# ICES WGIPEM REPORT 2018

INTEGRATED ECOSYSTEM ASSESSMENTS STEERING GROUP

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

16-20 April 2018

ICES Headquarters, Denmark


ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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## Contents

## Executive summary

The Working Group on Integrative Physical-Biological and Ecosystem Modelling (WGIPEM) met in Copenhagen, Denmark, on 16–20 April 2018. 29 participants from 11 countries discussed recent advances in biological-physical modelling approaches and how to make best used of complex models. Modelling approaches considered are various and range from hydrodynamic-biogeochemical models to individual-based models (IBM) as well as spatially explicit foodweb models and so called end-to-end models.

This year, a particular attention was put on addressing the possible uses of models by a wider community (including stakeholders). Through a joint session with the Working Group on Multispecies Assessment Methods (WGSAM) about model skill assessment, the group concluded on the necessary honesty regarding model skills and the value to transparently report strengths and weaknesses. Differentiating between model skills in hindcast and forecast was found important, and the usefulness of sensitivity analyses was reasserted for gaining insights in model and system behaviour and better prioritizing parameterization efforts. WGSAM and WGIPEM agreed to work together in future in order to produce practical guidelines on model skill assessment and harmonize methods within ICES. A joint session was also organized with the Working Group on Integrated Assessments of the North Sea (WGINOSE) and the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS) to increase interactions between these groups as we move towards the operationalization of the Ecosystem Based Management (EBM) in the North East Atlantic area. Intergrated Ecosystem Assessments (IEA) groups appear to have more contacts with stakeholders than WGIPEM, which is sometimes associated with semi-quantitative modelling approaches. Comparison of approaches and/or using complex models to better quantify the links between compartments in IEA approaches are two possible pathways for future collaboration. Furthermore, integrated models were proven useful to explore uncertainty due to sampling design of sea surveys, and such results could be transferred to other ICES groups.

As part of WGIPEM mission to identify gaps of knowledge, a discussion with WGINOSE and the Benthos Ecology Working Group (BEWG) was organized to advance on the representation of benthos within integrated models. Additionally to fruitful exchanges regarding available data on spatial distribution of benthic species, habitat mapping, state and trends of species, the importance of traits rather than taxonomic description was reasserted when aiming at modelling the functioning of ecosystems. Moreover, it was recognized that not only benthos descriptions, but also sediment fluxes are a challenge to model realistically.

A few WGIPEM model studies have considered climate change effects on species distributions and ecosystem dynamics and in some cases in combination with other stressors (e.g. eutrophication). However, it remains difficult to produce realistic future ecosystem projections under climate change, notably because most experimental studies have been looking at temperature effects on physiological responses, whereas effects of other drivers (e.g. pH, salinity…) are less numerous/lacking. Other model developments reported during the group concerns the representation of species (and man) behaviour: the movement routine implemented in NORWECOM.E2E for pelagic fish has been improved to allow adaptation of behaviour to future changes; an acclimation-based phytoplankton growth model proved to be useful for appropriately simulating the impact of nutrient reductions on lower trophic levels; using an IBM with passive

and active fish movement allowed to investigate interannual variability of anchovy migration routes. Over the past 3 years, model development of man (fishers) movement have remained scarce within the group. Trophic controls have also been explored by the group, first through a published intermodel comparison studying how changes in topdown forcing affect phytoplankton biomass in different cases of foodweb structure, and second through scenarios and sensitivity analysis performed with end-to-end model such as Atlantis, notably showing that perturbations at the basis of the foodweb has the strongest impacts on the system. Individual-based Lagrangian tracking models have been used to study population connectivity. In a first study, a sequential Bayesian procedure optimizing the particle release locations is used in a trait-based modelling framework for assessing the contribution of different traits to the dispersion pattern and the success of larval settlement. In another study, a larval dispersal model has been developed to assess comparatively the dispersal and connectivity patterns between spawning grounds and settlement areas of three hard substratum species in order to test the hypothesis of stepping stone owing to the introduction of OWFs in the North Sea. Finally, the group has demonstrated that bioenergetics modelling is developing more and more and starts to be coupled with various modelling approaches. Suitable data are scarce, and improving the realism of bioenergetics models could come from a stronger discussion with field and laboratory scientist, in order to make better links between measurements and model needs.

# 1 Administrative details

**Working Group name**

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

**Year of Appointment within the current three-year cycle**

2015

**Reporting year concluding the current three-year cycle**

3

**Chairs**

Morgane Travers-Trolet, France

Marie Maar, Denmark

**Meeting venue(s) and dates**

06–08 June 2016, Brest, France, (18 participants)

13–15 June 2017, Oristano, Italy, (11 participants + 1 remotely)

16–20 April 2018, Copenhagen, Denmark, (29 participants + 2 remotely)

## 2 Terms of Reference a) – h)

a) Advance and increase the reliability of Multispecies and Ecosystem models to allow for a strategic advice on an ecosystem based approach. This includes improvement of benchmarking, model stress tests, validation, sensitivity testing approaches and inter-model comparisons. Provide tools and methods like coupled bioeconomic models to enumerate trade-offs between management options.

b) Identify ways to make the best use of models and model outputs for management purposes. Maintain an interface for the public and scientific community by providing tools, outputs and algorithms through e.g. the WGIPEM webpage, workshops or conference sessions dealing with stakeholder engagement to finally increase visibility and end-user confidence in coupled physical-biological and ecosystem modelling approaches. Determine the potential use of models to improve sampling strategies and inform survey designers.

c) Identify gaps in knowledge that need to be closed and spot emerging fields in coupled physical-biological and ecosystem modelling approaches to improve process descriptions and ecosystem responses to anthropogenic and environmental drivers in order to eventually and on the longer term be able to give model based strategic management advices.

d) Discuss and provide basis for setting up future scenarios of anthropogenic pressure and climate variability. Based on the different scenarios, provide estimates of ecosystem states, functioning or services. Determine factors influencing species distribution. Discuss overarching interdisciplinary standards to be used in future scenarios.

e) Improve and develop routines to describe behaviour of species and man and to include evolution and adaptation in coupled physical-biological and ecosystem modelling approaches.

f) Advance our understanding of bottom up and top down controls within foodwebs. Identify drivers and rules of trophic coupling, the evolution of cascades and match–mismatch processes.

g) Provide tools to improve our understanding of habitat connectivity to support and advise spatial management plans.

h) Identify and include key physiological processes and mortality sources in models to understand recruitment dynamics, life cycle dynamics and population drivers.

# 3 Summary of Work plan

| | |
|---|---|
| **Year 1** | Annual meeting to report on the state-of-the-art of some of the identified topics in ToR b and their related gaps of knowledge – Update of the previous established model code library for sub-routines of biophysical and ecosystem models – Specific workshop on some of the identified topics |
| **Year 2** | Annual meeting to report on the state-of-the-art of the identified topics in ToR b, identification of gaps of knowledge and actions to take to fill some of them – Joint meeting with other expert groups – Update of the WGIPEM website – Specific workshop on some of the identified topics |
| **Year 3** | Final report on the state-of-the-art and gaps of the identified topics in ToR b – Joint meeting with other expert group – Specific workshop on some of the identified topics –update of the WGIPEM website |

# 4 Summary of Achievements of the WG during 3-year term

## 4.1 Publications and reports

Several publications have been written by WGIPEM during the 3-year term, either involving only few members of the group, or presenting studies entirely conducted within WGIPEM. They are listed in Annex 2.

## 4.2 Conferences and workshops

In 2016, Geir Huse and Rubao Ji co-organized a **workshop on "Zooplankton as the on the "To" in end-to-end models"** at the Zooplankton Production Symposium (Bergen, Norway, May 2016). The focus of the workshop was on presenting new ideas for improving the functionality of end- to-end models, emphasizing zooplankton implementation and how that affects the overall functioning and results of end-to-end ecosystem models. There were five oral presentations and one poster presentation, with an invited talk from Øyvind Fiksen. More than 30 people participated in the workshop. The main threads of the discussion were on collaboration between modelers and observationalists, examining model complexity, and usage of end-to-end models.

A **workshop on 'Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies'** was co-chaired by Myron Peck and Laure Pecquerie during the International symposium on 'Drivers of dynamics of small pelagic fish resources', Victoria, BC, Canada, March 2017. Discussion questions were focusing on (i) the ways research on ecophysiology has contributed a mechanistic (cause-and-effect) understanding of the effects of climate change on small pelagic fish, (ii) the most important recent advances in measurement / observation techniques that have advanced ecophysiological processes and have been implemented in models to explore the dynamics of small pelagic fish, and (iii) the kind of future, ecophysiological studies (laboratory, observational, and modelling) that are essential to conduct in order to improve our understanding and projection of small pelagic fish responses to climate change.

As an outcome of the 2016 WGIPEM meeting, two session proposals have been submitted by WGIPEM members to the **AMEMR 2017 conference**. Due to the large number of session proposals received, WGIPEM proposals were merged with others in order to produce the following themes: (i) AMEMR Theme "Building blocks: truth or dare?", with the subsection "Building the zoo" and (ii) AMEMR Theme 2 "Making an impact", where a global overview of WGIPEM activities, and more specifically examples of complex model use for decision or management have be presented (Title of the talk: Reducing the gap between complex ecosystem models and their use in operational context). Several WGIPEM members participated to this conference, in order to better communicate our work and stay up-to-date regarding modelling activities and possibly identify gaps of knowledge to be filled.

A workshop co-chaired by Myron Peck on "**Utilizing bioenergetics measurements and modelling to evaluate climate change effects on marine species and ecosystems**" will be held at the 4th International Symposium on the Effects of Climate Change on the World's Oceans (ECCWO), June 2018 in Washington, DC.

## 4.3 Tools and website

The advances of the group regarding models description and useful tools associated with complex models are currently transferred into a document, publically available and hosted in the WGIPEM webpage: http://www.ices.dk/community/groups/Pages/WGIPEM.aspx

On this document, the different models used by the group are briefly presented, with a focus on the spatial area covered and the pressure addressed. References to complete documentation of each model is also provided.

Several tools, either developed or successfully used by the group, are also presented. They are listed below, and more details can be found in the 2016 report and on the online document:

- Atlantistools R package: to visualize more easily and explore output from Atlantis models;
- Shiny R package: a user-friendly interface to communicate model outputs;
- Shiny app for the Quirks larval fish model: to simulate growth rates of different types of fish larvae under a wide range of environmental conditions;
- Zooplankton Model Library (ZoopLib);
- Ecosystem Code Generation Tool: to create ecosystem model code from a formal description of the ecosystem tracers and processes.

## 4.4 Project proposal

While some project proposals involving several members were developed during the 3-year term of this group, a dedicated project proposal entitled "Towards operational use of marine ecosystem models" has been submitted in 2018 to the COST Action program to push further the work conducted within WGIPEM. If successful, this project will help intersessional work of WGIPEM through the organization of several workshops and short-term scientific missions.

# 5 Final report on ToRs, work plan and Science Implementation Plan

## 5.1 Progress and fulfilment by ToR a

### 5.1.1 Joint session with WGSAM, 17 April 2018

ToR a is on advancing and increase the reliability of Multispecies and Ecosystem models to allow for a strategic advice on an ecosystem based approach. The annual meeting in Copenhagen had a joint session with WGSAM exchanging their experience on multispecies/ecosystem model skill assessments and outreach to stakeholders. Alexander Kempf (chair) gave an overview on the work done in WGSAM on skill assessments and Key-runs. There is an urgent need for proper skill assessments and benchmarks to strengthen the trust in the output from complex models. By doing this, skill assessments have to be carried out for hindcasts and forecasts separately and on the right scales dependent on the questions asked for advice. Different examples from literature with members of WGSAM involved highlighted different ways to conduct skill assessments with different skill metrics and focus on different aspects (e.g. sensitivity analysis, metrics to compare hindcasts and forecasts to observational data, Prebal for EwE models).

Examples from the work of WGSAM members in the last two years included analysis on the prediction skills of diet selection models (from Natalia Kulatska) as well as a study in Icelandic waters to evaluate the performance of EwE using Atlantis as operating model (from Erla Sturludottir and Gunnar Stefansson). The latter study highlighted the fact that the performance of hindcasts does not allow to judge on predictive skills. A study from Gaichas *et al.* tested the performance of three different multi species models and multi-model inference in an MSE type approach. The conclusion was that the model ensemble outperformed individual models with realistic input data conditions (i.e. uncertainty and bias in input data).

