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Report of the Working Group on Intergrative Physical-Biological and Ecosystem Modelling (WGIPEM)

25 February - 1 March 2013

Paris, France

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

The Working Group on Intergrative Physical-Biological and Ecosystem Modelling (WGIPEM) held its second meeting in Paris, France, from 25 February to 1 March 2013. The meeting was attended by 36 scientists from 13 countries. Working group members participated in plenary discussions surrounding six topics:

1) Climate session – large-scale projects to regional-scale consequences,
2) REPROdUCE session – biophysical, life cycle modelling of small pelagics,
3) Behaviourally driven movement of animals,
4) Zooplankton dynamics – coupling of lower and upper trophic levels,
5) MABIES Incorporating human effects within integrated ecosystem models,
6) End-to-end models – current status, successes and challenges.

In these workshops and separate breakout groups, WGIPEM members discussed activities broadly surrounding 1) outreach, 2) capacity building and, 3) model application.

Outreach: Group members have placed emphasis on linking to the broader community modelling key marine species and ecosystem dynamics. Ongoing outreach activities include the development of a model library that will contain information on i) key parameterizations of phytoplankton, zooplankton and fish such as representations of vital rates (growth, mortality, reproduction), ii) subroutines depicting movements (e.g. of both fish and fishing fleets / animal and human behaviour), iii) the representation of super-individuals, iv) an interactive information table on trophic coupling in ecosystem models, and v) a proposed database on end-to-end models. Outreach activities also include active collaboration of WGIPEM with other EGs to successfully generate theme sessions (3 at 2013 ICES ASC) and other international workshops. These venues should help promote and dovetail the activities of WGIPEM and other EGs. These outreach activities are especially relevant to increasing the capacity to model human behaviour and economic aspects within end-to-end approaches.

An important aspect of ongoing activity is testing the various "building blocks" of models to strengthen the realism of model estimates and advance coupled end-to-end models. Ongoing and planned activities include vi) testing the sensitivity of lower trophic level (LTT) models when coupled to upper trophic level (UTL) model estimates and vice versa, vii) examining how size-spectrum theory can be best utilized to reduce model complexity and/or allow more appropriately link between LTL and UTL models, and viii) exploring estimates derived from trait-based modelling of zooplankton or fish. Finally, in 2014 the group plans to ix) examine how adding physiological realism can increase predictive capacity of wide range of models (bioclimate to coupled LTL and UTL models).

The meeting highlighted a number of current applications of modelling approaches throughout the world from biophysical models (IBMs) examining population connectivity, coupled bioeconomic fleet dynamics models examining fishers decisions in light of changes in ecological resources. The parameterization of a number of end-to-end models (such as Atlantis) is well underway within various European ecosystems, matching the pace of development of end-to-end models for marine ecosystems in other parts of the world.

1 Opening of the meeting

The second meeting of the Working Group on Integrative, Physical-biological and Ecosystem Modelling (WGIPEM) was held in Paris, France from 25 February – 1 March 2013. The meeting was attended by 36 scientists from 13 countries (Annex 1). The agenda (Annex 2) was adopted. The terms of reference for the meeting are given in Annex 3.

The working group members thank Jean-Marc Guarini of University of Paris for his help with all of the local arrangements.

2 Convene an annual meeting with specific workshops to promote the development and review of coupled physical-biological and ecosystem modelling (ToR c)

The meeting was a combination of plenary sessions, targeted workshops and break-out group discussions. These allowed participants to discuss current topics of high relevance to the advancement of coupled physical-biological and ecosystem modelling, to report on intersessional progress, and formulate a list of new research themes. The workshops, attracted participants having a broad range of expertise (e.g. from hydrodynamics, physiology, trophodynamics, economics and social science). The 4-day meeting had 6 different workshops from Monday afternoon through Friday morning:

1) Climate session – large-scale projects to regional-scale consequences,
2) REPROdUCE session – biophysical, life cycle modelling of small pelagics,
3) Behaviourally driven movement of animals,
4) Zooplankton dynamics – coupling of lower and upper trophic levels,
5) MABIES Incorporating human effects within integrated ecosystem models,
6) End-to-end models – current status, successes and challenges.

The co-chairs invited a few keynote speakers for plenary sessions 1 and 3 to 6. Ryan Rykaczewski (University of South Carolina) and Momme Butenschein (PML) provided presentations in the climate session (theme 1). Juliane Metcalfe (Cefas) provided a talk for theme 3. Frederic Maps (Larval University) reported on recent advances in zooplankton modelling (Theme 4) and Tony Smith (CSIRO) gave the Australian perspective on end-to-end modelling, a talk which contained elements of themes 5 and 6. Workshop / theme leaders were asked to emphasize products (review manuscripts, websites, comparative analyses, etc.) that could result from their workshop discussions.

Along with the 6 plenary discussions, separate discussions were convened for the climate (theme 1), movement (theme 3), zooplankton (theme 4) and end-to-end (theme 6) breakout groups.

3 Report on the state-of-the-art within the ICES community and worldwide in coupled physical-biological and ecosystem modelling and simulation results (e.g. population connectivity, life cycle dynamics, foodweb interactions and/or ecosystem responses to human activities; ToRs a and b)

The following section provides a summary of the presentations made at the six, plenary workshops within WGIPEM. The next section (Section 4) summarizes discussions stemming from those presentations and breakout groups including recommendations by WGIPEM members for future activities.

Workshop 1: Climate Dynamics Chaired by Rubao Ji

Plenary Presentation 1 Modelling climate-driven changes in lower trophic coupling in the California Current System (Ryan Rykaczewski)

Five points were made in this presentation. 1) An understanding of the past is sometimes insufficient to project future ecosystem responses. Our observations of past ecosystem changes have been associated with local physical forcing over relatively short temporal (seasonal to decadal) and spatial scales. This biases our hypotheses about future responses. 2) Changes in boundary conditions may be essential to projecting future responses to climate change. Use caution if boundaries are assumed to be constant! In the case of eastern boundary currents, changes in water mass properties at the oceanic boundary may be the major source of climate-change related trends in future. While one might reasonably assume climatological boundary conditions for a regional model that is limited to a few years in scope, relying on a regional model for longer projections is not advised. 3) Do not assume that biogeochemical models represent cold, hard facts. Our understanding is still evolving and biogeochemical processes at the mesoscale and sub-mesoscale remain an area of rapid improvement in our understanding. For example, even coarse global models lack representation of ocean acidification and carbon fertilization. On a similar note, downscaling of ecology remains an essential step of relating climate change to ecosystems. Our understanding of fisheries is based on populations and regional factors. The results of projects which simply extrapolate coarse model output to species level spatial distributions should be placed under the greatest scrutiny. 4) The typically superficial "climate envelope" models need to be revisited in light of advances made in fisheries oceanography. Temperature or chlorophyll does not "make a habitat" but these proxies are used because they are easier to model than ecosystem interactions. Climate envelope models are based on empirical correlations which will fail to offer robust estimates unless real, ecological understanding of niches (fundamental vs. realized) are added. Finally, 5) Ecosystem structure and carbon transfer are not everything. Economics, governance, and social science issues are essential pieces of the puzzle.

Physical and biological climate modellers (in general) need to do a better job of engaging in research with social scientists and economists — we're dealing with issues that are tied to families and communities dependent on the ocean. Recommended first steps toward linking these different disciplines and their tools would be to establish some common terminology and recognize differences in model "currency," representation of fluxes, and use of equations and uncertainty.

Presentation 2: Some challenges in the modelling of the lower trophic level of the marine ecosystem (Momme Butenschön)

Momme Butenschön provided a provocative talk on issues surrounding lower trophic level (LTL) modelling. Significant progress has been made over recent years in the validation of lower trophic level ecosystem model to in-situ and remotely sensed data. While these works provide a valuable quantitative assessment of the system's capability to reproduce measured quantities of the system, they only offer limited information on the causes of the deviations and the functioning of the model and the ecosystem itself. In this talk some example are given how model data and in combination with measured data can be used to identify emerging properties of the system and how they are represented by the model in order to assess the proper functioning of the biogeochemical model that is to some degree independent on the framework it is implemented in including the errors and uncertainties in external forcing factors, ocean circulation or initial conditions.

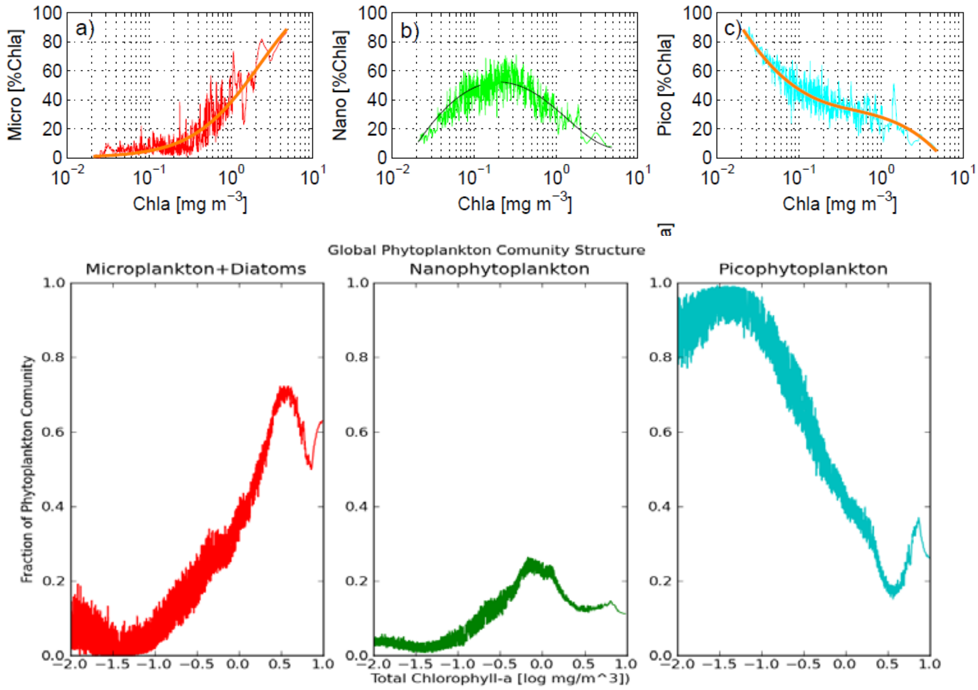

Figure 1. Emerging community structure of in-situ phytoplankton pigment data (top) and a global ERSEM model simulation (bottom).

Presentation 3: ICES-PICES strategic science plan and workshops: WGIPEM opportunities

Myron peck briefly updated the group concerning upcoming changes in the science plan of ICES. This information was contained in talks provided by Manuel Barange ICES Strategic Plan: 2013 to 2018 and Mark Dickey-Collas (Integrative Ecosystem Assessment: Methods towards Operation). The changes are moving towards offering advice that will be strengthened by the advancement of integrated modelling approaches. By 2018, one vision has ICES providing regional descriptions of state of the seas that is integrated across sectors to examine trade-offs. There will be no assumption of stability in ecosystems, hence ecosystem dynamics need to be better resolved to support marine environmental policy.

He also provided information on six upcoming theme sessions and workshops dealing with biophysical / ecosystem modelling as well as climate. These were:

1) ICES-PICES "*Global Assessment of the Implications of Climate Change on the Spatial Distribution of Fish and Fisheries*" (WK-SICCME-Spatial). 22–25 May

in St Petersburg Russia, Conveners: Anne Hollowed (PICES), Suam Kim (PICES) and Myron Peck (ICES).

2) Theme sessions at the ICES Annual Science Conference in Reykjavik, Iceland:

a) Theme Session B "Responses of living marine resources to climate change and variability: learning from the past and projecting the future" (co-sponsored by PICES), Conveners: Myron Peck (ICES), Vincent Saba (NOAA), William Cheung (PICES).

b) Theme Session C "*Modelling human behaviour in models of marine ecosystems".* Conveners: Jan Jaap Poos (the Netherlands), Olivier Thebaud (Australia), Rolf Groeneveld (the Netherlands)

c) Theme Session M "*Identifying mechanisms linking physical climate and ecosystem change: Observed indices, hypothesized processes, and "data dreams*" for the future (co-sponsored by PICES). Conveners: Emanuele Di Lorenzo (COVE-AP; USA, PICES), Arthur J. Miller, (USA, PICES), Marc Hufnagl, (Germany, ICES)

3) ICES PICES "*Workshop on comparison of size-based and species- based ecosystem models*"**,** 11 October, Nanaimo, Canada. Co-chaired by Jeff Polovina (NOAA Fisheries)**,** Myron Peck (ICES), Anne Hollowed (PICES) and Shin-ichi Ito (PICES).

Workshop 2: (Joint REPROdUCE / WGIPEM) – biophysical, life cycle modelling of small pelagics

Reproduce is an ongoing European project (ERANET Marifish) coming to an end in 2013, on understanding recruitment processes of fish based on coupled physical-biological models. A total of 6 presentations were provided by different partners within that project (HCMR, IEO, AZTI, Ifremer) on model developments, process understanding and model uses towards recruitment understanding in both case studies (Aegean Sea and Bay of Biscay).

Presentation 1: Lagrangian modelling of sardine early life stages in the Bay of Biscay (Luz María García García)

The complete Lagrangian model for sardine early life stages in western and northern Iberia has been presented. The offline Lagrangian software Ichthyop has been chosen to carry out this study because it allowed us to use existing simulations and it was already implemented for anchovy, hence just minor adaptations were required for sardine. However, vertical dispersion processes were not accounted for, and had to be implemented. The results of several experiments in which the importance of considering this process is highlighted has been shown for both the autumn/winter spawning peak in western Iberia and the spring one in the Cantabrian sea.

