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Report of the Working Group on Integrative Physical-biological and Ecosystem Modelling (WGIPEM)

16–19 March 2015

Plymouth Marine Laboratory, UK

ICES CIEM
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Executive summary

The Working Group on Integrative Physical-Biological and Ecosystem Modelling held their fourth meeting at Plymouth Marine Laboratory, Plymouth, UK. Scientists from Belgium, Denmark, France, Germany, Italy, UK, Netherlands, and USA joined the meeting either directly or by correspondence. The focus of the group is to advance state-of-the-art ecosystem-, individual-based and population modelling of marine systems within the ICES areas. It further addresses effective ways of model coupling and knowledge transfer on implementations, parameterizations and tools as well as sensitivity testing, model benchmarking, increasing of model confidence and quantifying model uncertainty. The group's activities help improve model-based advice on pressing questions related to fisheries and ecosystem management. Seven non-exclusive groups of interest have been created for the year to come, and will focus on: end-to-end modelling including bioeconomical dimension, fish and fisherman movement behavior, trophic controls including zooplankton as the key component between lower and higher trophic levels, analysis of model performance and uncertainty, connectivity models, frontiers or novel approaches in modelling, and bioenergetics modelling.

A focus of this year's meeting was on zooplankton modelling and included a joint, 1-day meeting with the WGZE. The workshop identified good examples of studies that included both models and observations to integrate knowledge, to better understand processes and to advance the science in the field, however, these are rather exceptions than the rule and more cooperation and interdisciplinary work is needed. This requires i) a standardization of measurements; ii) a stronger interaction between disciplines; iii) databases or catalogues that show where and which data are available; iv) iterative steps following data sampling, building models, integrating processes, identifying knowledge gaps, informing sampling programs on which parameters to measure etc. v) efficient and statistically sound ways to compare (or integrate) models and observations. It also became obvious that, for any type of model used now to interpret field data including those capable of providing advice on *Calanus* harvesting, better estimates of the different zooplankton mortality rates are required. Trait-based models might provide a more adaptive way for modelling zooplankton distributions or diversity but the parameterization is very complex and requires a wealth of data, which cannot always be provided for all taxonomic groups. A first step might be size-based models, to be modified with complementary traits once a traits database is initiated from the joint effort between modelers and zooplankton ecologists. Another future research focus should be to investigate genetic adaptation and plasticity of single (key) species and to also focus on the whole ecosystem by integrating knowledge of all trophic levels and environmental drivers for examples through end-to-end models, coupled models and closer cooperation of field and theoretical planktologists.

A joint Skype meeting with the WGIMM Chairs was also held to identify possibilities regarding coupling of models with economical and ecological focus, how to make a better use of models concerning stakeholder involvement and regarding how (and which) models can be used to provide spatial or indicator based advice.

1 Opening of the meeting

The fourth meeting of the Working Group on Integrative, Physical-biological and Ecosystem Modelling (WGIPEM) was held in Plymouth, UK from 16–19 March 2014. Due to illness of the first Chair, Myron Peck, Germany, it was decided that Morgan Travers-Trolet, France and Marc Hufnagl, Germany should act as Interim Chairs for this meeting. The meeting was attended by 17 scientists from eight countries (Annex 1). Supporting information regarding this year's Terms of Reference are given in Annex 2.

2 Terms of Reference a) – e)

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 including multi-model comparisons of key attributes of the productivity of marine ecosystems with special emphasis on fisheries;

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) Mechanistic modelling of processes (including both physical and biological factors) affecting the spatial distribution and productivity of fish stocks within marine ecosystems;
- ii) Socio-economics within coupled (end-to-end) models;
- iii) Interactions between physics, biology and/or economics and different spatial / temporal scales;
- iv) Downscaling of earth system dynamics to model at relevant scales for the integrated ecosystem-based management of living marine resources;

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) Discuss applications of spatially-explicit models investigating key processes impacting key marine species and their ecosystems as well as the application of models (biophysical to end-to-end) in providing advice to ecosystem-based management of marine systems;
- 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) Maintain an interface for the public and scientific community by:

i) Updating the WGIPEM website detailing recent group activities and accomplishments including, where possible, simulation results of end-to-end models applied within ICES ecoregions;

ii) Updating the previous established model code library for sub-routines of biophysical and ecosystem models;

e) Provide strategic dialogue within the ICES community on biological-physical and integrative models and their application to integrated ecosystem assessments and advice by forming close links and joint activities with other expert groups including but not limited to:

WGIMM	Integration of Economics, Stock Assessment & Fisheries Management
WGOH	Oceanic Hydrography
WGOOFE	Operational Oceanographic Products for Fisheries & Environ
WGHABD	Harmful Algal Bloom Dynamics
WGPME	Phytoplankton and Microbial Ecology
WGZE	Zooplankton Ecology
WGSPEC	Small Pelagic Fishes, their Ecosystems and Climate Impact
WGSAM	Multispecies Assessment Methods
WGINOSE	Integrated Assessments of the North Sea
SICCIME	Strategic Initiative on Climate Change Impacts on Marine Ecosystems

3 Summary of Work Plan

All tasks listed in the ToRs are on schedule.

4 List of Outcomes and Achievements of the WG in this delivery period

Different groups of interest were formed during the meeting to address different tasks. Coordinators of each subgroup have loosely been appointed to coordinate the activities.

Interest Group 1 (Morgane Travers-Trolet and Olivier Thébaud)

End-to-end modelling. Modelling of Management processes. Coupling biological and economy. Bioeconomic modelling. Habitat and Biodiversity models.

Interest Group 2 (Kenny Rose and Olivier Thébaud)

Addressing behaviour of fish, fisherman and fleets. Movement of fleets. Super individual concept. Model coupling

Interest Group 3 (Marie Maar and Karen van de Wolfshaar)

Trophic level coupling. Zooplankton slopes. Match–mismatch dynamics. Top down forced trophic cascades emerging in foodwebs. Bottom up vs. top down effects.

Interest Group 4 (Sigrid Lehuta and Marc Hufnagl)

Optimization of models. Sensitivity studies. Benchmarking. Transparency and Documentation. Model Stress Tests. Validation. Inter Model Comparisons. Model library. Field data and statistical modelling. Comparison with models. Reference Points. Including Ecosystem modelling in advice processes.

Interest Group 5 (Geneviève Lacroix and Marc Hufnagl)

Connectivity. Comparison, coupling and cross validation of genetics, otolith reading, microchemistry and drift modelling.

Interest Group 6 (Rubao Ji and Nick Records)

Frontiers in modelling. Viable control dynamic control. Database on traits and conversion. Trait based modelling. Communication between zooplanktologists and zooplankton modellers.

Interest Group 7 (Myron Peck and Martin Huret and Lorna Teal)

Bioenergetics. DEBs. Physiological modelling. IBMs

5 Progress report on ToRs and workplan

5.1 Presentations of recent modelling studies

Lower trophic level effects at higher trophic levels (Karen van de Wolfshaar)

The higher trophic level model OSMOSE was fed with the plankton fields from five different NPZD-models (LTL models). All LTL-models provided the same year and time-step, while the results were forced into the same spatial resolution needed to feed OSMOSE. OSMOSE was run with these five different inputs and the results at higher trophic levels showed large differences as well as agreements. Total fish biomass differed between models, with Norwecom and Ecosmo having high biomass and Ergom, Delft-3D and Ecoham with comparable levels of biomass, lower than that of Norwecom and Ecosmo (Figure 1).

