Enhancing the LInk between low- and high TROPhic levels in ecosystem models. Application of a size-structured model of unicellular and multicellular plankton coupled to small pelagic fish in the Bay of Biscay (ELITROP)

PhD supervisor: Thomas Gorgues, IRD, LOPS
PhD Co-Supervisor: Mathilde Cadier, IFREMER, ODE DYNECO PELAGOS
Martin Huret, UMR DECOD, IFREMER, RBE HALGO LBH

Host Structure: ODE/DYNECO/Pelagos
Doctoral School: ED Sciences de la Mer et de Littoral (EDSML)

Contacts: thomas.gorgues@ird.fr
mathilde.cadier@ifremer.fr
martin.huret@ifremer.fr

Summary

Plankton is a key component of marine ecosystem functioning. In particular, the population dynamics of small pelagic fishes (sardines and anchovies) strongly depends on the quantity and the quality of their zooplankton prey. Plankton communities are caracterized by a huge taxonomic and functional diversity distributed in space and time along environnemental gradients (i.e. hydrodynamical, biogeochemical and ecological properties). One way to study the dynamics and the composition of plankton communities in relation to the higher trophic levels is the use of ecosystem modelling. While biogeochemical models are generally focused on the phytoplanktonic compartment with zooplankton used as a closure term, fish models needs a knowledge on the prey seascape of planktonic copepods which is usually derived from total biomass missing the population size structure and trait distribution. The PhD candidate will build an ecosystem model linking plankton to small pelagic fish. A focus will be made on the zooplankton compartment (copepods ranging from 0.2 to 7 mm) by taking into account its population dynamics and life-cycle. The developed ecosystem model will extend throughout the full trophic chain from unicellular plankton to fish and will be applied in the Bay of Biscay in the context of the MEDIATION project (ANR funding, described below). A key question that will be addressed by the PhD candidate is the effect (feedback) of fish predation on mesozooplankton.

Keywords: plankton/small pelagic fish coupling, traits, size-structured models, mesozooplankton, ontogeny, trophic interactions, individual-based model, Dynamic Energy Budget model, regional modelling, Bay of Biscay

Background and context

At global scale, most of the biomass of marine exploited resources and diversity hotspots are found on the coastal areas (Reygondeau, 2019). Moreover, these ecosystems generally contributed to human welfare and socio-economic activities, producing ecosystem services, providing a large part of global primary production and playing a role in climate regulation (Constanza, 1999). However, the preservation of coastal areas is now threatened by global change and human activities (fishing, land and watershed use, eutrophication etc.). Therefore, predicting the trajectories of coastal ecosystem affected by multiple external and internal pressures should consider the whole complex, multi-compartment socio-ecosystem. To do so, an integrated modelling framework of marine ecosystem could be used but requires an alignment and coupling of different existing models for each compartment : hydrodynamics, waves, sediment, biogeochemistry, plankton ecology, fish ecology, halieutic management etc. The MEDIATION project aims to transform integrated modeling methodologies by targeting two questions of major societal interest: how will global change impact the functioning of regional marine ecosystems, and how to assess the effect of environmental preservation measures? To accomplish these tasks, methodological research will be deployed to develop a transversal digital modelling tool designed with a complete modelling chain. Using this tool, future scenarios will be developed with stakeholders that are consistent with practices, in order to inform decision-makers and guide public policies. In close interaction with the consortium of the MEDIATION project, the PhD candidate will work on the relation between the plankton compartment and small pelagic fish. For plankton, an existing mechanistic, trait-based and size-structured model, the NUM (for *'Nutrient-Unicellular-Multicellular'*) model (Chakraborty *et al*., 2017 ; Cadier *et al.*, 2020 ; Serra-Pompei *et al.*, 2020) will be used. The model is based on the processes occuring at the cell scale (protists, Andersen and Visser, 2022) or at the organism scale (mesozooplankton, Serra-Pompei *et al.*, 2020). The trait distribution (size, trophic strategies, nutrition mode) is an emergent property of the model. Regarding the small pelagic fish, the PhD candidate will work with the DEB (Dynamic Energy Budget)- IBM (Individual Based Model) for sardines and anchovies. This model gives the abundance, biomass and energetic state of the fish according to their population dynamics (growth, mortality, recruitment and migration) and bottom-up forcing (Bueno-Pardo *et al.*, 2020). It has been used to explain the distribution patterns of sardines and anchovies together with their physiological state at several spatial and temporal scales (Huret *et al.*, 2010 ; Huret *et al*., 2019). The DEB-IBM model can be coupled to an hydrodynamical model and a bioegeochemical model. The PhD candidate will design the complete modelling chain using the two model that will be runned in a coupled way (2-ways coupling, Travers *et al.*, 2009). The full integrated model will be used for hindcast and forecast (scenarios) regional simulations of the Bay of Biscay.