Presentation 2: Lower trophic level modelling in the Northern Iberian Shelf (Manuel Ruiz Villareal)

A Fasham-like lower trophic level model (Fennel, 2008) has been coupled to the ROMS configuration in the western and northern area of Iberia. Nutrient data from the Vaclan IEO cruises has been used to obtain a nitrate-temperature relationship that has been used to force the model at the boundaries. Since this model only accounts for phytoplankton functional groups, parameters corresponding to *Chaetoceros socialis*, the most abundant diatom at the beginning of the spring bloom in the area, have been considered. The model validation against both satellite images and in-situ data at different temporal and spatial scales confirm that it presents a reasonable ability to reproduce the observations.

Presentation 3: Anchovy life cycle model developments for the Bay of Biscay (Martin Huret)

Within Reproduce, the focus of this work has been to modify (improve) specific modules of the modelling system: configuration of the hydrodynamic model, trophic coupling between lower trophic coupling and larval fish using observed size spectra, vertical distribution validation for eggs, bioenergetics DEB model, and implementation of a movement module (Metropolis algorithm) based on observed size distribution of fish from surveys. This algorithm simulates the movement of individual fish that form the observed distribution of the population at every time-step. Individual strategies can then be analysed based on trajectories and related growth. Additionally, based on 0D simulations and for early life stages, map of preferential habitat based on growth have been proposed.

Presentation 4: Constructing simple indicators from complex model output (Pierre Petitgas)

An application of the Bay of Biscay anchovy biophysical model. Coupled 3d biophysical models are complex and provide information in great detail. Terrabytes of data are unsuitable for management purposes. A way forward to condense the information is by constructing indicators from model outputs to inform on a particular management question. To demonstrate the capacity of larval IBMs to help management decisions, sensitivity analysis and benchmarking procedures are critical. Procedures could involve, e.g. sensitivity analysis or scenario simulations to assess uncertainty in the indicators given uncertainty in the models.

An example was developed based upon the biophysical model developed for anchovy in the Bay of Biscay. Huret *et al.* (2010) analysed the sensitivity of larval dispersal kernels with a larval IBM. The outputs from that study (1996–2009) were used to derive a larval dispersion index for the entire spawning season and locations. Maps of particles concentrations were summarized using geostatistical spatial indices (Huret *et al.*, 2010). The larval dispersal index was the first principal component when applying a PCA to the matrix whose columns were the spatial indices and lines the time-steps (Petitgas *et al.*, 2011). The index correlated well with the index of recruitment as estimated by ICES (2011). Possible ways to continue the study were suggested to construct error around the IBM-derived indicator. Also suggested was a future study to benchmark larval IBMs in different areas to provide reliable indices. The discussion was about the interest and need for early warning indicators of recruitment rather than estimates of recruitment per se.

Presentation 5: Modelling the foraging and growth of anchovy larvae using prey size-spectra (Agurtzane Urtizberea)

This work focused on coupling a previously developed bioenergetic model for anchovy larvae (Urtizberea *et al.*, 2008) with a foraging model developed in this study. They analysed the effect of different slopes of the prey size spectra in the feeding behaviour of anchovy larvae at different environmental conditions. This model can be a link between the observed prey distribution in the field and foraging models for anchovy larvae.

Presentation 6: Movements of anchovy in a full life-cycle model coupled to a 3-D biophysical, lower trophic level model (George Triantafyllou)

A full life cycle model for European anchovy in the Aegean was developed a few years ago. This model is linked to the 3-D hydrodynamic/biogeochemical model (POM/ERSEM), operational within the HCMR POSEIDON forecasting system. The model is stage- and age-specific; it is on line linked to ERSEM and encompasses several fish modules (growth bioenergetics module, population module, drift-movement module, catch module as well as a dynamic egg production module). Diel vertical migration is introduced in the model as soon as the late larval stage. Validation efforts included comparisons of model-derived with mean growth rates in the field, horizontal distribution and abundance patterns of juveniles/adults with those from acoustic surveys, and the spatial distribution of egg production with distribution and abundance of eggs from egg (DEPM) surveys. The model base run produced population biomass values comparable to those of acoustic surveys. In REPROdUCE, the model has been used to identify areas important for recruitment, explore potential recruitment indices and to test different environmental and fishing scenarios.

Workshop 3: Behaviourally driven movement of animals

The Movement subgroup session had two formal presentations, and an update presentation by Kenny Rose. The update presentation listed the tasks that were defined at the previous year's meeting in Copenhagen. Progress made on each of these tasks is discussed in the next section of the report.

Keynote Presentation 1: Fish Migration and Behaviour: Animals we don't fully understand and environments we can't fully measure. (Julian Metcalfe, Cefas, UK)

The plenary talk by Julian Metcalfe highlighted the new developments in fish tagging that provide information on the movement trajectories of individual fish and the environmental conditions they experience. Examples included work on flatfish (plaice), Atlantic cod in the northeastern Atlantic shelf waters, eel migration from Europe towards the Sargasso Sea, and blue marlin and saifish in the Atlantic and Pacific basins. The latter indicated the effects of habitat compression related to zones of hypoxia. His messages included that 1) Fish occupy environments outside laboratory-defined physiological optima, 2) Regional differences in physiology and behaviour are real – "a cod here may not be the same as a cod there", 3) Combining results from laboratory and field studies is critical to understanding trade-offs and the value of marginal habitats, 4) mean values are meaningless – limits, boundaries and direction are important, 5) studies are normally performed on "winners" but, in a changed world, the losers may be winners.

Presentation 2: Movement schemes for anchovy in the Aegean Sea (Dimitris Politikos, HCMR, Greece / Ifremer, France)

A second presentation by Dimitris Politikos (HCMR, Greece; Ifremer, France) gave the second formal presentation on the way fish movement is represented in anchovy in their model of the Aegean Sea. He highlighted some initial testing they are doing on a simplified grid to simulate migration. His talk was entitled: "Anchovy Movement in the North Aegean Ecosystem."

The two formal presentations generated much discussion, especially about how the tagging data can be meshed with the movement submodels that are often used within larger individual-based population and foodweb models.

Workshop 4: Zooplankton dynamics – coupling of lower and upper trophic levels

Zooplankton forms the major link between ecosystems primary production and higher trophic level. Therefore it is crucial to ecosystem dynamics and need to be carefully addressed in biological and coupled biological-physical models. The WGIPEM subgroup on "Modelling zooplankton dynamics" aims in addressing related research questions by common work and discussions. For this year's meeting Frederic Maps was invited to give a keynote talk 'Toward an integrative numerical framework in pelagic ecology'. The other presentations given in the subgroup session were mainly related to the two major questions that arose during last year's subgroup discussion.

Keynote Presentation: Toward an integrative numerical framework in pelagic ecology (Frederic Maps, University of Lava, Canada)

Modern marine ecology is at a crossroad where the rapid accumulation of knowledge is exceeded only by the historical acceleration of environmental changes and anthropogenic pressures forcing marine ecosystems, especially in coastal areas where most of human activities concentrate. In this context, numerical modelling is necessary to interpret mechanistically the processes underpinning empirical relationships and to provide the quantitative tools required for forecasting ecosystems and for ecosystem-based management.

The principal objective of this work is to develop the capacity to forecast changes in the pelagic ecosystems with a focus on mesozooplankton (copepods, krill, and gelatinous species). This group is an essential trophic link in pelagic ecosystems and it is subject to both top–down or bottom–up controls of its productivity. Modern biogeochemical models are efficient at simulating primary producers. Their results and predictions can be measured through chlorophyll *a*. However, to get to fish we need a significantly better understanding of the dynamics of the zooplankton. That is why zooplankton is currently the focus of the development of end-to-end numerical models that mechanistically integrate several trophic levels in a coupled biophysical framework.

Most of current zooplankton models use either size or ontogenetic development stage as biological state variable. Size variables (mass or length) represent adequately processes such as predator–prey interactions, swimming speed or metabolic rates through allometric relationships. However, a metamorphosis during ontogenesis that let size relatively unaffected can radically change the shape of the individuals, their ways of feeding and sensing their environment. Hence, numerous zooplankton models use development stage as state variable. But reaching the principal objective of this study requires to mechanistically representing mass (m), development stage (s) and also volume (v) as state variables for numerous organisms that interact in one numerical framework. Taking into account volume (shape and energy density) allows dealing with a variety of different predator–prey relationships and it favors the study of fluxes inside ecosystems.

The presentation outlined an evolutionary modelling approach using different mesozooplankton taxa which are distinguished by a list of numerical traits (a vector of parameters) that will produce different growth and development rates, shape characteristics, life cycle strategies (including reproduction, migration behavior, dormancy, etc.) and mortality regimes. We aim at initializing this model with a collection of numerical taxa randomly generated within the traits space. The expected outcome is that only a fraction of the taxa will survive and reproduce, so that a complex foodweb adapted to the environmental conditions simulated will emerge. This approach of evolutionary modelling has been successfully employed to study diversity patterns in particular functional groups such as phytoplankton and copepods.

This framework will provide quantitative answers to three principal research questions:

1) How does the variability of physical conditions (sea ice, light, temperature, salinity, winds and stratification) determine the structure of pelagic foodwebs?

2) How does the structure of the pelagic foodwebs control the sensitivity of these ecosystems to perturbations such as environmental changes, the exploitation of living resources or invasive species?

3) What are the mechanisms that translate environmental perturbations (gradual or catastrophic) into long-lasting shifts in the structure of pelagic foodwebs?

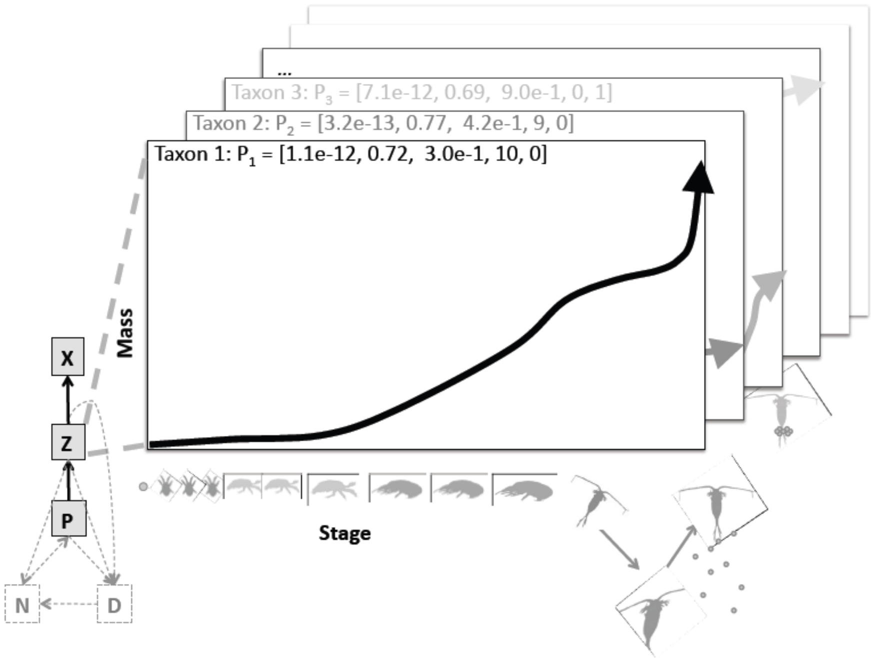

Figure 2. Schematic of the evolutionary modelling framework currently working for copepods (Record, Pershing, Maps, accepted for publication in Ecological Modelling).

Presentation 2: Update on OSMOSE in the North Sea (Karen van de Wolfshaar)

Most foodweb models used have either neglect spatial differences or take species defined by stages or functional groups (Mackinson *et al.*, 2009) or size-spectrum (Andersen and Pedersen, 2010). However, a mechanistic understanding of foodweb interactions and responses to harvesting could be hampered by such an approach, despite that in general results point in a similar direction (Travers *et al.*, 2010). Modelling individual interactions does allow for a mechanistic approach as it captures life–history ontogeny and changes thereof in relation to harvesting regimes. Many fish species change from being planktivorous when small to piscivory when large and may grow 4–5 orders of magnitude (Cushing, 1975). Individual growth and development have an impact on population and foodweb dynamics and are fundamental to understanding community responses to pressures such as harvesting (De Roos and Persson, 2013).

The individual based foodweb model OSMOSE is spatially explicit and captures individual level mechanisms. The model is parameterized for the North Sea, including 12 species (gadoids, forage fish and flatfish) and the four main fleets operating in the North Sea (demersal, pelagic, otter trawl and industrial). The results presented are the first results of the North Sea case, studying the effect of reducing fleet effort on the foodweb with a focus on the demersal fleet (Van de Wolfshaar in prep).

Reducing the effort of the demersal fleet results in an increase in biomass of the target species, yet the large predatory gadoids do not profit from this increase in prey biomass (Figure 3). The underlying mechanisms is that a change in the length frequency distribution of the flat fish towards more large individuals prevents the gadoids from profiting as the flat fish have outgrown their gadoid predators (Figure 4). Unexpectedly, the forage fish do profit from the change in flat fish length frequency distribution as with the increase in large flatfish their reproductive output also increases thereby providing prey for the forage fish (Figure 4).