Key-runs are a core activity of WGSAM and they refer to a model parameterization and output that are accepted as a standard by ICES WGSAM, and thus serves as a quality assured source for scientific input to ICES advice. The process of conducting key-runs has been explained based on the latest North Sea SMS key-run. The importance of detailed documentation of input, model settings and diagnostics has been highlighted. Output has to be presented in an easy accessible format for other working groups and people to allow an efficient use of model results. WGSAM uses Github, an extra stock annex on the ICES website, standardized main output (tables and figures) and puts effort into the direct communication with e.g. assessment working groups. The conclusions from the meeting with WGSAM was that 'Key-runs' can be conducted during expert group meetings. However, dedicated members are needed who work intersessionally. Extra effort needs to be put into model description and an effective communication of model results.

The conclusions from the meeting with WGSAM were that there are various ways of testing the skills of models in the literature and various examples can be found in ICES groups. However, different people focus on different aspects. Therefore, there is a need to come up with best practice guidelines for different types of models to establish standards in ICES before a model can be used for advice. Skill assessments for hindcasts only may not be sufficient (but depends on the questions asked). For decision-making, prediction skills are often important, but are less frequently tested. This needs to be changed. Model ensembles are an interesting way to improve the prediction skills compared to using one particular model only.

#### Skill assessment of a size-structured fish community model

Robert Thorpe from WGSAM presented some results from a hindcast evaluation of a size-structured model of the North Sea fish community, with the aim of understanding the potential skill of the model on the 0-5 year time horizon. Model performance was evaluated in terms of ability to a) reproduce assessment estimates of absolute biomass, b) reproduce violations of the ICES limit biomass $B_{lim}$, and c) reproduce trends in stock biomasses as described by the assessment. Model performance was then compared with the "null case" of persisting the last assessment in the tuning period. The raw model output was inferior to persistence of the last assessment, but when adjusted for known biases (as would be done for an operational forecast), the model outperformed persistence in terms of biomass levels, performed similarly with respect to violations of the limit reference point, and correctly predicted trends in 8 out of 10 assessed stocks. This work contributes to ToR a) by providing an example of model validation in the form of a medium-term hindcast, and in performing the evaluation in terms of readily understandable quantities (biomasses, trends, and reference points). This approach can also be extended to compare different models by substituting them for the null model. This work contributes to ToR b) by describing the skill assessment in terms of performance metrics that are directly related to management objectives, such as breaches of the limit reference point, and trends in stock abundance. The use of a "null model" against which to make the skill assessment is a novel factor of the work and also contributes to ToR b by providing information on the model's potential to add value in a management context.

### 5.1.2 Sensitivity analysis of the multispecies fish model OSMOSE for potential climate change effects

Morgane Travers-Trolet presented a sensitivity study on the effects of climate change on the fish community. Using the OSMOSE model applied to the Eastern English Channel, the importance of 4 processes (change in primary production, growth rate of fish, spatial distribution, and phenology of reproduction) on the fish community response to global warming was assessed separately and concomitantly. Simulating earlier spawning seasons has the greatest impact on fish biomass, followed by change in spatial distribution. Furthermore, the interaction of the different processes plays an important part in the results, and the interaction factor becomes more important as the global warming scenarios gets more pessimistic (higher warming). The work highlights i) the need to account for interactions between these processes and ii) that the ranking of effect in terms of their impact should not be determined a priori. This sensitivity analysis also points out that more research is required regarding phenology of processes under climate change.

### 5.1.3 Sensitivity analysis of the End2End model Atlantis

Cecile Hansen presented a local sensitivity study in the Nordic and Barents seas Atlantis model (NoBa), perturbing five key life-history parameters for nine components. It was shown that depending on their position in the ecosystem (lower trophic level, mid trophic level, top predators) their response to parameter perturbation was very different. Perturbations on the lower trophic levels had by far the strongest impact on the system (Figure 5.1). Combined perturbations often resulted in non-additive responses, including both dampened effects and increased impact. Identifying sensitive parameters and species in end-to-end models will not only provide essential information about the structure and functioning of the ecosystem in the model, but also enlighten areas where more information and research are needed for parameterization of these models, possibly reducing or at least quantifying the uncertainty in the model. This answers up to ToR a), and is a step towards better knowledge of the model.

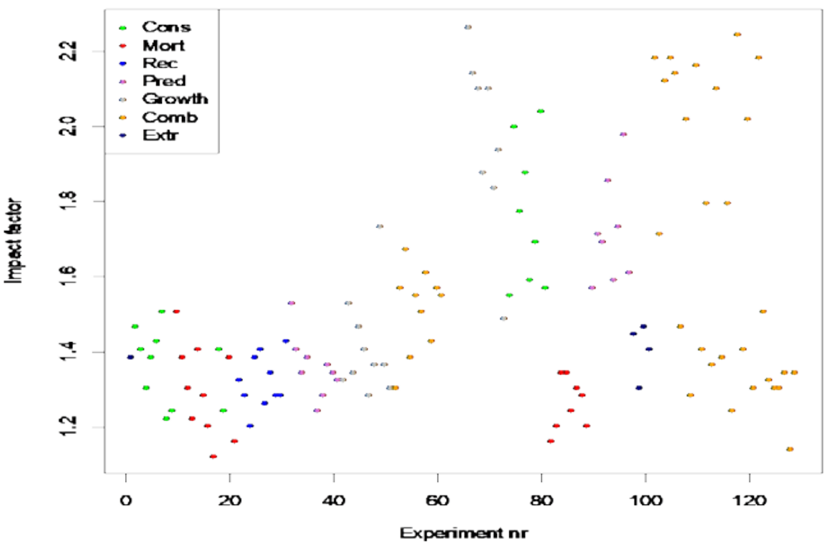


**Figure 5.1: The impact factor of all the experiments, except the control run. The impact factor indicates how many species experience a change in the biomass and is weighted according to the magnitude of the impact. The experiments are color-coded according to which parameter is tuned, where green is consumption rate (Cons), red is mortality rate (Mort), blue is recruitment (Rec), purple is availability of prey (Pred), green is growth and orange is combination runs (Comb), and the dark blue are the more extreme (Extr) parameter changes. (Hansen *et al.* submitted to PlosOne).**

Sieme Bossier showed how the newly developed end-to-end Baltic Atlantis ecosystem model was used to investigate the main dynamics in the Baltic Sea ecosystem (Bossier *et al.* in revision). The physical and bio-geo-chemical and hydrodynamic forcing was provided by the HBM-ERGOM model (Hiromb-BOOS model coupled to the Ecological Regional Ocean Model). During the meeting, the calibration of the model was highlighted with examples on how to verify the model with known data from observations or scientific surveys. The output of the model can be used to improve our management advice.

### 5.1.4 A general framework for combining ecosystem models

Michael Spence (WGSAM) presented the ensemble model, developed as part of the Marine Ecosystem Research Programme, which aims to combine outputs from different marine ecosystem models. The model, based on the ideas developed by Chandler (2013), treats the outputs from different marine ecosystem models as coming from a population that centres on the simulator consensus, which is itself not the truth but a bias version of it.

One of the major difficulties in applying these ideas is that marine ecosystem models have different outputs and are on different scales, for example in Strathclyde End to End (Heath, 2012) species are grouped by their living habitat whereas in the LeMans model (Thorpe, 2015) the species are modelled explicitly. The ensemble model uses correlations in other ecosystem models to determine what the models that group species would have predicted for individual species, for example what Strathclyde End to End would predict for sole given its prediction for demersal species. Using the ensemble model design in Figure 5.2, we can learn how each of the models is wrong relative to the simulator consensus known as the individual discrepancy, and then using noisy, possibly incomplete observations of the truth, we are able to learn how wrong the simulator consensus is from the truth, the shared discrepancy. The ensemble model was demonstrated by looking at what would happen, with robust measures of uncertainty, to demersal fish in the North Sea if we were to close the fishery (Figure 5.3).

Using this framework, the ensemble model implicitly exploits the strengths of each of the individual ecosystem models. For a simple example, where all the relationships are linear and Gaussian, it is possible to demonstrate how much each ecosystem model contributes to the ensemble model (for an example on this, see Chandler, 2013). We therefore advise that models should be very good at predicting a few aspects thing as opposed to being okay at predicting many things. We also advise that all available models be included in the ensemble, as there the ensemble model will discount the models if they are poor and take strengths from areas where they are strong.

In the case study, it is assumed that something that was skilled at predicting the past would also be skilled at predicting the future. In future work we are going to extend this to include models that can predict on different time-scales. For example, we expect single-species models to be skilled at predicting on short time-scales and multispecies models to be skilled at predicting on longer time-scales. This is done with the aim that the models in the ensemble can be used to give strategic advice and the best use of models and model outputs for management purposes. Another study, not presented here, examines the how different management strategies effects the future landings of the North Sea. The output of this study has fed into a Bayesian Belief Network that assesses the social and economic consequences of the different management strategies. For more details, see Spence *et al.* (2017).

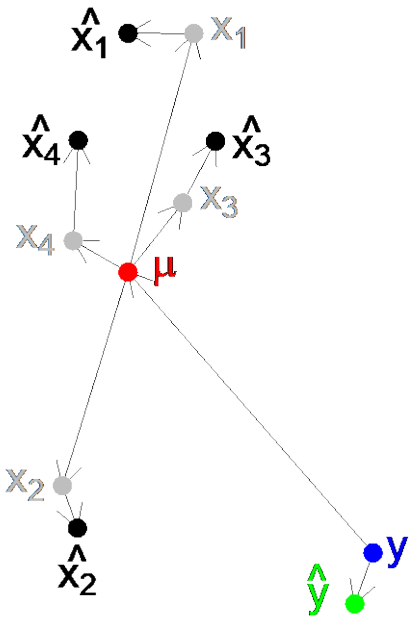


**Figure 5.2. The idealized model outputs, or "best guess", of each of the models, the value that the model would output if it were able to output all of the variables that we are interested in (e.g. what StrathE2E would predict if they we able to model cod) with no parameter uncertainty (i.e. fitted to an infinite amount of data) are the grey nodes and are centred on the simulator consensus, the red node. The actual model outputs are the black nodes. The difference between the model outputs and the simulator consensus is known as the individual discrepancy. The green nodes are noisy, possibly incomplete observations of the truth, the blue node. The difference between the truth and the simulator consensus is known as the shared discrepancy.**

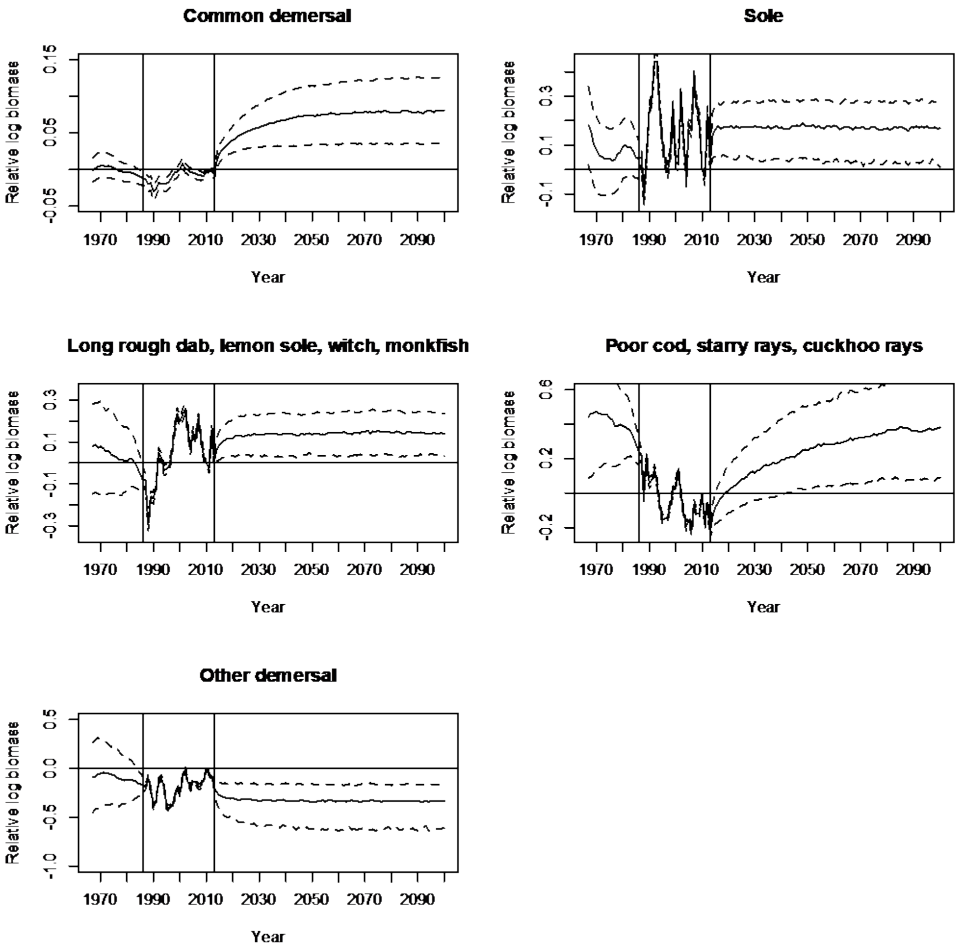


**Figure 5.3. The results of the ensemble model. Using five ecosystem models we were able to predict what would have happened to demersal species if we had stopped fishing in 2013.**

### 5.1.5 Summary of previous years advances

In previous years, work was presented related to model skill assessment and sensitivity analysis. S. Lehuta applied skill assessment technics to a multivariate spatial fishery model, M. Travers-Trolet evaluated the impact of structural uncertainty on management reference points in the Eastern English Channel. Literature was reviewed to offer leads and demonstrate the applicability of these methods to IPEM models. During the 2016 meeting, the group conducted a reflection on how to consolidate complex models parameterization by using sensitivity analysis and optimization technics and demonstrate model skills. The main challenges pertain to the number of parameters, the simulation duration and the many dimensions to consider in these models (space, time, compartments, trophic level, etc.). Regarding model skills data limitation is an issue, and attention must be paid to circularity in the validation process. Therefore, pattern oriented validation of model emergent properties is the favoured approach. The scope of ecosystem models is generally wide and not as focused on one output variable (such as biomass and F) as the assessment models. They are also likely to perform differently for different metrics and output variables, and i) priorities need to be defined based on the question to address and feedback from field biologists regarding important ecosystem features and ii) global metrics need to be investigated to summarize model behaviour on a more global scale.

