WGIPEM 2017 REPORT

ICES STEERING GROUP ON INTEGRATED ECOSYSTEM ASSESSMENTS

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Interim Report of the Working Group on Integrative Physical-Biological and Ecosystem Modelling

13-15 June 2017

Oristano, Italy

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 Oristano, Italy, on 13–15 June 2017. Presentations of the latest modelling work done within WGIPEM ToRs were given in plenary. End-to-end models (Atlantis, Osmose) have been used to explore trade-offs between fishing strategies, in the context of MSY targets. While validation of integrated model output is required to be used for advice, a comparison of different performance indices illustrated that the perception of the goodness-of-fit of complex models (e.g. ISIS-Fish) depends on the metrics and visualization tools used. Several tools have also been presented and discussed within the group, among which a R-package to handle outputs of Atlantis model and create various plots and another R-package to display model results in a friendly-form, easier for communicating them to stakeholders.

Regarding advance of modelling approaches, the fish movement of the norwecom.e2e ecosystem model has been refined, and the resulting seasonal migration patterns of pelagic fish will be used to validate stock monitoring and assessment. Another model of fish movement, individual-based and following the DEB theory, produced realistic interannual distributions of sardinella and diagnostics of population connectivity, that could fuel the development of international fishing agreements.

Initiated 2 years ago, the comparison study addressing top–down trophic control in the plankton community will be revised to focus only on 3 study areas (North Sea, Baltic Sea, Nordic Seas) modelled by 7 models, to better investigate the effects of model structure and ecosystem dynamics. Another study showed that the inclusion of upper trophic level (fish) and benthic-pelagic coupling (by integrating macro-benthos) led to significant changes of nutrient dynamics simulated by ECOSMO E2E, illustrating the importance of considering these trophic links in integrated models. Finally, in the North Sea, it has been corroborated that considering a variable predation, both spatially and seasonally, from the fish community upon early life stages of fish leads to changes in survival of different ontogenic stages, which might affect stock estimated dynamics.

Bioenergetics studies presented show that DEB models applied to anchovy and sardine and adjusted on energy density measurements allow the identification of distinct energy allocation strategy for these species. Another DEB application to cold-water corals explored the effects of starvation and climate change scenarios (acidification and temperature increase) and concluded that the combined impact reduces survival and leads to smaller coral. Finally, measurements of aerobic metabolic scope of fish can be used to explore potential competition between species under climate change, i.e. when their spatial distribution changes due to temperature increase (linked to their thermal preferences) and leads to the apparition of new competition.

During this meeting, two main gaps of knowledge were identified. The first one relates to data availability and more specifically to the need for collecting field and laboratory data on key parameters of bioenergetics processes. The second gap of knowledge discussed this year concerns the limited consideration of benthic fauna within physical-biological models, and the need for further modelling effort to suitably represent this group and integrate it in end-to-end models. Intersession exchanges with other working groups are expected to fill partly these gaps.

1 Administrative details

Working Group name

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

Year of Appointment within the current cycle

2015

Reporting year within the current cycle (1, 2 or 3)

2

Chairs

Morgane Travers-Trolet, France

Marie Maar, Denmark

Meeting venue

Oristano, Italy

Meeting dates

13–15 June 2017

WGIPEM Meeting participants, June 2017, Italy.

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 bench-marking, 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. through 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 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 advice 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 List of Outcomes and Achievements of the WG in this delivery period

Publications and reports

Akimova A, Hufnagl M, Kreus M, Peck M (2016) Modeling the effects of temperature on the survival and growth of North Sea cod (*Gadus morhua*) through the first year of life. Fisheries Oceanogr 25(3):193-209

Akimova A, Nuñez-Riboni I, Kempf A, Taylor MH (2016) Spatially-resolved influence of temperature and salinity on stock and recruitment variability of commercially important fishes in the North Sea. PLoS One 11(9):e0161917.

Daewel, U., Schrum, C., Towards End-2-End modelling in a consistent NPZD-F modelling framework: Application to North Sea and Baltic Sea submitted to Progress in Oceanography

Gatti P., Petitgas P., Huret M. (2017). Comparing biological traits of anchovy and sardine in the Bay of Biscay: A modelling approach with the Dynamic Energy Budget. Ecological Modelling, 348, 93-109.

Girardin, R., *et al.* (2016) Identification of the main processes underlying ecosystem functioning in the Eastern English Channel, with a focus on flatfish species, as revealed through the application of the Atlantis end-to-end model, Estuarine, Coastal and Shelf Science

Petersen, M.E., Maar, M., Larsen, J., Møller, E.F., Hansen, P.J. (2017). Trophic cascades of bottom-up and top–down forcing on plankton and nutrients in the Kattegat, evaluated by modelling. J Mar Syst. 169:15-39.

