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An Ecosystem Model of Intermediate Complexity to test management options for fisheries: A case study

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ABSTRACT

Reduction of complexity and capacity to evaluate management strategies are important considerations when modelling complex ecosystems. Models of Intermediate Complexity for Ecosystem assessments (MICE) achieve this by representing interactions among a restricted number of crucial species in the ecosystem considered. MICE applications are question-driven, heavily dependent on available data for conditioning and aimed at addressing tactical issues. Here we present the development of a MICE for the central Adriatic Sea. This area is important ecologically and economically because it supports a commercial stock of Norway lobster (*Nephrops norvegicus*), and a nursery ground for European hake (*Merluccius merluccius*), as well as being subjected to high levels of fishing pressure. Here, Italian and Croatian bottom trawl fisheries mainly target Norway lobster while impacting juvenile hake. Single-species stock assessments for the target species indicate fluctuating trends between 2006 and 2013, as do the survey biomass trends of most of their prey, underlining the need for a multispecies management plan. The diet of the target species were examined and prey items partitioned into four groups. Consumption of prey groups by predators was modelled using a Holling Type II functional response. A modified biomass dynamic model was used to represent the prey dynamics, projecting them into the future for 10 years (2013–2022) and testing different management strategies, including a discard ban. The most effective management option was the protection of larger individuals, which led to a clear improvement in the stock abundance and spawning stock biomass of both hake and Norway lobster without significant adverse effects on their prey. The discard ban scenario appeared to have knock-on effects on both predators and some of their prey.

1. Introduction

The successful management of fisheries resources is key to maintaining productive and functioning marine ecosystems. There is a need to develop models capable of assessing fish stocks and minimising their risk of depletion while taking into account the marine ecosystem as a whole. The key objectives of ecosystem-based fisheries management (EBFM) and an ecosystem approach to fisheries (EAF) include the protection of ecosystems from major degradation and irreversible change, as well as the broadening of our knowledge on the role of human activities in ecosystem dynamics (Garcia et al., 2003; Pikitch et al., 2004).

A suite of different models is available to implement this approach (Hollowed et al., 2000; Plagányi, 2007). These span from (i) extensions of single-species assessment models, accounting for target species and including complementary information, e.g. predation mortality in Multi-species Virtual Population Analysis (MSVPA – Livingston and Methot, 1998; Hollowed et al., 2000; Vinther, 2001; Tjelmeland and Lindstrøm, 2005), to (ii) whole-of-ecosystem models including a comprehensive representation of the ecosystem studied, e.g. ATLANTIS (Fulton and Smith, 2004) and Ecopath with Ecosim and Ecospace (Christensen and Walters, 2004), via (iii) dynamic multi-species models which are intermediate in complexity and describe the interactions among a restricted number of important species, answering specific management

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questions, e.g. Minimum Realistic Models (Punt and Butterworth, 1995) and the related Models of Intermediate Complexity for Ecosystem assessments (Plagányi et al., 2014).

Conventionally, single-species models have been the main tools used for the formulation of tactical management advice (short-term advice linked to operational objectives, e.g. gear restrictions, seasonal closures), whilst the more complex whole-of-ecosystem models are typically used in a strategic context (long-term, linked to policy goals, e.g. to simulate interacting systems over longer timescales). Models of Intermediate Complexity aim to bridge the gap between these two model types and advance the use of ecosystem models for tactical management advice.

The aim of this paper is to construct a Model of Intermediate Complexity for Ecosystem assessments (MICE, Plagányi et al., 2014) for use in developing an ecosystem-cognisant approach to evaluating management possibilities. MICE applications describe subsets of the ecosystem by accounting for the ecological processes driving a limited number of components or species subjected to human impacts (including fishing) with the aim of testing specific management questions. Thus, the kinds of model structures often used in a single-species context (Hilborn and Walters, 1992), like models for the abundance of predators and estimates of fishing mortality, are included into an ecosystem context allowing the use of established statistical methods for parameter estimation and uncertainty propagation. MICE are heavily question- and data-driven. Ecological information and interspecific interactions define the core of a MICE model, but wherever large amounts of corollary data are available, such as environmental and human components, anthropogenic effects and management actions, they can be included as well (Plagányi et al., 2014).