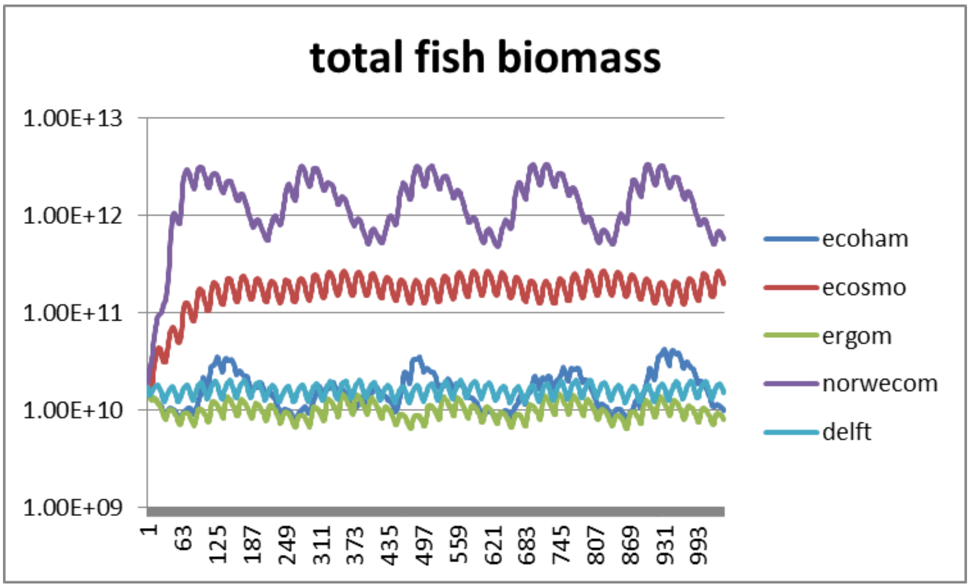

Figure 1. Total fish biomass from OSMOSE fed with the five different plankton fields.

All models showed large amplitude predator–prey cycles, while the lag between predator and prey maximum biomass differed. The spatial pattern in fish biomass did not differ between Delft-3D and Norwecom (others not analysed yet), but the total biomass was quite different, suggesting that the total plankton rather than the spatial distribution drives the difference between fish biomass (Figure 2). Further analysis will be done on the spatial differences and possible differences in predator–prey relationships in the higher trophic level foodweb.

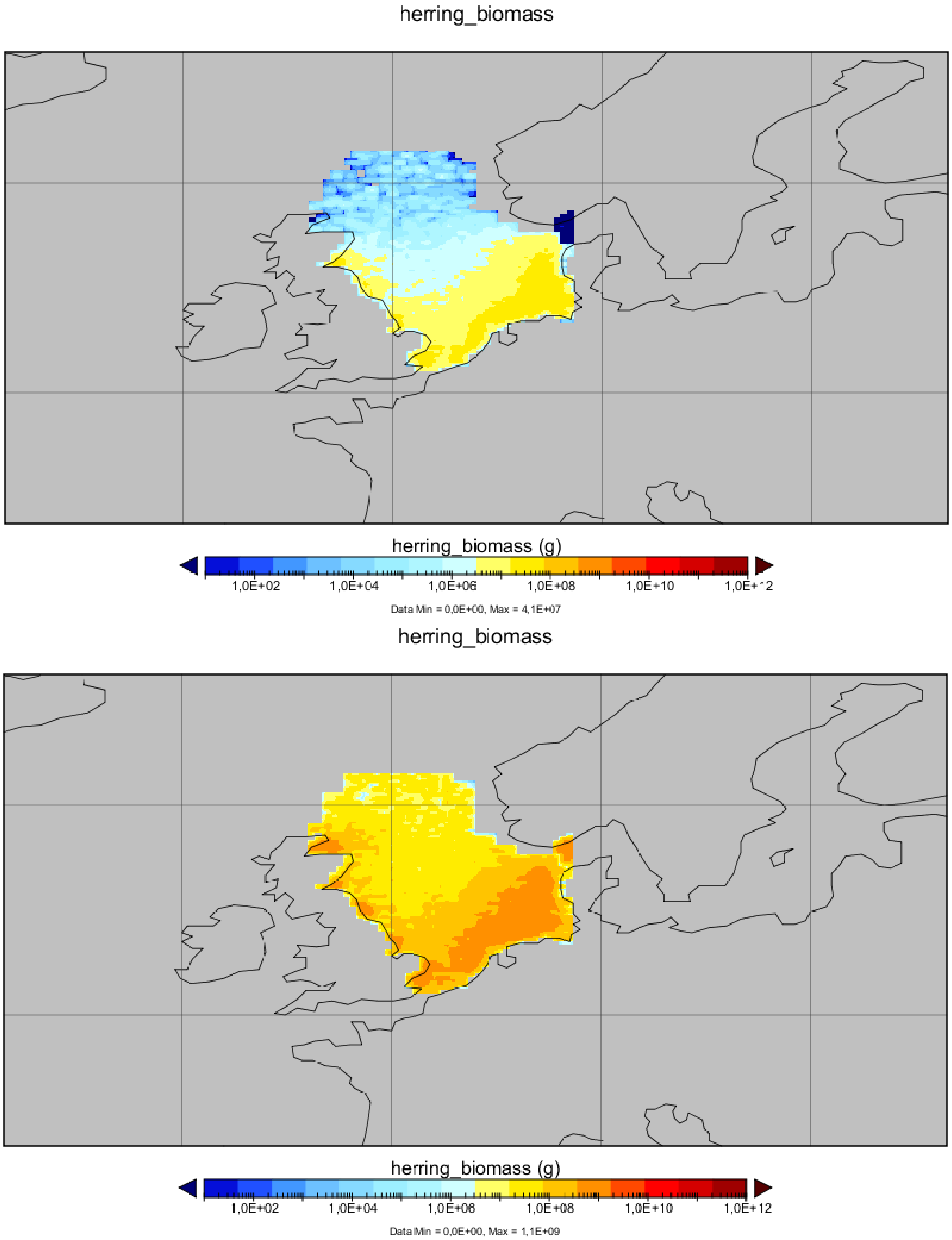

Figure 2. Spatial distribution of total herring biomass with plankton based on Delft-3D (top) and Norwecom (bottom).

Creating Eulerian end-to-end models (Hagen Radtke)

For the example of the Baltic Sea, we show how an Eulerian representation of fish can be used to easily couple higher and lower trophic foodwebs in spatially explicit models.

This approach is especially useful for representing predator–prey-interaction among different fish species.

Fish are represented on a two-dimensional grid. A different vertical distribution can be prescribed in each time-step (DVM possible) which will influence interactions both with the lower foodweb (3-dimensional NPZD model) and with prey fish. Mass conservation is automatically guaranteed by this approach.

The model and its components are described in a formal way, and the model code is automatically generated. This allows to easily couple different pre-existing single-species fish models into practically any NPZD model to obtain an end-to-end model system.

Modelling zooplankton: frontiers and WGIPEM activities (Rubao Ji with contributions from Marie Maar, Frédéric Maps, Nicholas Record, Hjøllo Solfrid)

There are many types of biological-physical coupled models being applied to understand zooplankton production process and population dynamics in the ocean. This presentation reviewed the commonly used models, including NPZD-type models, trait-based models (TBM) and population dynamics models (PDM; Figure 3). Case studies conducted by WGIPEM members using different models were also presented, including 1) the application of NPZD-type models and PDMs for Gulf of Maine, Norwegian Sea, North Sea systems; 2) the application of TBMs for the copepod diapause trait distribution and emerging community structure at different latitudes; and 3) the application of a PDM for the biogeography of four *Calanus* populations in the Arctic Ocean. The advantage and disadvantage of different models are discussed. The challenges and approaches of resolving zooplankton component in the end-to-end type of models were highlighted, including the difficulty in partitioning zooplankton from the NPZD-type of models into prey fields for fish populations. In the end, some important issues for discussion in linking model and observation data were suggested, including 1) necessity and possibility of data assimilation in zooplankton models; 2) parameterization of mortality; 3) the need for multispecies zooplankton population models but constrained by our knowledge of physiological processes of individual species. 4) how to link genetic data with model; and 5) urgent are of collaborations between zooplankton ecologists and modellers.

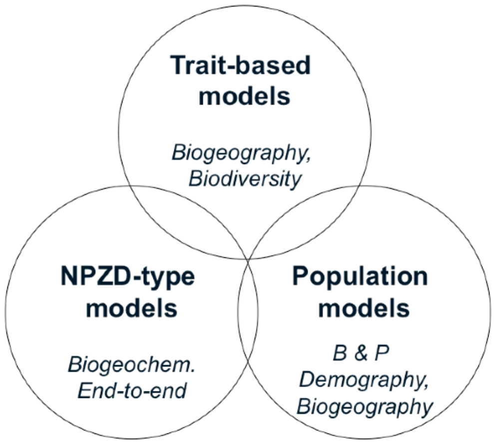

Figure 3. Different types of zooplankton models used for different purposes.