Conferences

A workshop on '**Recent advances in the life stage ecophysiology of small pelagic fish: Linking laboratory, field and modeling studies** (W5)' was held during the International symposium on 'Drivers of dynamics of small pelagic fish resources', Victoria, BC, Canada, 6–11 March 2017. Myron Peck, former chair of WGIPEM was one of the chair of this workshop, together with L. Pecquerie who was a participant of WGIPEM in 2016 in Brest.

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. More details on this workshop are provided in Annex 3.

Some of the work undertaken within WGIPEM has been recently presented at the **ICES ASC 2016**, and other conferences:

Akimova A, Nuñez-Riboni I, Kempf A, Taylor MH (2016) Spatially-resolved influence of temperature and salinity on stock and recruitment variability of commercially important fishes in the North Sea, 2016 ICES ASC

Akimova A, Hufnagl M, Kreus M, Peck M (2016) Modelling a 'where-to-be-born' index: spatially-resolved predation mortality of cod early-life stages in the North Sea, 2016 Larval Fish Conference

Barbut L., Lehuta S., Volckaert F., Lacroix G. (2016) Calibration and sensitivity analysis of a larval drift model of North Sea Sole. iMarCo annual meeting. June 2016.

Morten D. Skogen, Solfrid S. Hjøllo and Jerry Tjiputra: Projected changes in ocean acidification in the Arctic: effects of ongoing regional Modelling. The ESSAS Open Science Meeting, Tromsø, Norway 11-15 June, 2017

Morten D. Skogen, Solfrid S. Hjøllo, and Phil Wallhead: Projections of primary and secondary production in the Barents Sea in a future climate. The ESSAS Open Science Meeting, Tromsø, Norway 11-15 June, 2017

Rubao Ji : Calanus on the edge: biogeographic responses to climate change. 2017 ESSAS Open Science Meeting. Tromsø, Norway 11-15 June, 2017

As planned during the last 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:

- AMEMR Theme "Building blocks: truth or dare?", with the subsection "Building the zoo"
- 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 will be presented (Title of the talk: Reducing the gap between complex ecosystem models and their use in operational context)

Several WGIPEM members will participate 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 session proposal (Using ecosystem models to assess the effects of climate change on the productivity of marine ecosystems and fisheries) has been submitted for the 4th International Symposium on the Effects of Climate Change on the World's Oceans (ECCWO) to be held in 2018 in Washington, DC. A follow-up workshop proposal has also been submitted, on the following topic: Utilizing bioenergetics measurements and modelling to evaluate climate change effects on marine species and ecosystems.

Tools

An *Atlantistools* R package has been developed to more easily visualize and explore output from Atlantis models (see description under progress section on ToR b).

The *shiny* R package was presented as an example of how to use user-friendly interfaces to communicate model results and performance to stakeholders (see description under progress section on ToR b).

The Zooplankton Model Library (*ZoopLib*) is an open repository of code, commentary, and references to primary literature for zooplankton models (https://code.google.com/archive/p/zooplib/). The objectives are: (1) to provide a single portal or jumping off point for accessing the wide range of zooplankton models currently in use; (2) to provide a collaborative forum for discussion and improvement of models; (3) to facilitate exchange of models and standardization of modelling practices. No particular update regarding this tool was reported this year.

The ecosystem *Code Generation Tool* (CGT - https://ergom.net/index.php/code-generation-tool.html.) is a tool to create ecosystem model code from two ingredients: (1) a formal description of the ecosystem tracers and processes in a list of text files (2) a set of "code templates" for the host model. The tool then extracts the information from the text files and fills the code templates to create your model code.

Other promising tools have been quoted during the meeting, but have not been tested yet by WGIPEM members:

- **OpenMole** (https://www.openmole.org/). According to their website, OpenMOLE analyses your model dynamics using state-of-the art exploration methods taking advantage of distributed computing environments. The typical usages are model calibration, model exploration, machine learning, optimization, data processing." It seems that this tool provides a fast way to calibrate and test for sensitivity of submodels embedded in complex models, for example the behaviour of a single DEB configuration, a swimming algorithm, etc. The sensitivity tests or calibration would need to be done with a predefined environment input. The Genetic algorithm proposed is the NSGA-II (Deb et al., 2002, A fast and elitist multi-objective genetic algorithm: NSGA-II. IEEE Transactions on Evolutionary Computation 6, 182–197. doi:10.1109/4235.996017).
- **UQLab** (www.uqlab.com) is a general-purpose Uncertainty Quantification framework developed at ETH Zurich (Switzerland). As of V.1.0, it is made of a content management system called UQLabCore and open-source scientific modules, which allow users to carry out uncertainty propagation through computational models, sensitivity analysis, as well as to build surrogate models for general use. UQLabCore is freely licensed to academic users (universities and public research institutions). UQLab modules are available under the BSD license. The first stable version of UQLab (V1.0) was released on April 28th, 2017.

website

In order to improve the communication on tools, either developed by WGIPEM or identified to be of interest for the modellers community, a new webpage linked to ICES WGIPEM official webpage will be created and will contain general information about those tools and related links.