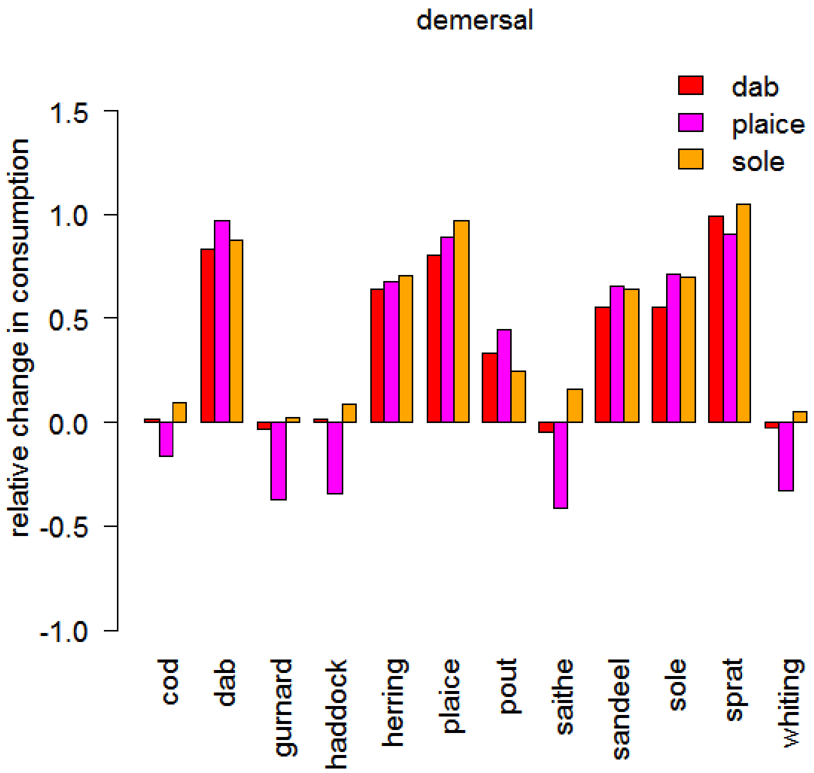

Figure 3. Relative change in flat fish consumption by the other species when reducing the effort of the demersal fleet (Van de Wolfshaar in prep).

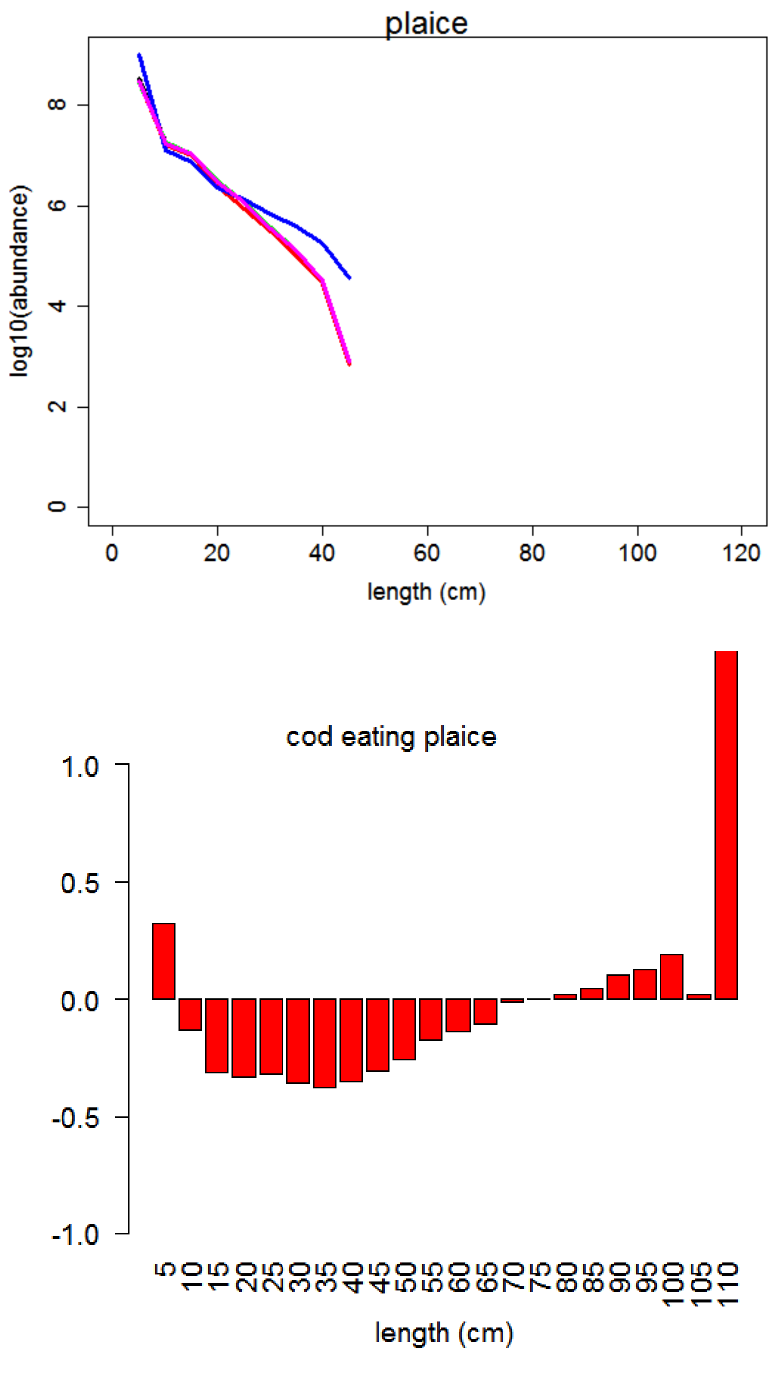

Figure 4. Left graph: Plaice length frequency distribution for the original effort (pink) and for a reduction in effort of the demersal fleet (blue). Right graph: Relative change in plaice consumption by different length classes of cod (Van de Wolfshaar in prep).

Presentation 3: Filling gaps in CPR data (Klaus Huebert)

Klaus Huebert reported progress towards generating empirically based zooplankton biomass maps from continuous plankton recorder (CPR) data. The maps are intended as input for the North Sea Osmose model, specifically the zooplankton subgroup's effort to examine how sensitive higher trophic level models are to differences in zooplankton input. In order to make continuous maps from CPR data of opportunity, a large number of gaps must be filled. The presented method used iterative principal component analyses to impute missing data points. A hierarchical scheme of different imputations at different spatial scales was used, with increased data availability resulting in higher resolution estimates. There was some interest in comparing the performance of this method with more traditional interpolation approaches such as krigging.

Presentation 4: How to best characterize food availability for small pelagics in the Bay of Biscay? (Martin Huret)

Linking lower to higher trophic levels can only be achieved through a clear understanding of the mid-trophic levels, i.e. zooplankton. One of the most pertinent information on zooplankton in terms of trophic transfer towards fish, and especially early life stages, lies in its size structure. Martin Huret and colleagues (P. Vandromme, E. Nogueira, M. Sourisseau) presented an extensive dataset of zooplankton size spectra covering the entire Bay of Biscay in spring and autumn, from 2005 to 2012. Data were collected during coordinated Spanish and French small pelagic fisheries surveys. Zooplankton size spectra were characterized using two complementary methods: (i) in situ measurements of the size distribution by the Laser-Optical Plankton Counter (LOPC), a particle counter recording individuals from 100 to 2000µm ESD at a vertical resolution of about 50cm and (ii) in lab imaging of nets samples (WP2 and Multinet, 200µm mesh size) using the ZooScan methodology. The main patterns of spatial and interannual dynamics of zooplankton size-spectra were presented. First attempt in using this dataset as prey field for an anchovy early life stages IBM was presented. The objective is now to combine this dataset with the outputs of our ECOMARS-3D biogeochemical model to obtain the most accurate information (spatially, size structured and all year-round) on prey for anchovy and sardine in the Bay of Biscay.

Presentation 5: Trophic control of zooplankton dynamics: a review on observations and models (Ute Daewel, Solfried Sætre Hjøllo, Martin Huret, Rubao Ji, Marie Maar, Susa Niiranen, Morgane Travers-Trolet, Myron A. Peck, Karen E. van de Wolfshaar)

We performed a literature review to examine to what degree different regional ecosystems across the Atlantic Ocean are controlled by top–down and bottom–up processes, and how trophic control on zooplankton is addressed by available modelling approaches. In general top–down processes were found to play an important role in all of the ecosystems, but at different spatial and temporal scales. In ecosystems with extreme environmental conditions (e.g. low temperature, ice cover, large seasonal amplitudes) and low species diversity top–down processes were reported to play a significant role. In contrast, ecosystems having moderate environmental conditions and high species diversity are stronger determined by 'bottom–up' processes, but top–down processes were found to shape the zooplankton dynamics on small spatial and at seasonal time-scales. Furthermore, methods utilized to parameterize trophic control on zooplankton in ecosystem models range from simplified approaches with fixed mortality rates to complex coupled multispecies models. The applicability of a method depends on the observed state of the ecosystem and the spatial and temporal scales considered. Here, we can hypothesize that the more vulnerable an ecosystem is to changes in the trophic control, the stronger is the demand for a consistent, spatial-temporal dynamic implementation of predation mortality on the zooplankton compartment.

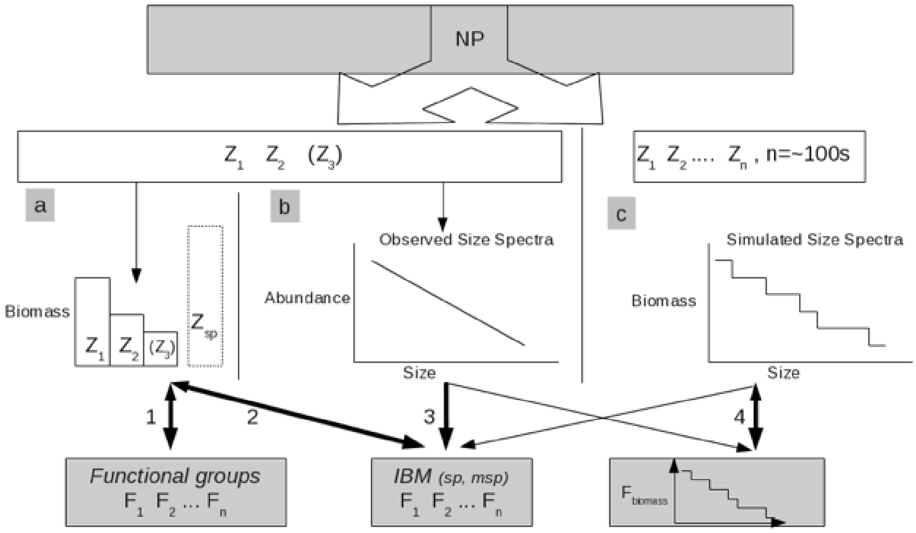

Figure 5. Schematic of the coupling between LTL (Nutrient-Plankton type) and fish (F) models through different zooplankton (Z) formulations: (a) zooplankton is represented as 2 or 3 functional types (FT) with potentially an additional dominant single species (Z_{sp}) for which population dynamic is simulated (e.g. Hjøllo *et al.*, 2012); (b) zooplankton FT are transformed into continuous size distribution from available size-spectra data (e.g. Daewel *et al.*, 2008b); (c) zooplankton is dynamically size-resolved (e.g. Baird and Suthers, 2007). Available models for trophic transfer to fish are indicated by bold arrows: (1) e.g. Fennel (2008) (single species groups); (2) OSMOSE (Travers *et al.*, 2009); (3) Daewel et al., 2008a; (4) Maury *et al.*, 2007, Zhou *et al.*, 2010. Possibility of one- or two-way coupling is indicated by the arrow direction. Thin arrows indicate other possible links between zooplankton and fish.

Presentation 6: Implementing spatially explicit mortality on zooplankton by pelagic fish in the North Sea (Marie Maar)

The implementation of a fish index as a closure term in 3D ecosystem modelling of LTLs was tested for the North Sea, where there is regular monitoring of commercial fish species. The fish index was shown to have profound effects on the interannual, seasonal and spatial patterns of mesozooplankton biomass, production and mortality in comparison with a reference run. However, the fish index did not increase the overall model performance with respect to mesozooplankton biomass data for the years 2001 to 2004. The fish induced mortality generally became too low in autumn and for the year 2004, causing the model to overestimate mesozooplankton biomass in comparison with CPR and monitoring data. Thus, further work on the fish index and its coupling to LTL models is necessary before it can become operationally as a closure term for 3D ecosystem models of the North Sea. Especially, the variability of the consumption by carnivorous zooplankton is suggested to be important when a plying the fish index before a correct description of zooplankton mortality can be obtained.

Presentation 7: Sensitivity of copepod populations to bottom–up and top–down forcing: a modelling study in the Gulf of Maine region (Rubao Ji, Christoph Stegert, Cabell S. Davis)

The spatio-temporal variability of marine copepods, like other aquatic and terrestrial organisms, is controlled by both bottom–up (through changes in physical environment and/or food resource) and top–down (through changes in predation) forcing. Canonically, climate-related changes in hydrography, nutrient chemistry and circulation can modulate phytoplankton production process, thus impose a bottom–up control on marine copepods; whereas human activities such as fishing may affect the predation mortality of copepods through foodweb re-organization such as trophic cascading. Evaluating the sensitivity of copepod populations to the bottom–up and top–down forcing is an essential step towards the prediction of future marine planktonic ecosystem changes. In this study, we used a coupled hydrodynamics/foodweb/population-dynamics model to identify the key processes controlling the observed seasonality and distributional patterns of two copepod groups in the Gulf of Maine region, including *Pseudocalanus* spp. and *Centropages typicus.* Numerical experiments were conducted to assess the sensitivity of the modelled species to changes in phytoplankton biomass and bloom timing, as well as the changes in mortality regime. The results show that both copepod groups are more sensitive to changes in mortality rates than to food availability and peak timing. Bottom–up processes alone cannot explain the observed variability of *Pseudocalanus* and *Centropages* population sizes. Top–down control plays a critical role in copepod population dynamics in the Gulf of Maine region.