Update on the development of the E2E model Atlantis in the Strait of Sicily (Matteo Sinerchia, Fabio Fiorentino, Germana Garofalo, Michele Gristina, Andrea Cucco, Fabio Badalamenti, Francesco Colloca)

The state-of-the-art of the implementation of the End-2-End ecosystem model Atlantis was described for the Strait of Sicily. This work represents the first ever attempt at systematically gathering data for the whole ecosystem (from bacteria to top predators and fishing fleets), and creating an E2E model as a step to achieve an Ecosystem Approach to Fisheries Management tool and to explore the impact of climatic changes and capture fisheries on the strait of Sicily ecosystem. The strait of Sicily ecosystem currently includes 45 functional groups, 19 of which vertebrates, with some of the most commercially important species represented at species level. The presentation describes the pelagic compartment dynamics, with particular focus on anchovy and sardine, which represent the main fisheries of this area, contributing 33% to 51% of the total Mediterranean landings. Model results of the phytoplankton, zooplankton, sardine and anchovies biomass are shown and reproduced within range of the observations.

How full life cycle bioenergetics models handle variability in fish condition and reproductive patterns? (M. Huret, P. Gatti)

Over the last decade, a large effort was set in the development of full life cycle models of fish. These models are based on bioenergetics principles for mass conservation between energy input (food) on one hand, and growth and output (maintenance, reproduction) on the other hand. These models have been validated mostly on length and weight-at-age data. However, seasonal data, especially on weight or energy density are challenging them in their capacity to simulate observed seasonal variability, with maximum reserve energy in autumn and minimum at the end of winter. We here review the ability of two different bioenergetics classes of models, the WISCONSIN and the DEB, in considering variation in fish condition throughout the year. Another key process in these life cycle models is reproduction, which, not specifically to any particular bioenergetic model, lacks any generic parameterization of the observed patterns (incoming vs. capital breeders, initiation of spawning, duration, fecundity parameters). The way existing models handle this process is also reviewed in the presentation. An application of a DEB model of anchovy in the Bay of Biscay will provide basis for discussion. This presentation is a follow-on to last year's bioenergetics session, and will likely initiate a bioenergetics subgroup within IPEM, with proposed joint work.

Benchmark Steering Group and model quality control (Sigrid Lehuta)

Within the new ICES strategic plan, the Benchmark Steering Group (BSG) is in charge of facilitating the transfer of science into advice and ensuring the quality of the advice provided. The presentation summarized the main goals and tasks of the BSG: improvement of current benchmark process, integration with data quality groups, integrating assessment and benchmark, integrating bycatch (marine mammals) advice with fish stocks advice, role of WGSAM and reviewing of multispecies/ecosystem models for use in benchmarks, improving the use of survey data for assessment and advice. The presentation aimed at questioning the group about its potential contribution to the BSG efforts toward more effective transfer of ecosystem information to advice. The author suggested two approaches to do so, first, building on a review of frameworks and best practices for effective use of complex models for advice, it appears that methods need to be developed and applied to assess skills and increase the credibility and transparency of ecosystem and complex models (model documentation, optimization, sensitivity analysis and validation). Second, following the steps of the WGSAM, modellers could propose results from their models (survival to recruitment, stock structure, scenarios…) to the integrated assessment groups or to the ACOM assessment groups during benchmarks or during case studies specific back-to-back meetings.

Impact of climate change on sole larval recruitment in the North Sea and match–mismatch between larvae and phytoplankton (Geneviève Lacroix, Dimitry Van der Zande, Léo Barbut, Filip Volckaert)

The transport of sole (*Solea solea*) larvae from the spawning grounds to the nurseries is driven by hydrodynamic processes but the final dispersal pattern, larval abundance and connectivity may be affected by behavioural and environmental factors. A temperature increase could affect for instance the spawning period, the duration of the pelagic stage, the mortality of eggs and larvae, and the match–mismatch with prey fields. Modifications in the magnitude and direction of the wind regime might affect egg and larval retention and dispersal through changes in the hydrodynamics. We compared scenarios of a particle-tracking transport model (IBM) coupled to a 3D hydrodynamic model to investigate the impact of climate change through hypothetical temperature increase and changes in wind magnitude/direction inspired from IPCC scenarios. The model is implemented in the English Channel and the North Sea (between 48.5°N-4°W and 57°N-10°E) over the period 1995 to 2011.

The overlap between remote sensing algal bloom (used as a proxy for prey fields) and first-feeding larvae requirement period is computed. On the average (2003–2011), the algal bloom period coincides exactly with the spawning period in the Belgian area and with the first half of the first-feeding larvae period. A preliminary comparison between the overlap and the recruitment-at-age 0+ from DYFS in the Belgian nursery shows no correlation but trends.

From the climate change projection (wind magnitude increase, SW wind increase and SST increase), the model predicts:

1) A reduction (resp. an increase) of larval recruitment in the French, Belgian and Norfolk (resp. Dutch, German and Thames) nurseries.

2) A reduction (resp. an increase) of the number of connections between spawning grounds and French, Belgian and Thames (resp. German) nurseries.
3) A possible mismatch between algal bloom and first-feeding larvae.

Update on the North Sea Atlantis Model (Marc Hufnagl, Beth Fulton, Bec Gorton, Alexander Keth, Alexander Kempf, Bernardo Garcia-Carreras, Will Le Quesne, Marie Savina-Rolland, Myron Peck)

Within the VECTORS Project (Vectors of Change in Oceans and Seas Marine Life, EU FP7, 266445) the Atlantis model, originally developed by Beth Fulton (CSIRO), has been adapted to examine how various pressures of change such as the massive installation of wind farms will influence the North Sea Ecosystem. Scientists from the University of Hamburg, the Centre for Environment, Fisheries & Aquaculture Science (Cefas) and the Thünen Institute of Sea Fisheries (TI) in close cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Institut francais de recherche pour l exploitation de la mer (Ifremer) are involved in this process. A total of 25 areas, so called polygons or boxes, have been defined consisting of 91 interacting polygon boundaries 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. Polygons were defined based on species compositions, hydrographic features, bathymetry, sediment types and influence of coastal processes such as river run-offs.

The model includes a large number of parameters including growth rates, clearance rates, mouth gapes, vertical distribution and migration, stock recruitment relations, linear and quadratic mortality rates representing habitat limiting factors, viruses and diseases and habitat types and preferences. Better estimates for some parameters (beyond generic settings) are still needed and were be included based on published literature for North Sea species or databases. Future work will include several consistency and scenario tests to create a model that represents the features of the ecosystem in a robust manner. When ready, this tool can be used to evaluate different ecosystem management strategies in light of projected changes in interacting pressures (fishing, wind farms, conservation and climate) on a variety of time-scales. For example within the VECTORS Project Atlantis is being used to test the effects of installing large numbers of wind farms in combination with closing these and NATURA 2000 sites for fishing. Utilizing Atlantis as a management evaluation framework can be done after the economy module is parameterized and calibrated.

Addressing the variability of drift models: The North Sea Model Intercomparison Project. (Hufnagl Marc, Payne Mark, Bolle Loes, Daewel Ute, Dickey-Collas Mark, Gerkema Theo, Huret Martin, Janssen Frank, Kreus Markus, Lacroix Geneviève, Pätsch Johannes, Pohlmann Thomas, Ruardij Piet, Schrum Corinna, Skogen Morten, Tiessen Meinard, Petitgas Pierre, van Beek Jan, van der Veer Henk, Callies Ulrich)

Hydrodynamic Ocean Circulation Models and Lagrangian particle tracking models are frequently used methods in oceanography, biology and risk assessment. Often they are the only tools to address questions like where do water masses, marine species, pollutants or lost cargo drift to or originate from but studies that focus on the accuracy or variability of the results are scarce. Here we addressed the variability of a set of North

Sea models and performed an ensemble approach to identify uncertainties when calculating drift routes of quasi larval stages of three important and well-studied North Sea fish species: herring (*Clupea harengus*), sole (*Solea solea*) and plaice (*Pleuronectes platessa*). Eleven different hydrodynamic North Sea models using eight different Lagrangian modules were compared. Simulated scenarios were inspired by the spawning times, spawning areas and development times of the early life stages of the chosen species. Active behavior of particles was not included to focus on passive drift processes and to allow for a direct comparison of physically model properties. We applied kernel statistics of the final positions and ranges of temperatures experienced by particles in selected scenarios to identify model variability and uncertainty. In contrast to earlier comparison studies here, model settings (beside start conditions) were not standardized but "best practice" settings were used. Four years with varying conditions of temperature and circulation patterns were used and thus model results showed, besides the inter-scenario variability large interannual variability. However, inter-model variability for certain years was even higher than the interannual variability, which is mainly the result of integrating small model differences over a long time span. Besides providing valuable insight into the variability of the models and the early life-history transport of plaice, sole and herring the study shows that large-scale and long-term field data for validation and challenging models are missing and need to be collected.