This year, the joint meeting with WGSAM, allowed presenting a larger overview of the advances in model skill assessment for a wide range of models. Discussions concluded on the necessary honesty regarding model skill and the value to report transparently strengths and weaknesses. The presentations helped structuring further the future approach by differentiating between model skills in hindcast and forecast, how to correct projections using systematic bias, and how sensitivity offers insights in model and system behaviour, and helps prioritize parameterization efforts.

#### 5.1.6 Science highlights from ToR a

Ecosystem based fisheries management implies the use of ecosystem models to address complex management objectives. The transfer of model results to advice requires improving confidence in their results. Benchmarking has been promoted by ICES for assessment models since 2009 but the applicability of the procedures to more complex models stay uncertain. In order to advance benchmarking of ecosystem models, WGIPEM:

- Reasserted the need for proper ecosystem model skill assessment in order to increase credibility and usefulness of model results for management purpose;
- Reviewed and contributed to validation exercises, methods and guidelines in the literature;
- Listed objectives and challenges pertaining to the assessment of complex model skills;
- Provided first results on application of skill assessment, sensitivity analysis, and ensemble approaches to complex models;
- Started the discussion with WGSAM, to share and harmonize methods within ICES and produce practical guidelines;
- Decides that more work is needed on this topic and renewed ToRa for the next period.

**References:**

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Spence, M. A; Blanchard, J. L., Rossberg, A. G., Heath, M. R., Heymans, J. J., Mackinson, *et al.*, 2017. Multi-model ensembles for ecosystem prediction, arXiv:1709.05189.

Thorpe, R.B., Le Quesne, W.J.F., Luxford, F., Collie, J.S., and Jennings, S. 2015. Evaluation and management implications of uncertainty in a multi-species size-structured model of population and community responses to fishing. Methods Ecol. Evol. 6(1): 49–58.

### 5.2 Progress and fulfilment by ToR b

ToR b is on maintaining an interface for scientific and public community. Several papers were published by WGIPEM members (see Annex 2) reviewing the models applied by group members, dealing with the current state-of the-art and future challenges. A session was organized at the AMEMR conference 2017 (http://www.amemr.com) on the use of mechanistic ecosystem model outputs in advice on behalf of the group. Tools were developed or used to ease access, use and exploration of complex models by scientists (R package AtlantisTools, ecosystem code generation tool, UQLab, openMole) and stakeholders (R package Shiny). Example of the use of the Shiny application for the ISIS-Fish model of the Eastern English Channel can be found here http://sirs.agrocampus-ouest.fr/discardless_app/app10/. An update of the WGIPEM webpage is ongoing in order to collect models and model descriptions and make the above mentioned tools easily available to group members and the scientific community.

WGIPEM posed a recommendation on liaising with the Integrated Environmental Assessment (IEA) groups in the last report. The objective is to identify if some of their needs in term of mechanistic ecosystem models could be addressed by some of the models developed by WGIPEM group. The group therefore had joint meetings this year with the WGINOSE (North Sea) and WGEAWESS (western European shelf seas) and WGSAM (multispecies assessment methods) to discuss how complex models can be applied to stakeholder questions. An overview of the work developed by each group in the last years was provided during this a back to back session between WGIPEM, WGEAWESS, and WGINOSE. The goal of this session was to evaluate and identify potential ways of interactions between WGIPEM and IEA groups, since they are all trying to move towards the operationalization of the EBM in the North East Atlantic area. The need of a harmonization of methods among the different IEA groups was discussed by the group, in line with the road map communicated by the ICES Secretariat for the following years. Additionally, the group missed some integration of climate change related science and knowledge in these groups, being already highlighted as one of these group's tasks for the near future. A discussion table was opened afterwards between the IEA groups (WGINOSE, WGEAWESS) and the chair of the new Working Group on Seasonal-to-Decadal Prediction of Marine Ecosystems (WGS2D), Mark Payne.

WGINOSE aims to take IEA past ecology oceanography to evaluate effects of human activates and illustrate trade-offs between uses. This was inspired by WGNARS qualitative modelling (Depiper *et al.*, 2017). On the joint meeting with WGINOSE, Erik Olsen presented the qualitative model 'Mental modeler' (www.mentalmodeler.org). This presents a different kind of approach, which focus on fuzzy logic and can be used as a screening tool for communication with stakeholder before developing more complex models. The YouTube video 'What is mental modeler?' (https://youtu.be/By24uhIbBn4) was used to demonstrate the capacity of mental modeler. It is mostly fuzzy cognitive modelling, where components and their relationships (weighted between -1 and 1) are identified. In 2017, WGINOSE started trying it out developing a model for the North Sea. The model was further developed (more components) with the help of WGNARS. So far, WGINOSE have developed a template model, as well as specific regional models for Skagerrak. In February 2018, WGMARS and WGINOSE developed one such model with Dutch stakeholders (mostly planners). This was a great exercise of building mental models with stakeholders. It was also useful to identify what is important to them and their perspective of the system and management. Additionally, mental modeller allows also running very simple "what if?" scenarios. For example, small reduction in pelagic and demersal fisheries. These are informative and a great tool for screening processes and communicating with skateholders. They can be used to help develop questions, once it has been used for the initial screening, then the effort can move into more advanced/complex modeling tools. Though Mental modeler is not a replacement for existing quantitative, mechanistic, models. It is a good communication tool for bridging between researcher of WGIPEM, WGINOSE, WGNARS, and stakeholders.

During this join session with IEA WGs, Eider Andonegi presented the work conducted by the Working Group on Ecosystem Assessments of Western European Shelf Seas (Celtic Seas, Bay of Biscay, and Iberian waters) which undertakes IEA to support ecosystem-based management (EBM) measures at the local, national, regional and EU levels. Relevant to key EU Directives (e.g. MSFD, WFD, and CFP), IEA makes explicit links between human activities and ecosystem health, assessing the scale of impact and recovery, allowing targeted management and mitigation measures. Employing a combination of integrated trend analyses to generate time-series of pressures and impacts, semi-quantitative methods to fill data gaps and inform future research effort, and reviewing and updating existing ecosystem models throughout the regions, WGEAWESS reviews and assesses patterns of human activities, their pressures, and ecosystem components to underpin the process. Ecosystem overviews, species cards were also shown as products developed by WGEAWESS for the ICES community. Different methodologies such as the Integrated Trend Analysis (ITA), the ODEMM framework and ecosystem models using EwE were also shown as part of the methods agreed by the group to inform IEAs.

Morten Skogen demonstrated through examples using the NORWECOM.E2E model in the Norwegian Sea, how primary production, zooplankton biomass and the effect of zooplankton harvesting can be estimated from models, and some of the problems faced when estimating zooplankton biomass from observations due to uncertainties from the cruise design. According to Levin *et al.* (2009), a key component of ecosystem based management is a holistic assessment of the status of marine ecosystem, and an integrated assessment is a formal synthesis and quantitative analysis of information on relevant natural and socio-economic factors. Ecosystem models is a consistent way to do repeated assessment of status and quantitative analysis of ecosystems as done in the ICES-IEA groups. Especially on the lower trophic levels, anthropogenic impact, trophic flows and interannual variability, there are a number of benefits using ecosystem models compared to traditional *in situ* observations.

### 5.2.1 Science highlights from ToR b

- Advertise WGIPEM products to other ICES workings groups and communities (conference, back to back meetings and new website);
- Use and report on tools to communicate model results to scientists and stakeholders (keyruns, webapplications);
- Demonstration of integrated models utility for evaluate uncertainty linked to survey designs.

#### References:

DePiper *et al.* (2017) ICES Journal of Marine Science, 74(8), 2076–2086. doi:10.1093/icesjms/fsx038

Levin PS, Fogarty MJ, Murawski SA, Fluharty D (2009) Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. PLoS Biol 7(1): e1000014. https://doi.org/10.1371/journal.pbio.1000014

## 5.3 Progress and fulfilment by ToR c

ToR c is about identifying gaps in knowledge that need to be closed and spot emerging fields in coupled physical-biological and ecosystem modelling approaches. At the last meeting, we identified a knowledge gap of how to represent different benthos groups, their role and dynamics in our ecosystem models. This led to a new recommendation to liaise with BEWG in order to i) identify available data on benthic species biomass and assess their potential match with model needs and ii) identify contact persons working on benthic community models to start exchange and collaboration between our groups. At this year's meeting, we had joint discussions with Silvana Birchenough (chair of BEWG) and Andrew Kenny (chair of WGINOSE), both working on benthos data. During the discussions in relation to ToR c, it was recognized that not only benthos descriptions, but also sediment fluxes are a challenge to describe realistically in the models. Sediments play a key role in the biogeochemical cycling of organic matter in marine ecosystems. This is especially true for shallow near-coastal areas, which often also exhibit the largest productivities up to the trophic levels of fish. Macrozoobenthic communities and microbial activities in the sediment interact with each other and shape the response of the seabed to the input of organic matter from the pelagic. Despite its importance in nature, the benthic system is often paid little attention in biogeochemical models, which often focus on the pelagic ecosystem. This is, in part, a consequence of the complexity of the benthic ecosystem component and its spatial diversity, which makes it hard to obtain sufficient empirical information, which would allow for the validation of a modelling approach, which extends beyond simple general parameterizations.

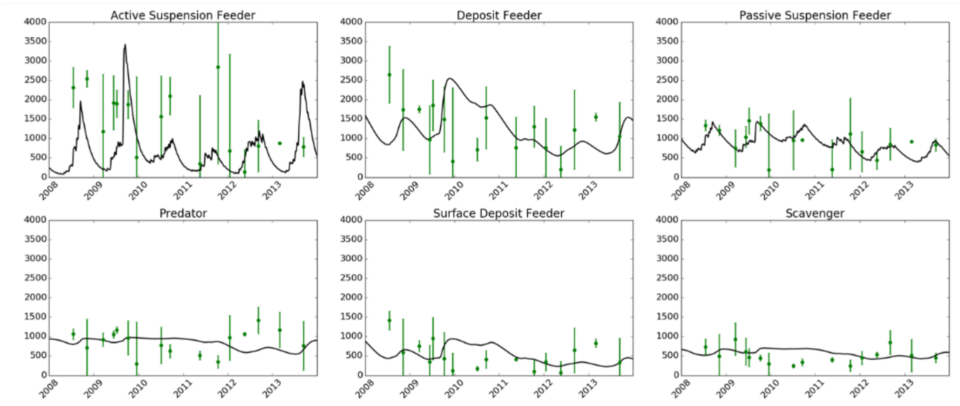
### 5.3.1 Collaboration with other WG's on benthos data and knowledge exchange

Silvana Birchenough presented the work of BEWG and gave examples of studies, which could be of relevance to WGIPEM, e.g. data on spatial distribution of species, habitat mapping, state and trends of species, a table showing the different traits of species, and sediment fluxes. It was concluded that the groups have some shared interests and should keep in contact, e.g. at the next BEWG meeting in May 2018.