Workshop 5: (Joint MABIES / WGIPEM) Incorporating human effects within integrated ecosystem models

Joint ICES WGIPEM – MABIES workshop on "Building ecological-economic models and scenarios"

Olivier Thébaud introduced the workshop organized jointly with MABIES participants on "Building ecological-economic scenarios". He stressed the fact that, as part of the ecosystem approach to managing fisheries and other uses of marine ecosystems, there has been a growing call for the development of integrated assessment tools to support the provision of both tactical and strategic management advice. Of particular importance in this domain is the development of models that capture the dynamic interactions between social and economic systems, and marine ecosystems, allowing identification of scenarios for the future, and evaluation of potential responses to alternative management strategies.

The aim of the workshop was to bring together experts to discuss recent advances and key methodological challenges posed by this field of research. The workshop combined presentations of recent research on a diversity of these challenges, and open discussion of the key domains currently thought to be crucial to progress both the development of these modelling approaches and their application to actual management decision problems.

A first challenge addressed in the workshop relates to the growing demand for tools that, in evaluating the trade-offs associated with managing marine resource systems, fully account for the multiple (economic, ecological and social) dimensions of such trade-offs and the distributional impacts of scenarios across stakeholder groups. Presentations by Luc Doyen, on the viability approach to ecological-economic scenarios, and by Martin Quaas, on the identification of winners and losers in the transition towards sustainable fisheries, illustrated recent efforts at developing such evaluations, while also taking into account the complex set of interactions and the multiple sources of uncertainty which characterize marine ecological-economic systems.

A second challenge relates to process understanding of marine ecosystem uses (including but not limited to commercial fisheries), how this can be modelled, and coupled to biophysical models in order to gain better understanding of the potential consequences of alternative economic, environmental or management scenarios. The presentations by James Innes on modelling fishing behaviour in the Australian Eastern Tuna and Billfish Fishery, and by Christian Mullon on modelling the global tuna catching and trading network illustrated two extremes of the spectrum over which such research has been developing, in an effort to reduce the key source of uncertainty in fisheries management (Fulton Smith *et al.*, 2011; van Putten, Kulmala *et al.*, 2012).

A third challenge relates to the growing complexity of models that couple representations of ecological, economic and social processes, each of which may be affected by uncertainty, making the systematic exploration of sensitivity of model projections to these different sources of uncertainty increasingly difficult. The presentation by Stephanie Mahévas on sensitivity analysis for complex models illustrated the research efforts underway to address this issue, and develop formal methods which enable the systematic evaluation of model projections to the assumptions relating to their parameters. The summary presentation of a workshop focused on "modelling from first principles", by Benjamin Planque, illustrated the need felt by members of this research community to use simple, well-established models, to delimit domains within which projections from the more complex models should remain, and should provide additional understanding or predictive capacity.

Finally, a fourth important challenge relates to the key issues that need to be considered when models are expected to be used in decision-support processes involving multiple stakeholders. The presentations of key steps in developing operational bioeconomic models for fisheries management support by Claire Macher, and of the lessons learned from the SPICOSA European research project in adopting a systems modelling approach to co-construct models of coastal-zone management issues with stakeholders, both emphasized the role which models may have in assisting the management process, as well as the many practical issues which need to be addressed for this role to be effective. The presentation by Tony Smith also illustrated the importance of "social license to operate", and the dangers of taking for granted that evidence-based decision-making can withstand public perceptions relayed through social networks.

Altogether, the approaches presented at the workshop provided a strong illustration of the diversity of modelling challenges which may be involved in attempting to include "human dimensions" in models of marine resources management. Following the session, a subgroup discussion was held, which is summarized in the following section. The abstracts of the presentations at the workshop are presented in the subsequent section. Key references cited by participants during the workshop and in the discussion are listed at the end of this note.

Workshop 6: End-to-end group

Presentation 1: Coupling of ERSEM and Ecosim (Jonathan Beecham, Steve Mackinson, John Aldridge)

Jonathan Beecham reported on the considerable investment made by Cefas in the production, specification and parameterization of two models (ERSEM and Ecosim). which will be integrated to create and end-to-end model; The use of existing models presents considerable modelling challenges as the models use different grids (water column for ERSEM vs. single layer for Ecosim / Ecospace), the basic North Sea EwE model lacks of seasonality, and the functional groups are not wholly compatible. I "Couplerlib" has been developed to marshal data between models, document model contents, compress water columns and convert units, using xml files to specify and document. The Couplerlib has been used to produce a system where a North Sea

Ecosim model of some 64 Functional Groups was driven by the plankton production data from the ERSEM Lower trophic level model.

A comparison has been made of the relative impacts of climate change (2080-2100), changes in management pressure to MSY and changes (reduction) in nutrient loads. The general findings was that climate change had a relatively small effect on plankton production, resulting in typical increases in fish productivity of around 5%, whereas the switch to MSY and reduction in nutrients had a profound effect on production of some groups such as small pelagic species. The reduction of nutrient concentration by 50% had a 33% reduction effect in biomass of small pelagics.

However, these results were interpreted to result from the elements of the linked models (i.e. models were nutrient limited and had no components describing the effects of temperature on fish survival, growth and behaviour). The exercise highlighted the importance of considering more than plankton availability when considering the likely effects of global climate change on upper trophic levels. In particular there was a need for a better zooplankton model and for fish physiology modules in future linked models.

Presentation 2: Atlantis in the Nordic and Barents Sea – NoBa Atlantis (Cecilie Hansen)

Cecilie Hansen provided an overview of an Atlantis model being parameterized for the Nordic and Barents Seas. The model grid covers an area of 4 million km^2, represented by 60 polygons. The shape and extension of the polygons are defined mainly with the aim of keeping the hydrography as homogeneous as possible within the polygon, but do also take biology into consideration (not splitting benthic habitats, spawning grounds, etc.). The model includes seven depth levels and one sediment layer. Physical forcing (temperature, salinity, volume fluxes, and in future ice thickness, ice concentration and snow cover) is from ROMS, which covers the area with a horizontal resolution of roughly 20 km. Light is computed within each polygon, based on longitude and latitude. The 52 functional groups and species are defined based upon published and grey literature as well as via personal communication with experts within the different areas. The groups/species intend to represent the ecosystem in the Nordic and Barents Seas, and the interactions between these (spawning and feeding migrations, transport of zooplankton etc.). Important commercial (e.g. cod, haddock, mackerel), vulnerable (e.g. polar bear, redfish) or key links in the foodwebs (e.g. capelin) have their own groups, whereas other species have been aggregated within functional groups (e.g. skates and rays, mesopelagic fish, small pelagic fish).

At the present time, the Nordic and Barents Sea Atlantis model is being tuned, with several vertebrate groups functioning well. Lower trophic levels capture the seasonal fluctuations, and the total biomass of these trophic levels does not markedly decay or increase during 50-year simulations. Information on Russian and Norwegian fishing fleets in the Barents Sea are now being incorporated in the model, together with harvest control rules (HRC), with the aim of looking at combined effects on the ecosystem from collaboration between Norway and Russia, changes in HCRs and climate change. Through the BarEcoRe project, there are now available observations on several trophic levels in all polygons in the Barents Sea.

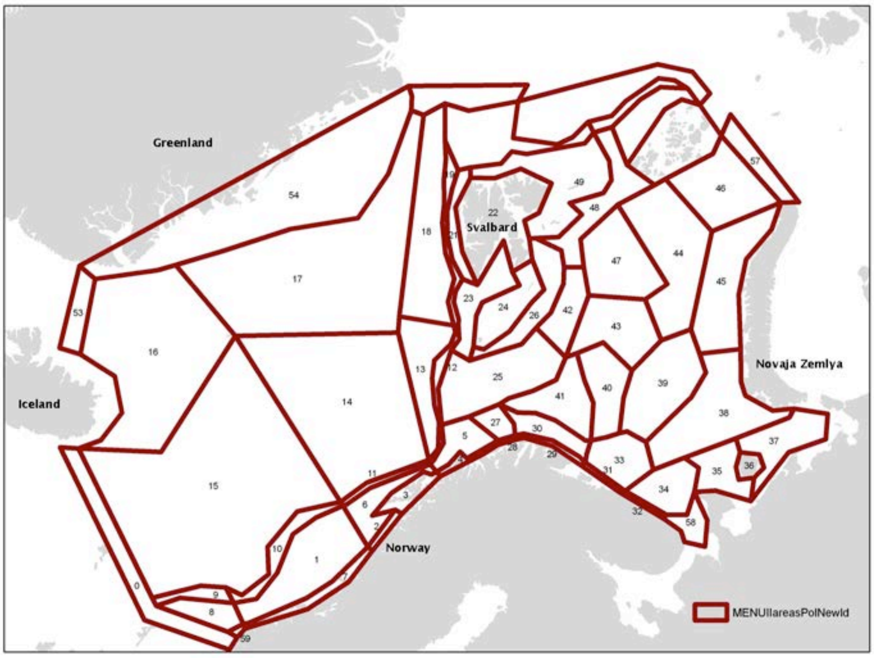

Figure 6. Outline of the Atlantis polygons developed for the Barents and Norwegian Seas model.

Presentation 3: Progress of implementing Atlantis in the North Sea (Marc Hufnagl)

Within the VECTORS Project (Vectors of Change in Oceans and Seas Marine Life, EU FP7, 266445) University of Hamburg (Germany), the Centre for Environment, Fisheries & Aquaculture Science (UK) and the Thünen Institut - Sea Fisheries (Germany) are currently developing an Atlantis type application for the North Sea to examine how the massive installation of wind farms will influence the North Sea ecosystem. The ongoing development involves to a large part of data assimilation and parameter definition. Following the steps outlines by Link *et al.* (2010; Figure 7), the North Sea model is currently in phase 1.

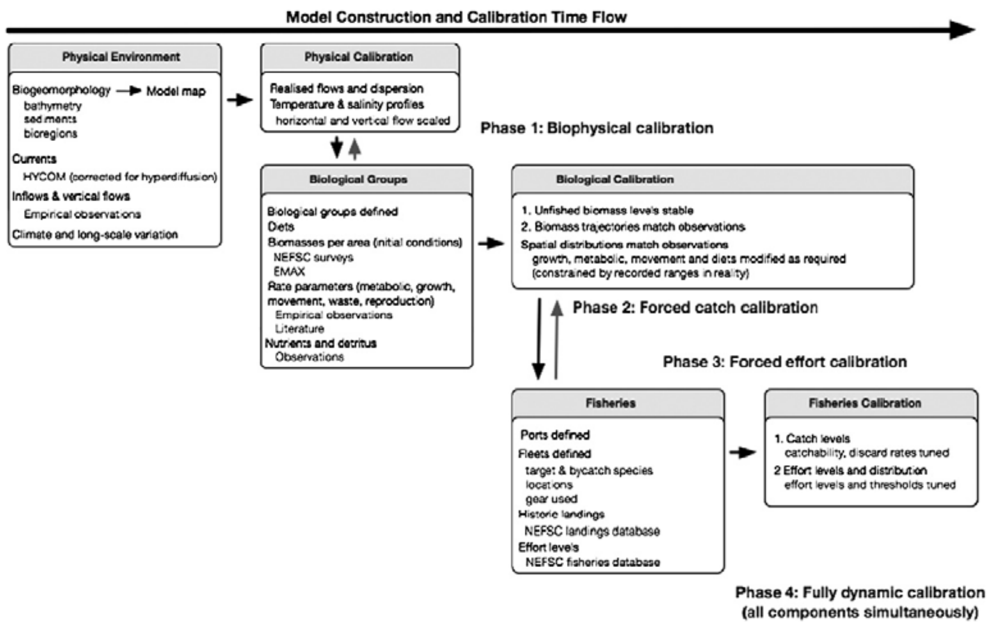

Figure 7. Flow chart of model construction of an end-to-end (Atlantis) model for the North Sea. The chart was developed by Link *et al.* (2010).

The areas, polygons, have been configured (Figure 8) including 25 areas with 91 interacting polygon bounds and a maximum of 7 different depth layers. Depth layers were set to 0, 10, 20, 30, 50, 100, 200 and 1000 m water depth.

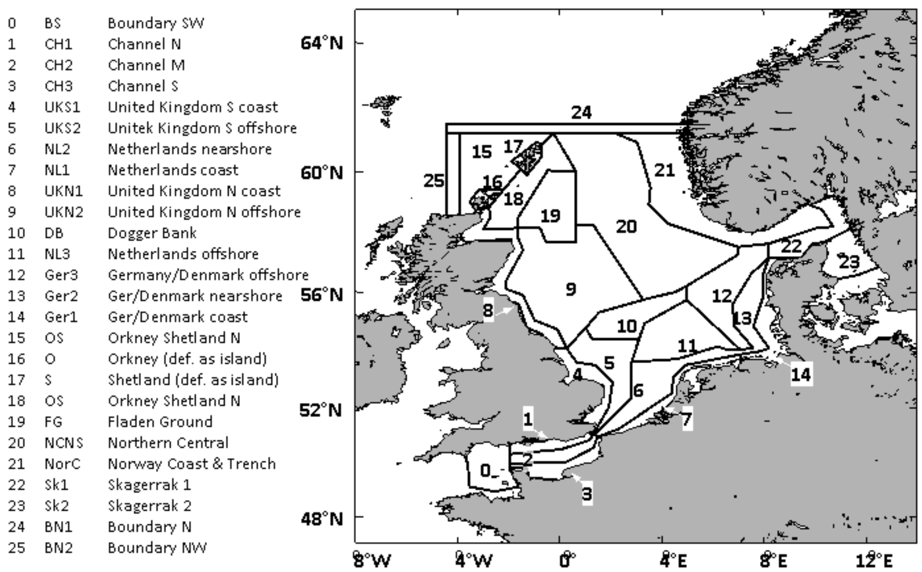

Figure 8. Map of the end-to-end model domain for the North Sea including the location of 25 polygons. Polygons were defined based upon hydrography, bathymetry and species composition (benthic and pelagic).

