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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 2: Sensitivity analysis and management measures

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ABSTRACT

In this paper, the ISIS-fish model was used to assess the impact of spatial and seasonal management measures on the dynamics of the white seabream population (*Diplodus sargus sargus*) in the French Catalan fishery (north-western Mediterranean). This work is the second part of a paper (Hussein et al., 2011) which describes the parameterization of the model. Here we carry out a sensitivity analysis to identify the most significant model parameters. The simulation results show that the model is particularly sensitive to some parameters such as natural mortality, stage length, fecundity, number of inactive days per strategy and gear standardisation factors. Second, the impact of several management measures was evaluated (e.g. marine protected areas (MPAs) in the nursery and spawning zones, changes in gillnet mesh size and fishing effort reduction). Management scenarios were then assessed and compared using a simulation design. The results indicate that the permanent closures in the white seabream juvenile habitat for all gears, a change in gillnet mesh size and fishing effort reduction would result in an important increase in the population biomass and catch. The closures of the spawning zones appear inefficient in restoring *D. sargus* biomass.

1. Introduction

Traditional management measures (quotas, limiting fishing effort and minimum legal size) face difficulties to ensure the long-term sustainability of certain fisheries (Pauly et al., 2002). One of the primary goals of marine protected areas (MPAs) is the protection of biodiversity (Holland, 2000; Sumaila et al., 2000). MPAs are also considered as important tools for restoring fisheries sustainability (Botsford et al., 1997; Verdoit et al., 2003; Doyen et al., 2007; Pelletier et al., 2008). This study aims to use a fisheries simulation model to explore the impact of implementing different management measures in a single-species fishery and to specifically investigate the hypothesis that the establishment of MPAs will increase both population abundance and fishery yields. We used the ISIS-Fish model to evaluate the ability of various alternative spatial and seasonal management policies for maintaining a Mediterranean resource, the white seabream population (*Diplodus sargus sargus* L. 1758), denoted *D. sargus* in this paper, whose yields have decreased in recent years (FAO, 2002; D'Anna et al., 2004). The work undertaken here extends an earlier study which examined model parameterization in this fishery (Hussein et al., 2011).

Fishery simulation models can be characterized by a large number of parameters whose estimation can be uncertain in some cases. Such is the case in our model, given there is a lack of knowledge for some of the parameters. Moreover, there is likely to be considerable natural variation related to fecundity (Morato et al., 2003), recruitment (Planes et al., 1999), growth (Mariani, 2006), natural mortality rates (MacPherson et al., 1997) and catchability (Pelletier, 1991). A sensitivity analysis was thus carried out to identify the parameters which are most responsive to the model inputs (Kitchell et al., 1977) or that have the greatest influence on the model results.

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Management aims to balance the observed or anticipated benefits of introducing measures to mitigate population declines and untoward costs to the fishing industry. It is also important to look for benefits, or at least acceptance of management measures, for all the user-groups (notably artisanal and recreational fishermen) in the current and long-term. There are several alternative options in evaluating the potential impacts of fishing and management strategies for the *D. sargus* stock.

MPAs have been suggested to be relevant for reducing technical interactions in mixed fisheries, since they control effort. Implementation of MPAs in nursery and spawning areas during the recruitment and reproductive periods were tested in our model. In practice these scenarios have been extended to protect stocks that are heavily exploited. Scenarios related to technical fisheries management measures were also proposed, as they play a potentially important role in the management of many fisheries around the world. Technical measures aim to control various aspects of fishing operations, ranging from gear restrictions to by-catch limits. Finally, a reduction in fishing effort for both artisanal and recreational fisheries was simulated over two decades. The behaviour of fishermen in response to these measures was also taken into account.

In this paper, our interests are twofold: (i) to study the influence of uncertainties on the model through sensitivity analysis, which consists of identifying, quantifying and analysing how the model reacts to disturbances on the entered variables and (ii) to present results of the numeric simulations to assess quantitatively the impact of various management measures on the white seabream population.

2. Materials and methods

2.1. Output variables of the model

The parameterization of the ISIS-Fish model was presented in the first part of this study (Hussein et al., 2011). All simulations begin with the same initial population size per area. The simulations were performed over twenty years and the following five output variables were analysed: biomass (B1), abundance (A1) and catch (in weight) in the last year of simulation (C1), cumulative catch over the last five years (C5) and cumulative nominal effort (E). The first three outputs give an idea of the final state and can be compared to the initial state and the last two integrate results over a larger period and account for the evolution of the *D. sargus* exploitation dynamics. The abbreviations of terms used in this paper are presented in Table 1.