Andrew Kenny presented the work of WGINOSE on benthos functional traits in the North Sea. They have been involved in the BENTHIS project, which constructed a large dataset centred on the North Sea. He presented a map of sample locations (about 700 No. of stations comprised of data from 4–5 participants; collect a number of environmental and biological info) for the period 1995–2010. Most of their analyses are spatial, not temporal (yet). Traits (e.g. max size, morphology, egg dev., feeding mode, bioturbation, etc.) are used instead of taxonomic/species grouping, because traits give rise to processes, which provide function and which again define goods and services (e.g. Bioturbation leads to nutrient fluxes, which feed into maintenance of primary production and water purification). The ecosystem functions considered include regulation, habitat, and production (Bolam *et al.*, 2017). Some traits were best described by sediment grain size and some traits were best at describing water depth. It is recommended to select those traits, which exhibit a continuous response to gradients in environmental conditions, e.g. longevity and size. They developed a simple matrix of depth vs. sediment to describe the basic traits of corresponding species and corresponding habitat. Benthos longevity and size as indicatory of benthic/habitat state changes in integrated assessments. It was concluded from the discussions that the approach of using functional traits and the relation to habitat type was very relevant to how to describe the functional groups of benthos in ecosystem models.

### 5.3.2 Examples of benthos and sediment descriptions in ecosystem models

An example of diversifying functional types of benthic macrofauna in an ecosystem model was presented by Sevrine Sailley (on behalf of the authors Gennadi Lessin and Jorn Bruggeman). The presentation showed the approach taken to increase diversity in the biogeochemical ecosystem model ERSEM (European Regional Seas Ecosystem Model). Benthic macrofauna are originally represented by two groups (a deposit-feeder and a suspension-feeder), which have been split into a further six groups (active suspension-feeder, passive suspension-feeder, surface deposit-feeder, subsurface deposit-feeder, scavenger, and, predator) (Figure 5.4). Increase in the diversity of the group allow for better representation of process and ecosystem services, with the composition and biomass of the benthic community being affected by food availability (deposition of pelagic production) and hydrodynamic (resuspension of organic matter). Simulation on the European shelf showed how biodiversity of the benthos (as measured by Shannon index) varies on the shelf, and the difference in the foodweb structure and functioning at different sites. The three-dimensional simulations with a high benthos species diversity in the North Sea is the first of its kind and still in the experimental phase. Several knowledge gaps were identified during the process, including: 1) dynamics of benthic-pelagic boundary layer (resuspension, deposition), 2) the role of bacteria and meiobenthos, 3) diet composition and habitat ranges of major microbenthic groups, 4) dynamics of bioturbation and bioirrigation, 5) representation of physical and biogeochemical processes in various sediment types.




**Parameterisation:**

- **Optimisation with "default" macrofauna groups**
- **Literature**
- **Expert judgement/opinion**

**Figure 5.4: ERSEM benthos groups compared with monitoring data from 2008 to 2013.**

Marie Maar showed how potential offshore fish farms (rainbow trout) could affect the environment in the inner Danish waters using a modified version of the ERGOM model with two benthos functional groups, deposit-feeders and suspension-feeders (Maar *et al.*, 2018a). The fish farms were mainly found to affect the sediment below the farms due to deposition of fish faeces and feed pellets and the sediment organic matter content accumulated over time. The two benthos groups responded differently to the organic enrichment below the fish farms depending on prevailing resuspension events and oxygen conditions (Figure 5.5). However, benthos were found to be important in mitigation the negative effects of organic enrichment. Changes in DIN and Chl *a* concentrations were observed in open waters near the farms, but were diluted over time and with distance from the farms. There was a transport of added nutrients from the fish farms into the water coastal areas (app. 20% of total farm input) protected by the EU Water Framework Directive although causing minor changes in water quality. Future implementation of fish farms in the area requires detailed spatial planning, optimization of farm design and nutrient compensation by marine measures, e.g. blue mussel farming. Knowledge gaps were related to the few data of the natural spatial distributions of benthos and sediment nutrient fluxes in the area and below fish farms, which could be used to validate the model responses.

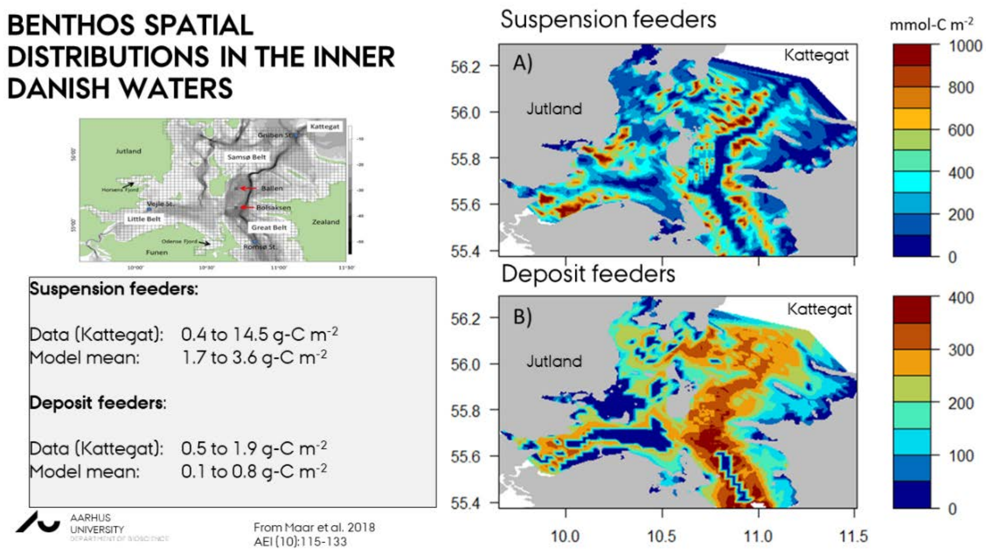



**Figure 5.5: Model bathymetry of the inner Danish waters in the upper left figure, comparison between model and monitoring data in the box, and spatial distributions of suspension-feeders and deposit-feeders from model results in the right figures.**

Ute Daewel presented a study on the role of macrobenthos for the impact of bioengeneering projects related to Baltic Sea eutrophication. From 1950 onwards, the Baltic Sea ecosystem suffered increasingly from eutrophication. The most obvious reason for the eutrophication is the huge amount of nutrients (nitrogen and phosphorus) reaching the Baltic Sea from human activities. Additionally permanent stratification limits ventilation of the Baltic Sea water deep water to occasional Major Baltic Inflows (MBAs) from the North Sea and thus promotes lasting hypoxic conditions. Although nutrient loads have been decreasing since 1980, the hypoxic areas have not decreased accordingly. Thus, geo-engineering projects were discussed and evaluated to artificially ventilate the Baltic Sea deep water and suppress nutrient (particularly phosphate) release from the sediments.

Here, the aim was to understand consequences of proposed geo-engineering projects using long-term scenario modelling. For that purpose, they utilized the tridimensional coupled ecosystem model ECOSMO E2E, which is a novel NPZD-Fish model approach that allows estimating lower trophic level dynamics, biogeochemical cycling and higher trophic level production potential and integrate the model over a 68-year long period (1948–2015). The model additionally includes one functional group representing macrobenthic fauna (Figure 5.6), which is highly relevant to transferring carbon to higher trophic levels, but also for nutrient recycling in sediments. They performed and analyse model scenarios that consider changes related to proposed geo-engineering projects such as artificial ventilation of Baltic Sea deep waters and phosphorus binding in sediments with polyaluminium chlorides. The results particularly showed that changes in the Baltic Sea bottom-water oxygenation result into additional sediment phosphate binding only in the first years after installation of the ventilation pump. After 4–5 years, macrobenthos will recolonize the deeper now oxygenated basins of the Baltic Sea and alter the sediment carbon recycling. Consequently, the overall system productivity will generally increase while cyanobacteria bloom decreases. This study is also of relevance to ToRs d and f.

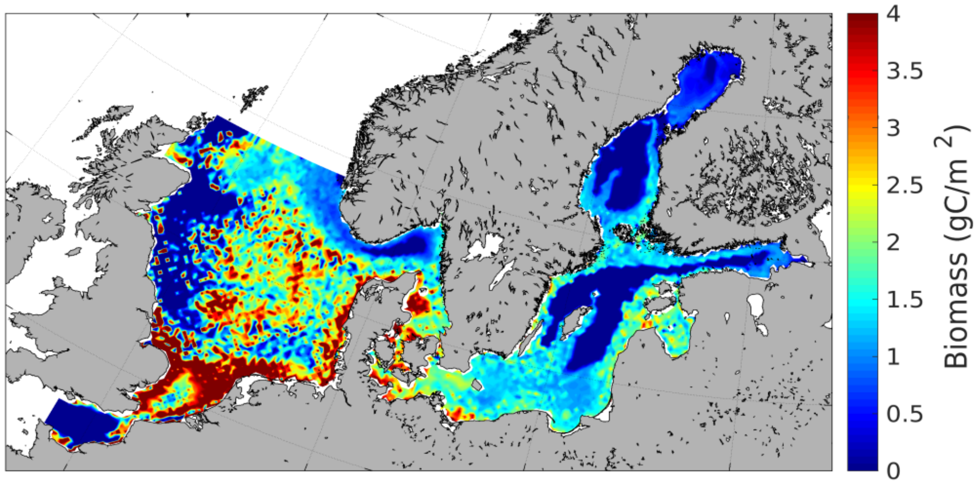



**Figure 5.6: Mean annual macrobenthos biomass (1980–1989) estimated with ECOSMO E2E for the North Sea and Baltic Sea ecosystems.**

Hagen Radtke presented a benthic extension to the ERGOM ecosystem model. A depth-resolving model of early diagenetic processes is directly coupled to the pelagic part of the ecosystem model. The model has been applied to the German EEZ in the Baltic Sea and validation with different observed sediment data were shown. This type of model is, in contrast to the previous, more simplified one, mechanistic and therefore contains predictive capacity on how external stressors may affect benthic nutrient cycling and in this way have an effect on the pelagic ecosystem state as well. Knowledge gaps, which future modelling approaches will have to close are the responses of sedimentary key functions to external forcing. These functions include nutrient recycling, nutrient removal (burial/denitrification), and functions of the macrozoobenthic community such as sediment oxygenation or provision of food to predator fish.

Elin Almroth-Rosell presented a study on challenges in modelling benthic nutrient fluxes and the importance of observations. It has been concluded in several studies that the benthic nutrients are of great importance for the recirculation of nutrients in the ecosystems and the subject is highly relevant in terms of management of the marine environment in e.g. the Baltic Sea. To able to answer scientific questions and to reach new levels of knowledge the work with development of the sea models used in by the research community is very important and as well, continuously on going. In this work, there is a need to use observations of good quality.

The conclusion from the talk is that the availability of observational data of sediment parameters is often missing, or of a quality not good enough for a proper evaluation. It is important that it is not only single parameters to be measured but also a set of back ground data. Thus, the units of observations and model data must be comparable, otherwise the observational data will be hard to use for modellers and thus also the model development. In addition, there is a need for better communication on what observations that are needed from a modeller's perspective, resources to do the observations and also routines to store benthic data. For more information see Lessin *et al.* (2018).

### 5.3.3 Knowledge gaps in parameters related to bioenergetics

The knowledge gaps concerns the need for more field and laboratory data on key parameters required to calibrate and validate life cycles models of marine fish, including traditional bioenergetics and dynamic energy budget (DEB) models. These models are widely used in individual-based modelling and often integrated in biophysical models of fish early-life stages and population dynamics models, as well as to some end-to-end models. However, for many fish species bioenergetics models and DEBs still remain poorly parameterized and this may result in strong biases of model predictions. Field data and laboratory experiments are important sources of information about model parameters and their functional responses. For example, additional data are required on food consumption and energy content of fish at different life stages and seasons, observed growth rates of young fish and their feeding conditions, etc. The group planned to identify further biological and physiological parameters of interest to feed discussions with WGBIOP[1] and WGISUR[2] groups concerning joint effort in improving reliability of life cycle and ecosystem models. This task needs more work and should be included in the ToRs for the next period.

### 5.3.4 Knowledge gaps related to microzooplankton data

An inter-model comparison paper by Maar *et al.* (2018b) revealed that ecosystem models were mainly validated for nutrients and Chl *a,* and to some extent phyto- and mesozooplankton biomass, but rarely for microzooplankton biomass (Table 5.1). There is, to our knowledge, no coherent dataset on microzooplankton for the North Sea and the Baltic Sea. Further, microzooplankton covers a wide range of species with different sizes, growth rates, prey preference, mixotrophy and feeding strategies, which makes it difficult to define them as a functional group and to parameterize the general physiological processes. More data are therefore needed to parameterize and calibrate the microzooplankton functional group in ecosystem models.