Connecting survey data in space and time: modelling beyond passive drift! (Marc Hufnagl, Friedemann Keyl)

Simulations that deal with transport and connectivity of lower trophic level species or early life stages of higher trophic levels, often neglect behavior and reduce complexity to a minimum by treating them as passive drifters. In the presentation, we showed that this assumption could lead to significant bias in the estimated transport rates and final positions of the species of interest. Furthermore, we showed what could be learned about the behavior if only "snapshots" of distribution patterns are available. We used spatially interpolated field observations on the distribution of spawning whiting in spring and compared their location with interpolated observations on juvenile whiting six month later. A Lagrangian passive drift approach using a hydrodynamic model and the spawning locations as start points was not able to transport drifters to the locations where juveniles were observed half a year later. As this already suggests the importance of behavior and swimming we tested different approaches to identify the maximum radius that can be reached by larvae when active swimming was included. The first approach considered optimized swimming towards a target based on an algorithm known as Zermelo approach, here solved in 4D including vertical and horizontal optimization in an environment with temporal variable currents. Additionally, we used a navigation system approach, which is a modified Dijkstra algorithm - again solved in 4D - that allows detection of the shortest track between two points including changing water currents. Both approaches have the potential to provide valuable insight into the swimming behavior of larval fish where no observations are present - besides the start and endpoints – simply by considering the most likely swimming track.

Zooplankton dynamics on the northern Benguela hypoxic shelf: Integrating numerical modelling and field data from the in situ SUCCESSION experiment in 2011 (Anja Eggert, Martin Schmidt, Lutz Postel)

We developed a regional, fully coupled hydrodynamic-biogeochemical ecosystem model for the northern Benguela Upwelling System that is designed to analyse contributions of hydrodynamic and biogeochemical processes to the local oxygen content. A main focus of the model development was the implementation of zooplankton functional types and their activity, particularly their interaction with low oxygen water. Three functional types are implemented that differ in their food preferences, thermal constraints and diel vertical migration behaviour. The model results indicate that vertical migration of zooplankton in response to the oxygen conditions provides a regulating feedback, which may prevent a complete deoxygenation of hypoxic shelf waters. However, we have to admit that parameterization of zooplankton functional types remains difficult. Zooplankton biomass data alone are insufficient for model development. Parameterization of zooplankton functional responses, such as grazing, food selection, mortality and respiration, is crucial to model stability, but such data are often very scarce. In 2011, we performed an in situ experiment off Namibia to follow the ecosystem succession along a cross-shelf transect. We considered a wide set of variables such as stock parameters and a large number of process rates. To quantify short-term variability of the data, sampling was repeated three times along the transect. We believe that such experiments are an excellent opportunity for ecosystem model development and evaluation.

Modelling framework to assess biodiversity offset management strategies under alternative scenarios (Olivier Thébaud)

A modelling framework, which has been developed to assess stylized biodiversity, offset management strategies under alternative scenarios relating to (i) ecological response to the implementation of multiple developments and offset actions, in particular the time delays involved in ecological recovery, and (ii) societal response to the damages caused by development, determining the objectives for compensatory restoration actions.

The biophysical component of the model is adapted from the formal representation of habitat – fisheries interactions proposed by (Foley *et al.*, 2012). The model captures four main processes spanning both the physical and human components of the system within which offsetting occurs: (i) a biological resource which provides a range of ecosystem services, (ii) a habitat which supports the biological resource and is negatively impacted by economic development, (iii) a management body which assesses the level of restoration required for a development proposal to be approved and (iv) a social process which determines the permitted extent of ecosystem service loss over a given time horizon.

The approach could be applied to a range of case studies for which empirical modelling of habitat – fish population dynamics are advanced enough to permit simulating the potential impacts of developments affecting marine habitats, and scenarios regarding ecological restoration strategies.

Update on the eastern English Channel Atlantis model - Ecosystem and fishers' behaviour modelling: two crucial and interacting approaches to support Ecosystem Based Fisheries Management in the Eastern English Channel (Raphaël Girardin, Paul Marchal, Olivier Thébaud, Beth Fulton, Marie Savina-Rolland, Morgane Travers-Trolet)

The implementation of the ecosystem approach to fisheries management (EAFM) requires an enhancement of our knowledge of ecosystem complexity. Understanding the ecosystem reaction to management regulation is a key to achieve conservation objectives. Ecosystem modelling improves our knowledge of ecosystem functioning in interaction with human activities, and it is now widely used to evaluate management strategies. The fishers' behaviour of the French demersal fisheries in the Eastern English Channel (EEC) has been investigated. Results showed that fishers tended to adhere to past annual fishing practices and maritime traffic may impact on fishing decision. A global analysis of the fisheries science literature during the last three decades corroborated the influence of tradition and species targeting in fishers' behaviour. The exploration of ecosystem dynamics required the use of the ecosystem model Atlantis with a focus on two commercial flatfish species, sole (*Solea solea*) and plaice (*Pleuronectes platessa*). The importance of estuary areas and of nutrient inputs has been revealed as well as the role of discards and of two key species, cod (*Gadus morhua*) and whiting (*Merlangius merlangius*). Sole and plaice did not have a strong influence on the trophic network excepted on the benthic invertebrates' dynamics. Finally, we investigated the consequences of area closure and effort reduction on fishers' behaviour and the ecosystem impacted. We observed a noticeable benefit of combining area closure and effort reduction on the biomass of most commercial species and on the total value landed per unit effort.

Foodweb induced variations of natural mortality of exploited stocks under sustainable management strategy (Morgane Travers-Trolet, Audrey Delannoy)

For a long time stock assessments have considered specific natural mortality to be constant. In the current context of ecosystem approach to fisheries, this assumption is no longer acceptable, and natural mortality must now integrate the variability due to predation relationships. Using an end-to-end model built from coupling a multispecies model of fish (OSMOSE) with a biogeochemical model of plankton (MARS3D); we investigate the variations of mortality due to predation of the exploited stocks in the eastern English Channel. The coupled model used is individual-based and simulates local predation interactions, allowing the foodweb structure to emerge from individual relationships. Over the 14 species explicitly modelled, we first estimate the fishing mortality of the 12 exploited stocks that corresponds to the maximum sustainable yield (MSY). Several fishing scenarios going from no fishing to MSY and overexploitation are run, and mortality sources are quantified for each species. Each scenario is also characterized by a set of ecological indicators that inform on the status of the ecosystem. Variations of natural mortality for each species are put in relation with variations of fishing mortality and ecosystem status. These results are discussed with the perspective of better considering the effects of foodweb dynamics when aiming at assessing stocks and fishing at sustainable levels.

