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Assessing the impact of artisanal and recreational fishing and protection on a white seabream (*Diplodus sargus sargus*) population in the north-western Mediterranean Sea using a simulation model. Part 1: Parameterization and simulations

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ABSTRACT

This study focuses on the parameterization of a model describing the dynamics of an exploited population and aims at improving management practices by simulating various measures. The study species is white seabream, an important resource exploited by the mixed fisheries of the French Catalan coast, where the Cerbère-Banyuls marine reserve was created more than 30 years ago. We used the ISIS-Fish fishery simulation model to evaluate the population's sustainability under the current fishing regime. This simulator combines three sub-models within a single working environment: population dynamics, multi-fleet exploitation and management measures. Knowledge of the white seabream and related fishing activities was compiled from both literature and analyses of existing fisheries data, and is used to parameterize and calibrate the model. Simulation results highlighted that: (i) under current management, the white seabream population biomass has declined to 88% of initial biomass over 20 years; (ii) with various scenarios of recruitment, the population dynamics tends to stabilize over the long term. In a second article (Hussein et al., 2011), we undertook an analysis of the sensitivity of the model to uncertain parameters and explored scenarios aiming at evaluating the impact of fishing activities and the effects of protection effects on white seabream dynamics.

1. Introduction

In the Mediterranean, coastal fisheries are of special interest in terms of the conservation of regional traditions and lifestyle. Two important features of the fishing activity are the multi-species nature of catches and the absence of large single demersal stocks compared to other seas (Farrugio et al., 1993). The artisanal fishery (i.e. the professional component of small-scale fisheries), mostly practiced using traditional methods, is characterized by highly diverse fishing gear and target species, as well as by marked seasonality, determined by local knowledge of species behaviour and abundance throughout the year. Artisanal fishing activity, accounting for about 60–80% of the European Mediterranean fleet, represents more than 30,000 vessels (Colloca et al., 2004). On the other hand, the importance of recreational fishing is growing rapidly in coastal areas of developing countries, particularly in the Mediterranean, and represents more than 10% of total fisheries production in the area (European Commission, 2004). Therefore, it is necessary to take into account all types of fishing practices, including recreational fishing, in fisheries management as the role they play in the decline of coastal stocks is increasingly recognized (Cox et al., 2002; Williams and Blood, 2003).

Sustainable fishing practices are needed to address the problem of marine species overexploitation (Safina, 1995; FAO, 2009) and to protect marine biodiversity. Management measures such as redirecting fishing effort according to seasons and fishing areas are among the most important measures to be considered (Holland, 2003) and evaluating the impact of such alternative management options is essential for fisheries management (Verdoit et al., 2003).

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More generally, marine protected areas (MPAs) are increasingly used as a tool to limit the effects of fishing on an ecosystem (Botsford et al., 1997; Doyen et al., 2007; Pitchford et al., 2007). The effectiveness of MPAs depends on the seasonal timing of closures, location, size, duration (Sumaila et al., 2000; Jamieson and Levings, 2001; Stelzenmuller et al., 2008; Forcada et al., 2009) and interactions with other management measures (Francour et al., 2001; Jameson et al., 2002).

Many models have been developed for evaluating the impact of MPAs on exploited resources and fishing activities, ranging from tactical to strategic models, including spatially explicit, bioeconomic and ecosystem models (see Pelletier and Mahévas, 2005, for a review). However, predicting such impact is not easy because fisheries are complex systems with many interactions at various spatial and temporal scales (Lehuta et al., 2010). Consequently, complex spatially explicit models that incorporate MPAs are required. There are few examples of subdivided population models that explicitly depict spatial and seasonal aspects linked to ontogenic processes (Holland, 2000; Pelletier and Mahévas, 2005). In this article, the ISIS-Fish (integration of spatial information and simulation for fisheries) model (Pelletier et al., 2009) was used because: (i) it integrates the spatial and seasonal information on population and exploitation dynamics of any type of fishery, and (ii) it allows the consequences of various management measures, including MPAs on multi-species and multi-fleet fisheries, to be tested, as well as fishermen's reactions to the measures. The first versions and equations of the model were described in Mahévas and Pelletier (2004) and Pelletier and Mahévas (2005). In Pelletier et al. (2009), version 3.0 of ISIS-Fish is presented, which encompasses new developments in the software and underlying model, such as a bio-economic model of fisheries dynamics. Recently, this simulation tool has been applied to a number of case studies in several North Atlantic European fisheries: the French Gulf of Biscay *Nephrops norvegicus*–*Merluccius merluccius* (Drouineau et al., 2006; Pelletier et al., 2007), the eastern Baltic Sea cod (*Gadus morhua callarius*) (Kraus et al., 2008) and the Bay of Biscay anchovy (*Engraulis encrasicolus*) fisheries (Lehuta et al., 2010).