The physical forcing (exchange between polygons, temperature and salinity data) were extracted from a shallow water baroclinic hydrodynamic model (HAMSOM, Backhaus, 1985; Pohlmann, 1996a&b, 2006). The Ecosystem will contain 53 different biological groups representing all trophic levels as outlined below.

Index	Code	Name	Long Name
1	BWH	baleen_whales	Baleen whales
2	TWH	toothed_whales	Toothed whales
3	SEL	seals	Seals
4	SEB	seabirds	Seabirds
5	PSH	piscivorous_sharks	Spurdog, large piscivorous and juvenile sharks
6	OSK	other_sharks	Other small sharks
7	RAY	skate_ray	Spotted ray, skate and cuckoo ray
8	COD	cod	Juvenile and adult cod
9	WHG	whiting	Juvenile and adult whiting
10	HAD	haddock	Juvenile and adult haddock
11	POK	saithe	Juvenile and adult saithe
12	HKE	hake	Hake
13	WHB	blue_whiting	Blue whiting
14	NOP	norway_poud	Norway pout
15	OLD	other_large_demersals	Other large gadoids, catfish and large demersal fish
16	OSD	other_small_demersals	Other small gadoids, dragonets and small demersals
17	MON	monkfish	Monkfish
18	GUR	gurnards	Gurnards
19	HER	herring	Juvenile and adult herring
20	SPR	sprat	Sprat
21	MAC	mackerel	Mackerel
22	HOM	horse_mackerel	Horse mackerel
23	SAN	sandeel	Sandeels
24	PLE	plaice	Plaice
25	DAB	dab	Dab and flounder
26	WIT	witch	Witch, long rough dab and lemon sole
27	SOL	sole	Sole
28	TUR	turbot	Turbot, brill, megrim and halibut
29	ESB	bass	Bass
30	MUR	red_mullet	Red mullet
31	SPF	small_pelagic_filterfeeders	miscellaneous filter feeding pelagic fish
32	SQZ	squid	Cephalopod
33	PAD	pandalus	Pandalus borealis
34	CSH	crangon	Crangon crangon
35	NEP	nephrops	Nephrops
36	LCR	large_crabs	Large crabs
37	SEP	small_epifauna	Small mobile epifauna
38	SES	sessile_epifauna	Sessile epifauna
39	MEP	epifaunal_macrobenthos	Epifaunal macrobenthos
40	MIP	infaunal_macrobenthos	Infaunal macrobenthos
41	SIN	small_infauna	Small infauna
42	GEL	gelantinous_zoo	Gelatinous zooplankton
43	BMI	benthic_microflora	Benthic microflora
44	MEI	meiofauna	Meiofauna
45	MIZ	micro_zoo	Microzooplankton

Index	Code	Name	Long Name
46	MEZ	meso_zoo	Mesozooplankton
47	PMI	planktonic_microflora	Bacteria and heterotroph nanoflagellates
48	PHD	diatoms	Phytoplankton (diatoms)
49	PHO	other_phytoplankton	Phytoplankton (non diatoms)
50	SPO	sediment_detritus	Particular organic matter in sediment
51	LDT	labile_detritus	Labile detritus
52	RDT	refractory_detritus	Refractory detritus
53	CAR	carrion	Discards

The potential top–down control of the ecosystem in the form of fishing pressure will be included as catch time-series for the different sectors extracted from the general assessment reports (e.g. ICES WGNSSK, WGmixfish, WGSAM etc.). These data are already available and need to be included in the NS-Atlantis version.

In March and April 2013, the group will finish the compilation of the parameters and will start to include all values, parameters and start condition into the Atlantis formats. Members of the group will also travel to CSIRO to work with Beth Fulton to move through the initial steps of Phase 1. Calibration of the physics and the biology and balancing energy flows between the biological groups should be accomplished by the end of 2013. Fishing effort data (partial F) are already included so that balancing will include the fisheries pressure. At the moment it is not intended to run Atlantis with the full economical module. Thus, Phase 1 and portions of Phase 2 will be completed within the VECTORS project. Phase 3 and 4 will be conducted in 2014.

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4 Identify gaps in knowledge in these modelling activities and recommend activities to advance coupled modelling approaches and that will make model outputs useful to the management of marine systems (ToR-c)

Workshop 1: Climate Subgroup (4 participants)

Most of the participants of WGIPEP are working on tools relevant to examining climate impacts on marine ecosystems and/or their key species. However, there was a perception in this small subgroup discussion that a mismatch exists between the spatial scales of models being developed by WGIPEM members and those of physical climate scientists. Therefore, there is a need to strengthen the physical oceanographic expertise of the group including researchers involved in dynamic downscaling of IPCC-class earth system models to provide regional forcing appropriate to modelling biological consequences (See Stock *et al.*, 2012). A similar spatial-scale mismatch (between fisheries and ecosystem scientists and the physical oceanographic community has been discussed in reports of the WGOOFE.

Next Steps

1) WGIPEM along with members of the ICES-PICES SICCME will convene two theme sessions at the 2013 ICES ASC on climate impacts (sessions B and M). At the writing of this report, nearly 50 talks and 35 posters have been accepted for session B.

2) Members of WGIPEM along with ICES-PICES SICCME will meet intersessionally in St Petersburg to discuss climate change impacts on the spatial distribution of fish and fisheries.

3) Continue to build inroads to the physical oceanographic community perhaps through joint discussions with the ICES WGOH.

Workshop 3: Fish Movement Subgroup (16 participants):

The Movement subgroup had defined 6 tasks at the Copenhagen meeting:

(a) Document the existing movement algorithms used and create a library of movement models.

(b) Test all or some of these movement models using the method of Watkins and Rose.

(c) Review and select some spatially explicit single-species models and foodweb-oriented models (e.g. Atlantis, OSMOSE) to further test the movement models under conditions (actual models) they would be used in.

(d) Determine scenarios (e.g. baseline, harvest strategies, closed areas, climate change) for quantitatively comparing the effects of the different movement models on model predictions of population and foodweb dynamics.

(e) Find a volunteer(s) to take the lead on the papers:

(e.1) theoretical basis for modelling movement

(e.2) validating movement models

(f) Determine subgroups to outline a methods paper on how to simulate super-individuals in end-to-end models and a subgroup to outline a paper on past and emerging methods for testing movement model predictions.

Progress was made during the intersession on tasks (a), (b), (e.2), and (f).

Progress on Tasks (a) and (b). – Dimitris Politikos sent K. Rose the movement algorithm they are using for representing movement of anchovy in North Aegean Sea. K. Rose (and Katherine Shepard) then coded the movement model and ran their evaluation tests (Shephard and Rose, 2013) so the performance of the Politikos *et al.* movement model could be judged and compared to the performance of four other movement models commonly used to simulate fish movement in IBMs. K. Rose then presented the results of the evaluation in his update presentation to demonstrate the methods and results of the Shepard and Rose method for evaluating movement models under tasks (a) and (b).

Summarize the idea of numerical lab to evaluate skills of movement modules?

Progress on Task (f). — During the intersession, Geir Huse and K. Rose developed a detailed outline on the bookkeeping and other issues related to using super-individuals in IBMs. Super-individuals (Scheffer *et al.*, 1991) are now widely being used in many IBMs, including end-to-end models. While the general concept is simple, there are many challenges to ensuring accurate solutions when super-individuals are used in full life cycle and spatially explicit models. This paper will be a methods paper that identifies the common problems faced with using super-individuals in end-to-end models and some possible solutions to these problems.

Progress on Task (e.2) — The subgroup meet in working session and outlined a paper on validating movement models. The idea is that most validation of fish movement models to date have focused on matching snapshot distributions generated by the model with spatial maps of biomass and abundance of fish estimated from surveys and acoustic sampling. These comparisons are very important for ensuring that the movement model results in fish being the appropriate places at the appropriate times. However, these comparisons do not enable judgment as to whether the pathways or trajectories of the individual fish were realistic. The data collection (tagging technology) described by Julian Metcalfe does provide the trajectories of individual fish, and the technology is now cheap enough to allow for large sample sizes and information not only on position but also on the environment (e.g. temperature, dissolved oxygen) experienced by the fish.

The subgroup developed a detailed outline of a paper that identifies this situation of rising use of IBMs in coupled biophysical and end-to-end models and the increasing availability of trajectory data. The issue in the near future will be to use the combine the two in order to develop more confidence in our movement submodels that are often imbedded in larger models of population and foodweb dynamics.

Next steps (Action Items)

The Movement subgroup identified the following activities during intersession:

(1) *Increase the number of movement submodels to be compared.* Models will be sent to K. Rose to add to the Politikos *et al.* model and to continue the development of the movement model library and evaluation (Tasks (a) and (b)).

(2) *Produce an outline of the methods for using super-individuals* (Task f) will continue by Geir Huse and K. Rose, and will be circulated to the entire working group during intersession for input and comment.

(3) *Review and summarize movement research in other fields* (e.g. birds) to compare movement model output to trajectory data and what statistical methods have been applied to analyse and generalize the patterns observed in measured trajectories. These mini-reports will be circulated to the subgroup members and used as the basis of whether to proceed with a paper. The paper could be a workshop report published as a short paper in a journal or a longer perspectives-type paper for a journal. At the 2014 meeting, there is interest to examine various metrics and statistical ways of comparing trajectories of animal movements.

(4) *Convene a joint meeting* with human dimensions subgroup on similarities of fleet and fish modelling at the 2014 WGIPEM meeting.

Workshop 4: Modelling Zooplankton Dynamics Subgroup (14 participants)

The zooplankton subgroup identified two main research objectives at the kick-off meeting in Copenhagen. These were based upon two questions:

a) What is the effect of different phyto- and zooplankton fields from NPZD models on higher trophic levels, such as Osmose or single species IBMs?

b) How is predation by higher trophic level and top–down control addressed in modelling approaches and how does that compare to observations in different regional ecosystems?

Progress on Task a) An update on related work was given by Karen van de Wolfshaar on the implementation of OSMOSE in the North Sea, and by Klaus Huebert on the use of CPR zooplankton data as input for HTL-models. Another highly relevant topic concerns the size resolution of modelled zooplankton fields and has been addressed by Martin Huret who talked about 'Combining size-spectra observations and biogeochemical model to feed small pelagics in the Bay of Biscay'

Progress on Task b) Here the group decided to work on this question in the frame of a common paper including both literature review as well as process oriented modelling experiments. During the last year the group has thus worked on a common review paper that was recently submitted to the ICES Journal of Marine Science and Ute Daewel gave a short overview on the paper during the meeting. Related to this topic, Marie Maar presented ongoing work on how to derive spatial-temporal fields of fish consumption from available observations in the North Sea, Tineke Troost introduced Latest developments in grazer modules in the Delft3D software, and Rubao Ji talked about copepod modelling at Georges Bank with a focus on the sensitivity of copepod populations to the bottom–up and top–down processes.

Discussions at the 2013 WGIPEM meeting highlighted the need for dissemination and exchange of the group's expertise focussing on two major aims: (i) sharing model codes and experience via a model library, and (ii) identifying research needs related to "inter-trophic level" modelling by providing an interactive review/information table on model structure and linkages.

Next Steps (Action Items)

(1) Build a zooplankton model library. The purpose of a library for the zooplankton group would be more than an overview of meta-information but should also include

routines, models and scripts. Solfrid Hjøllo has agreed to lead this effort at the first meeting in Copenhagen. A Google code site (http://code.google.com/p/zooplib/) will be used which includes version control on codes and comments, and allows specifically an interactive, multi user development of the library. The library will include:

- Codes and routines to create a community on zooplankton routines
- Parameter setting for comparison and discussion
- The library will not be limited to members of the zooplankton group but should be available to all interested members of WGIPEM
- At a later stage the library can be linked to the ICES WG on zooplankton ecology (WGZE) and relevant project webpages like MEECE.
- The responsible (and contact) persons for the library are Solfrid Hjøllo and Rubao Ji.

(2) Create an interactive information table on trophic coupling (zooplankton-HTL) in ecosystem models. The basic idea is to provide a visual overview about current approaches (model structure, model aims, basic information) and the structure of applied zooplankton fields. Additionally the table should include information about the actual requirements of HTL models in terms of zooplankton fields to identify research needs for zooplankton model development. Figure 9 shows a possible realization of the table. The subgroup members agreed to provide the relevant information from their own models for a first attempt on the table. (Nicolas Dupont, Ute Daewel, Rubao Ji)

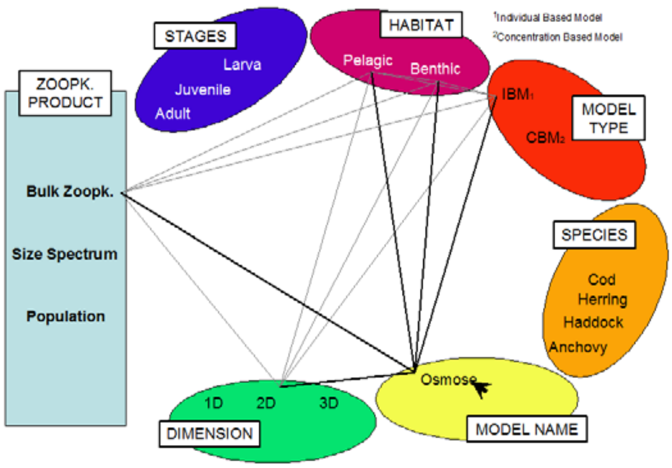

Figure 9. Example of an interactive, visual table representing trophic coupling within ecosystem models.