Virtual fish larvae and their modelled prey (Klaus B. Huebert)

Phytoplankton and zooplankton data from NPZD-like biogeochemical models can be used to characterize the prey fields available to higher trophic-level organisms such as fish larvae. However, biogeochemical models describe plankton in terms of bulk carbon distributed among functional groups, whereas larval fish models require input in terms of carbon (or biomass) distributed among prey size bins. The assumption of well-defined biomass size spectra, with constant slopes between the logarithm of normalized bin biomass and the logarithm of individual biomass, allows for a conversion from functional groups to arbitrarily high-resolution size bins. We have previously taken this approach, setting biomass spectrum slopes to a value of –1.2, which is theoretically and empirically average for aquatic ecosystems. We have now discovered a simple way to infer spatial and temporal variability of biomass spectrum slope from the underlying biogeochemical model. Using ECOHAM4 North Sea data, we calculated spatially and temporally dynamic slopes from the ratios of nano- plus microplankton (assumed to fall in the size range of 0.002 to 0.2 mm) to mesoplankton (0.2 to 20 mm). The resulting slopes have a mean of –1.2 (as expected) and a range of –1.5 to –0.9. We are now using prey fields calculated from these slopes and total plankton biomass (0.002 to 20 mm) to drive our generic larval fish model Quirks and hindcast species-specific and spatially explicit time-series of larval fish growth.

Including behavioural and physiological responses to prey in models to more realistically depict foraging dynamics (Myron Peck, Björn Illing, Marc Hufnagl)

The ability to mechanistically model the costs and trade-offs faced by early life stages foraging in different prey environments may be critical for our ability to understand the reasons for poor and strong year classes of fishes. The year-class success of Atlantic herring (*Clupea harengus*) spawning in autumn/winter in the North Sea (NSAS stock) and in spring in the western Baltic Sea (WBSS) appears driven by prey match–mismatch dynamics affecting the survival of larvae during the first weeks of life. We adapted an individual-based model (IBM) based on measured aspects of the physiology and behaviour of NSAS and WBSS herring larvae foraging and growing in markedly different prey concentrations. When matched with prey (ad libitum concentrations of the copepod Acartia tonsa) larval growth, swimming activity, nutritional condition and metabolic rates were relatively high. When prey was absent (mismatch), swimming and feeding behaviour rapidly declined within 2 to 4 days, concomitant with reductions in nutritional (RNA-DNA ratio) and somatic (weight-at-length) condition. After several days without prey, respiration measurements made on WBSS larvae suggested metabolic down-regulation (8 to 34%). An individual-based model depicting the time course of these behavioural and physiological responses suggested that i) a 25-mm larva experiencing a mismatch would survive 25–33% (10, 7°C) longer than 12-mm larva, ii) warmer temperatures exacerbate starvation-induced decrements in performance, and iii) behavioural and metabolic adjustments of larvae in mismatch situations prolong survival by ~30%. Our findings highlight how adaptive behavioural and physiological responses are tightly linked to prey match–mismatch dynamics in larval herring and how these responses can be included in models to better explore how bottom–up processes regulate larval fish growth and survival.

5.2 Joint meeting WGZE-WGIPEM

On 17 March, a joint meeting between WGZE (Working Group on Zooplankton Ecology) and WGIPEM (Working Group on Integrative Physical-Biological and Ecosystem Modelling) was held. The day was organized around plenary state-of-the-art talks in order to provide an overview of the work currently achieved within each working group, and subgroup discussion on the following topics:

Topic 1 - Representing (climate-driven) spatio-temporal variability within models

1) *What are the best examples of research combining observations and models to address temporal-spatial variability of zooplankton dynamics? Hopefully several studies will be listed.*

2) *What do these studies have in common? Is the same approach applicable across different regions?*

3) *How much model complexity and/or spatio-temporal resolution in field data are needed to adequately represent variability.*

4) *For linking models and observations, what are the implications for modelling approaches and data requirements (type, format, resolution…)? What is the most urgent area of cooperation?*

Topic 2 - Observing and simulating zooplankton diversity: Frontiers in zooplankton ecology and modelling

1) *What traits help define biogeographical changes in zooplankton composition among species and how have these been represented in trait-based models?*

2) *Within species (complexes), what natural barriers to populations have been inferred from genetic / taxonomical analyses of species/complexes and do models reproduce these barriers to gene flow?*

3) *If models do not capture observed population boundaries, are biological processes responsible, which may not be adequately captured, in models? The general question would be: Can we use models to understand processes establishing different populations of zooplankton species?*

Topic 3 - Harvesting zooplankton (krill, *Calanus*): Observations and modelling carrying capacity

1) *What are critical physical/biological processes affecting Calanus population biomass, distribution and productivity and how are they represented within models such as behavior (DVM, diapause) and mortality/loss terms and are critical processes (sensitive parameters) similar across regions?*

2) *What are current gaps in knowledge and what new data exist that may provide answers?*

3) *Regarding ongoing Calanus modelling, how can various models help to increase our understanding of zooplanktons role in the ecosystem as well as the response of zooplankton community to the dynamics at lower trophic levels?*

4) *What are viable harvest rates of Calanus (among regions?) and how much are these expected to vary from year-to-year? Can models be used to forecast exceptionally poor or strong year classes?*

Topic 1: Representing (climate-driven) spatio-temporal variability within models

Several examples of research combining observations and models to address temporal-spatial variability of zooplankton dynamics have been listed:

Pires, *et al.* (2013) used a bio-physical model to track/predict dispersal and recruitment of two species, one coastal and the other estuarine. Pires, R.F.T., Pan, M., Santos, A.M.P., Peliz, Á., Boutov, D., dos Santos, A. (2013). Modelling the variation in larval dispersal of estuarine and coastal ghost shrimp: Upogebia congeners in the Gulf of Cadiz. Marine Ecology Progress Series, 492:153–168. doi: 10.3354/meps10488

In Lewis *et al.* (2006), CPR data are used to validate the ERSEM model for the North Sea region. (Lewis, K., Allen, J. I., Richardson, A. J., and Holt, J. T. 2006. Error quantification of a high resolution coupled hydrodynamic-ecosystem coastal-ocean model: Part 3, validation with Continuous Plankton Recorder data. Journal of Marine Systems, 63: 209–224.)

In Padmini *et al.* (2012) the Norwegian model "NORWECOM" is used to study seasonal and spatial variability of zooplankton biomass in Barents Sea. (Padmini, Ingvaldsen, Stige, Bogstad, Knutsen, Ottersen, Ellertsen, 2012. Climate effects on Barents Sea ecosystem dynamics. ICES Journal of Marine Science. doi:10.1093/icesjms/fss063)

Chust, *et al.* (2013) used statistical model (GAMS) and CPR data to study the northward shift of *Calanus*. (Chust, G., Castellani, C., Licandro, P., Ibaibarriaga, L., Sagarminaga, Y., and Irigoien, X. Are *Calanus* spp. shifting poleward in the North Atlantic? A habitat modelling approach. – ICES Journal of Marine Science, doi:10.1093/icesjms/fst147.)

Chust, *et al.* (2014). Using GAMS model in the North Atlantic (essentially habitat modelling), study on biomass changes/diversity in a warmer ocean. (Chust *et al.* 2014. Biomass changes and trophic amplification of plankton in a warmer ocean. Global Change Biology (2014) 20, 2124–2139, doi: 10.1111/gcb.12562)

Li, *et al.* (2005) studied the population dynamics of *Calanus finmarchicus* distribution and abundance on Georges Bank using a Finite element model (Li, X., McGillicuddy, D.J., Durbin, E.G., and P.H. Wiebe, 2006. Biological control of the vernal population increase of *Calanus finmarchicus* on Georges Bank. Deep-Sea Research II, 53 (23–24), 2632–2655, doi:10.1016/j.dsr2.2006.08.001).

Carlotti, and Wolf (1998). Population dynamics model on *Calanus finmarchicus* IBM model, with a field data component (Carlotti, F., and Wolf, K.-U. (1998), A Lagrangian ensemble model of *Calanus finmarchicus* coupled with a 1D ecosystem model. Fisheries Oceanography, 7: 191–204. doi: 10.1046/j.1365-2419.1998.00085.x).

Neuheimer, and Gentleman *et al*. published a modelling study of *Calanus finmarchicus* mortality on Georges Bank adjusting stage dependent mortality rates to give observed stage structures. (Neuheimer, A.B., W.C. Gentleman, P. Pepin and E.J.H. Head, 2010. Explaining regional variability of copepod recruitment: Implications for a changing climate. Progress in Oceanography, 87: 94–105.)

