at coupling the oildrift model Fates with a larval IBM for cod and herring with physical forcing from ROMS and output fed into the stock assessment model Gadget. While Pribase addresses oildrift, larvae and physical forcing, Symbioses also address primary and secondary production. Pribase ends early 2013 while Symbioses ends 2015. It is a focus in both projects to construct generic coding so that submodels can be replaced with alternative codes (e.g. ROMS instead of SINMOD). An important feature of the Symbioses project is the development of a state-of-the-art toxicology model, which based on the input of past bodyburden, ambient concentration and composition of oil components, details of the organism addressed provide an updated bodyburden of each individual.

Super individual processes

Computational efficient estimation of encounter rates between predators and prey will have to be developed. Since super-individuals represents numerous individuals, but share the exact same geographical position, some vertical and horizontal smoothing is needed to ensure reasonable overlap between super-individuals. These calculations will be performed very frequently and thus have to be kept lightweight and efficient. We aim to develop an approach where a predator super-individual forage on the nearest prey super-individual and where the perceived density of the prey is scaled in relation to the horizontal and vertical distance between the two. If the predator still needs more prey, we continue calculating the overlap with the next closest prey until the predator is either full or its maximum search limit exceeded. Espen, Morten

Mass balance for N: for now the detritus is taken out as part of the zooplankton feeding on phytoplankton. An alternative formulation is to calculate the N loss to dissolved N and detritus as part of the transfer between each trophic level. In the fish bioenergetics model the losses are specified to excretion and egestion (detritus) and the transfer of these sources back to these pools in the biogeochemical model is straight forward. In the Calanus and Krill models there is only an egestion term that can be converted to detritus.

Usage areas

NORWECOM enables virtual studies of ecosystem dynamics and interactions between different functional groups and trophic components in a complex end-to-end ecosystem structure. Since the process formulations in the model are based on generic and mechanistic approaches it is possible to conduct sensitivity analyses and scenario studies in response to variables with a physical and biological meaning, and beyond the variable ranges usually constraining statistical models.

Sensitivity analysis of model parameters (e.g. natural mortality, fisheries mortality, growth rates, and reproduction) or external drivers of the model system (e.g. wind, river runoff, nutrient inflow) provides information about how changes in processes at one part/level of the ecosystem will affect other local and distant parts of the system through trophic cascades and feedback mechanisms. Sensitivity analysis thus enables assessment of the local and global importance of specific processes and components of the ecosystem and how sensitive the system dynamics are to changes in these.

Scenario analysis is an approach to test how the model system responds to changes in the external forcing variables. Setting up and running the model at different ranges and combinations of the forcing functions, based on realistic estimates of effects from e.g. climate change, anthropogenic nutrient inputs or fishing pressure, it is possible to simulate if and how the ecosystem changes and develops in response to changes in the external forcing regime.

Improved process and ecosystem understanding. Dag

Jeg foreslår at dette flyttes fram som motivasjon/forventet resultat.Tas i neste runde.

Strategic management (cross sectoral, ecosystem approach). Geir: Management strategy evaluation (MSE) is a procedure for evaluating the performance of harvest control rules. The procedure involves a harvest model, an operational model and an observation model in addition to the harvest control rule. NORWECOM.E2E can be used “hand in glove” with MSEs to evaluate the ecosystem consequences of multiple harvest control rules. Furthermore the model can be used to improve the operational model in the MSE loop for example by taking addressing emergent species interactions found in the NORWECOM model. NORWECOM.E2E can also be used to test other

Input

Ocean circulation - Frode

20 km standard
Daily mean 3 dimensional (32 vertical layers) output of velocities, temperatures, salinity and turbulence on a 4 km grid covering the Nordic Seas, North Sea, and the Barents Sea is available on an IMR server with backup at the hexagon taperobot for the period 1958-2007. The years 2008-2011 will be produced within early April. Validation studies are ongoing and intended to be published within 2012. and will be put locally (1958-2007).
Daily and hourly mean 3 dimensional (35 vertical layers) output of velocities, temperatures, salinity and turbulence on a 800 m grid covering the Norwegian Coast is available for selected years (2009 and 2010?, hourly only for the spring period) on an IMR server. A technical report can be found here; http://www.imr.no/filarkiv/2011/07/fh_2-2011_til_web.pdf/nb-no and a validation report will become available within April 2012.

Surface light - model based.

Nutrients

Nutrients (river output, new E-HYPE (hydrology) module available for 1970-2008). This will be implemented (see anthropogenic drivers above).

Pollutants

While Fates developed by SINTEF is a commercial oildrift model where users outside SINTEF are typically handed an executable, other communities, e.g. met.no, develop open source oildrift models. When coupling such a model tool with ecosystem models it is essential to bear in mind that the composition and toxicity of oil is specific for each well and this should be reflected in the modeling approach. (new module developed by met.no). Frode

Initial values

Initial values for the different species from observations should be used if available. For fish modules (herring, blue whiting and mackerel), observed year specific migration patterns and biomass/ weight-age distribution based on vpa surveys are used. For zooplankton (C. finmarchicus), not sufficient observations of ovwewintering biomass and distribution is available, and a non-year specific overwintering field (i.e. spatial distribution of super-individuals) is generated by distributing biomass uniformly in the model area, and then run one year (1997) repeatedly until stable conditions (integrated biomass, no of individuals etc) are reached. For nutrients, climatologically values are used, and the model is reset at first timestep every year.