The group also aims at adding a new webpage listing the main models used within WGIPEM, to increase the visibility of the methods used for other working groups and for other scientists who might be interested in joining WGIPEM. Finally, a schematic of the links between WGIPEM and other ICES working groups will be created and added to the website.

Models intercomparison and comparison between model predictions and observations is a vital part of building models of natural systems. Various statistical metrics have been used for such comparisons and a multimetrics approach seems to be most objective way to evaluate model skills and quantify uncertainties (Allen et al., 2007, http://dx.doi.org/10.1016/j.jmarsys.2006.02.010; Olsen *et al.*, 2016 https://doi.org/10.1371/journal.pone.0146467). A library of widely used statistical metrics of biophysical and ecosystem models will be compiled and published on the web page of the group

5 Progress report on ToRs and workplan

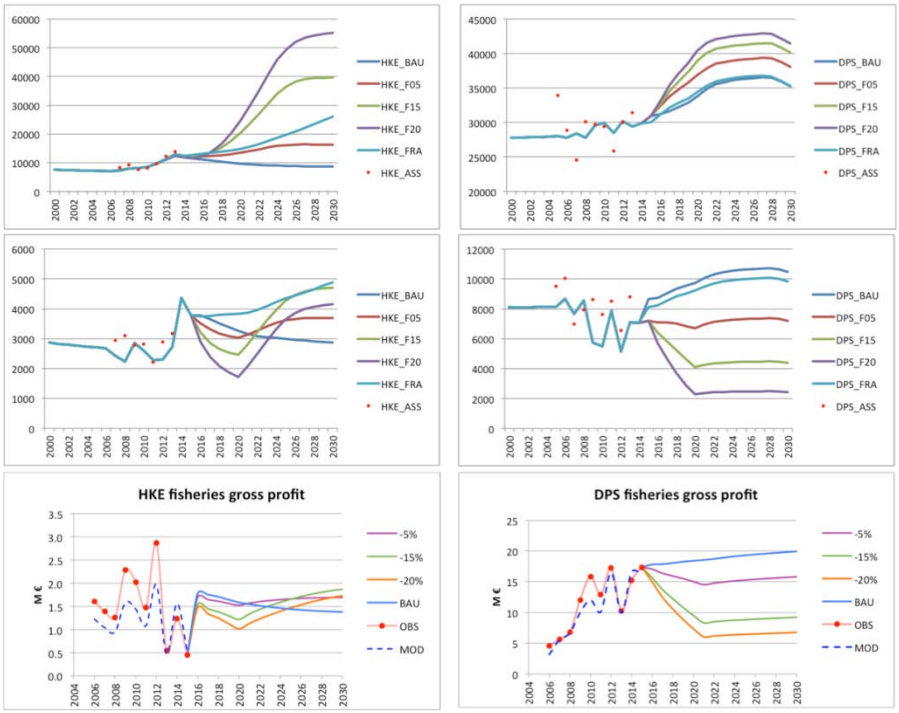
5.1 Progress on end-to-end (E2E) model development and their use for strategic advice (ToR a)

Presentation: Update on the development of the E2E model Atlantis in the Strait of Sicily by Matteo Sinerchia (IAMC-CNR)

The presentation describes the development and implementation of the E2E ecosystem model Atlantis for the Strait of Sicily. End-to-end (E2E) models are specifically suited for linking climate and oceanography to the foodweb and human activities and provide a workbench for evaluating the effect of alternative decisions to support the ecosystem-based management.

The ecosystem is composed by 58 functional groups, 26 of which are vertebrates. The most important commercial species (anchovies, sardine, red-mullet, hake, red prawn, and pink prawn) are represented at species level. The fisheries fleet is composed by subfleets: two inshore and offshore bottom trawlers, pelagic trawlers, large longliners, small and large purse-seiners, small-scale fishery, and mixed gears fishery.

The model was used for scenario testing and trade-offs evaluation related to the application of different fisheries management scenarios that have been proposed by stakeholders. In particular model results were used to estimate the effects on the establishment of three fishing restricted areas and the introduction of gradual reduction of fishing mortality from current F (F_{curr}) to F_{MSY} by 2020 for hake and deep-water rose shrimp and other target species.



Hake biomass, landings and the gross profit of the targeting fleets under different scenarios. Dots represent assessment estimates.

