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Systems approach modelling of the interactive effects of fisheries, jellyfish and tourism in the Catalan coast

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ABSTRACT

Despite the large fluctuation in annual recordings of gelatinous plankton along the Catalan coast in the north western Mediterranean and the lack of long term data sets, there is a general perception that jellyfish abundances are increasing. Local authorities are concerned about the stranding events and arrivals of jellyfish to beaches and believe it could reduce the recreational appeal of the beaches – a valuable ecosystem service for the regional tourist industry. Previous studies also demonstrate the predation of jellyfish (*Pelagia noctiluca* ephyrae) upon some small pelagic fish larvae (*Engraulis encrasicolus*). Small pelagics are the principal source of revenue for the local fisheries. A social-ecological model was created in order to capture the effects of changes in abundance of *P. noctiluca* upon the local fisheries, the tourist industry and the wider economy. The following sub-models were constructed and connected following the systems approach framework methodology: an age-class based fisheries model; a jellyfish population matrix model; a jellyfish stranding model; a study on the impact of jellyfish strandings on beach users; and an economic input–output matrix. Various future scenarios for different abundances of jellyfish blooms were run. The "Expected blooms" scenario is similar to the quantity and size of blooms for 2000–2010. For a hypothetical "No blooms" scenario (standard background level of jellyfish but without any blooms) landings would increase by around 294 tonnes (5.1%) per year (averaged over 10 years) or approximately 0.19 M€ in profits per year (4.5%), and strandings would decrease by 49%. In a "Frequent blooms" scenario, landings would decrease by around 147 tonnes per year (2.5%) and decrease profits by 0.10 M€ per year (2.3%), and strandings would increase by 32%. Given the changes that these scenarios would cause on the regional gross domestic product and employment, this study concludes that the overall impact of either of these scenarios on the economy would not be significant at the regional scale.

1. Introduction

Jellyfish occur naturally in the coastal waters of Catalonia in the North Western Mediterranean Sea (Calvo et al., 2011; Condon et al., 2012; Gili et al., 1988; Goy et al., 1989). Despite the widespread perception that their numbers are increasing (Canepa et al., 2013), there is a lack of long term observations to confirm this hypothesis (Pauly et al., 2009; Purcell et al., 2007). Speculation regarding this possible long term increase has been attributed to climate change, over-fishing of predators and competitors, eutrophication, habitat modification (creating more habitats for polyps), and introduction of non-native species (translocation via ballast water or ship hulls) (Canepa et al., 2013; Duarte et al., 2013; Purcell et al., 2007; Richardson et al., 2009).

There is concern among academics, managers and the general public (Canepa et al., 2013) that an increase in jellyfish bloom frequency will have a detrimental effect on a number of economic sectors, including but not limited to, fisheries and tourism. In many cases around the world, stranding events of jellyfish reduce the recreational appeal of beaches and bathing waters for beach users being detrimental for the local tourist industry (Purcell et al., 2007; Richardson et al., 2009). In this context, jellyfish outbreaks can be conceived of as an event that potentially diminish the benefit humans receive from marine and coastal ecosystem services (Daily, 2003; Hassan et al., 2005; Hattam et al., 2015), particularly cultural services (e.g. tourism and recreation) (De Donno et al., 2014;

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Ghermandi et al., 2015; Kontogianni and Emmanouilides, 2014; Nunes et al., 2015; Palmieri et al., 2015) and provisioning services (e.g. seafood) (Angel et al., 2014; Conley and Sutherland, 2015; Graham et al., 2003; Nastav et al., 2013; Palmieri et al., 2014).

Cultural and provisioning services valuation is already robustly backed up in theoretical and empirical terms, by a large number of case studies around the world (Brenner et al., 2010; De Groot et al., 2002; Farber et al., 2002; Heal, 2000). There is a lack of studies regarding changes in the delivery of ecosystem services both in the presence and absence of jellyfish outbreaks though. Our work proposes to assess the impact of these changes, specifically on the tourism and seafood producing industries in Catalonia, under different future scenarios of jellyfish outbreaks, with models parameterized based on data corresponding to the past 15 years.

In Catalonia, beach-based, sun-and-sand tourism and fisheries are the main uses of the coastal zone (Sardá et al., 2005). For instance, tourism revenues are increasing and are currently around €14 billion per year with around 16 million visitors (IDESCAT, 2010), with the majority resulting from "sun and beach" tourism (Ariza et al., 2008). Increasing jellyfish blooms result in beach strandings that may be visually unpleasing to beach users or actually detrimental to human health (Ghermandi et al., 2015).

The contribution of fisheries to the coastal economic is much lower and declining, with a production value (at first sale) of ca. €110 million per year (IDESCAT, 2010). Jellyfish are thought to impact fisheries by feeding on fish larvae (Purcell et al., 2014, 1994; Purcell and Arai, 2001; Sabatés et al., 2010) as well as competing with adults for food (Purcell and Arai, 2001; Purcell and Grover, 1990). Fisheries along the Catalan coast largely consist of semi-industrial and artisanal fleets with the main contributors to landings being the small pelagics sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), which account for around 50% of total annual landings in weight and 25% in economic value (IDESCAT, 2010; Lleonart and Maynou, 2003; Palomera et al., 2007).