Closure

Unspecified mortality can be kept as is for now (but see above).

Model validation

Proper validation of a model is normally considered to be an absolute criterion for a model to be accepted as trustworthy. The IMR field and laboratory databases contain valuable information for model validations. Annual survey data on zooplankton, fish and mammal spatial distribution and density gathered from acoustics, trawl and net samples will be used to evaluate the models performance regarding horizontal and vertical species distribution. Several target species in NORWECOM.E2E also undergo annual assessments (virtual population analyses) for standing stock biomass and these assessments will be valuable in order to validate NORWECOM.E2Es emergent population sizes and stage distributions. Lastly, stomach sample data can give us important information on both the quantity, species composition and seasonal/regional variation on who eats who. This is valuable to data that will be used to validate species overlap and trophic flow in the model.

Output

The output of the model is planned to be in the NetCDF4 format, which is ideal for structured, aggregated model output. NetCDF4 provides a fast method for writing results to file where the layout of the output file can be determined at runtime depending on what modules are currently used and require output. The NetCDF4 is also efficiently linked to the zlib library that enables compression of the output files. Compared to the classical NetCDF3 format, NetCDF4 in combination with zlib creates about 4 times smaller files. The model results will also be written to file for specific stations (e.g. station M, fixed coastal stations), or sections (e.g. Svinøy section, ICES grid) that are pre-defined and typically represent an area where frequent observations have been made for a longer time series. The station and section output will provide a quick method for analyzing the model output from these specific geographic locations.

The model results will be written to file using a specific subroutine that is generic by layout and can handle writing the output of any individual-based module. It is uncertain at the moment whether each module will write to separate file or if all aggregated results will be written to one big file.

A standardized output file format will be accompanied by a library of scripts written in Python, R, or Matlab, that can be used to visualize the model results in high quality 2D and 3D figures, as well as animations. We will also provide a tool for creating a standard representation of the model output that can be used to quickly visualize and validate the latest model runs.

Technology choice

FORTRAN (INTEL LINUX, latest version). The model uses Fortran 2003 features (type extensions, ASSOCIATE construct, polymorphic entities and SELECT TYPE construct) that are not available in all compilers. An updated overview of compilers and how they have implemented the 2003 standard can be found at http://fortranwiki.org/fortran/show/Fortran+2003+status. The ifort compiler version 12.0 or higher includes all these features.

Version control system (SVN) and TRAC to keep track of changes in files. Espen

Access from outside fire wall (contact Åge Strand).

Need to develop user manual.

Standardized variable naming.

Oasis studio for output data.

Organisation of work

Development in several projects.
Integrated research group within the Bergen Marine Research Cluster with representation from IMR, UiB and UNI Research (and others?) with weekly meetings at BIO for presentations and organization of work. Schedule posted on TE page.
Establish homepage for external and internal usage, post code and papers.
Financing Geir
NFR projects
EU projects
Some FKD financing
SFF projects
Mantra: simulations will always be available for users – no wait for next version.
Online library will be made available and new simulations will be added on.
Ambition - Dag
Jeg foreslår at dette flyttes fram som motivasjon/forventet resultat.Tas i neste runde
Contribute to improve understanding of the structure and functioning of marine ecosystems at the global level.
Generic model version.

ORWECOM.E2E Overview

Models that include a fine scale representation of the physical features of the ecosystem as well as the biogeochemistry and the main components of the ecosystems are referred to as End to end models (E2E). The NORWECOM.E2E is under development to become an end to end model of the Norwegian Sea ecosystem. The model is a merger of two models, the NORWECOM model for the lower trophic levels and nutrient cycling (Aksnes et al. 1995, Skogen et al. 2007) and different individual based models developed initially for fish (Huse and Giske 1998, Strand et al. 2002, Huse et al. 2004, Huse and Ellingsen 2008) and zooplankton (Huse 2005, Samuelsen et al. 2009). These models have now been integrated into a fully coupled model system illustrated below. The components that are presently implemented are delineated with full lines while the components that are planned implemented are indicated with broken compartment lines.

Prioritised challenges for NORWECOM

1. Closed life cycle loop for fish populations
2. Implementation of krill module

Funding opportunities

-SEAS ERA: 24. May (2 mill per år til norsk partner)
  -Consortium: Corinna leads with IMR, NERSC and international partners
    -Focus: phytoplankton production in NORWECOM, in situ measurements

-FRIBIO: 30. May (210 mill.)
  -Trait based

-EU utlysninger på ENVIRONMENT og KBBE
    Date of publication: 10 July 20121
    Deadline: 16 October 2012 2 at 17.00.00, Brussels local time

Milestones for model implementation in NORWECOM

Date	Feature	Responsible
01.06.12	Standardised output module	Bjørn Ådlandsvik, Solfrid Hjøllo, Espen Strand
1.07.12	Implementation of krill module	Espen Strand, Morten Skogen
1.07.12	Improved light parameterisation	Dag Aksnes, Morten Skogen
5.09.12	Submission of NORWECOM.E2E proposal	Geir Huse, Dag Aksnes, Morten Skogen, Jarl Aksnes,++
1.10.12	Coupling of larval and adult fish ibm	Kjell Utne, Trond Kristiansen, Morten Skogen
15.05.14	Individual-based Ecosystem Modelling workshop	Geir Huse, Jarl Giske

Ongoing projects

Title	Deliverables	Project lead

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