Presentation: Effects of trophic and technical interactions on the definition of MSY reference points in a mixed-fisheries ecosystem by Morgane Travers-Trolet (Ifremer)

While reference points such as maximum sustainable yield (MSY) have been estimated for decades in a single-stock framework, this methodology can be questionable when

trying to reach these sustainable levels for all stocks simultaneously. On the one hand, technical interactions can prevent attaining F_{MSY} for several stocks caught together in a mixed fisheries context. On the other hand, predation interactions can dampen or exacerbate stock dynamics, and thus modify the fishing mortality level allowing MSY. Here we investigate the effects of both interaction types using the multispecies trophic model OSMOSE applied to the eastern English Channel, an ecosystem characterized by mixed fisheries. First, we estimated the classical F_{MSY} for several species, by varying the fishing mortality of each species independently in order to maximize their yield. Current stock status compared to the resulting reference points are discussed and put in parallel with outputs from classic stock assessment when available. Second, we explored how variation of fleets' effort, i.e. varying the fishing mortality of a set of species together, would affect the MSY levels obtained previously. Results show that single-stock MSY cannot be reached for all species together, but more importantly that these reference points vary according to the ecosystem state, due to technical and predation interactions. The ecosystem model applied here shows the potential of complex models for helping refining the methodology underlying reference points such as MSY, in order to be suitable for use in a multispecies management context.

Presentation: An application of skill assessment technics to a multivariate spatial fishery model by Lehuta Sigrid (Ifremer)

The presentation first proposed a quick review of recent papers related to Tor A: Guidelines for the use of ecosystem models for management (Grüss *et al.,* 2017; Hyder *et al.* 2015; Lehuta *et al.,* 2016); use of skill assessment metrics for the evaluation of ecosystem models (Olsen *et al.,* 2016).

An example of application of various skill assessment metrics for the validation of a fishery dynamics model was then presented. The validation process starts with the listing of the structuring dimensions along which model fit and emergent properties should be scrutinized: space, time, populations, age, fleets, and gears. Then data available for validation are listed, characterized in term of quality and classified in the dimensions. Several metrics are proposed and compared to evaluate various outputs variables (abundance, catch) of the model against data: sum of squared error, percentage of error, correlations. Various graphical representations are also proposed in order to investigate model adjustment in multiple dimensions: radar plots, maps, boxplots and barplots. The (dis)advantages and properties of each tool are discussed.

The application shows how different the perception of model adjustment to data can be depending on the choice of aggregation scale, metrics, and visualization tool. It demonstrates the potential of the validation process to get insight in model functioning and identify strengths (outputs and scales), weaknesses and priorities for model improvement. The work highlights the need for a transparent process of validation, and calls for a clearer exposure of model objectives and corresponding assessment metrics and scales.

5.2 Progress on communication and best use of model outputs (ToR b)

Presentation of Atlantistools R package, realized and presented by Alexander Keth

Atlantis is an end-to-end marine ecosystem modelling framework. It was originally developed in Australia by E.A. Fulton, A.D.M. Smith and D.C. Smith (2007) and has since been adopted in many marine ecosystems around the world (<http://atlantis.cmar.csiro.au/www/en/atlantis.html>). The output of an Atlantis simulation is stored in various file formats like .netcdf and .txt and different output structures are

used for the output variables like e.g. productivity or biomass. Currently, there is no unified approach to analyse the complex output of an Atlantis simulation. An R package was developed to fill this knowledge gap. The "atlantistools" package can be used to convert the different output types to a unified format according to the "tidy-data" approach by H. Wickham (2014) <DOI:10.18637/jss.v059.i10>. Additionally, ecological metrics like for example spatial overlap of predator and prey or consumption can be calculated and visualized to improve model calibration and benchmarking. Another key feature of "atlantistools" is the automated generation and perturbation of model parameter files which is essential to apply a sensitivity analysis. The unified data structure offers the possibility to easily share model output with each other and perform inter- and intraspecific model comparisons. "atlantistools" is freely available on CRAN (version 0.4.2, https://CRAN.R-project.org/package=atlantistools). The package is developed collaboratively using the Internet hosting service github (https://github.com/alketh/atlantistools).

Proposition for the use of shiny interfaces to communicate model results and performance by Sigrid Lehuta

Stakeholders often find model output graphs too complex and advise that we present them sequentially so they progressively get familiar to them. They also often ask for new graphs at different scales that are difficult to provide in the course of a meeting without coming back to the code. Shiny is an R library that allows to interface R code and create web applications https://shiny.rstudio.com/. It was used in order to create an interface that facilitates the exploration of ISIS-Fish model results in various dimensions and at different scales without a line of code. The interface is intended to be used within meetings with stakeholders and made available online for stakeholders to play with. Such kind of web applications could be used to make model validation results available online and increase the transparency of model performance. An example will be available on WGIPEM webpage soon.

5.3 Progress on identifying emerging fields and gap of knowledge (ToR c)

Discussions within the group allow identifying 2 gaps of knowledge:

The first one 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 will identify further biological and physiological parameters of interest to feed discussions with WGBIOP and WGISUR groups concerning joint effort in improving reliability of life cycle and ecosystem models (see recommendations).