McGillicuddy, *et al.* (1998) used a Lagrangian model with data assimilation on Georges Bank. (McGillicuddy, D. J., Jr., D. R. Lynch, A. M. Moore, W. C. Gentleman, C. S. Davis and C. J. Meise, 1998. An adjoint data assimilation approach to diagnosis of physical and biological controls of *Pseudocalanus spp*. in the Gulf of Maine Georges Bank region. Fish. Oceanogr., 7, 205–218.)

Lutz Postel cited a study of Namibia in 2011 that used an Eulerian approach with measurements at differing distance from shore over a 4 week period. They are currently using the Cushing approach that uses different distance from upwelling to mimic seasonal difference. (Postel, L., V. Mohrholz and T. T. Packard (2014). Upwelling and successive ecosystem response in the northern Benguela region. J. mar. syst. 140, Part B, Special issue: Upwelling Ecosystem Succession: 73–81, doi:10.1016/j.jmarsys.2014.07.014). The *in situ* experiment covered changes in the pelagic and benthic domain over a wide set of stock and process parameters, which might be suitable for model adjustments.

Concerning what these approaches have in common and why people thought they were significant was that most if not all studies listed above involved broad spatial scale monitoring data with monthly or better sampling, i.e. dense data in space and time. In some cases, additional (spatially focused) sampling was used to supplement the otherwise regular sampling periods. The question whether the predictive modelling community considered “statistical models” to really be models was raised and it was concluded that there should be a distinction between statistical models that try to match/explain already sampled data and predictive models that use mechanism or interactions to better understand ecosystem structure and functioning, and couple them to projections into the future. It was mentioned that none of the listed studies so far included sized-based models but were all focusing on biomass based or NPZD type models.

The use of model data and outputs is already a common practice and all scientists present regularly include model data in their analysis. Modelling of currents, circulation and drift was the most common model element in combined observation+model approaches which in several cases further include behaviour (most often diel vertical migration) in different degrees of complexity. Concerning future work the question of the possible use of satellite data in combined approaches was raised.

During the discussions, it became obvious that clarifications between commonly used definitions were needed. The different groups (and also scientists within the groups) had different interpretations of the word ”high frequency”. It further became apparent that while some of the WGZE members regarded “data assimilation” as a process to derive parameters, WGIPEM members regarded it as a method to be used within an “operational” context to enhance the predictive capacity of models. Following that discussion questions were raised such as: whether data assimilation allows for interpolation or prediction, whether it should rather be used to improve models and, how it should/can be applied for population models?

While the subgroups tried to answer the question: “How much model complexity and/or spatio-temporal resolution in field data are needed to adequately represent variability?” the simple global answer would be “as much as possible”, but also “it depends on the question that is being addressed”. Concerning resolution and model complexity it is not possible to draw simple conclusions such as the larger or smaller the scale the simpler or more complex the model should be. Studies (and models) addressing life stage dynamics in small but dynamic regions require rather complex biological models, high resolution physical models and a detailed understanding of the underlying biological processes. Studies that address large-scale questions require a high complexity as well as here a large variety of processes and organisms need to be included (and simplified) to resolve the interacting processes.

There seemed to be a tendency that models designed by modellers are generally “simpler” than those designed by biologists which are often rather complex. Re-worded: A modeler may focus on how to create the best (but still possible to program and manage) model for a question, while a taxonomist may get so tied up in the smallest details that the model is never formulated (or is overly complex). It was asked if anyone had read a study on primary production models that found that the more complex models were less accurate than simpler models or vice versa. It was noted that it is often necessary to start with a simplified “first step” before trying to capture every fine detail.

The main consensus of this discussion topic was that more taxon-specific size and biomass information is required to improve modelling capabilities. More species-specific information especially from the time-series sites is needed that also focuses on taxa other than copepods. The biomass of species other than copepods can be very important (e.g. gelatinous, macrozooplankton) in certain areas and during certain times of the year. In some systems, meroplankton can be a huge/dominant component of the seasonal biomass, but often it is neglected or not included in models. One problem of linking observations and modelling efforts is the use of different units. While in models often biomass is used biologists generally generate species counts. There is a need to generate seasonal and regional specific conversions between the two forms. The avoidance of sampling systems by some species, especially euphausiids, will cause bias in biological sampling data. Simplifying models or taxonomic analysis also depends on the region. While at northern latitude, models can be species-specific lower latitude need to simplify and combine species groups. It was also pointed out that seasonal cycles and interannual variability of zooplankton abundance could not be modelled without an appropriate estimate of zooplankton mortality. Simply using a "closure term" for zooplankton in NPZD models will never adequately represent interannual or spatial zooplankton variation. Existing models and studies are not always transferable to other areas and have less explanatory power for the coastal ocean if they were designed for offshore areas. There are big differences in the questions asked about coastal/estuarine areas relative to the deep ocean. Modelling tools could be used to manage coastal areas as long as it is clear what the important variables are. Cooperation between modelers and observationalists is thus very important, but it remains a challenge to bring groups together for longer term studies or to at least study annual cycles. Monitoring observations are relatively limited because they are oriented towards stocks, but it is time to move forward and to also measure rates and to look at the bigger pictures and consider the whole ecosystem and all interactions. The holistic approach and the ecosystem based approach for management is moving more and more into focus, hence it is important to also have a holistic approach to observations, to obtain as much information as possible from expensive survey time and to include/provide these data in end-to-end models to obtain a better understanding of the ecosystem functioning.

The discussion focused on how useful data from the WGZE Zooplankton Status Report are and how they can be used. If "best" areas could be identified and analysed by representatives of both groups this could result in a presentations to be given at the Zooplankton Production Symposium. Such a presentation would constitute a major outcome of this joint meeting.

A remark was made on the degree to which patchiness is considered. Models tend to operate on rather coarse spatial scales while observations collected within these cells are usually limited. Since zooplankton distributions are inherently patchy, collecting only a few samples will result in a mean value (biomass, abundance) with very high variance. It is likely that model predictions will fall within this error range but if higher resolution data were collected, it is possible that model predictions won't fall anymore within the error bars. The question remains: How can we do a better job of collecting data to validate models and how can we mimic stochasticity and patchiness in models to fit observations? It might be useful to consult with the PGDATA - who provide guidance to those collecting standardized data - on how to provide the obtained information to the ICES data center in a unified format (e.g. standardized units, measurements).

Topic 2: Observing and simulating zooplankton diversity: Frontiers in zooplankton ecology and modelling

Depending on the question being asked, considering size as the only trait will not be sufficient. Diapause, ratio of volume vs. biomass, growth rate (linked to temperature and tolerance for low oxygen) could be used. There is also a large variability of zooplankton stoichiometry (nutritional value for higher trophic level) and for example, *Calanus finmarchicus* is quite lipid-rich. It has been shown that reproductive strategy is associated with the seasonality of the species. Egg-carrying species for example have an increased visibility to predators and lower fecundity, but egg mortality rates are very low. It is important to consider traits important for the question asked: considering *C. finmarchicus* being replaced by *C. helgolandicus* with temperature, will it have impact on fish only through size spectrum or does it also involve change in the caloric content of food? Furthermore, behavior needs to be included as behaviors of species differ, and this will influence for example catchability or feeding interactions as different hunting strategies (visual or filtering) are used by different species. One possibility to address this diversity is by using trait-based models that include other factors in addition to size. These models already exist and use a number of traits that could also help to define bio-geographical changes in zooplankton composition among species. For these models, knowing the diversity and taxonomy is critical. Information at the taxa (species) level may reveal important differences in traits. A summary by Thomas Kiørboe in a recent review lists specific differences in key attributes (the information is also available on Pangea). While full trait based models including all species and all important factors seem to be, due to the data basis, unrealistic at the moment, one first step could be to start with size-based models. When collecting data, it is recommended to record several traits but at least taxon and size. There is a need to have size distribution of species for trait-based (and size spectrum) studies.

At larger scales, a trait based approach might allow for differences in life-history strategies to emerge. As several traits are linked, a suitable first step would be to identify "macro-traits". It was concluded that the trait-based approach may be a good avenue of cooperation between zooplankton ecologists and zooplankton modelers, e.g. by linking species lists and trait lists. A roadmap would be to identify which data for which trait already exist, which traits should be focused on, which information should be collected in future, and which traits matter most.

