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Modelling food web structure using an end-to-end approach in the coastal ecosystem of the Gulf of Gabes (Tunisia)

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ABSTRACT

Given the ecological importance and high socio-economic value of the fishery of the Gulf of Gabes, an end-to-end model was applied to its continental shelf ecosystem to characterize the structure of the food web in the 2000s. This approach consisted in forcing a high trophic level model (OSMOSE) with an existing biogeochemical model (Eco3M-MED) representing the seasonal dynamics of the low trophic levels. The two models were linked through trophic interactions to represent the ecosystem dynamics from primary producers to top predators. In this study, we developed the multispecies, individual-based model OSMOSE in the Gulf of Gabes (OSMOSE-GoG). This model aims to capture the main processes that influence species life cycle and simulate the functioning of the ecosystem according to opportunistic predation process based on size selection and spatio-temporal co-occurrence between a predator and its prey. The spatial distribution of the eleven modelled species was derived from a Multi-Scale Species Distribution Modelling approach. We calibrated OSMOSE-GoG model with available data of biomass and fishing yield, using an optimization method based on evolutionary algorithms which is suitable for complex and stochastic models. Finally, OSMOSE-GoG was validated against independent data sets at different hierarchical levels: the individual (diet composition), population (mean size of commercial catch) and community levels (mean trophic level) following the Pattern-Oriented Modelling approach. The model outputs were overall consistent with the diet compositions and mean trophic levels derived from the ECOPATH model of the Gulf of Gabes (ECOPATH-GoG) and the observations of mean size of catches. The OSMOSE-GoG can be considered as a baseline model to investigate ecosystem responses to environmental changes and fishing management measures in the Gulf of Gabes.

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1. Introduction

Given the limitations of single-species approaches to address the complexity of marine ecosystems, ecosystem models have been increasingly developed and applied worldwide to support the Ecosystem Approach to Fisheries (EAF) (Garcia, 2003; Plagányi et al., 2007). By taking into account the interactions between the different components of the ecosystem, as well as the direct and indirect impacts of human activities, these models have an important role to play in Management Strategy Evaluation (Food and Agriculture Organization of the United Nations, 2008). The use of ecological models such as OSMOSE (Shin and Cury, 2004, 2001), Ecopath with Ecosim (Christensen and Walters, 2004) and Atlantis (Fulton et al., 2004) can provide an overview of the ecosystem functioning and have the potential to deliver useful information in support of fisheries management procedures.

In the Mediterranean Sea, fishing is one of the most important threats to biodiversity in addition to habitat loss (Coll et al., 2010). The Gulf of Gabes located off south Tunisia presents typical ecosystem management issues. On the one hand, the Gulf is under anthropogenic threats (i.e. overfishing, chemical pollution, degradation of Posidonia seagrass meadows, invasion of alien species, climate change) (Ayadi et al., 2015; Ben Rais Lasram et al., 2015b). On the other hand, the ecosystem supports a multispecies fishery which represents more than 40% of national production. Hence, a holistic approach of the ecosystem is needed which takes into account the abiotic environment, the ecosystem complexity and the human activity. To assess fishing impacts, several models have been applied to the Gulf of Gabes, i.e. Ecopath with Ecosim (Halouani et al., 2016; Hattab et al., 2013), Species Distribution Model (Hattab et al., 2014), and EcoTroph (Halouani et al., 2015b).

In the context of increasing computational power, End-to-End models (E2E) are considered as relevant tools to adress questions about ecosystem functioning (Fulton, 2010). E2E modelling approaches attempt to include the major processes that structure the different parts of the ecosystem, considering the human components and the abiotic environment, and integrating physical and biological processes at different scales in a single modelling framework (Fulton, 2010; Travers et al., 2007).

The increasing interest in developing E2E modelling approaches have arisen from the need for considering the complexity of interactions and feedbacks between factors that control ecosystem functioning (Rose et al., 2010). Indeed, to further explore the effects of multiple drivers on the ecosystem, E2E models that represent the ecosystem from the physics to the biogeochemistry and exploited fish resources (Travers et al., 2007) allow to address questions from both ecological and fisheries perspectives and to investigate the combined effects of climate change and fishing (Travers-Trolet et al., 2014b). The development of such approaches is also motivated by the need for quantitative tools for ecosystem based management (Rose et al., 2010). By incorporating spatial structure and environmental processes, E2E models can be used as new analytical and management tools for the ecosystem-based fisheries management (Pikitch et al., 2004).