The second gap of knowledge relates to the consideration of benthic fauna in integrated model approaches. Macrobenthos constitutes a key component in marine foodwebs, particularly in shallow coastal seas where the pelagic is tightly linked to the benthic ecosystem on all trophic levels. However, in many marine ecosystem models this part of the ecosystem is or only insufficiently considered. Therefore, the group wants to

emphasize the importance of including macrobenthos into existing modelling frameworks. This would encompass a variety of topics, including e.g. an evaluation of existing macrobenthos models and modelling approaches to understand how the consideration of this group in ecosystem models affects model performances… Additionally questions arise on what kinds of data are necessary to parameterize, calibrate and validate the models and where they can be found. The group will try to address this topic together with BEWG (see recommendation).

5.4 Progress on setting up future scenarios (ToR d)

Not addressed this year

5.5 Progress on integrating behaviour into models (ToR e)

Presentation of The PELagic Fish Observation System Simulator by Solfrid Sætre Hjøllo (IMR)

The PELagic Fish Observation System Simulator (PELFOSS) project is new project at Institute of Marine Research (IMR), in cooperation with a fisheries organization. The aim is to develop a simulator of an observation system for pelagic fish in the Norwegian Sea, to optimize stock surveys based on several types of data from IMR surveys, fishery float and other sources. This will lead to more effective monitoring of the pelagic fish stocks by using data from fish floats and other sources, and reduce the uncertainty in stock estimates. A central element in the project is the simulation model, based on the ecosystem model norwecom.e2e, including the pelagic fish modules for mackerel, herring, and blue whiting, extended with detailed seasonal migration patterns for these species. Stock estimates and monitoring will be validated based on simulated migration patterns, and different sampling strategies tested with the simulator.

5.6 Progress on the understanding of trophic controls (ToR f)

Presentation: Lower trophic level complexity mediates responses to top–down forcing: insights from a comparative modelling approach? by Marie Maar.

The aim of the present study is to provide new knowledge of top–down (TD) trophic cascades on the plankton community by applying similar zooplankton mortality scenarios to a wide range of 3D NPZD-models, which are currently applied to support management or scientific studies in different marine ecosystems. The objectives are to reveal differences in model responses to changes TD forcing and if there are any overall patterns of trophic cascades within and between ecosystems generated by the models.

The collaborative manuscript was submitted earlier this year and the reviewers' comments were presented and discussed in plenary. It was decided to remove the study areas covered by only one model. The study now focuses on the responses to TD changes: i) within the same system using different models and ii) across ecosystems using the same model. This study will include 3 study areas (North Sea, Baltic Sea, Nordic Seas), 7 different models resulting in a total of 10 model results. The plan is to resubmit the manuscript within 3-4 months.

Presentation: an update on the development of ECOSMO E2E by Ute Daewel

ECOSMO E2E is a consistent functional group type NPZD-Fish modelling approach that bases on the fully coupled biological-physical ecosystem model ECOSMO II. Both fish and macrobenthos were included in the 3d model formulation as functional groups that are linked to the lower trophic levels via predator–prey relationships. The model allows investigating bottom–up impacts on primary and secondary production and

cumulative fish biomass dynamics, but also top–down mechanisms on the lower trophic level production.

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.

5.7 Progress on connectivity of habitats for fish larvae (ToR g)

Presentation: by Timothee Brochier

The strong spatio-temporal variability of ocean dynamics and associated primary/secondary production drives large seasonal migrations of Small pelagic fish (SPF) in the Canary Upwelling System (CUS), including round *sardinella*, a critical species for the local economies and food security. It appears that round *sardinella* seasonal migrations can be simulated with a full life cycle biophysical model forced by realistic hydrodynamic and biogeochemical simulations of the year 1990–2009. The fish traits considered were (1) their capacity of exploration (which increased with age/size), and (2) the natal homing behaviour, which was considered to affect the fish perception of its habitat quality. In the model, super-individuals represented micro-cohorts with temperature and food dependent growth provided by a dynamic energy budged model (DEB) and size-dependent mortality. Robust population dynamics patterns emerged in the model, and compares well with seasonal but also interannual variability of round *sardinella* abundance observations. The model analysis provided a finer understanding of the migration scheme historically described in this area (Figure 5.7.1). Sensitivity tests highlighted the decisive role of exploration ability linked to swimming capacity. In the present model, the spatial distribution of the population was largely driven by swimming capacities and variability of the intensity of the nearshore current provided by the ROMS simulation. Interestingly, natal homing was an essential model assumption to produce realistic interannual variability of abundance. The model produces diagnostics for population connectivity that could be used in international fishing agreement scenario. The individual life history emerging from the model must be validated prior the use of this results for management purposes, most probably through spatio-temporal distribution of fish energy-density diagnostics as proposed by Huret during this workshop.