(3) Utilize size-spectrum theory to partition bulk formulations of zooplankton carbon from NPZDs into size-structured prey fields. Based on the importance of size based feeding interactions of higher trophic levels there is a need for a more size-differentiated zooplankton product from the NPZD models, while currently most of the latter provide bulk estimated of phyto- and zooplankton. A conversion of the bulk biomass to size bins is not straightforward and depends on the availability and quality of relevant observations. To identify the applicability of different modelling methods Martin Huret will compare results from a 'NP-Zooplankton size-spectrum' model to zooplankton bulk estimates from a 'standard' NPZD model (bulk biomass converted to size spectra using observations) using the so called Observing System Simulation Experiment concept.

(4) Test how different LTL models influence the dynamics of upper trophic level foodweb models. This is a continuation of the work on the effects of LTL model output (from a common year – 2004) on HTL model results. The sensitivity of the HTL simulations to differences in model-derived plankton fields will be examined.

(5) Explore trait-based modelling of zooplankton using the theoretical framework provided by Frederic Maps with an emphasis on changes in species composition and how that could affect upper trophic levels. For example, changes in species composition may lead to differences in energy contents of zooplankton affecting feeding and growth dynamics of zooplanktivores – with cascading effects to higher trophic levels.

(6) Publish a review paper comparing the processes (top–down, bottom–up) controlling zooplankton within various ecosystems and how mortality is implemented in different types of models

A total of 14 people expressed interest in ongoing activities of the zooplankton discussion group: Ute Daewel, Morgane Travers, Rubao Ji, Frederic Maps, Susa Niiranen, Martin Huret, Marie Maar, Luz Garcia, Tineke Troost, Nicolas Dupont, Karen van de Wolfshaar, Klaus Huebert, Rosa Barciela-Fernadez and Myron Peck (the final three were not present during some discussions).

Workshop 5: Human Dimensions (Summary by Olivier Thébaud)

Olivier Thébaud presented an update on the "human dimensions" component of the WGIPEM's activities since the 2012 meeting in Copenhagen. As had been agreed, the first steps involved strengthening linkages with other researchers in this space, and seeking to increase participation of economic and social science researchers in the activities of the WG. This was pursued via networking activities, including:

a) Participation in a special session of the biannual conference of the International Institute for Fisheries Economics and Trade, organized by Dan Holland and SGIMM co-chair Eric Thunberg, on "Coupled Economic-Ecological Models for Ecosystem-Based Fishery Management: Exploration of Trade-offs Between Model Complexity and Management Needs", and discussion with SGIMM co-chairs J. Rasmus Nielsen and Jörn Schmidt of the potential links that could be established between the activities of the study group and WGIPEM;

b) Submission of a proposal for a special session at the 2012 Bioecon conference. The proposal was accepted but failed to attract submissions in time for the session to be held, due to the short timeline under which it was organized;

c) Submission of a proposal for a special session at the 2013 ICES Annual Science Conference in Reykjavik, Iceland, on the theme "Modelling human behaviour as part of integrated models of marine ecosystems", which was accepted;

d) Proposed organization of a joint session at the annual WGIPEM meeting, with scientists attending the MABIES (http://cermics.enpc.fr/~delara/MABIES/MABIES/) initiative organized as part of the 2013 "Mathematics of Planet Earth" year, in Paris during the same period.

On behalf of J. Rasmus Nielsen, Eric Thunberg and Jörn Schmidt, who were unable to attend the meeting (and the lack of availability of video conferencing at the Paris meeting rooms), Olivier Thébaud gave a brief presentation of the activities of the

ICES Study Group on Integration of Economics, Stock Assessment and Fisheries Management (SGIMM). Rationale for the activity of SGIMM is based on the increasing demand for coupled ecological and economic models in advisory bodies, while the benefits of coordinating ecological and economic expertise have not yet been captured to their full extent. The goal of the study group is to contribute to progressing the coupling of economic expertise directly with ecological understanding within ICES, to enhance the quality of fisheries assessments and the value of the advice. Activity of SGIMM has focused on (i) initiating a survey of existing bioeconomic models with a broad coverage within the ICES community; (ii) developing a standardized model characterization and evaluation matrix to describe each model; (iii) establishing cooperation with international research networks relevant to this field, including via the organization of special sessions at the World Fish Congress (20 presentations at a theme session entitled " Ecological-Economic Modelling Tools to be Used in Integrated Fish Stock and Fisheries Management, May 2012, Scotland) and the International Institute for Fisheries Economics and Trade (Invited presentations and panel discussion at a theme sessions entitled: "Coupled Economic-Ecological Models for Ecosystem-Based Fishery Management: Exploration of Trade-offs Between Model Complexity and Management Needs", July 2012, Tanzania). Questions discussed in the latter included modelling feedbacks from the economic system to the ecological system, model complexity, model robustness, scales of economic vs. ecological models, inclusion of non-market values and communication of results. SGIMM identified a large number of models being developed across a wide range of issues and scales, with both strategic and tactical applications.

Next Steps (Action Items)

1) *Convene a theme session at the 2013 ICES ASC* which hopefully leads to papers on coupled ecological and economic modelling tools.

2) Publish a summary of this workshop in a peer-reviewed journal such as Marine Policy

3) *Compare movement approaches* used for modelling fleet dynamics and fish movements (from movements subgroup)

Workshop 6: End-to-end (Atlantis) Subgroup (4 participants)

The small group discussed philosophical questions concerning model complexity and design in light of the different approaches represented within WGIPEM and elsewhere. The importance of end to end modelling has increased as a result of legislation such as the Marine Strategy Framework Directive (European Union) and various white papers on ecosystem based approach to management (e.g. Olsen *et al.*, 2007) which requires fisheries managers to think in a holistic way, with reference to multiple pressures (climate change, invasive species, changes to fishing pressure, eutrophication etc.) and outputs (biodiversity, foodwebs, commercial species, seabed integrity; Brander 2007). Consequently there has been large-scale initiatives, particularly those instigated at European Union: VECTORS, MEECE, and OPEC. Furthermore, a globally unique regional effort on studying the ecosystem effects of climate change, from biogeochemical cycles to fish, was carried out on the Baltic Sea in a project ECOSUPPORT using a multi-model approach linking models of different hierarchies (Meier *et al.*, 2012; Wake, 2012).

A number of forward looking reviews have been produced (e.g. Plaganyi, 2007) which have concentrated on considering the most appropriate strategies for devising end to end models, and have asked a number of provocative questions e.g. Kenneth

Rose has suggested that inappropriately joined and over complex models can be the modelling equivalent of 'putting lipstick on a pig'. However, the subject is still in its infancy and, although there are general directions for taking modelling forward, there is yet to be a comprehensive evaluation of the suitability for different end to end models for a variety of tasks.

Next Steps (Action items)

As recognition of the continued development of different end-to-end modelling approaches in the ICES community and elsewhere, the group had decided to:

1) Construct and test end-to-end models in various ecosystems. Some members of this subgroup plan to meet in Hamburg to discuss model parameterizations and create the first model simulations for the North Sea, the Channel, and the Straits of Sicily. Further steps towards creating an Atlantis model for the Baltic Sea will be taken at that meeting. Other end-to-end models for European waters (e.g. NPZD-OSMOSE approaches) are in more advanced phases of development and should be reporting results by the next meeting (2014).

2) Create a database of end-to-end models which helps address ToR d and is consistent with the role of ICES as the repository for a large amount of information concerning fisheries and the marine environment. In view of the critical role of WGIPEM in this area, the group has decided to construct a database of end to end model systems, their properties and, crucially, an evaluation of their advantages, disadvantages and performance. In addition, we will explore different ways of evaluating these models, their results and vulnerability to input parameters and estimations, and give an overview of these.

A draft proposal for this database was provided by Jonathan Beecham. It included:

1) Critical Properties of Model Systems (with an emphasis on systems and pressures (e.g. 'modelling of climate change and fisheries management in the bay of Biscay')

- a) Strategic questions
    - a. Why are we doing this? Probably the most important question to start with when evaluating E2E models
    - b. What do we want to get out of this? Is knowledge primarily quantitative or qualitative, is it about exploring the system or producing real numbers and predictions which can inform policy?
    - c. What is the actual 'end' of the E2E model? – Fish, fisheries, communities, value etc.
    - d. Who are the players involved in the model – fishers, communities, states, environmental organizations, scientists etc. Each will have different expectations of what they want to get out of the model.
- b) Technical Questions about the Models. Some of this information will be about the end to end system, some about the components in the model and some specifically about the system being modelled.
    - a. What is the location and time frame of the model?
    - b. What type of system is being modelled (benthic, pelagic, coastal, open ocean, all of these, etc.?)
    - c. What is the fundamental numerical methodology: Is it a numerical model or a softer model focussing on knowledge and less quantitative information, is the model deterministic or stochastic?
    - d. What models (e.g. EwE OSMOSE) and computer systems are being used, what language is it programmed in?

  e. How are ecological entities represented: Species groups based, functional Group based, size-spectrum, IBM or other?
  f. What grid type is used, including vector representation or non-spatial? What are the temporal and spatial dimensions of the models?
  g. How many species / functional groups / types of individuals are included in the models?
  h. How many parameters does the model use? Which of these what are explicitly measured, available in the literature, estimated (e.g. by fitting or genetic algorithm), taken as model defaults, or guessed
  i. How are the various models linked? Online / Off-line / one way / two way?
  j. How are the mismatches between data and scale dealt with in the case of model linkage?

c) Questions about Testing / Evaluation of Model System
  a. What validation metrics are generally produced by the model?
  b. What independent data are used to calibrate the model?
  c. What representation of uncertainty is there in the model?
  d. What sensitivity analysis can / has been carried out on the model?
  e. What are the greatest areas of success / failure in the model output / predictions
  f. Evaluation of critical outputs on the six point scale
    i. Crash and Die – Either the computer program crashes or the output is largely made up of non-values (NaN), inappropriate negative or too high values.
    ii. Fails the Laugh Test – The numerical values of the model components are clearly unreasonable – excessively fat / thin fish, excessive populations etc.
    iii. Expert Says No – An expert in the domain could view the results and clearly say that the model output is not realistic of the system in question e.g. that a stock size is not what is commonly encountered.
    iv. Not Empirically Validated – Superficially the model predictions look right, but fail validation with a good dataset.
    v. Fantastic Figures – Numeric validation of model aspect is good, seems to fit existing hindcast data.
    vi. Bet the Planet – We are confident that the model could be used for critical evaluation of systems of major ecological and economic value.

d) Future Directions for the Model System
  a. Is it likely that other model approaches may be used in future?
  b. What is the scope for simplifying the model, and what would be gained/lost with a simplification?
  c. What components / algorithms etc. would we like to add to the model in future?
  d. What new parameters do we wish to add to the model / do we have a good way of obtaining their values?
  e. What new ways are there likely to be to test the model?
  f. Is the model likely to be used in different areas / system domains in the near future?

g. Possibilities of exchanging information on the boundaries/overlapping areas of the models

The idea is that the end-to-end subgroup should collate this information and that, as the models evolve, the information will increase /improve. We should retain this information and update it on a regular basis. Once this information has been gathered online, the group could move towards producing a review paper focussing on performance evaluation. Members of WGIPEM will discuss this activity intersessionally and start activities after the 2013 ICES ASC.

Proposed Workshop for 2014: Projections from physiological-based models

Metabolic theories aim to capture how organisms acquire energy and matter from their environment and allocate it to growth, maintenance, development and reproduction. A number of tools being developed by WGIPEM participants utilize metabolic theory including aspects of the growth physiology of target organisms. Recent reviews have suggested how to strengthen the predictive capacity of various types of models (from bioclimate envelop to foodweb models) by incorporating physiology (Jørgensen *et al.*, 2012). Physiological traits expressed at the organismal level have community- and ecosystem-level consequences. The WGIPEM recognized the importance of accurately parameterizing the growth bioenergetics including the physiology underpinning growth, movement and feeding. WGIPEM meeting include a specific workshop on bioenergetics. This workshop would include topics such as Dynamic Energy Budget (DEB) theory (see below), traditionally balanced bioenergetics rates of zooplankton and fish as well as impacts of environmental factors on growth physiology (rate, tolerance, efficiency, etc.).

Background information on DEBs (Lorna Teal)

DEBs describes the metabolic dynamics of an individual organism through its entire life cycle and DEB models can provide a mechanistic tool to understand energy flow in an organism. The strength of DEB theory is its generality not only across taxa, but also between plants and animals, ectotherms and endotherms, heterotrophs and autotrophs. Such generality requires a degree of abstraction in the formulation of the theory and it is here where the, in effect, simple theory can be difficult to grasp. The formulation contains, for example, primary variables, which cannot be directly observed. The parameters used to describe the processes and which have dimensions that relate to the primary variables are therefore also not possible to measure in real life.