Here, we develop an E2E model in a continental shelf ecosystem which consists in a one-way coupling between OSMOSE (high trophic levels model) and NEMOMED12-Eco3M-MED (low trophic levels model) (Alekseenko et al., 2014; Guyennon et al., 2015). The choice of this approach for the Gulf of Gabes ecosystem is mostly explained by the need to make the transition from the single-species management to a more holistic approach. Since the Gulf of Gabes is subject to high fishing pressure and global anthropogenic threats affecting the different components of the ecosystem, the use of an E2E model is appropriate to better understand the ecosystem dynamics and management trade-offs between conservation and fisheries objectives. In this context, the choice of the OSMOSE modelling framework was appropriate as it allows to simulate various fishing and environmental change scenarios, while relying on a parsimonious size-based predation assumption, and providing a diverse range of output indicators at the individual, population and community levels. Moreover, the application of the OSMOSE model in the Gulf of Gabes was timely and feasible given (i) the large number of empirical studies on life history traits (growth and reproduction parameters) (Tsikliras et al., 2010; Tsikliras and Koutrakis, 2013) allowing to parameterize the model, and (ii) the availability of a biogeochemical model (Eco3M-Med) applied to the study area allowing to develop a fully integrated E2E modelling approach

As a first step underpinning future simulation work, this study aims to represent the food web structure of the Gulf of Gabes in the 2000s. The application of OSMOSE to the Gulf of Gabes ecosystem requires a careful and extensive parameterization work. Based on a size-based opportunistic predation, the model is parsimonious in trophic data requirements but then needs to be properly fitted to biomass and catch data as well as be confronted to an independent set of data and other modelling approaches' outputs. All these modelling steps are presented here.

2. Material and methods

2.1. Study area

The Gulf of Gabes is located in the South-central Mediterranean Sea and covers a total area of approximately 35,900 km^2 (Fig. 1). Recognized as one of the most productive area in the Mediterranean Sea (Papaconstantinou and Farrugio, 2000), the ecosystem of the Gulf of Gabes is under multiple anthropogenic threats (Hattab et al., 2014; Lamon et al., 2013) and its biodiversity is subject to great changes (Ben Rais Lasram et al., 2015a; Hattab et al., 2011). This region has a relatively wide continental shelf since the isobath 200 m is located about 400 km offshore and it has the highest tidal amplitude in the Mediterranean Sea (up to 2 m height) (Sammari et al., 2006). The seabed of the Gulf of Gabes is characterized by large meadows of *Posidonia oceanica*, an endemic Mediterranean seagrass (Ben Mustapha and Afli, 2007; Zucchetta et al., 2016). This habitat provides an important nursery, feeding, and breeding for several marine species (Hattour and Ben Mustapha, 2013).

2.2. The end-to-end model

The end-to-end model applied to the Gulf of Gabes aimed to represent the ecosystem structure and dynamics based on two existing sub-models, the individual-based model OSMOSE (Grüss et al., 2015; Shin and Cury, 2004), representing the dynamics of high trophic level (HTL) organisms, which was coupled with the biogeochemical model Eco3M-Med (Alekseenko et al., 2014; Guyennon et al., 2015) representing the low trophic levels (LTL) dynamics. The outputs of the biogeochemical model were used as inputs for OSMOSE without any feedback (forcing mode or one-way coupling).

The two models were linked through trophic interactions to represent the food web from plankton to top predators. In this application, OSMOSE is forced by the biomass of four LTL groups (phytoplankton, nanozooplankton, microzooplankton, and mesozooplankton) and one benthos group. The plankton concentrations obtained from the biogeochemical model serve as prey fields for HTL species in OSMOSE over space and time. The prey fields link the two models through an opportunistic predation process based on size selection (*i.e.* minimum and maximum predator to prey size-ratio parameter) and spatio-temporal co-occurrence between a predator (HTL species) and its prey among the LTL groups (Travers et al., 2009; Travers-Trolet et al., 2014a).