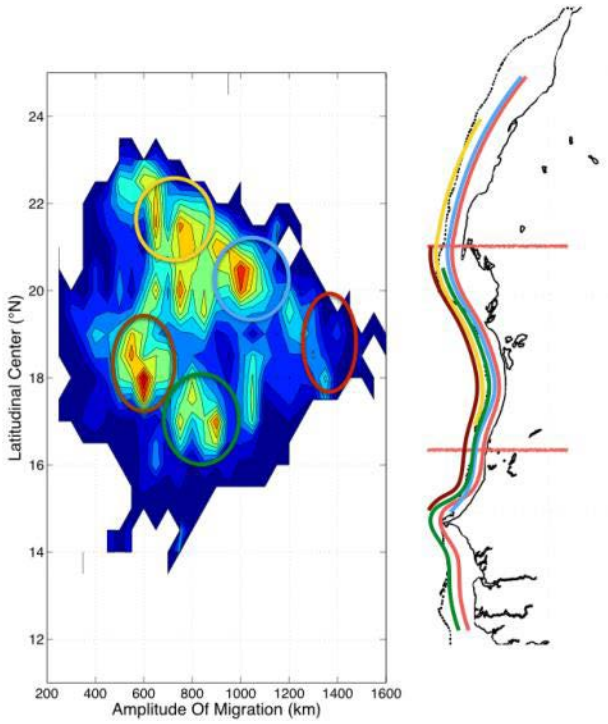


Figure 5.7.1. Diversity of the fish migration routes an amplitude emerging from the model of round *sardinella* migrations off Northwest Africa. On the left plot, the colour scale illustrate the average number of individuals with a given migration center and with a given distance from extreme north to extreme south of the trajectory (Migration amplitude). The corresponding trajectories of the circled spots on the left plot are illustrated on the right plot.

5.8 Progress on modelling key physiological processes and mortality sources (ToR h)

Presentation: Integrating spatio-temporal dynamics of predators within biophysical models of marine fish early life stages: A case study for Atlantic cod (*Gadus morhua*) in the North Sea by Anna Akimova (TI-SF, UHH, Germany)

Predation is believed to be one of the most important sources of mortality of fish early-life stages (ELS), but realistic predation has been rarely included in individual-based models (IBMs) aiming better understanding of fish recruitment. The aim of presented study was twofolded: 1) to demonstrate the importance of including spatially-explicit predation in IBMs of fish early-life stages 2) to quantify the importance of various factors, influencing interannual variability of predation mortality (temperature and circulation, changes in predators' biomass, predator spatial redistribution). The model specimen was Atlantic cod in the North Sea. Our models showed that including spatially and seasonally variable predation does not only affect the spatial distribution of the ELS survival and productive potential of known spawning areas of cod in the North Sea, but also affects strongly the modelled interannual variability of total survival. Following this finding, we conducted three sensitivity experiments in order to identify most important factors influencing the interannual variability of cod ELS survival. Our simulation demonstrated that the relative importance of factors mentioned above varied between the ontogenic stages (egg, larval, and juvenile). For the total ELS mortality the interannual redistribution of predators was more important than interannual variability of predators' biomass. Our findings emphasize the importance of predator–prey spatio-temporal overlap for the survival of prerecruit fish, i.e. a factor, which is normally ignored in one-dimensional trophic interaction models currently used in routine stock assessments.

Presentation: A bioenergetics approach to compare anchovy and sardine in the Bay of Biscay. From energy density data to a DEB model. by Martin Huret, Paul Gatti, Pierre Petitgas (Ifremer, France)

A growing amount of literature aims at explaining the distinct population dynamics of anchovy and sardine by specific responses to biotic and abiotic factors through slightly distinct biological traits, e.g. temperature preferenda or feeding behaviour. Integrative approaches are then required to understand the respective and combined impacts of such factors. A bioenergetics approach aims at quantitatively assessing energetic condition and energy fluxes within an organism from energy acquisition (feeding), to storage and latter allocation (to soma or reproduction). To compare anchovy and sardine, we considered both energy density (Ed) measurements and Dynamic Energy Budget (DEB) modelling. Data analysis first showed large differences in absolute Ed values and seasonal magnitude, likely reflecting a higher storage capacity for sardine. Size, age and ontogeny strongly affect Ed values, highlighting increased storage capacity during the first years of life. DEB models for both species were calibrated and species compared on the basis of model parameters and predictions. We showed that bioenergetics strategies of both species differ in energy acquisition, storage capacity, and later allocation for both growth and spawning. In this context the spawning phenology appears to be strongly interlinked with specific bioenergetics strategies. Overall, our results showed that anchovy has an almost "all or nothing" energy allocation strategy, while sardine shows lower and more regular metabolic activity throughout the year. Such bioenergetics approach could, in a near future, offer a framework to further investigate specific responses of both species to external drivers.