In a standard DEB model (Figure 8, an individual organism is described by three state variables: structural body volume (Structure, V, cm^3), reserves (Reserve, E, J) and reproduction buffer (Maturity or Reproduction Buffer, R, Joule). Energy flows between the sources, sinks and state variables through processes indicated by the arrows in Figure 10.

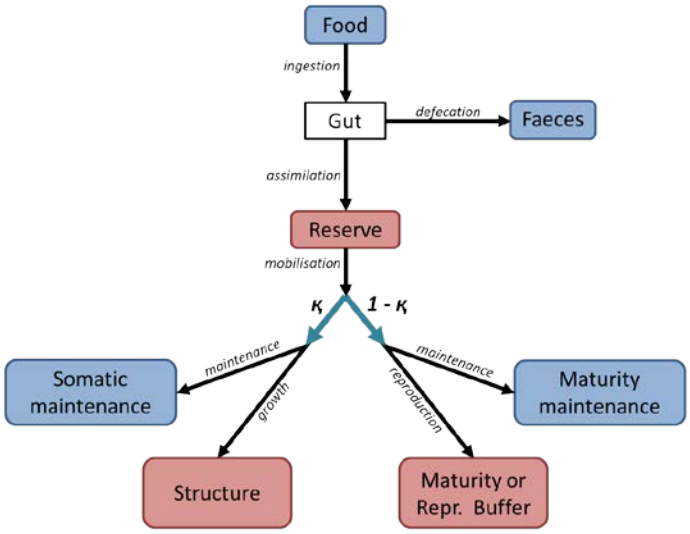

Figure 10. A schematic representation of the standard DEB model showing the paths of energy flow through an organism. Blue boxes represent sources or sinks of energy, red boxes indicate the three state variables describing the organism. Processes by which energy flows are described by black arrows.

A number of approaches have been developed to estimate DEB parameters but have typically involved only a subset of the core DEB parameters and have required very specific and rarely collated experimental datasets. recent publications (Lika *et al.*, 2011a) present a methodology for estimations a consistent manner across species, ensuring direct comparability of the resulting parameters (Kooijman, 2009). To ensure consistency, software has been developed and it is hoped the developed procedure will help guide experimental research (see http://www.bio.vu.nl/thb/deb/deblab/debtool). Joint efforts of scientists studying specific species has allowed a (to some extent quality controlled) DEB parameter library to be assembled which can provide useful parameter information for modellers.

Core parameters are intimately linked to the underlying assumptions of DEB theory and relate directly to processes controlling state variable dynamics, such as life cycle transitions, feeding, digestion, assimilation, mobilization, allocation, maintenance, growth, reproduction, development, respiration, product formation and ageing. All aspects of the fluxes of energy and mass (i.e. chemical elements) are covered in dynamic environments (temperature, food availability), including stoichiometric constraints on production, while biomass can change in chemical composition (Lika *et al.*, 2011b). Auxiliary parameters link the abstract variables to quantities that can be directly measured (e.g. length, wet or dry weight, respiration, fecundity, etc.). The auxiliary theory thus specifies the relationships between volumes and weights, energies and other measurable quantities in the context of DEB theory (Lika *et al.*, 2011b). The combination of core and auxiliary theory defines "mapping functions" from the abstract to the real world and vice versa (Figure 11). Both core and auxiliary theory substantially simplify a very complex reality on the basis of a list of explicit assumptions that, in combination, fully specify DEB theory (Kooijman, 2010).

Primary parameters are related to a single underlying process. Compound parameters typically depend on several underlying processes. The core and auxiliary parameters are considered as primary parameters, on which compound parameters can be based.

Real data, i.e. empirical observations of physiological processes are used by the co-variation method to estimate the core DEB parameters. However, the estimation procedure may be guided by prior knowledge of parameter values, in a similar way to the use of a 'prior' in Bayesian parameter estimation methods. Conceptually this prior knowledge is treated as data and is therefore referred to as pseudo-data. Real data used in the estimation procedure can take the form of zero-variate data, i.e. single numbers such as age or length at birth or maturity, maximum reproductive output etc. or univariate data, such as age–length, length weight, growth-temperature data etc.

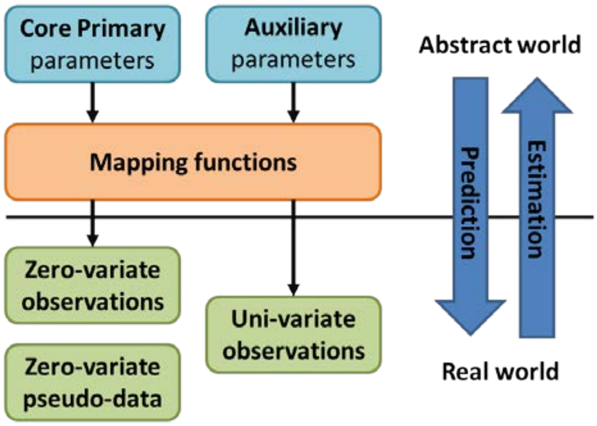

Figure 11. A schematic diagram of the linkages between the abstract DEB theory and parameters and the real world observations (from Lika *et al.*, 2011b).

DEB models have been applied to look at effects of climate change on spatial distributions of flatfish (Teal *et al.*, 2012) by inputting environmental data (temperature, food conditions) from ecosystem models into a DEB model and calculating scope for growth. Spatial maps of scope for growth can be used to look at shifts in fundamental niche in relation to seasonal or interannual variation in the environment (see also Fässler *et al.*, 2012). Understanding these shifts through the underlying physiology of the species gives a more mechanistic understanding on which to base future projections.

Apart from growth, DEB can also be used model reproduction (Pecquerie *et al.*, 2009, Teal and van der Hammer, in progress) and therefore a link between environment and species productivity. As DEB can be applied to the full life cycle of an organism it is a useful model for work connectivity between life stages as was discussed in work on anchovy in the Bay of Biscay by Martin Huret and Pierre Petitgas.

Rates and processes in DEB are driven by species temperature tolerance ranges and a number of parameters govern the temperature dependant output of the model: Arrhenius temperature (TA), upper and lower tolerance range (TL and TH) and rates of decrease at upper and lower boundary (Tlow, Thigh). Knowledge of these values or data that could be used to reliably parameterize these values is lacking for those species that have not been extensively studied in the laboratory (a drawback for using DEBs to explore climate impacts). As effects of climate change are often seen at the limits of a species tolerance, more accurate information on these critical thresholds is needed. In terms of DEB this means either collation of specific data to allow parameterization of these values or a better understanding of the physiology which would allow theoretical modelling of the physiological knowledge within the model.

The WGIPEM will discuss the best format of this workshop and build consensus on its duration and content. It is envisioned that one or two keynote speakers will be invited to discuss physiological-based modelling tools.

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5 Provide an interface to the public and scientific community by building a model code library and maintaining a website (ToR-d)

The launching of the new ICES website directly before the 2013 meeting in Paris provides an opportunity to work with the secretariat to provide a website dedicated to the products and activities of the group. Based upon last year's discussions, the website should contain 1) ample links to other modelling website, 2) a model code library, and 3) selected examples of ongoing work of WGIPEM. The co-chairs agreed to discuss the website with ICES prior to the ASC in Iceland. As previously stated, the zooplankton subgroup will use Google code.

6 Preparation of 2014 meeting

The time and place of the 2014 meeting are currently under discussion. An offer by IMARES / DELTARES for hosting the next meeting in Haarlem / Amsterdam, The Netherlands was well received. Given the size of the group and the need for video conferencing (which was not available during the 2012 meeting), a second option is to hold the meeting at ICES HQ in Copenhagen, Denmark.

A week-long meeting will be planned that includes both workshops, plenary (similar to the 2013 meeting). That meeting will include follow-up workshops on 2013 action items including updates on recent advancements in end-to-end modelling including i) parameterization of ecosystem components (hydrodynamics, lower and upper trophic levels) and ii) human activities and behaviour. Specific workshops will be convened to discuss how iii) elements of the growth physiology of animals as depicted within classical and dynamic energy budgets and iv) first results of new end-to-end models developed for European waters. These workshop themes will be discussed in the coming months.

It is envisioned that the meeting will take place at some point between early March and early April 2013. A doodle calendar will be established in an attempt to find the most suitable dates.

7 Other business

Similar to the first meeting in 2012, there were ad hoc discussions throughout the 2013 meeting about how best to obtain funding to promote the activities of the group. Many group members were involved in consortia addressing recent EU research calls which may provide funding for attendance within and outside Europe.

Photo including 23 of the 36 participants of the 2013 WGIPEM meeting in Paris. The photo was taken on Friday 1 March, 2013 and some participants departed prior to the photo: (standing, left to right) Jean-Marc Guarini, Anna Akimova, Frédéric Maps, Alejandro Gallego, Jonathon Beecham, Cecilie Hansen, George Tryantafyllou, Susa Niiranen, Kenny Rose, Pierre Petitgas, Luz García, Ruiz Manolo, Nicolas Dupont, Karen van de Wolfshaar, Dimitris Politikos, Kostas Tsiaras, and Klaus Huebert: (sitting, left to right) Dimitris Politikos, Martin Huret, Momme Butenschön, Myron Peck, Rubao Ji, and Lorna Teal.

Annex 1: List of participants

NAME	AFFILIATION	COUNTY	E-MAIL
Anna Akimova	TI Sea fisheries	Germany	anna.akimova@vti.bund.de
Jonathan Beecham	Cefas	UK	jonathan.beecham@cefas.co.uk
Momme Butenschön	PML	UK	momm@pml.ac.uk
Marina Chifflet	AZTI	Spain	mchifflet@pas.azti.es
Ute Daewel	University of Bergen	Norway	ute.daewel@gfi.uib.no
Nicolas Dupont	University of Bergen	Norway	nicolas.dupont@bio.uib.no
Alejandro Gallego	Marine Scotland Science	UK	a.gallego@marlab.ac.uk
Luz María García García	IEO	Spain	luz.garcia@co.ieo.es
Jean-Marc Guarini	University of Paris	France	guarini@obs-banyuls.fr
Cecilie Hansen	IMR	Norway	Cecilie.Hansen@imr.no
Klaus Huebert	University of Hamburg	Germany	klaus.huebert@uni-hamburg.de
Marc Hufnagl	University of Hamburg	Germany	Marc.hufnagl@uni-hamburg.de
Martin Huret	Ifremer	France	martin.huret@ifremer.fr
Rubao Ji (Co-chair)	WHOI	USA	rji@whoi.edu
Marie Maar	NERI	Denmark	mam@dmu.dk
Diego Macías	CSIC	Spain	diego.macias@icman.csic.es
Stephanie Mahevas	Ifremer	France	Stephanie.Mahevas@ifremer.fr
Julian Metcalfe	Cefas	UK	julian.metcalfe@cefas.co.uk
Frédéric Maps	University of Larval	Canada	frederic.maps@gmail.com
Susa Niiranen	Stockholm University	Sweden	sniir@mbox.su.se
Myron Peck (Co-chair)	University of Hamburg	Germany	myron.peck@uni-hamburg.de
Pierre Petitgas	Ifremer	France	pierre.petitgas@ifremer.fr
Benjamin Planque	IMR Tromsø	Norway	benjamin.planque@imr.no
Dimitris Politikos	HCMR	Greece	dimpolit@ath.hcmr.gr
Kenneth Rose	Louisiana State University	USA	karose@lsu.edu
Ryan Rykaczewski	University South Carolina	USA	rykaczer@mailbox.sc.edu
Lorna Teal	Wageningen IMARES	Netherlands	lorna.teal@wur.nl
Tony Smith	CSIRO	Australia	tony.d.smith@csiro.au
Olivier Thebaud	CSIRO	Australia	olivier.thebaud@csiro.au
Morgane Travers	Ifremer	France	morgane.travers@ifremer.fr
Tineke Troost	DELTARES	Netherlands	tineke.troost@deltares.nl
Kostas Tsiaras	HCMR	Greece	tsiaras@hcmr.gr
George Tryantafyllou	HCMR	Greece	gt@ath.hcmr.gr
Agurtzane Urtizberea	AZTI	Spain	aurtizberea@azti.es
Karen van de Wolfshaar	Wageningen UR CMP	Netherlands	karen.vandewolfshaar@wur.nl
Yongsheng Wu	DFO	Canada	yongsheng.wu@dfo-mpo.gc.ca

No Webex was available at the meeting site.