This study proposes an integrated approach to the analysis of the impact of jellyfish blooms on the key sectors of tourism and fisheries. The modelling dimension of the Systems Approach Framework (Hopkins et al., 2011; Tomlinson et al., 2011) was undertaken in which the ecological and socio-economic components are defined, modelled and linked together. Future possible scenarios were run for various intensities of jellyfish blooms, and the impact that they would have on the local tourism and fisheries economy was estimated, in order to contribute to a partial evaluation of the consumer surplus of marine ecosystems free of abnormally high jellyfish outbreaks.

2. Material and methods

A model was constructed using the software ExtendSim. Various sub-models were constructed using different techniques and methodologies as outlined below. A simplified approximation of the overall model is shown in Fig. 1, indicating how each sub-model is connected within it. Spatially, the model is divided into three zones representing approximately equal areas of the Catalan Sea. Each zone extends from the coastline to the shelf break – the area where most of the small-pelagic fishing activity and jellyfish occur. The zones cover the area heading south from Cap de Creus to the Ebro Delta and are named after the adjacent provinces: Girona; Barcelona; and Tarragona (Fig. 2). Cap de Creus and Ebro Delta are not included in the study area due to the differing fisheries practised there. In this study, we refer to all three zones together as "Catalonia" but it should be remembered that this does not include the entire administrative region of Catalonia.

The model examines the impact of one species of jellyfish, *Pelagia noctiluca*, because it is one of the most abundant in the study zone, has a powerful sting (affecting beach users), and is relatively well studied and documented (Canepa et al., 2014), particularly its predation effects on small pelagic larvae (Purcell et al., 2014; Sabatés et al., 2010). Although many other species of scyphomedusae have been found in the study zone, there is no evidence to suggest that they prey upon fish larvae and so have been excluded from the model.

2.1. Fisheries sub-model

The fisheries sub-model was based on a simplified and adapted version of the MEFISTO model. MEFISTO (MEditerranean FIsheries Simulation TOol) is an age-structured bio-economic model which is multi-species, multi-fleet, within a single predefined zone, where the central management lever is effort limitation. The MEFISTO model has been applied in various analyses including red shrimp, hake, anchovy and sardine fisheries within the Mediterranean and is fully documented and available to download and use (Lleonart et al., 2003, 1998; Maynou et al., 2006).

For this analysis, the model was adapted in order to capture the predation of jellyfish upon the small pelagics larvae. The MEFISTO model runs at a time-step of one year so all the forecasts of fish mortality, growth, biomass, catches and recruitment are aggregated over the year. Given that anchovy and sardine larvae only occur in the plankton at specific times of the year (summer and winter respectively), in order to ascertain the impact of *P. noctiluca* predation upon these fisheries, the resolution of the model was increased to a time-step of one month, in order to capture this temporally specific interaction. The forecast was run for a period of 120 months (10 years).

The MEFISTO model aggregates the fisheries dynamics over one spatial zone, but in order to capture the various degrees of jellyfish strandings upon different Catalan beaches, a greater spatial resolution was needed. Previous information has shown that the degree of jellyfish strandings can largely be divided into three zones, where the north of Catalonia (Girona) receives a high number of strandings, central Catalonia (Barcelona) receives low strandings, and south Catalonia (Tarragona) receives a medium level (Canepa et al., 2014). Therefore, the spatial resolution was adapted to reflect this, and three zones were used.

Given that principal objective of the analysis is to capture the interaction of jellyfish with small pelagics and not the dynamics of resource allocation within the fisheries themselves, a number of the MEFISTO model elements were simplified: Effort and catchability were fixed; there were no bycatches or discards; all stochastic elements were removed; the market and fishermen components (described as "boxes" in (Lleonart et al., 2003)) were left static (i.e. fish prices are fixed and there is no reinvestment in vessels or bank loans).

The majority of the equations for the biological sub-model are typical to all age-structured models and have been fully documented elsewhere so they are not reproduced here (Lleonart et al., 2003, 1998). An exception to this is the recruitment sub-model. In MEFISTO and other age-structured models, recruits are generally calculated by using one of three equations: constant recruitment, Beverton and Holt's model; or Ricker's model. This calculates the number of recruits to the following year's cohort at age 0. For our analysis, this is not sufficient because we want to analyse the impact of *P. noctiluca* when it preys upon the larvae of the small pelagics. In our age-structured model, the fish are assumed to be larvae only during their "Age 0" time-step (i.e. for the first month of their life (Palomera et al., 2007)), after which they become classed as "juveniles". After 6 months or older, they then become susceptible to fishing mortality. Incorporation of larvae to fish population is therefore calculated using the fecundity rate of anchovy