**Table 5.1. Data sources used for model validation of nutrient concentrations, biomass of different phyto-PFT's, Chl *a* concentration, primary production, biomass of different zoo-PFT's and Z1 biomass. I=ICES data, H=HELCOM data, N=National monitoring data, C=Continuous Plankton Recorder (CPR) data, W=World Ocean Atlas, R=Research projects, RS=Remote sensing data, L=literature values and O=other data (e.g. PhD project). The last column shows the validation period for the different variables. From Maar *et al.*, 2018.**

| Model name | Nutrients[a] | Phyto-PFT's[b] | Chl a[c] | Primary production[d] | Zoo-PFT's[e] | Z1 biomass[f] | Validation period |
|---|---|---|---|---|---|---|---|
| DELFT3D-GEM | N, R | N, R | N, R, RS | - | Not relevant | L | a,c) 1975-2012 b) 1998 f) 2008 |
| MIRO&CO | N, R, O | R, O | N, R, O, RS | - | R, O | R, O | a,b,c,e,f) 1989-1999 and a,b,c) 1991-2003 |
| NORWECOM-NS | I, N, R | - | I, N, R | L, R, O | - | - | a, c) 1980-2006, d) 1985-1994 |
| NORWECOM-NO | - | - | N, RS | L | - | N, L | c) 1981-2007, d) 1981-2006, f) 1997-2007 |
| ECOSMO | I, H | I, W | I | L | - | R, C | a,d) 1970-2008, b,c,f) 1984-1986 and f) 1995 |
| HBM-ERGOM | I, H, N, W | - | I, H, N | N | N | N, C | a) 2001-2006, c-d) 2001-2010, e) 2010 and f) 2001-2004 |
| POLCOMS-ERSEM | I, W | C | I, RS, W | L | - | C | a, c ) 1970-2004 (I), a, c) 1981-2004 (W), c) 2003-2004 (RS), d) bulk values and b, f) 1988-1989 |
| MOM-ERGOM | I, H, N, R | - | I, H, N | - | Not relevant | - | a) 2008-2013 and b) 1970-2008 |

### 5.3.5 Science highlights from ToR c

- Started the discussion with WGINOSE and BEWG on how to identify available data on benthic species traits and biomass and assess their potential match with model needs;
- Provided first results on how to implement benthos diversity and sediment fluxes into models;
- Identified trait-based approaches to be an innovative and promising modelling field that needs further research;
- Identified a new knowledge gap related to making bioenergetics parameters available to modellers;

[1] Working Group on Biological Parameters (WGBIOP)

[2] Working Group on Integrating Surveys for the Ecosystem Approach (WGISUR)

- Identified a new knowledge gap related to available microzooplankton data to calibrate ecosystem models;
- Decided that more work is needed to fill the identified knowledge gaps and this should be included in the renewed ToRs for the next period

**References:**

Bolam *et al.* 2017. Differences in biological traits composition of benthic assemblages between unimpacted habitats. Mar Environ Res. 126:1–13.

Maar, M., Larsen, J., Dahl, K., Riemann, B. (2018a). Modelling the environmental impact of offshore fish farms in the inner Danish waters. Aquac Environ Interact 10:115-133.

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## 5.4 Progress and fulfilment by ToR d

ToR d aims at discussing and providing basis for setting up future scenarios of anthropogenic pressure and climate variability. This ToR was addressed in the session ‘Future model scenarios’. Myron Peck reported on different projects aiming at assessing the impact of climate change and management scenarios on fisheries. Geneviève Lacroix presented a study on the impact of climate change on connectivity and larval recruitment of sole in the North Sea and Sofia Saraiva presented future climate projections for the Baltic Sea region.

Myron Peck reported on the CERES project, where the climate scenarios applied are the RCP 4.5 and RCP 8.5. The project includes fisheries and aquaculture, economics and risks with stakeholder engagement as an important interaction. There are 27 story lines across the work packages. A large number of studies have been looking at temperature effects, but effects of other stressors are less numerous/lacking (Figure 5.7). The PESTLE approach to frame future climate change scenarios eventually gave four different scenarios, where the management in each is fundamentally different. These scenarios are useful to get a dialogue with stakeholders. Myron Peck also gave a short report on the SICCME and FishMIP working groups, in which common scenarios across ecosystems from the northern hemisphere are proposed. FishMIP has 10 global models doing model/ecosystem comparisons. Workshops will be held on 2 June 2018 (SICCME) and 9 June, workshop PESTLE 2018. On 4–8 June 2018, the conference on the ‘Effect of climate change on the world oceans’ took place in Washington, DC. The new PANDORA project (2018–2022) is on building engagement with fishers using data from fisheries, improvement of stock assessment models with regards to density-dependence, spatial structure, foodwebs and environmental drivers. The project will provide toolbox for fishers and scientists.

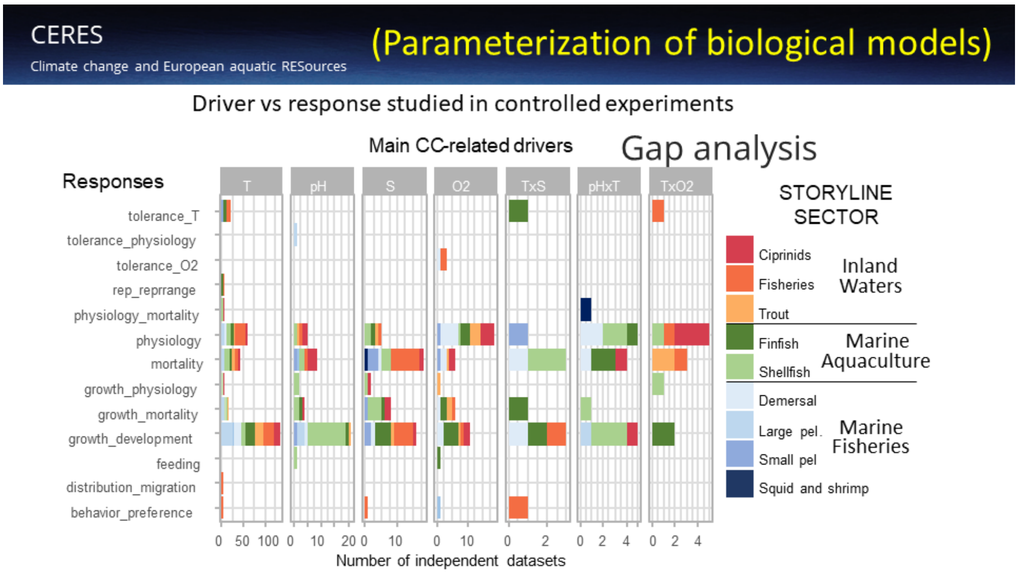


**Figure 5.7. Results of a GAP analysis performed within the EU CERES project (Ignacio Catalan, CSIC, personal communication) on the number of independent datasets generated divided by the effect of selected drivers on responses (Y axis) for specific storyline sectors (colour bar). Results for various commercially important fish and shellfish from various European fisheries and aquaculture sectors are shown. Here, the "x" in the drivers indicates an interaction between abiotic factors. The response variable "physiology" embraces usually metabolic rates of different types. In the responses, the underscore symbol indicates that both responses are studied, but interaction is not considered. Specific terms needing clarification are: responses preceded by "tolerance", are tolerance measures to the respective driver. "rep_reprange" stands for studies on reproductive variables or reproductive range.**

Geneviève Lacroix presented a study on impact of climate change on connectivity and larval recruitment of sole in the North Sea. Climate change not only alters ocean physics and chemistry but also affects the biota. Larval dispersal patterns from spawning to nursery grounds and larval survival are driven by hydrodynamic processes and shaped by (a)biotic environmental factors. Therefore, it is important to understand the impacts of increased temperature rise and changes in windspeed and direction on larval drift and survival. We apply a particle-tracking model coupled to a three-dimensional hydrodynamic model of the English Channel and the North Sea to study the dispersal dynamics of the exploited flatfish (common) sole (*Solea solea*). We first assess model robustness and interannual variability of larval transport over the period 1995–2011. Then, using a subset of representative years (2003–2011), we investigate the impact of climate change on larval dispersal, connectivity patterns and recruitment at the nursery grounds. The impacts of five scenarios inspired by the 2040 projections of the Intergovernmental Panel on Climate Change are discussed and compared with interannual variability. The results suggest that 33% of the year-to-year recruitment variability is explained at a regional scale and that a 9-year period is sufficient to capture interannual variability of dispersal dynamics. In the scenario involving a temperature increase, early spawning and a wind change, the model predicts that (i) dispersal distance (+70%) and pelagic larval duration (+22%) will increase in response to the reduced temperature (-9%) experienced by early hatched larvae, (ii) larval recruitment at the nursery grounds will increase in some areas (36%) and decrease in others (-58%), and (iii) connectivity will show contrasting changes between areas. At the regional scale, our model predicts considerable changes in larval recruitment (+9%) and connectivity (retention -4% and seeding +37%) due to global change (Figure 5.8). These factors affect the distribution and productivity of sole and therefore the functioning of the demersal ecosystem and fisheries management. More details can be found in Lacroix *et al.* (2018).

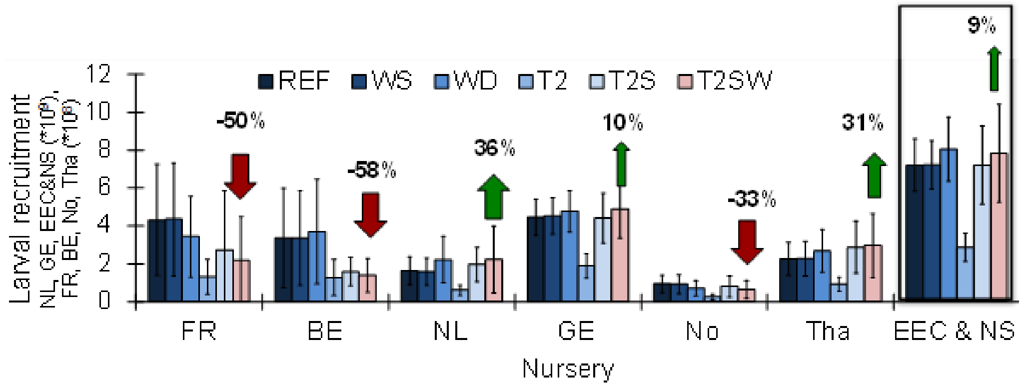


**Figure 5.8. Mean larval recruitment at the nursery grounds and at the regional scale for the reference run and the perturbed simulations. The mean covers the period 2003–2011, and the error bars represent the interannual standard deviation. REF: reference run, WS: windspeed increase by 4%, WD: south-westerly wind increases applied by adding 20% to the northern component and 10% to the eastern component of the wind intensity used for the reference simulation resulting in a change in wind direction by 13° north-eastwards, T2: SST increase by 2°C increase, T2S: in addition to the perturbation of scenario T2, an early spawning of 42 days is considered and T2SW: combination of all previous perturbations. FR: French nursery, BE: Belgian nursery, NL: Dutch nursery, GE: German nursery, No: Norfolk nursery, Tha: Thames nursery and EEC and NS: Eastern English Channel and North Sea (Redrawn from Lacroix *et al.*, 2018).**

Sofia Saraiva presented a study on future climate projections for the Baltic Sea region. Many coastal seas worldwide are affected by human impacts such as eutrophication, causing, inter alia, oxygen depletion and extensive areas of hypoxia. Depending on the region, global warming may reinforce these environmental changes by reducing air-sea oxygen fluxes, intensifying internal nutrient cycling and increasing river-borne nutrient loads. The development of appropriate management plans to more effectively protect the marine environment requires projections of future marine ecosystem states. However, projections with regional climate models commonly suffer from shortcomings in the driving global General Circulation Models (GCMs). The differing sensitivities of GCMs to increased greenhouse gas emissions affect regional projections considerably. In this study, they focused on one of the most threatened coastal seas, the Baltic Sea, and estimated uncertainties in projections due to GCM deficiencies relative to uncertainties caused by future greenhouse gas emissions and nutrient load scenarios. To address the latter, transient simulations of the period 1975–2098 were performed using the initial conditions from an earlier reconstruction with the same Baltic Sea model (starting in 1850). To estimate the impacts of GCM deficiencies, dynamical downscaling experiments with four driving global models were carried out for two greenhouse gas emission scenarios, RCP 4.5 and 8.5, and for three nutrient load scenarios covering the plausible range between low and high loads. The results of primary production, nitrogen fixation, and hypoxic areas show that uncertainties caused by the various nutrient load scenarios are greater than the uncertainties due to global model deficiencies and future greenhouse gas emissions. In all scenario simulations, a proposed nutrient load abatement strategy, i.e. the Baltic Sea Action Plan, will lead to a significant improvement in the overall environmental state (Figure 5.9). However, the projections cannot provide detailed information on the timing and the reductions of future hypoxic areas due to uncertainties in salinity projections caused by uncertainties in projections of the regional water cycle and of the global mean sea level rise.