Annex 2: Agenda

25 February to 1 March 2013

	Keynote speakers - 1 hr talk	short update talks (5 minutes)	warmup session organization		
	Monday 25.02	**Tuesday 26.02**	**Wednesday 27.02**	**Thursday 28.02**	**Friday 1.03**
9:00		General Intro to day 2	General Intro to day 3	General Intro to day 4	General Intro to day 5
9:20		Zooplankton (Coupling)	Movement Subgoup	Human Dimensions	Session / sub-group summaries
9:40		**(Keynote)**	**(Keynote)**	Joint with MABIES	
10:00				**(Keynote)**	
10:20					
10:40					
11:00		Health Break	Health Break	Health Break	Health Break
11:20	**no meting**				Report Generation
11:40				(building ecological-	
12:00				economic models	
12:20				and scenarios)	
12:40		Warmup End-to-end			
13:00	Welcome (housekeeping)				WGIPEM 2013 Finish
13:20	Discussion of Goals / agenda	lunch	lunch	lunch	
13:40	Climate Session Start				
14:00	**(Keynote)**				
14:20		End-to-end subgroup	model library (website)	Sub-group work	
14:40		**(Keynote?)**	Sub-group work		
15:00					
15:20					
15:40					
16:00	Health Break	Health Break	Health Break	Health Break	**no meeting**
16:20	Joint Session with				
16:40	Reproduce				
17:00		Warmup Movement			
17:20		Small Groups			
17:40		WGIPEM & Management		WGIPEM	
18:00		Discussion		Forward Looking Discussion	
18:30	Warmup Zooplankton	re-convene & summary			
18:45	**close for day**	**close for day**	**close for day**	**close for day**	

Annex 3: WGIPEM terms of reference for the 2013 meeting

The **Working Group on Integrative, Physical-biological, and Ecosystem Modelling** (WGIPEM) chaired by Myron Peck, Germany and Rubao Ji*, USA will meet at the University of Paris, Jussieu Campus, Paris, France, 25 February to 1 March 2013 to:

a) Report on the state-of-the-art within the ICES community and worldwide in coupled physical-biological and ecosystem modelling and simulation results (e.g. population connectivity, life cycle dynamics, foodweb interactions and/or ecosystem responses to human activities) including:

  i) Components of coupled biophysical integrated models (single species to foodwebs;

  ii) Coupled, integrative ecosystem (end-to-end) models including all core components;

  iii) Calibration, corroboration and confidence in model estimates and management application;

b) Identify gaps in knowledge in these modelling activities and recommend activities to advance coupled modelling approaches and that will make model outputs useful to the management of marine systems including estimates related to:

  i) Physics (from small-scale turbulence, mesoscale structures, to basin-scale transport);

  ii) Biology (e.g. behaviour, growth physiology, foodweb dynamics such as bentho-pelagic coupling);

  iii) Socio-economics within coupled (end-to-end) models;

  iv) Interactions between physics, biology and/or economics and different spatial / temporal scales;

  v) Downscaling of earth system dynamics to model at relevant scales;

c) Convene an annual meeting with specific workshops to promote the development and review of coupled physical-biological and ecosystem modelling, with the aim to attract participants that have broad range of expertise (e.g. from hydrodynamics, physiology, trophodynamics, to economics):

  i) Provide an interface to the public and scientific community by building a model code library and maintaining the ICES Operational Oceanographic Products for Fisheries and the Environment (WGOOFE) activities, including its website;

  ii) Liaise with expert groups at ICES (other WGs) and elsewhere (CIESM, and PICES) to develop a roadmap for research collaboration including the application of these biophysical model tools within and beyond the ICES community;

d) Create and/or maintain an interface for the public and scientific community by:

  i) Creating an online library of model code for existing biophysical models and their subroutines, and ii) Maintaining and updating the ICES Operational Oceanographic Products for Fisheries and the Environment website attracting meteorological experts to the group (seen as a merger with WGOOFE). The new Working Group will hold dedicated workshops to achieve these public / community outreach goals;

- Provide strategic dialogue within the ICES community on biological-physical and integrative models and their application by forming close links and joint activities with other expert groups.

Supporting Information

Priority	This group's activities will support the ecosystem approach to fisheries science by combining knowledge of physical and biological processes, bioeconomics of multiple marine sectors, and modelling expertise that is required to strengthen our understanding of ecosystem functioning. The Group will foster the development of "end-to-end" modelling tools (e.g. Atlantis) and will provide an interface for physical and biological model code and oceanographic data including those from operational modelling. For these reasons, the activities of the Group should be given high priority.
Scientific justification and relation to action plan	ToR a and b: Physical, biophysical and coupled integrative modelling are rapidly advancing research tools and providing a synthetic overview is needed, especially to identify gaps in knowledge and to make these tools more applicable to management. ToR c : Hosting an annual meeting is a core activity of the group and, given its broad mandate, both plenary discussions and targeted workshops will be necessary. A 5-day meeting is envisioned that includes 2.5 days of targeted workshops (e.g. WGOOFE activities) to facilitate cross-disciplinary collaboration between modellers, experimentalists / ecologists and economists. ToR d: A web-based interface linking this WG's activities to the public and scientific community are needed. Construction of a library of model code has already started (via MEECE, etc.). Ongoing activities of WGOOFE would be continued in this new WG, eliminating membership overlap and strengthening the group's membership with additional meteorologists / modellers. ToR e: An "application" component is considered critical for success and will ensure that this group's work is not conducted in isolation of other expert groups / organizations. The identification of concrete routes of collaboration and research activities (e.g. leading to peer-reviewed manuscripts) between this and other groups is a high priority for the first meeting. None of the ToRs answer requests from other groups, they are all self-generated and contribute to building scientific capacity. The ToRs relate to all three priority areas of ICES (i) Understanding ecosystem functioning, (ii) Understanding of interactions of human activities with ecosystems, and (iii) Development of options for sustainable use of ecosystems. ToRs a-e contribute to coded topic areas including: Climate Change (112, 114, 115), Biodiversity and Health of Ecosystems (123), Life History (144, 145, 147), Role of Top Predators (173), Impacts of Fishing (211), Renewable Energy issues ( ).
Resource requirements	This group will be composed of members of the former WGPBI, ongoing WGOOFE, and formerly proposed, End-to-End ICES working groups. In many cases, resources were already committed to the formation and maintenance of the activities of those groups. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	It is envisioned that this group will attract a large community of biologists / experimentalists, and modellers – with an annual meeting attended by some 25–40 members and guests. Annual meetings will include workshops on specific topics, increasing interests / attendance.
Secretariat	We are proposing that the first meeting take place at the secretariat headquarters at

facilities	some point in March /April, 2012. Two dates have been tentatively reserved.
Financial	No financial implications.
Linkages to advisory committees	There are no obvious direct linkages with the advisory committees.
Linkages to other committees or groups	The working group will actively pursue strong links to other groups within ICES and will propose joint meetings (workshops). A previous group (WGPBI) met with the Working Group on Zooplankton Ecology and the Working Group on Harmful Algae Bloom Dynamics. This proposed WG is recommending membership that includes chairs or co-chairs of other ICES WGs (e.g. Phytoplankton and Microbial Ecology, Multispecies modelling), and a merger with WGOOFE.
Linkages to other organizations	None. However, it is envisioned that this initial group will include members from Mediterranean (CIESM) and North Pacific (PICES) scientific organizations. We will seek co-sponsorship of this group by other organizations in future. The expertise of working group members would encompass a range of disciplines required to construct and apply biological-physical models in marine systems including: 1) hydrodynamics, 2) numerical methods, 3) ecophysiology, 4) foodweb dynamics, 5) socio-economics, and 6) Earth System dynamics. It is envisioned that this group will be composed of both modellers and experimentalists, fostering interdisciplinary discussions with the end goal of advancing coupled modelling in marine systems. The involvement of leading researchers with active links to ongoing, large-scale European, North American and Asian research programs will help build bridges beyond the ICES community, particularly to recruit new working group members and co-sponsorship by PICES as part of the proposed ICES-PICES strategic initiatives.

Annex 4: WGIPEM terms of reference for the 2014 meeting

The **Working Group on Integrative, Physical-biological, and Ecosystem Modelling** (WGIPEM) chaired by Myron Peck, Germany and Rubao Ji, USA will meet for one week in March 2014 in Amsterdam, The Netherlands to:

a) Report on the state-of-the-art within the ICES community and world-wide in coupled physical-biological and ecosystem modelling and simulation results (e.g. population connectivity, life cycle dynamics, foodweb interactions and/or ecosystem responses to human activities) including:
  - i) Components of coupled biophysical integrated models (single species to foodwebs;
  - ii) Coupled, integrative ecosystem (end-to-end) models including all core components;
  - iii) Calibration, corroboration and confidence in model estimates and management application;

b) Identify gaps in knowledge in these modelling activities and recommend activities to advance coupled modelling approaches and that will make model outputs useful to the management of marine systems including estimates related to:
  - i) Physics (from small-scale turbulence, mesoscale structures, to basin-scale transport);
  - ii) Biology (e.g. behaviour, growth physiology, foodweb dynamics);
  - iii) Socio-economics within coupled (end-to-end) models;
  - iv) Interactions between physics, biology and/or economics and different spatial / temporal scales;
  - v) Downscaling of earth system dynamics to model at relevant scales;

c) Convene an annual meeting with specific workshops to promote the development and review of coupled physical-biological and ecosystem modelling including participants that have broad range of expertise (e.g. from hydrodynamics, physiology, trophodynamics, to economics) including a workshop on:
  - i) incorporating human behaviour and economic sectors into coupled biophysical ecosystem modelling frameworks
  - ii) methods used to depict animal movements within spatially explicit models of marine systems
  - iii) exploring the coupling between lower and upper trophic levels including issues of seasonality in bottom–up and trop-down forcing
  - iv) physiological rates and dynamic energy budget models and their application to key marine species or ecosystems
  - v) the development and application of various end-to-end (e.g. physics to fish to fisheries) models within and outside the ICES area;

d) Create and/or maintain an interface for the public and scientific community by:

i) Creating an online library of model code for existing biophysical models and their subroutines including an interactive information table for stand-alone and coupled models

ii) Provide a strategic dialogue within the ICES community on biological-physical and integrative models and their application by forming close links and joint activities with other expert groups.

Supporting Information

Priority	This group's activities will support the ecosystem approach to fisheries science by combining knowledge of physical and biological processes, bioeconomics of multiple marine sectors, and modelling expertise that is required to strengthen our understanding of ecosystem functioning. The Group will foster the development of "end-to-end" modelling tools (e.g. Atlantis) and will provide an interface for physical and biological model code and oceanographic data including those from operational modelling. For these reasons, the activities of the Group should be given high priority.
Scientific justification and relation to action plan	ToR a and b: Physical, biophysical and coupled integrative modelling are rapidly advancing research tools and providing a synthetic overview is needed, especially to identify gaps in knowledge and to make these tools more applicable to management. ToR c : Hosting an annual meeting is a core activity of the group and, given its broad mandate, both plenary discussions and targeted workshops will be necessary. A 5-day meeting is envisioned that includes 2.5 days of targeted workshops (e.g. WGOOFE activities) to facilitate cross-disciplinary collaboration between modellers, experimentalists / ecologists and economists. ToR d: A web-based interface linking this WG's activities to the public and scientific community are needed. Construction of a library of model code has already started (via MEECE, etc.). Ongoing activities of WGOOFE would be continued in this new WG, eliminating membership overlap and strengthening the group's membership with additional meteorologists / modellers. ToR e: An "application" component is considered critical for success and will ensure that this group's work is not conducted in isolation of other expert groups / organizations. The identification of concrete routes of collaboration and research activities (e.g. leading to peer-reviewed manuscripts) between this and other groups is a high priority for the first meeting. None of the ToRs answer requests from other groups, they are all self-generated and contribute to building scientific capacity. The ToRs relate to all three priority areas of ICES (i) Understanding ecosystem functioning, (ii) Understanding of interactions of human activities with ecosystems, and (iii) Development of options for sustainable use of ecosystems. ToRs a-e contribute to coded topic areas including: Climate Change (112, 114, 115), Biodiversity and Health of Ecosystems (123), Life History (144, 145, 147), Role of Top Predators (173), Impacts of Fishing (211), Renewable Energy issues ( ).
Resource requirements	This group will be composed of members of the former WGPBI, ongoing WGOOFE, and formerly proposed, End-to-End ICES working groups. In many cases, resources were already committed to the formation and maintenance of the activities of those groups. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	It is envisioned that this group will attract a large community of biologists / experimentalists, and modellers – with an annual meeting attended by some 25–40 members and guests. Annual meetings will include workshops on specific topics, increasing interests / attendance.
Secretariat facilities	None.

Financial	No financial implications.
Linkages to advisory committees	There are no obvious direct linkages with the advisory committees.
Linkages to other committees or groups	The working group will actively pursue strong links to other groups within ICES and will propose joint meetings (workshops). A previous group (WGPBI) met with the Working Group on Zooplankton Ecology and the Working Group on Harmful Algae Bloom Dynamics. This proposed WG is recommending membership that includes chairs or co-chairs of other ICES WGs (e.g. Phytoplankton and Microbial Ecology, Multispecies modelling), and a merger with WGOOFE.
Linkages to other organizations	None. However, it is envisioned that this initial group will include members from Mediterranean (CIESM) and North Pacific (PICES) scientific organizations. We will seek co-sponsorship of this group by other organizations in future. The expertise of working group members would encompass a range of disciplines required to construct and apply biological-physical models in marine systems including: 1) hydrodynamics, 2) numerical methods, 3) ecophysiology, 4) foodweb dynamics, 5) socio-economics, and 6) Earth System dynamics. It is envisioned that this group will be composed of both modellers and experimentalists, fostering interdisciplinary discussions with the end goal of advancing coupled modelling in marine systems. The involvement of leading researchers with active links to ongoing, large-scale European, North American and Asian research programs will help build bridges beyond the ICES community, particularly to recruit new working group members and co-sponsorship by PICES as part of the proposed ICES-PICES strategic initiatives.

Annex 5: Recommendations

Recommendation	For follow up by:
1. ICES should develop a template for group websites to help WGIPEM (and other groups) effectively communicate activities and foster collaboration. WGIPEM would like the ICES secretariat to help establish and maintain this group's website including model code library, interactive visual tables and review documents.	SCICOM, SSGEF
2. ICES should foster links between WGIPEM and PICES modelling groups by funding travel to joint workshops (e.g. PICES FUTURE workshop, April 2014). This appears appropriate to not only WGIPEM but also the joint ICES-PICES SICCME activities.	SCICOM, SSGEF