Presentation: Applying Dynamic Energy Budget (DEB) theory to determine the impact of climate change on marine organisms by Daan J. Gerla (Wageningen Marine Research, The Netherlands)

Dynamic Energy Budget (DEB) theory provides a framework for mechanistically modelling the growth, development and reproduction of organisms. The so-called standard κ-rule DEB model (Kooijman, 2012) describes a generalized animal, the state of which is given by its energy reserve, volume and maturity. In the model, assimilated energy first enters the energy reserves and from there is mobilized to fuel growth, maturation and reproduction. The energy available for these processes is limited by the energy required for maintenance of volume and maturity. Since food uptake is proportional to surface area and maintenance costs are at least in part proportional to volume, the animal reaches a maximum size when energy available for volume is all spent on maintenance. The standard model can be made specific to a given species by assigning values to the parameters of the model (which may be obtained from an online DEB database or can be determined from experiments) and if needed by changing or adding assumptions. An example of applying DEB theory to climate change is given by a DEB model of cold-water coral used to assess survival under starvation under different scenarios of ocean warming and acidification. Adaptations of the model for this purpose include that food uptake rate is assumed to be independent of temperature whereas maintenance requirements rise with temperature. This shows that especially the combined impacts reduce survival and lead to smaller corals. DEB theory could also be applied by determining the temperature and food conditions under which species can subsist, giving a valuable tool for predicting how the range of species change with climate change.

Presentation: Thermal habitat suitability of fish: a modelling approach linking ecophsyiology and oceanography by Paolo Domenici (IAMC-CNR)

The talk by Paolo Domenici presented the theory, methodology and application of ecophysiology studies on fish to estimate the thermal suitability of a given habitat. The method is based on the measurement of Aerobic Metabolic Scope (AMS) of a fish under controlled experimental conditions. AMS is a way of representing the energy potential of a fish to fuel all its activities, for example growth, under different environmental conditions (e.g. temperature, hypoxia, acidification and examples were given on how these factors influence the metabolic and behavioural response of different fish species). The equations derived are linked to an oceanographic model that computes the changes in these environmental conditions and produces maps of the spatial distribution of AMS. The talk continued with the application of such approach in the Strait of Sicily comparing the metabolic performance and potential competition of two herbivorous fish species, the native *Sarpa salpa* and the lessepsian *Siganus rivulatus* under two climate warming scenarios. They have similar size and diet, although *S. rivulatus* is known to have a detrimental effect on the vegetation it feeds on. However, they do have different thermal preference. The invasive species has a higher temperature optimum than the native species. Results from future scenarios showed that under intense water warming the overlap of thermal suitable areas for the two species increases, leading to the spread of the invasive species on the south coast of Sicily. The study concluded that projected temperature warming may favour the invasive species with the risk of outcompeting the native species and habitat degradation.

5.9 Changes/ Edits/ Additions to ToR

No changes have been made to any ToRs

5.10 Cooperation with other WG

Discussions with WGS2D were initiated prior to the meeting. As both groups were meeting at the same time, a joint discussion was envisaged but unfortunately could not occur. These exchanges are then postponed to next year, depending on the time and location of both groups meeting.

Possible contact, discussion and collaboration with other working groups have been identified and listed as recommendations to accelerate the joint actions.

5.11 Cooperation with Advisory structures

Future cooperation is envisioned as soon as efficient ways in output provision are established and the analysis of the benchmarking and sensitivity group has advanced.

5.12 Science Highlights

See abstracts on presentations

6 Revisions to the work plan and justification

No joint meeting was organized this year, partly because of agenda incompatibilities (e.g. WGSAM is meeting in autumn) and because of a limited number of participants (e.g. joint meeting with WGS2D was initially planned but cancelled at the last moment).

The group plan to submit a project proposal for COST funding as it will allow organizing and funding workshop on specific topics. Funds to travel several times a year appear to be the main issue preventing the organization of dedicated workshops. A core group, consisting of Marie Maar, Morgane Travers and Ute Daewel, was identified and will work on the definition of themes and organizing the work.

7 Next meeting

The 2018 WGIPEM meeting is planned to be held in Copenhagen from the 16–20 of April.

Annex 1: List of participants

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Tineke Troost (by visioconference)		

Annex 2: Recommendations

Recommendation	Adressed to
1. Liaise with data provider groups to identify how parameters related to bioenergetics (energy contents…) could be collected and made available to bioenergetics modellers, when parameterizing and validating the models.	WGBIOP, WGISUR
2. 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.	BEWG
3. Discuss the possibility to organize a common workshop about complex model benchmarking methods	WGSAM
4. Liaise with IEA groups to identify if some of their needs in term of mechanistic ecosystem models could be adressed by some of the models developed by WGIPEM group	WGIBAR, WGINOSE, WGINOR, WGIAB, WGNARS, WGEAWESS, WGCOMEDA
5. Liaise with WGS2D to organize common discussions and identify how our groups could exchange methods and/or scenarios	WGS2D

Annex 3: Workshop on Recent Advances in the Life Stage Eco-physiology of Small Pelagic Fish: Linking Laboratory, Field and Modelling Studies

Chairs: Myron A. Peck (University of Hamburg, Germany), Kirstin K. Holsman (NOAA Fisheries, USA), Shin-ichi Ito (University of Tokyo, Japan) and Laure Pecquerie (IRD, France)

A workshop was convened to provide a forum for field biologists, laboratory experimentalists and modellers to discuss recent physiological measurements and modelling that has advanced our understanding of the drivers of population dynamics of small pelagic fish. The workshop was convened on Saturday 11 March 2017 as part of the ICES-PICES International Symposium on Drivers of Dynamics of Small Pelagic Fish Resources held in Victoria, Canada and was attended by 32 scientists from 12 countries.