In terms of monitoring programs in Europe, it is hard to reconcile all the data needs. Modelers might be interested in one certain aspect while stakeholders and policy-makers are interested in other aspects (e.g. biodiversity, indicators, productivity, etc.). It is time to start with an inventory of what the various stakeholders/users need in order to then decide what is tractable. It is worth pointing out that while there is a tendency to collect many smaller datasets because they are tractable, it is often hard to reconcile/combine these datasets for examination of questions over larger domains. Open access, integration of information and standardization of measurements and reporting is therefore required from both sides: observations and model results. Modelers and observationalists do not encounter the same constraints but need to communicate more on the possible areas of information exchanges. On one hand, modelers could focus on models that utilize data that can be collected and that have practical applications; on the other, they should also emphasize which data are required to improve predictions and ecosystem understanding. Given the limited budgets for monitoring, there is a need to know precisely which data are needed to inform the models, or if relatively inexpensive value-added measurements could be collected to enhance and inform models. For example, if modelers only need biomass in 3 or 4 size fractions in addition to total counts and total biomass - which are often/generally used for monitoring purposes - this could be obtained without an excessive extra effort. Since EU-MSFD budgets will not be expanded, there is a limit as to what can be done and provided by individual nations. Due to the number of countries involved, the observing systems are fragmented thus it might be useful to develop a proposal for unified collection of monitoring/observing data across national boundaries. For the modelers, it is important to know which data are available and where/for how long these data have been/are being collected in order to reconcile their ideal data requirements with the reality of what is actually being measured. The uncertainty of the observations would also be very useful information. From this, modelers could provide a priority list of data needed for the models. This list could be discussed in a second step to adjust measurements and data collections or to identify knowledge gaps. Furthermore, models (and data) should be critical tested by, for example, Litmus tests following the general guidelines 1) do the results make sense given the expert knowledge of zooplankton ecologists of the system, and 2) do the model fit the observations. This might start an iterative process such that if the model does not fit the data and yet includes all known major processes, then the question becomes – what is missing? On the other hand, if the model fits the data well, and the major processes are represented and understood we can move on to provide predictions and prognosis.

When moving towards the question of genetic (taxonomical) analyses of species (complexes) to infer natural barriers to populations, it appears that in most of the subgroups there was not enough expertise in the room to discuss the barriers. Some study results were briefly mentioned, that showed no genetic variation on a basin scale. However, that could have been linked to the genes selected for analysis. Some are conserved over broad spatial scales. A question was whether genetics might be used to determine some subpopulations?

Time was also spent discussing within-species plasticity. Zooplankton ecologists want to understand how the distribution of species will change, and this requires information on the species physiology. Latitudinal gradients exist in specific traits – growth, reproduction and survival (temperature-dependent vital rates) but these are intraspecific traits. Could it be that physiological plasticity is not the result of genetic differences? This could be an interesting future area of work: examining the genetic differences among populations and how these differences are linked to key life-history traits. Incubation experiments have shown that metabolic rates and reproductive performance change among populations. Do we need to know what they experienced beforehand? Perhaps yes, and temperature vs. length-at copepod C6 was one example. A comment was made regarding *Calanus finmarchicus,* that is difficult to maintain in the laboratory and that can interbreed with *Calanus* congeners. Phenotypic plasticity may or may not have a genetic basis, and it is also important to know how quickly traits can change within a species.

One very important question is: What limits the northern and southern distribution of species in the ocean? Stages and diapause traits can provide answers for Arctic systems, but can we use a similar approach in more temperate areas? Studying subpopulation distributions can prove to be a successful method to understand the overall presence of a species. Thus modelling populations instead of species would help but this requires looking at genetics in order to identify populations within a species. Another idea would be to use a trait-based approach where traits are linked to geographical presence.

When transported (e.g. through ballast water) some species can establish themselves in new areas, but for such processes that are not "natural": what and where are the barriers to range expansion? As well, what controls interannual or seasonal changes in species distributions and community composition? How can models deal with invasive species (e.g. size based model do not take account of taxonomic variability)? Some examples were mentioned: *Pseudodiaptomus marinus* has invaded the Dover Strait area, and its abundance is strongly increasing year after year.

As well, concerning the shift from *Calanus finmarchichus* to *Calanus helgolandicus* (e.g. in the North Sea), if we understand the shift, can we model it? In models we have control on the habitat, so habitat change could drive distributions. However, one has to be careful when using these kind of results, since habitat may not be the only determining factor for the success of a particular species.

A recent paper (Melle *et al.*, 2014 The North Atlantic Ocean as habitat for *Calanus finmarchicus*: Environmental factors and life-history traits. Prog. Oceanogr., 129: 244–284) shows that there are differences in *C. finmarchicus* populations between the eastern and western North Atlantic. Mortality is an important process that may limit the northern distribution of *C. finmarchicus*. Where the species co-occur, *C. glacialis* and *C. hyperboreus* may prey on younger stages of *C. finmarchicus* and limit its northward expansion as the North Atlantic warms. On the other hand, it is more likely that the dependence of *C. finmarchicus* on phytoplankton to fuel its reproduction in spring limits its ability to reach a stage with the capacity to overwinter in areas where the growth season is short. One question is: why is *C. finmarchicus* not shifting northward from the Gulf of Maine? The Gulf of Maine is now warmer than the statistical models suggest should be optimal for *C. finmarchicus*. Mean annual surface temperature appears to be an important limit defining the range of *C. finmarchicus*. An annual average of 10°C is thought to represent the statistical limit, but the Gulf of Maine has been warmer than this for quite a while. One interpretation is that the Gulf of Maine is seeded annually by *C. finmarchicus* from the Scotian Shelf via a cold coastal current, which provides conditions for high production by *C. finmarchicus.* These individuals then diapause in the deep basins of the Gulf of Maine. When they emerge from diapause, they enter warm waters, which accelerate metabolism of their stored lipids. A large proportion of these animals and their offspring are likely advected south and ultimately lost from the Gulf of Maine, so that the Gulf is a one-way system. This shows the complex system understanding required if one wants to make future predictions.

Variables that could be considered include interspecies competition, temperature effects (noting that increasing temperature also increases the activity of (and potentially overlap with) predators), differences in inflow (e.g. in the Baltic), feeding environment (but note that most of the models only discuss "Chlorophyll a", which is probably a poor representative/predictor of food quality). It was noted that ecosystem complexity is easy to model when simple, but requires many things to be considered in more complex (e.g. tropical) areas.

The global questions remain: what are the reasons for the trait values to be observed there? To address this, the rest of the ecosystem needs to be taken into account in combination with the foodweb.

Topic 3: Harvesting zooplankton (krill, Calanus): Observations and modelling carrying capacity

A presentation of the potential *Calanus* fishery and the current model was made in plenary, but based on this talk a full assessment of knowledge gaps was not possible.

Several questions arose, notably about:

- Which predators of *Calanus* have been identified (e.g. so far have only commercial fish predators been included?)
- What is the current knowledge of the extent and location of *Calanus* fishing? If the fishing is only on the shelf, what is the magnitude of the catch compared with the standing stock of *Calanus finmarchicus* on the shelf?
- If, as estimated by the model, only 10% of the *Calanus* production is consumed by the commercial species, where does the other 90% go?
- There is a general need for more information about how the model is being applied (e.g. the variables, parameters etc.)
- Does the model (mathematical or conceptual) consider effects on lower trophic levels as well as on species subject to commercial fisheries?
- It had been shown that herring condition varied with total zooplankton biomass (interannually), which was dominated by *C. finmarchicus*, but it, was not clear, how fishing might affect this relationship.

It was also suggested that the model being used (NORWECOM) should be further developed and tested at different catch levels and that its performance should be examined by other modelers. It was concluded that this issue should be a topic for exploration by the WGZE and WGIPEM working together, since the proposed "plan" involves models and knowledge of *Calanus finmarchicus* ecology. Both WGZE and WGIPEM are science working groups that do not report to (or discuss results with) an advisory counterpart group. If these two ICES working groups do not explore this, who will/can/should do it?