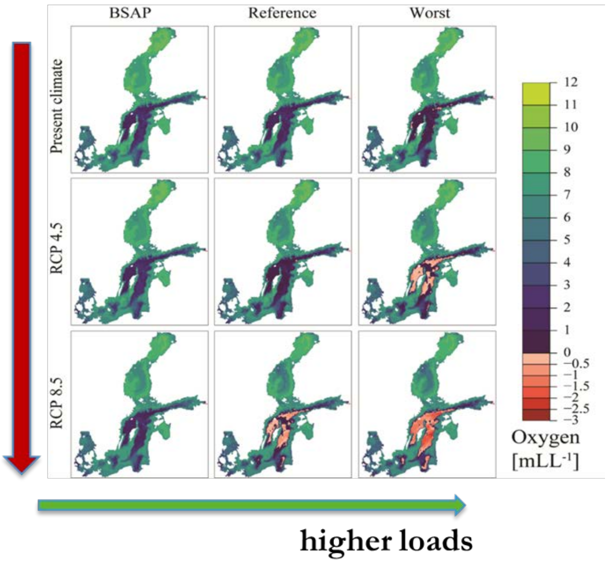


**Figure 5.9. Model results showing changes in bottom oxygen from three nutrient load scenarios: the Baltic Sea Action Plan (BSAP), Reference and Worst Case conducted under present climate and two greenhouse gas emission scenarios, RCP 4.5 and 8.5. From: Saraiva *et al.*, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2018-16, in review.**

### 5.4.1 Science highlights from ToR d

- A large number of studies have been looking at temperature effects, but effects of other stressors are less numerous/lacking, which makes it difficult to make realistic future projections of changes in species distributions and ecosystem properties in response to climate change and other stressors;
- A larval transport model has been used to assess the impact of climate change scenario at the horizon 2040 on larval sole recruitment and connectivity between spawning grounds and nurseries in the North Sea;
- Future IPCC climate projections have been applied for the Baltic region and uncertainties in projections relative to uncertainties caused by future greenhouse gas emissions and nutrient load scenarios have been estimated (Baltic region). Downscaling products are available upon request to SMHI;
- Group agreement that more work is needed to fill the identified knowledge gaps and this should be included in the renewed ToR's for the next period

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Lacroix G., Barbut L., Volckaert F.A.M. 2018. Complex response of projected sea temperature and wind change on flatfish dispersal. Global Change Biology, 24:85-100.

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Saraiva, S., H.E. Markus Meier, Helén Andersson, Anders Höglund, Christian Dieterich, Matthias Gröger, Robinson Hordoir, Kari Eilola. Baltic Sea ecosystem response to various nutrient load scenarios in present and future climates. Climate Dynamics.

## 5.5 Progress and fulfilment by ToR e

ToR e is about improvements and routine development to describe behaviour of species and man and to include evolution and adaptation in coupled physical-biological and ecosystem modelling approaches. This ToR has been addressed in the session 'behaviour of man and species'. Erik Askov Mousing presented a statistical approach to understand behavioural rules of fish. Onur Kerimoglu presented an acclimation-based phytoplankton growth model. Ceren Guraslan presented the impact of climate variability on overwintering migration of anchovy in the Black Sea.

Erik Askov Mousing presented a model study on niche dependent migration for pelagic fish in the Nordic seas using a statistical approach to adaptive behaviour and potential use cases. In the NORWECOM.E2E model, migration timing and routes have traditionally been determined based on the known distributions at certain times of the year. While this approach is good at modelling current conditions, it is limited in its ability to predict future changes in fish behaviour with changes in the environmental conditions. Here, they present a new migration routine for pelagic fish (exemplified by the Northeast Atlantic mackerel), based on the fish thermal niche as well as food density responses. Statistical distributions of the temperature niche and food search traits were fitted to empirical data from survey data collected 2007–2016. The fitted probability density functions are then used to guide decision on when and where to move due to changes in temperature and food density. They highlight two potential use cases: 1) modelling changes in migration timing and distribution during a decade of climate change; and 2) investigating impacts of selective fisheries on the distribution of fish thermal niche traits. Preliminary results show a food agreement between modelled summer distributions of mackerel and the known contemporary distribution. In addition, with climate change, we observed earlier migration timing and a shift in the distribution towards the northwest Norwegian Sea, corresponding to changes in the temperature distribution during the model period.

Onur Kerimoglu presented a model-based projection of phytoplankton in the pristine state of the southern NS. The work is ongoing in the Wadden Sea and German Bight. Phosphate and ammonia concentrations display strong gradients and to adequately depict these, the model examines the acclimation of autotrophs. Irradiance effects the concentration of Chl per unit Carbon – most models assume a fixed stoichiometry. The nutrient supply also affects this Chl-C ratio, which gets higher with nutrient dilution. An acclimation-based phytoplankton growth model was developed based on the assumption of phytoplankton maximizes is cellular allocation and is fit to laboratory data on phosphorous or nitrogen limitation. The changes in allocation of cellular machinery is also modelled. A high-resolution model is used (1.5 km to 4.0 km grid) across the region (Kerimoglu *et al.*, 2017). Historical changes in Chl *a* (growing season) and winter nutrient concentration. Changes at depth between the control (current) and historical run were large – Chl was higher in deeper winters in the historical run. The pristine state displayed very little differences (with regard to phytoplankton carbon) with low nutrient supply – but the Chl/C shifted to lower values. The physiological allocation of phytoplankton have likely shifted. Organic matter input was lower and attenuation was lower and therefore the light environment changed. The growth rates changed and the grazing rate was lower in the historical state (as zooplankton were lower). The phytoplankton to zooplankton carbon ratio changed dramatically. The N and P bound to phytoplankton has dramatically decreased and zooplankton excretion much change to maintain homeostasis. Adaptability of phytoplankton can add dynamics to biogeochemical model estimates, which may be needed to appropriately simulate the impact of nutrient reductions on lower trophic levels. Observations suggest that the type of phytoplankton have shifted with nutrient status, which is not included in the model. Stochiometry of microzooplankton can also shift.

Ceren Guraslan presented a study on modelling the impact of climate variability on overwintering migration of anchovy in the Black Sea. Anchovy is an important fishery of the countries surrounding the Black Sea. Anchovy spawns from June to September. There is no life below 200 m in this system, which reaches 2.2 km deep. The system is characterized by large cyclonic currents (western and eastern gyres). Strong eddies occur with interactions with the coast during the anchovy migration. The fisheries collapsed after the 1989–1990. USSR surveys found exclusive spawning along NW shelf but later survey have found more widespread egg distributions. Based on NW shelf spawning, two pathways occur for migration to the southeast (protection from winds). Anchovy accumulate fat reserves (14%) and migrate without feeding (Shulman, 2002). The influence of changes in SST and surface geostrophic currents was examined. Advection field generated and movement schemes were tested. Spatial changes in temperature were different among the three years (2002 had a stronger west-east gradient and had few eddies and a poor connectivity to overwintering areas). Success was low in the other years (12–15%) based on new spawning. Release throughout the whole domain suggests that eastern areas may be important. Three migration pathways are suggested to change with time due to the dynamic feature of eddy fields.

### 5.5.1 Summary of previous year's achievements

Additionally to the annual updates regarding the development of the fish movement routine within NORWECOM.E2E, a study about fishers' movement was reported in the 2016 WGIPEM report. Following a Dutch fisheries sector request, a mechanistic model of brown shrimp in the North Sea was developed to test different harvest control rules. A bioenergetics model of shrimp linked to a shrimp population model was coupled to an agent-based model of fishing fleets, allowing catches to be an emerging property of the system.

### 5.5.2 Science highlights from ToR e:

- A routine that guide movement behaviour of pelagic fish has been implemented in NORWECOM.E2E and improved years after years. Decision-making is controlled by sensing the environment and allows for adapting their behaviour to future changes. In addition, the routine allows for variation within the temperature and food search traits allowing changes in the distribution of trait space under selection pressure, e.g. through fisheries;
- A model of acclimation-based phytoplankton growth has been developed and included in a coupled physical-biological model;
- Representing passive and active fish movement allowed to investigate inter-annual variability of anchovy migration routes in the Black Sea;
- Model development of man (fishers) movement remains scarce and could constitute a field of research to investigate in future.

#### References:

Kerimoglu *et al.* 2017. The acclimative biogeochemical model of the southern North Sea. Biogeosciences 14:4499.

Shulman, G. E. (2002). Anchovies of the Azov and the Black Sea: regularities of wintering migrations. Mar. Ecol. J. 1, 67–77.

## 5.6 Progress and fulfilment by ToR f

This ToR is about advancing our understanding of bottom up and top down controls within foodwebs. This topic was investigated this year using the Baltic Atlantis End-2-End model. Further, an inter-model comparison study by Maar *et al*. (2018) investigated the sensitivity of summer Chl *a* concentrations to changes in top–down forcing using model results provided by the WGIPEM members.

Sieme Bossier presented the newly developed end-to-end Baltic Atlantis ecosystem model that was used to investigate the main dynamics in the Baltic Sea ecosystem, with a focus on spatial explicit interactions such as differences between offshore and coastal-zone areas. During the WGIPEM meeting, an example was given for the interactions between the lower trophic levels (zooplankton and phytoplankton) in relation with density-dependence and trophic controls. One of the challenges identified is to model the lower trophic levels. First, because a few groups only represent them, compared to the high detail in which the groups of the higher trophic levels are calibrated. Secondly, because the different and complex life stages of the zooplankton groups are not included. It was identified that there was a high weight on the zooplankton groups in terms of importance of the ecosystem functioning. Future work on this will help us to better understand bottom–up and top–down controls within the foodweb. Further, it is the plan to integrate socio-economic parameters, dynamics and fisheries (technical) interactions in the holistic ecosystem and fisheries system model instead of using the current constant fishing mortality rates. This integrates dynamics on catch, effort, revenue, costs, fish prices, profit, fleet capacity, and exit-entry dynamics, as well as fuel consumption according to area, time, and Baltic fishing fleets. The model application will evaluate impacts of eutrophication and climate forcing scenarios on biological interactions, resource availability and fisheries bioeconomic dynamics with a high resolution according to space, time and fleet components on a long-term strategic basis.

In the newly published joint WGIPEM paper by Maar *et al.* (2018), the responses of summer phytoplankton biomass to changes in top–down forcing (expressed as zooplankton mortality) were investigated in three ecosystems (the North Sea, the Baltic Sea and the Nordic Seas) across different three-dimensional ecosystem models. In each of the model set-ups, we applied the same changes in the magnitude of mortality (±20%) of the highest trophic zooplankton level (Z1). Model results showed overall dampened responses of phytoplankton relative to Z1 biomass. Phytoplankton responses varied depending on the foodweb structure and trophic coupling represented in the models. Hence, a priori model assumptions were found to influence cascades and pathways in model estimates and, thus, become highly relevant when examining ecosystem pressures such as fishing and climate change. Especially, the different roles and parameterizations of additional zooplankton groups grazed by Z1, and their importance for the outcome, emphasized the need for better calibration data. Spatial variability was high within each model indicating that physics (hydrodynamics and temperature) and nutrient dynamics also play vital roles for ecosystem responses to top–down effects (Figure 5.10). In conclusion, the model comparison indicated that changes in top–down forcing in combination with the modelled foodweb structure affect summer phytoplankton biomass and, thereby, indirectly influence water quality of the systems.