This 3-hour workshop featured a keynote presentation by Pierre Petitgas, on behalf of Martin Huret, which described the main features of a Dynamic Energy Budget (DEB) model simulating the seasonality in growth and reproduction of anchovy and sardine in the Bay of Biscay and in other European waters. This anchovy DEB model provided the bioenergetics module of an Individual-based Model (IBM) of the anchovy population. This IBM includes a separate movement module within which the direction and speed of swimming depend on both the physical environment and nutritional condition (bioenergetics) of the fish. In the Bay of Biscay, migration was necessary for fish to meet their energy requirements for growth and reproduction. Based on the annual climatology of temperature and zooplankton, habitat suitability for anchovy was compared across European waters (from the Norwegian to Mediterranean Seas). The IBM predicted that survival was higher for adult anchovy with smaller body sizes in warmer and oligotrophic waters (predicted to be preferred habitats) and that survival (life cycle closure) was limited to latitudes lower than the Norwegian Sea, both of which agree with observations.

Two subsequent talks, one by Paul Gatti and another by Laure Pecquerie, discussed data requirements of DEBs and provided additional examples of model applications. A powerful aspect of DEBs is the ability to make phylogenetic (cross-taxa) comparisons due to the generic structure of the model. For small pelagic fish, seasonally-resolved measurements of energy density are extremely helpful to calibrating the model and understanding how the environment regulates growth and reproduction. In particular, energy density can exhibit seasonal changes in condition (e.g. due to spawning) at a higher resolution than growth or weight-at-age (which may remain constant across seasons). Water, ash, protein, and lipid content measurements provide alternative data to energy density data. Furthermore, depicting energy allocation to reproduction using DEB or bioenergetics-based models is easiest if data are available on the fecundity, spawning frequency and composition of eggs but remains challenging for indeterminate spawners such as small pelagic fish. Laure Pecquerie also discussed a coupled DEB-Otolith model which can reveal a wealth of information from otolith image analysis (annual and daily variation in opacity, i.e. changes in grey nuances). For example, that model can not only estimate growth but also the amount of food assimilated by a fish.

A third talk by Eneko Bachiller discussed bioenergetics-based estimates of the annual consumption of zooplankton by three pelagic fish (spring-spawning herring, blue whiting, and Northeast Atlantic mackerel) in the Norwegian Sea. There were distinct

differences in diet composition across seasons and species, with blue whiting consuming more euphausiids while the other two species consume large quantities of copepods. The consumption to biomass (C/B) ratio was between 8 and 11 for mackerel and herring but was much lower (2.5) for blue whiting. To fuel observed rates of annual somatic growth, the three species were estimated to need to consume about 100 to 120 M tonnes of zooplankton.

A wide array of topics was discussed including how prey fields are depicted within models and whether models have deterministic (i.e. one-way) or dynamic (i.e. two-way) coupling between fish and lower trophic levels and between physical and trophic structuring processes. In particular, changes in prey quantity as well as prey quality may be important to include if we hope to adequately simulate bottom–up processes potentially influencing small pelagic fish populations. Unfortunately, most models are poorly equipped to include prey quality, a factor largely governed by changes in fatty acid composition of food items. Prey inputs to DEBs and other models include daily, available energy and, in other models, prey items are depicted in discrete size classes and/or into components such as protein and lipid. The choice of how to depict prey within a model will depend on the research goals. It was agreed, however, that standard formats would be welcomed.

Workshop participants thought that a follow-up workshop discussing the coupling of field, laboratory and modelling research would be worthwhile. A follow-up workshop would likely occur in June 2018 as part of the 4th International Symposium on the Effects of Climate Change on the World's Oceans in Washington, D.C. USA. Future topics mentioned at this workshop included the ability of models to i) simulate the impacts of low oxygen on the distribution and productivity of small pelagic and other fish, ii) make projections of climate-driven changes in distribution based on mechanistic, cause-and-effect, understanding of fish physiology, and iii) explore the 'growth-survival paradigm' (e.g. faster growth = higher survival) of fish early life stages. Ideally, such a workshop would similarly include discussion around emergent empirical approaches and findings as well as comparative bioenergetics modelling methodologies.

Some of the participants of Workshop 5 at the ICES-PICES symposium on small pelagic fish in March 2017 in Victoria, Canada.