Scientific Objectives

On the last two decades, some changes in abundance and a decrease in size and weight of SPS has been observed in the Bay if Biscay, together with a decline of their physiological state (Doray *et al.*, 2018, Véron *et al.*, 2020). On the same period, the spatial distribution also changed (Pettitgas et al., 2020). Those changes can be explained by changes in the zooplankton distribution and seasonality (Gatti *et al.*, 2018, Saraux *et al*., 2019). Furthermore, sardines and anchovies experience specific and ontogenic variations in their food preferences, in particular on the size of their prey (Van der Lingen *et al.*, 2006 ; Costalago *et al.*, 2015). It is therefore essential to better characterize the size structure of the zooplankton community. The PhD candidate will work on a coupled model of low/high trophic levels (LTL/HTL) taking into account the size structure and the life cycle of the fish prey (i.e. copepods). This work will help to fill the gap in ecosystem models by addressing the inter-compartemnt connection issue by (i) producing more realistoc prey seascape for small pelagic fish and (ii) accounting for the resulting feedback loop on LTL dynamics (Daewel *et al.*, 2014, Maar *et al.*, 2014). The application of the model in the Bay og Biscay is a key action in one of the two demonstrators (MANGA) selected in the MEDIATION project.

Methodology

First, the PhD candidate will work on the coupling between the NUM model and the DEB-IBM fish model. 0D simulations with a simplified design will be used to analyze the interactions between the two compartments.

Second, he/she will use an existing configuration of the Bay of Biscay (CROCO-MUSTANG MANGA) in which he/she will implement the full plankton model (NUM). The outputs of the model will be validated and compared to existing dataset (PELGAS cruises) on the 2000-2020 period (yearly, during spring and autumn ; Vandromme *et al*., 2014, PhD of Nina Grandremy, HALGO EMH).

Third, the DEB-IBM fish model will be used in 3D Bay of Biscay configuration with an ‘offline’ forcing using the prey seascape derived from the NUM simulations (1-way coupling).

Last, the ‘online’ 2-ways coupling will be tested on the same hindcast periods and one or two scenarios can be produced and analyzed.

Resources at disposal (human, technological, partnership)

The PhD candidate will benefit from the expertise of the interdisciplinary supervising team. Thomas Gorgues is specialised in physical/biogeochemical coupled models and biogeochemical cycles. Mathilde Cadier is competent to implement and analyze trait-based plankton ecology models. Martin Huret is an expert to develop and apply DEB-IBM models to small pelagic fish. The PhD

candidate will also work co-operativelly with Ken H. Andersen (DTU Aqua, Copenhague, Danemark) who has developed the plankton model that will be used and completed during the PhD. Therefore, the PhD candidate will visit Ken's team during one or several stays at DTU Aqua. He/she will also work with Marc Sourisseau (IFREMER, DYNECO Pelagos) for the zooplankton data collection and validation of the model outputs and with Martin Plus (IFREMER, DYNECO Pelagos) for the biogeochemical/plankton ecology coupling.

The PhD is included in the MEDIATION ANR project which will provide the PhD candidate a rich and simulating scientific environment with a large consortium of scientific experts in different complementary fields : coupled CROCO-Sediment-Biogeochemical-Ecology modelling, Bay Of Biscay, *in situ* surveys, numerical imprivements of the modelling tools etc.

Finally, another PhD project will start in October 2022 under the supervising of M. Huret focusing on the foraging seascape of dophins in the Bay of Biscay. The PhD candidate will aim at producing a prey seascapes composed of small pelagic fish to better understand and predict the dolphin distribution and use the same CROCO-DEB-IBM models for sardines and anchovies than the one used by the PhD candidate in this project, thus enabling collaborations between the two PhD candidates.

The PhD candidate will be provided by a personnal computer and access to DATARMOR cluster hosted at IFREMER for numerical calculations.

Expected results and valorisation

The main expected result of the PhD is the development of a complete ecosystem model ranging from bacteria (0.5 µm) to small pelagic fish (10-15 cm) in which all compartments (protists, zooplankton metazoa and fishes) are explicitely simulated and interact with each other. The model will be based on size-dependent processes: metabolism, use of resource and predator-prey relationships. The developed model will be used to conduct simulations of the Bay of Biscay in the context of the MEDIATION ANR project. Spatial and temporal distribution of the main plankton and fish traits will be assessed using the model outputs.

The results be valorized in science conferences and original scientific peer-reviewed publications.

Originality

Two-ways coupling of plankton (full size range, size-structured trait-based model) and fish (DEB-IBM model) in an ecosystem model applied at regional scale is a step forward the better understanding of multi-compartment functioning of marine trophic food webs (low/high trophic levels coupling). The PhD will provide crucial breakthroughs in both the regulation of small pelagic fishes traits and ditribution by zooplanktonic resource and the control of planktonic communities by

the higher trophic level predator (Daewel *et al*., 2014), thus reconciliating biogeochemical and fish modelling approaches by linking them in a common modelling framework.

Required candidate profile

We seek for a motivated candidate with solid academic background in marine ecology either/or numerical skills. He/she must have already developed some skills in programming languages and softwares (Python, Fortran, Matlab, Unix environment, NetCDF files). He/she must also have intellectual curiosity and an affinity for team working in an interdisciplinary context, but also be comfortable with working in independently. Confidence and ease in giving oral presentations to share her/her results to a large audience as well as skill in english spoken and writing are also mandatory.

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