We have considered that the interactions between species were not central to this study, although a consensus has emerged in fishery science to complement the single-species approach with an ecosystem approach to fisheries (Cury et al., 2008). This additional aspect guides us in the choice of the ISIS-Fish model instead of ecosystem models, such as Ecopath (Walters et al., 1997). The species used in this study was white seabream (*Diplodus sargus sargus* L., 1758) (Sparidae), a demersal species widely distributed in the north-western Mediterranean Sea. It is found at depths of up to 70 m (Lloret and Planes, 2003) on various types of sea bottoms (Harmelin-Vivien et al., 1995). This species was chosen because: (i) it constitutes an important and high value fishery resource along Mediterranean coasts; (ii) several genetic, biological and ecological studies have been undertaken on this species in the area (e.g. Jouvenel, 1992; Lenfant, 1998, 2003) providing a good base of knowledge; (iii) despite the presence of the Cerbère-Banyuls marine reserve created more than 30 years ago, protecting a part of the population, a decline in the catches has been observed in the area. It is exploited by artisanal fisheries as a by-catch fish and it is a target species for recreational fishermen (Verdoit-Jarraya et al., 2010). It represents ~7% of the catch by weight for artisanal fisheries (Lenfant et al., 2010) along the French Catalan coast. Moreover, violations of regulations are frequent in the study area, such as illegal catches or landings, misreported landings or catching fish in the MPA (Verdoit-Jarraya et al., 2010; Lenfant et al., 2010).

This study provides a compilation of baseline data on white seabream population dynamics. A synthesis of knowledge of *D. sargus* from the literature served to define many biological parameters such as natural mortality and growth, which are required in the ISIS-Fish model. Additional field data were collected (mainly related to recreational angling and commercial fishing in and around the Cerbère-Banyuls marine reserve) and analyzed in order to estimate model parameters with their corresponding uncertainties. The purpose of this study was also to investigate *D. sargus* population dynamics with respect to the current situation (reserve protection) in the study area and to assess which maturity stage of the population and essential habitat (such as spawning areas) are affected by the catches from artisanal and recreational fisheries.

In the present study, a generic model of the dynamics of mixed fisheries is first presented and its parameterization is discussed. Second, the model is calibrated by comparing simulated and observed catch. Third, the current situation of the population is evaluated. Finally, various scenarios of recruitment variability are tested to investigate the potential impact on population dynamics. A companion article (Hussein et al., 2011) reports on a sensitivity analysis to assess the impact of each parameter and to compare the performance of several management measures on white seabream dynamics.

2. Materials and methods

2.1. The study area

The study area (Fig. 1) in the Gulf of Lion (north-western Mediterranean) stretches along 85 km from the French border with Spain in the south to Salses-Leucate lagoon in the north. These limits were chosen on the basis of spatial genetic studies indicating that *D. sargus* populations around Banyuls differ from those of other sites in Italy and Spain (Lenfant and Planes, 1996). This area was divided into two coastal ecological sections: a rocky section stretching from the Spanish border to Argelès-sur-mer and a sandy section from Argelès-sur-mer to Salses-Leucate lagoon. It includes the Salses-Leucate lagoon and the natural reserve of Cerbère-Banyuls (7 km coastline). The latter comprises two major zones: a partial marine reserve (PMR, 585 ha), allowing some exploitation and a marine reserve (MR, 65 ha), closed to exploitation, respectively created in 1974 and 1979. The PMR regulations allow recreational angling (free license with an angling effort restricted to 6 shore hooks and 12 hooks per fishing vessel), limits commercial fishing to 8 licenses per year, and prohibits spear fishing, night fishing and bottom trawling (Lenfant et al., 2000). In the MR, all activities (notably fishing and diving) are prohibited (except scientific studies). Navigation speed is restricted to 5 knots throughout the reserve (Lenfant et al., 2000). The spatial resolution of the regular grid of the model was chosen according to the MR size (0.0089° latitude and 0.014° longitude, corresponding to 1029 km^2). The limits of the modelled area extend from 42.430° to 42.934° N and from 2.936° to 3.258° E (using the world geodetic system of projection WGS 84).

2.2. The generic model

ISIS-Fish is a spatially explicit deterministic dynamic model with a monthly time step. This fishery model encompasses three sub-models: a population dynamics sub-model, which depicts growth, reproduction, mortality, recruitment and movements according to sex, age or size; an exploitation sub-model, which calculates fishing effort; and a management sub-model, which describes the management measures. The mathematical formulae used in the ISIS-Fish model are based on recurrence equations; time and space are modelled discretely. The population sub-model is age- or size-structured. It is not a multi-agent model because individuals are not represented by autonomous interacting entities. Furthermore, the population model is linear, which may lead to three possible outcomes for population dynamics: exponential increase, expo-