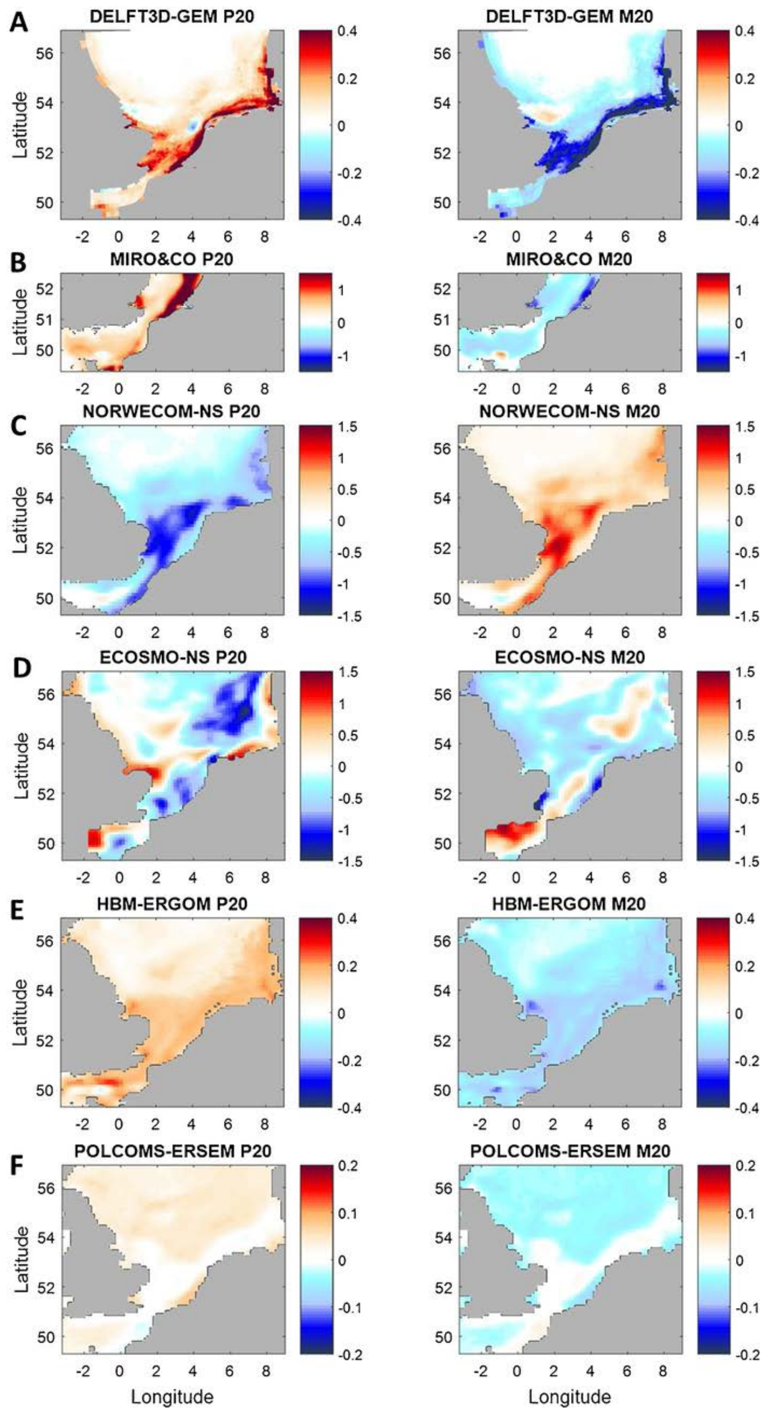


**Figure 5.10. Spatial patterns of changes in total summer phytoplankton biomass (ratio) in the North Sea models; A) DELFT3D-GEM, B) MIRO&CO, C) NORWECOM-NS, D) ECOSMO-NS), HBM-ERGOM-NS and POLCOMS-ERSEM for the scenarios +20% zooplankton mortality (P20, left) and -20% zooplankton mortality (M20, right). Please note the different scales. From Maar et al. 2018.**

### 5.6.1 Summary of previous year's achievements

Ute Daewel presented in 2017 the newest development of the 3D ECOSMO E2E model including fish and macrobenthos linked to the lower trophic levels via predator–prey relationships. The model has been tested for the coupled North Sea and Baltic Sea ecosystem and integrated for a 10-year period 1980–1989 to understand emerging interactions between the different trophic levels. The analysis for this test period indicates that, by implementing fish and macro benthos as functional groups in the model, both zooplankton and phytoplankton biomass and production is affected through changes in top–down effects, but also through bottom–up effects, since especially the implementation of macro benthos has significant effects on the nutrient dynamics. The new model development provides a consistent approach for formulating specially and temporally explicit zooplankton mortality rates. Furthermore, it stresses the importance for considering benthic-pelagic coupling in complex marine ecosystem models.

### 5.6.2 Science highlights from ToR f:

- It was identified that zooplankton groups and macrobenthos were of importance for the ecosystem functioning in complex end-to-end models such as Atlantis and in lower trophic level models. Future work on this topic will help us to better understand bottom–up and top–down controls within the foodweb;
- A model comparison study indicated that changes in top–down forcing in combination with the modelled foodweb structure affect summer phytoplankton biomass and, thereby, indirectly influence water quality of the systems;
- A priori model assumptions were found to influence cascades and pathways in model estimates and, thus, become highly relevant when examining ecosystem pressures such as fishing and climate change;
- Decided that more work is needed to fill the identified knowledge gaps and this should be included in the renewed ToRs for the next period

**References:**

Bossier, S., Palacz, A.P., Nielsen, J.R., Christensen, A., Hoff, A., Maar, M., Gislason, H., *et al.*, (in press). The Baltic Sea Atlantis: An integrated End-To-End Modeling Framework for Testing Ecosystem-Wide Effects of Human-Induced pressures. PLOS ONE.

Maar, M., Butenschön, M., Daewel, U., Eggert, A., Fan, W., Hjøllo, S.S., Hufnagl, M., *et al.*, (2018) Responses of summer phytoplankton biomass to changes in top-down forcing: Insights from comparative modelling. Ecol Model. 376:54-67.

## 5.7 Progress and fulfilment by ToR g

ToR g is about providing tools to improve our understanding of habitat connectivity to support and advice spatial management plans. This ToR has been addressed in the session 'behaviour of man and species'. Rubao Ji presented a key talk about traits and connectivity and Geneviève Lacroix presented a study about the impact of man-made structures on connectivity patterns of hard substratum species in the North Sea.

Rubao Ji presented a study by Ben Jones (Jones *et al.*, 2016) about traits and connectivity. Traits are fundamental properties that define each species and differentiate them from other species. Emergent properties are attributes of species that emerge from interactions between traits and the environment. Traits affect connectivity of various life stages (e.g. fecundity of adults, larval behaviour and ecophysiology) (Treml *et al.*, 2015). These traits were incorporated into IBMs to explore how connectivity was influenced in the Gulf of Maine, an advective system with gyres, eddies, and productive system for fisheries on scallop, lobster, and groundfish. Most of these species have larval stage durations of several weeks to months, which influence dispersion and habitat connectivity. The region has a complicated, spatial management plan. Understanding dispersion/connectivity patterns, as well as the traits that affect spatial patterns of dispersion and traits that lead to successful settlement in good habitats, can provide much needed advice for spatial management plans. Four challenges to these simulations were discussed. 1) Configuration – allocating resources for tracking simulations, 2) Operation – how to efficiently simulate particles, 3) Analysis – how to recognize connectivity patterns, and 4) Interpretation – how to assess the role of traits. Aspects related to configuration and interpretation were discussed in detail.

Regarding configuration, i.e. the number of particles needed, Brickman and Smith (2002) use the replicate approach (keep doubling release numbers until stability is reached). An opposite approach (Simons *et al.*, 2013) is to release a great number of particles and subsample different quantities to explore changes in patterns. A sequential Bayesian procedure was developed in Ji's group (Jones, Solow and Ji, 2016). The procedure allows one to run fewer particles to estimate the expected connectivity, and also allows one allocate particles efficiently across the domain if more particles need to be run.

The products associated with this work are:

- Web interface: btjones.scripts.mit.edu/index.fcgi/research/sequential-analysis-method;
- R package: github.com/btjones16/sequential-analysis-software;
- C++ library: github.com/btjones16/sequential-analysis-software.

The model looked at traits related to adult (spawning time, spawning substratum, maximum spawning depth) and larvae (PLD, competency window, settlement substratum, maxim settlement depth and behaviour (passive, surface only, DVM or pycnocline seeking)). The domain was established by the Finite Community Ocean Model (FVCOM) grid developed for the Gulf of Maine and surrounding areas. Tests were performed with four species (yellowtail flounder, sea scallops, herring, and haddock) with known fixed traits. Artificial species were used and a range of traits (randomly chosen but with some realistic links) were applied. Based on this analysis, 14 regimes were identified encompassing 100 "artificial" species. Traits defining spatial structure were examined using partitioning classification tree. Maximum spawning depth and maximum settlement depth were the first two, initial separators. The number of species was normally distributed with respect to the number of successful larvae. Successful settlement was affected positively by gravel spawning and log(max settlement depth), and negatively by surface-tracking and standard deviation in settlement probability (the width of the window of settlement time).

Geneviève Lacroix presented a study with title 'Do man-made structures impact the connectivity patterns of hard substrate species in the North Sea?' Pelagic life stages are critical in invertebrate and fish dispersal and connectivity in the marine environment. Man-made structures such as offshore wind farms (OWFs) proliferate in the North Sea, possibly acting as stepping stones for fouling species and hence allowing species to expand their distribution range over large distances. Effective marine management requires the understanding of how (artificial) hard structures are ecologically connected and what processes influence larval retention and dispersal. The transport of marine organisms from the spawning grounds to settlement areas is driven by hydrodynamic processes. However, the final dispersal pattern, larval survival and successful settlement of the larvae are affected by environmental factors, physiology, behaviour and reproductive strategies (spawning period/areas). Biophysical models help assessing the dispersal potential of marine species during their pelagic phase. Here, they use a particle-tracking transport model coupled to a three-dimensional hydrodynamic model (Larvae&Co), to assess the larval dispersal of blue mussel (*Mytilus edulis*), European flat oyster (*Ostrea edulis*) and common limpet (*Patella vulgata*) in the North Sea and to quantify the increase of connectivity of populations as a consequence of man-made structures. A comparative analyse of the stepping-stone effect of OWFs for the three species with different larval life traits has been realized in the frame of the UNIDNE project (https://www.insitenorthsea.org/projects/undine/). Results showed that European flat oysters (summer spawner, short larval stage) from natural coastal populations are restricted to reach structures only in the southern half of the southern North Sea, blue mussels (spring spawner, long larval stage) as well as common limpets (winter spawner, short larval stage), in turn, displayed dispersal in a much wider area, reaching OWFs in the entire southern and central North Sea. Our results contribute to a better understanding of the impact of OWFs on larval dispersal and connectivity in the North Sea.

### 5.7.1 Summary of previous year's achievements

Based on a comparison between several drift model and their underlying hydrodynamic model, the range of variability of similar scenarios in connectivity analysis were compared in the previous 3-year period and published in 2017. Connectivity between habitats was investigated in the North Sea for species with different reproductive and larval strategies, showing that dispersal patterns depends on these strategies. Last year, connectivity between spawning and feeding habitats for the round sardinella in the Canary upwelling System was used to better understand migration patterns and the resulting population connectivity was found promising for discussion on international fishing agreements.

### 5.7.2 Science highlights from ToR g:

- Population connectivity is affected by species biological traits and physical environment. Individual-based Lagrangian tracking model is a commonly used, and powerful tool to assess population connectivity, but has its own challenges in term of model configuration, computational operation, model results post-processing and interpretation. Obtaining accurate results from tracking models requires simulating a sufficient number of particles that are strategically allocated. A sequential Bayesian procedure is developed to optimize the particle release locations to minimize the requisite number of particles. This sequential procedure is used in a trait-based modelling framework for the Gulf of Maine to assess the contribution of different traits to the dispersion pattern and the success of larval settlement.
- A larval dispersal model has been developed to assess comparatively the dispersal and connectivity patterns between spawning grounds and settlement areas of three hard substrate species in order to test the hypothesis of stepping stone owing to the introduction of OWFs in the North Sea.

**References:**

Brickman, D., and P. C. Smith, 2002: Lagrangian stochastic modeling in coastal oceanography. J. Atmos. Oceanic Technol., 19, 83–99,

Jones, B. T., A. Solow, and R. Ji. 2016. Resource Allocation for Lagrangian Tracking. Journal of Atmospheric and Oceanic Technology, 33(6):1225–1235, https://doi.org/10.1175/JTECH-D-15-0115.1.

Dannheim, J, Beermann, J, Lacroix, G, De Mesel, I, Kerckhof, F, Schön, I, Degraer, S, *et al.*, (2018). Understanding the influence of man-made structures on the ecosystem functions of the North Sea (UNDINE) Alfred Wegener Institute (Germany), UNDINE summary report, 24pp.

Simons, R. D., D. A. Siegel, and K. S. Brown, 2013: Model sensitivity and robustness in the estimation of larval transport: A study of particle tracking parameters. J. Mar. Syst., 119 & 120, 19–29.

Treml et al. 2016. Identifying the key biophysical drivers, connectivity outcomes, and metapopulation consequences of larval dispersal in the sea.

## 5.8 Progress and fulfilment by ToR h

This ToR aims to identify and include key physiological processes and mortality sources in models to understand recruitment dynamics, life cycle dynamics and population drivers. During the session, Morten Skogen showed examples of IBMs for pelagic and mesopelagic fish in the Norwegian Sea, Sofia Saraiva discussed the role of bivalves in the Balgzand, Klaus Huebert talked about key physiological processes and mortality sources in flounder populations and Martin Huret (on WebEx) gave an update on anchovy DEB-IBM activities in the Bay of Biscay.