2.2. Sensitivity analysis

2.2.1. D-optimal design

The methodology used to evaluate model sensitivity to the parameters under the existing management measures was a group-screening technique combined with a D-optimal design. The group-screening technique aims to group and reduce the number of factors. Parameters in a given group should affect each output variable in the same direction (Kleijnen, 1987). Each group of parameters was then considered as a single factor. For example, the four fecundity coefficients relative to the various mature stages were gathered. For some other groups, such as selectivity or standardisation factors (initially six parameters relative to all gears), we performed a pre-selection of the most influential factors relative to the gear on the basis of various simulation designs. Thus, three types of gear were retained (boat gillnets, shore line and boat line). D-optimal designs, provided by a computer algorithm, are particularly useful when classical designs do not apply. The objective of optimal experimental design is to reduce the number of simulations by selecting a set of experiments among the possible experiments sufficient to assess the sensitivity to factors (Tinsson, 2010). In this type of design, the algorithm selects the combinations of factor level and arranges them in whole plots so that the D-optimality criterion is maximized. D-optimal designs maximize the determinant of the information matrix, $|M| = |X'V^{-1}X|$ (X, the matrix of the different combinations of factor level for each experiment and V the covariance matrix of the responses), equivalent to maximizing the efficiency of the estimation (Tinsson, 2010).

In our case, fifteen groups of uncertain key parameters were considered. Six were relative to *D. sargus* population dynamics: fecundity coefficient (Fe), natural mortality for the juveniles (C_0 and C_1 stages) (NMJ) and adults (C_2–C_7 stages) (NMA), migration coefficients (MigA: migration toward reproduction sites and MigB: migration from lagoon to sandy sites) and length at stage (i.e. the maximum length at each stage) (Sl). Nine parameter groups were relative to the fishery: catchability coefficients (Ca), gear standardisation factors (the ratio in the overall catch between each type of gear and a reference gear) for boat gillnets (Fstd1), shore line (Fstd2) and boat line (Fstd3), number of inactive days (NbInactDays), gear selectivity for boat gillnets (Sel1), shore line (Sel2) and boat line (Sel3) and target factors (Ta) (Table 1). As the range of variation of most of the various uncertain parameters was difficult to assess, we arbitrarily considered a ±20% range of variation.

A full factorial experiment was not parsimonious since it would involve 2^{15} = 32,768 simulations (fifteen factors with two levels of variation) and the number of categories in this case makes it impossible to use a full factorial design (Tinsson, 2010). Regarding the number of factors and factor levels, the most appropriate experimental design was a D-optimal design (NIST/SEMATECH, 2004).

Table 1
Description of the abbreviations used for sensitivity analysis, output variables and management measures.

Sensitivity analysis	
Ca	Catchability coefficient.
Fe	Fecundity coefficient.
Fstd1	Gillnet standardisation factor.
Fstd2	Shore line standardisation factor.
Fstd3	Boat line standardisation factor.
MigA	Migration to reproduction sites.
MigB	Migration from the lagoon to sandy sites.
NbInactDays	Number of inactive days.
NMA	Adult natural mortality.
NMJ	Juvenile natural mortality.
Sel1	Gillnet selectivity.
Sel2	Shore line selectivity.
Sel3	Boat line selectivity.
Sl	Length at stage.
Ta	Target factors.
Output variables	
B1	Biomass in the last year of simulation.
A1	Abundance in the last year of simulation.
C1	Catch in the last year of simulation.
C5	Cumulative catch over the last five years of simulation.
E	Cumulative nominal effort over the 20 years of simulation.
Management scenarios	
$MpaSS_1$	MPAs in the spawning zones for all gear, during the first semester (S_1) (January–June).
$MpaSS_2$	MPAs in the spawning zones for all gear, during the second half year (S_2) (July–December).
$MpaJT_1$	MPAs in the juvenile zones for all gear, during the 3th quarter (T_1) (July–September).
$MpaJT_2$	MPAs in the juvenile zones for all gear, during the 4th quarter (T_2) (October–December).
G70	Increases the mesh size from 60 to 70 mm.
G80	Increases the mesh size from 60 to 80 mm.
0.3EffA	30% artisanal effort reduction during the simulation period.
0.5EffA	50% artisanal effort reduction during the simulation period.
0.3 EffR	30% recreational effort reduction during the simulation period.
0.5 EffR	50% recreational effort reduction during the simulation period.