The central Adriatic Sea (Fig. 1) is a transition zone between the northern and southern sections. It is characterised by the waters of the Pomo/Jabuka pits, a series of three consecutive depressions with maximum depths of 225 m, 270 m and 240 m from west to east (Marini et al., 2006). The cold, nutrient-rich waters generated in winter in the shallow northern Adriatic Sea flow towards the southern Adriatic Sea, and, owing to the topography of the area, are retained in these depressions (Artegiani et al., 1997). This phenomenon is responsible for strong nutrient recycling processes within the Pomo/Jabuka pits, resulting in rich fishing grounds. Consequently, it is an intensely exploited area, especially by the European hake (*Merluccius merluccius*) and Norway lobster (*Nephrops norvegicus*) fisheries. These are two of the most important commercial species of the Adriatic Sea and they are mainly caught by bottom-trawl nets (Vrgoč et al., 2004); their landings have decreased in the past two decades (FAO, 2012).

The Pomo/Jabuka pit area represents the main nursery ground for hake but also hosts a distinctive stock of Norway lobster, characterised by a high density of small-sized, slow-growing individuals (Froglia and Gramitto, 1982; Mediterranean Sensitive Habitats, 2013; Druon et al., 2015). Adequate management strategies that facilitate sustainable exploitation of these species as well as ongoing functioning of the ecosystem overall are required. These resources are shared by the fleets of Italy and Croatia, which further complicates management. The possibility of creating a fisheries-restricted area has been extensively discussed in the past decade (e.g. AdriaMed, 2008; De Juan and Lleonart, 2010). This has resulted in a temporary closure of the Pomo/Jabuka pits to bottom trawls from 26 July 2015 to 26 July 2016 (D.M. 3/07/2015).

The high density of Norway lobster, the fact that it hosts a hake nursery and the high levels of exploitation, make the central Adriatic Sea a good candidate for the evaluation of multispecies management alternatives and a suitable case study to apply a MICE approach.

This paper describes the construction of a MICE in a step-wise manner: starting with single-species stock assessments for the target species, then linking them to their prey, based on their interactions, with the aim of investigating:

- how the dynamics of predators and prey influence each other:
- how the fishery may have the power to modify their interactions indirectly, as well as directly, further impacting the hake and Norway lobster stocks in the study area;
- how different management strategies influence the predator–prey system. In particular, the imposition of a discard ban is investigated. EC Regulation No. 1380/2013 determines that in the Mediterranean from 2017 (or 2019 in some cases), all catches of species subject to catch limits and/or minimum landing sizes should be retained and landed (EC, 2013). This decision is considered controversial for a number of ecological and economic reasons and may result in unforeseen outcomes; for example, it may increase the fishing mortality in particular on juvenile fish, and have a high probability of enhancing the black market (Sardà et al., 2013; Bellido Millán et al., 2014).

2. Materials and methods

2.1. Modelling framework

The MICE ethos advocates the use of ecosystem models representing a limited number of populations to provide tactical advice within a framework that quantifies the uncertainty associated with predictions and estimates (Plagányi et al., 2014). We adhered to the principles that MICE should: (1) model a subset of the ecological system in question, explain ecological processes for the chosen populations and explicitly represent at least one ecological process, e.g. interspecific interactions such as predation, competition or cannibalism; (2) model the impact of human activity on these ecological processes; and (3) assess how both the ecological system and the human processes are affected by management alternatives, providing tactical advice (e.g. the estimation of current abundance or the prediction of future population size under different management scenarios).

To obtain this, the model should be parameterised by fitting to available data and the uncertainty of parameters should be quantified using statistical tools (e.g. Markov Chain Monte Carlo (MCMC) sampling or likelihood profiles) (Plagányi et al., 2014).

Simplicity is at the core of the MICE philosophy: making use of the simplest possible representation of the processes modelled, reducing the complexity of the model while retaining enough structure and detail to obtain good model fits, and taking advantage of all data available (Plagányi et al., 2014).

Our model describes the interactions between European hake, Norway lobster and their prey in the Pomo/Jabuka pits (Fig. 2), where the two target species are both exploited by the same bottom trawling fleets from two different countries, severely impacting the juvenile hake population (Vrgoč et al., 2004). The target species do not directly interact with each other, but they compete for shared prey, some of which are themselves targeted by the same bottom trawl fishery (Jardas, 1976; Wieczorek et al., 1999; Vrgoč et al., 2004). Both species exhibit a degree of cannibalism (Vrgoč et al., 2004) that needs to be considered in model development.

The data available to fit a model describing these dynamics can be considered in some respects relatively rich (e.g. the time series of landings and length distributions for target species, and scientific surveys) but in other respects rather poor (e.g. data on prey, actual long-term contrast in the abundance data). To overcome this latter problem we have used all the data available as priors within a Bayesian framework (e.g. in the estimation of the intrinsic growth rate, r and the carrying capacity, K). Uncertainty related to estimated parameters was determined using a number