Morten Skogen gave a talk on "Towards IBMs for pelagic and mesopelagic fish in the Norwegian Sea". The vision for the NORWECOM.E2E model is to have Individual Based Modules (IBMs) for all key species in the Norwegian Sea. During the last year, the old IBM for adult Norwegian Spring-spawning Herring has been extended to a full life cycle IBM, and a new module for the mesopelagic Glacier lanternfish has been included in the model. Both species are plankton feeders, and in the model they feed on the *calanus finmarchicus* IBM and the mesozooplankton component from the NPZD part of NORWECOM.E2E through a 2-way coupling. Both modules include the full life cycle from eggs to adults and are including processes like: feeding, growth, movement, migration, spawning and mortality. In the talk, it was demonstrated that both modules run stable producing realistic life-patterns for single individuals, as well as long stable term estimates for total-stock biomass for a 20-year long simulation.

Sofia Saraiva gave a talk on the role of bivalves in the Balgzand: First steps on an integrated modelling approach. The talk describes a process oriented modelling tool that integrates physical, biogeochemical, ecological and physiological factors governing bivalve populated marine ecosystems. This modelling tool is the result of the coupling between an individual-based population model for bivalves (based on the Dynamic Energy Budgets theory, DEB) and a hydrodynamic/biogeochemical model (MOHID Water Modelling System). The model was implemented in the Balgzand area (Wadden Sea, The Netherlands) in a fine resolution domain to study mussel population dynamics and to quantify the influence of mussel communities on the pelagic system. Model results for a reference scenario (2009–2010) are in agreement with observations, and provide a consistent quantitative description of local hydrodynamics and biogeochemical cycles. The Balgzand acts as a sink of phytoplankton due to bivalves' filtration, and a source of ammonia, exporting about 40% more than the input flux. These results suggest significant ammonia regeneration. Results show that despite the long and almost continuous spawning season, only a few cohorts are able to survive. Early stage mortality (top-down), in particular cannibalism and shrimp predation, can control the persistence of new cohorts in the first month although starvation (bottom–up) represents the main cause of biomass loss in an overall. The tendency is that new mussel beds are formed in areas adjacent to already existing mussel beds and channel edges. Bivalves' activity intensifies the seasonal patterns of food and nutrients in areas close to the mussel beds, though not changing their overall spatial distribution. This study not only confirms but also quantifies mussels' potential to influence ecosystem functioning due to their role in nutrient cycling. As the first integrated modelling study that focus on the mussels' beds in the Balgzand, the main difficulties on the model design, setup and results analysis were overcome. The model can now be used further, tested and improved in the same or other systems in order to serve as an effective and reliable scientific and management tool.

Klaus B. Huebert presented results from a study of key physiological processes and mortality sources in an individual-based winter flounder population model. They are developing an individual-based population model to synthesize data from $CO_2$ and temperature experiments conducted with winter flounder (*Pseudopleuronectes americanus*) eggs, larvae, and juveniles. Our goal is to extrapolate from laboratory measurements (e.g. growth, development, and survival) to potential consequences for fish populations. Our model framework tracks the full life cycle of multiple generations of (super)-individuals from eggs until senescence, including their maternal lineage with potential for implementing trait heritability and therefore assessing adaptive responses to climate-based selective factors. Physiological processes and mortality sources early in the winter flounder life cycle are modelled in detail. For example, temperature-dependant oocyte maturation is used to determine spawning season, and mortality of eggs through juveniles is stage-, size-, and temperature-dependent (as well as density-dependent for juveniles). A representative subsample of survivors from the early life-history stages is carried over to a separate population model, which simulates subsequent growth and mortality, but without additional climate effects. Model outputs include young-of-the-year stage abundances and durations, total annual spawning population abundance, age-structure, and recruitment. The model allows for quantifying $CO_2$ and temperature effects on annual dynamics and, cumulatively, over multiple generations.

Martin Huret presented a DEB-IBM study on the impact of climate change on anchovy in the Bay of Biscay. Anchovy of the Bay of Biscay is an important resource for pelagic French and Spanish fisheries. Due to their short lifespan, anchovy populations are strongly related to variations in recruitment and environmental "bottom–up" forcings. A model describing the population variations of anchovy in the Bay of Biscay has been implemented, rooted on an Individual Based Modelling with a Dynamic Energy Budget (DEB) module capturing the full life cycle of anchovy individuals. Forcing for this model was provided by the physical-biogeochemical model POLCOMS-ERSEM, which was first used for calibration using the time-series between 2000 and 2016, and the anchovy biomass and age structure from the stock assessment. Within the European project CERES, the POLCOMS-ERSEM model was then run forced with IPCC climate scenarios RCP4.5 and RCP8.5 (+2 and +4°C average temperature increase respectively) over the period 2006-2099. The resulting time-series of temperature and zooplankton biomass, together with the current management strategy of the stock, will be used to compare the population dynamics and bioenergetics condition of anchovy. in the Bay of Biscay between the beginning and the end of the our century.

### 5.8.1 Summary of previous year's achievements

Advances in bioenergetics models have been presented on a regular basis. In 2016, a specific session was held on this subject and discussed, among others, about the mismatch between available data and models needs. In 2017, a laboratory scientist participated to the meeting and allowed better understanding of important factors affecting fish energy, especially in a climate change context.

### 5.8.2 Science highlights from ToR h:

- Bioenergetics modelling is developing more and more and start to be coupled with various modelling approaches;
- Suitable data are scarce, and improving the realism of bioenergetics models could come from a stronger discussion with field and laboratory scientist, in order to make better links between measurements and model needs.

**References:**

Saraiva, S., L. Fernandes, J. van der Meer, R. Neves, S.A.L.M. Kooijman. The role of bivalves in the Balgzand: first steps on an integrated modelling approach. Ecological Modelling 359:34-48.

# 6 Cooperation

## 6.1 Cooperation with other WG

While some discussions were initiated in 2016 and 2017 with other groups, notably through recommendations and at the WGCHAIRS meeting, the most relevant cooperation with other WG occurred in 2018. During the meeting, a better description of subject of common interests and specificities of different groups was realized and shown in Figure 6.1.

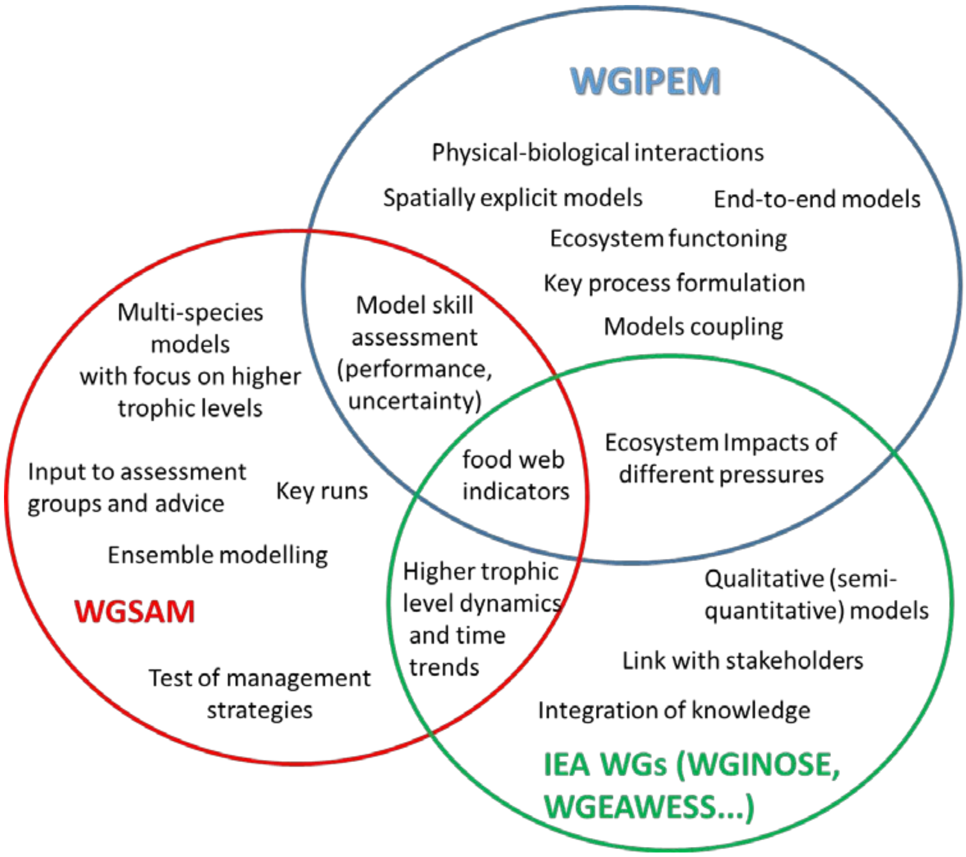


**Figure 6.1. Main specificities and common scopes (at the intersection of the circles) of WGIPEM, WGSAM and IEA WGs based on discussion of the 2018 WGIPEM meeting.**

## 6.2 Cooperation with Advisory structures

None

## 6.3 Cooperation with other IGOs

A collaboration with PICES led to the organization of SICCME (Strategic Initiative on Climate Change Impacts on Marine Ecosystems) workshops, co-chair by Myron Peck (former chair of WGIPEM).

# 7 Summary of Working Group self-evaluation and conclusions

**1 ) Working Group name.**

Working Group on Integrative Physical-biological and Ecosystem Modelling

2 ) **Year of appointment**.

2015

**3 ) Current Chairs.**

Morgane Travers-Trolet, France

Marie Maar, Denmark

**4 ) Venues, dates and number of participants per meeting.**

06–08 June 2016, Brest, France, (18 participants)

13–15 June 2017, Oristano, Italy, (11 participants + 1 remotely)

16–20 April 2018, Copenhagen, Denmark, (29 participants + 2 remotely)

### WG Evaluation

**5 ) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.**

The group contributes to the science priorities of 1) understanding of ecosystems and 2) Human interactions with the sea. Further, the work is related to sub priorities: 'Food from the sea', 'Understanding ecosystems', 'Impact of humans activities' and 'Emerging techniques' (if model developments are considered as new techniques).

**6 ) In bullet form, highlight the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. ***

- Several workshops and conference sessions were organized by the group;
- Several model tools have been developed, tested and made available by the group;
- Several publications have been written by WGIPEM during the 3-year term, either involving only few members of the group, or presenting studies entirely conducted within WGIPEM;
- Provided first results on application of skill assessment, sensitivity analysis, and ensemble approaches to complex models;
- WGIPEM products were advertised to other ICES workings groups and communities (conference, back to back meetings and new website);
- A dedicated project proposal entitled "Towards operational use of marine ecosystem models" has been submitted in 2018 to the COST Action program to push further the work conducted within WGIPEM. If successful, this project will help inter-session work of WGIPEM through the organization of several workshops and short-term scientific missions. Other project proposals involving several members were also developed during the 3-year term of this group.

**7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.**

No contribution from WGIPEM to Advice during the 3-year term

8) **Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.**

See question 6

7 ) **Please indicate what difficulties, if any, have been encountered in achieving the workplan.**

At the second meeting there were rather few participants and it was not possible to cover all the ToR's at that meeting. Hence, the group activity level depends on the people attending the meetings, where the main work is presented, discussed and planned. It was therefore decided to held the meeting in spring (instead of early summer) at locations with easy access and to advertise future meetings in good time.

### Future plans

8 ) **Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)**

The group discussed the continuation at the last meeting and we agreed that more work is needed in several of the ToR's, some of the topics are listed here:

- There is a need for a proper ecosystem model skill assessment in order to increase credibility and usefulness of model results for management purpose
- Several knowledge gaps were identified with regard to bentho-pelagic coupling in three-dimensional models, bio-energetic parameters for higher trophic level models, and representation of more zooplankton functional groups in lower trophic level models.
- More work is needed to make realistic future projections of changes in species distributions and ecosystem properties in response to climate change and other stressors incorporating the newest knowledge from experimental studies.
- A priori model assumptions were found to influence trophic cascades and pathways in model estimates, and the coupling between lower and higher trophic levels should be further advanced.
- The last meeting was held with some of the other EIA WG's on how to apply model operationally and how to integrate the knowledge from the other EIA WG's into models. This collaboration should be followed up in a new period.
- Formulation of some processes (e.g. fish and fisher movement, mortality) remains to be further explored as their impact on model results is not negligible

9 ) **If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.**

(If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat.)

10 ) **What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?**

WGIPEM members already have a variety of expertise at hand, but according to the years, the participant list varies and so does the overall expertise. However, last meeting proved the feasibility of having remote discussion (through webex) with experts not able to come to the meeting when a specific subject needs a particular expertise.

11 ) **Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)**

Knowledge of ecosystem functioning and response to multiple drivers could be used for integrated ecosystem assessments. The time-scale on which the models developed in WGIPEM are relevant is longer than the year, so short-term advice might not beneficiated from the group achievement. However, longer-term advice, such as management plans or spatial planning could use some tools developed by the group. As demonstrated during our 3-year term, ecosystem models could also be used to assess the uncertainty of data linked to sampling design of sea survey (and not to the variability of the population).

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## Annex 2: WGIPEM Publications during the 3-year period


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