It was suggested that the "*Calanus* question" should be a topic at the upcoming Zooplankton Production Symposium. Although there will be a workshop on zooplankton fishing (in general) it was suggested that the issue of *Calanus* fishing should be highlighted.

- Observation activities across countries and programs are fragmented and are not coordinated: data are not always standardized and only partially represented in databases.
- It is not clear that the sampling frequency and sample analysis best suits modelling needs.
- There is a need for information exchange and guidance from modelling community as to their data requirements.
- There is a need for data collection that contributes to a dynamic, mechanistically driven understanding of change and impacts on ecosystems and processes
- There could/should be a synthesis presentation from WGZE and WGIPEM: "Reconciling zooplankton data collection with modelling needs in observing systems to understand ecosystem change"
    - What is being done vs. what is needed?

    - What are the questions and types of models that need observing data? (biogeochemical, ecosystem, coupled physical biological population dynamics)?
    - What variables needed by these models that are not currently or consistently measured by present observing activities?
    - Data distribution and management issues.
    - Making best use of WGZE data archiving efforts.
    - Making use of fisheries data management experience to help streamline data distribution and availability for modelling needs.
- Examples
    - Analysis of zooplankton samples to provide information on energy (lipid) concentration of zooplankton community, as determined from zooplankton species abundance and laboratory measurements of lipid content/species and developmental stages within species
    - High frequency (monthly to semimonthly) sampling with stage resolution for coupled physical biological models of key species population dynamics
- Are the zooplankton indicators recommended for MSTS by HELCOM and OSPAR needed by models?
    - Biomass calculations
    - Mean size of zooplankton community
    - Plankton life form analysis

Actions

- Propose a joint presentation at the 6th Zooplankton Production Symposium to be held in 2016 in Bergen

Geir Huse and Rubao Ji will co-convene a workshop at the Zooplankton Production Symposium on the following topic: "Zooplankton as a "to" in end-to-end models". Since this workshop is 'hands-on' can we address the question "What do the modelers need in terms of data?" "How can we fit zooplankton into the end-to-end models?". Furthermore, there might be one or two talks that would be relevant to the Symposium with at least two possible sessions where modelling/zooplankton ecology could fit in (see Session 2: Response of zooplankton communities to changing climate and Session 6: Individual variability and its response to environment and climate).

- Initiate a precise list of data required by modelers and applied zooplanktologists (including traits to be informed by keeping the taxonomic information) to inform zooplankton ecologist in charge of data collection or data analysis.

5.3 Joint meeting WGIMM

On 18 March a Skype conference including all present WGIPEM members and the Chairs of WGIMM the Working Group on Integrating Ecological and Economic Models: Eric Thunberg, Jörn Schmidt, Rasmus Nielsen was held.

The following topics, questions and actions were discussed:

- How have different types of ecological models been used in the past with respect to economic and advice aspects? How case specific doe they need to be?
- Is it possible to use models beyond fisheries and to give advice on Marine Spatial Planning? Is it possible to connect fisheries yield/impacts and economy to biological, climatic, or anthropogenic drivers?
- Can we calibrate and validate models and provide uncertainty estimates, accuracy, benchmarks and prognosis? How complex must a model be?
- How can specific or strategic models be included in the advice process?
- Can we use existing models to provide meaningful and solid economic or ecosystem indicators that can easily be provided to stakeholders or interest groups?
- What do processes do we address and what can be provided concerning: fleet dynamics, behavior or fish and fisherman, Fisheries Management, Spatial Management?
- What kind of management are we talking about and which information is needed?
- Can we provide input to the Marine Strategy Framework Directive?
- Can models used in WGIPEM or WGIMM help to improve the acceptance of models by stakeholders. Can we provide stakeholder engagement tools?
- What economic advice does the society need, how can we give an integrated advice?
- What is a good trade-off between Complexity and Usefulness?

It was envisioned to plan a joint workshop addressing the topics

- Evaluation and comparability
- Indicators
- Outreach (see also MAREFRAME Project)

Furthermore, Olivier Thébaud presented the ICES/PICES symposium **"Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments"** which will take place in Brest, France, from 30 June to 3 July 2016 and that could be of interest for both groups. The symposium was developed following a WGIPEM supported session on this topic at the 2013 ICES ASC. The focus of the symposium will be on integration and assessment across multiple ocean uses and sectors, including: fisheries, renewable energy, coastal development, oil and gas, transport, and conservation. There will be a particular emphasis on the methodological and empirical challenges involved in including human dimensions in integrated ecosystem assessments. The symposium will be global in scope, with a focus on regions in which integrated ocean management policies have been developing in the last two decades.

5.4 Upcoming SICCME workshop (August 2015)

An ICES/PICES Workshop on Modelling Effects of Climate Change on Fish and Fisheries (WKSICCME) co-organized by a WGIPEM member (Myron Peck) will be held in Seattle, Washington, USA, from 10–12 August 2015. This workshop dedicated to common projections for modelling climate impacts on fish and fisheries will particularly focus on:

a) Identifying a suite of representative future fishing and ecosystem scenarios that could be employed for use in evaluating climate change effects on fish and fisheries.

b) Identifying a suite of climate models and representative concentration pathways that would be used to project climate change.

c) Identifying suites of single species climate enhanced projection models, multispecies climate enhanced projection models, full foodweb (e.g. EcoSIM), and dynamic spatially explicit ecosystem models that would be used to project the implications of a) and b) on commercially important marine fish stocks in the northern hemisphere.

WGIPEM members will participate to this workshop, reinforcing the collaboration with the WKSICCME organizers and offering the possibility to participate to the definition of common scenarios to be simulated.

6 Revisions to the work plan and justification

Work on all ToRs have progressed following the work plan.

7 Next meeting

The 2016 meeting of WGIPEM will be held in Oristano (Sardinia), Italy – dates still to be confirmed.

Annex 1: List of participants

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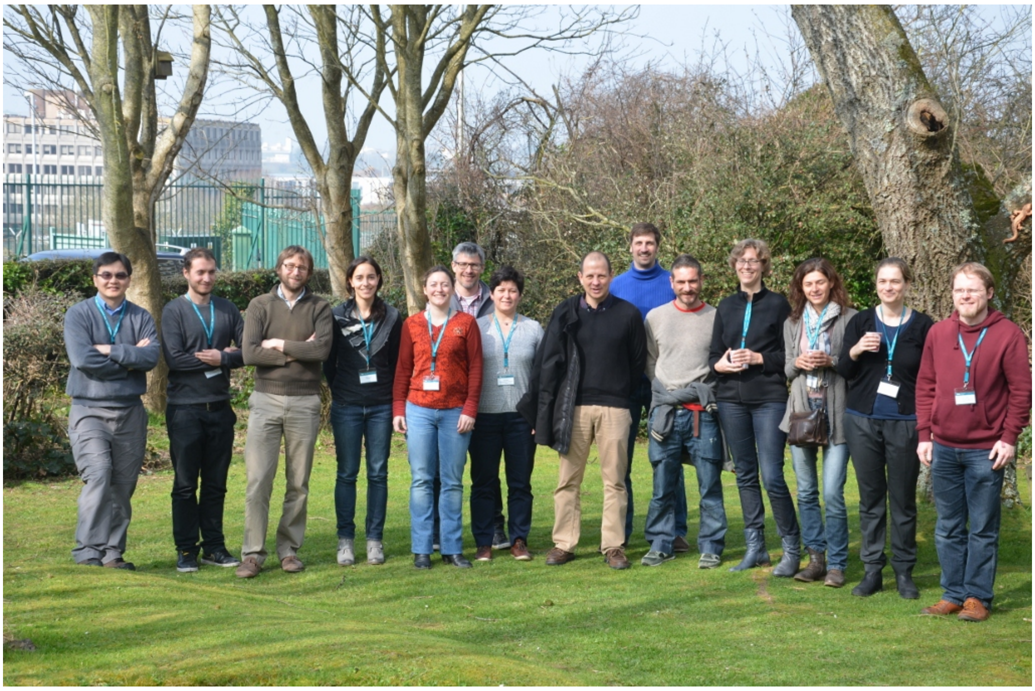

Annex 2: Supporting information for WGIPEM terms of reference

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	ToRs 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 Committee.

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.