DISPAS: an Agent-based Tool for the Management of Fishing Effort

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Abstract. We introduce DISPAS, Demersal fIsh Stock Probabilistic Agent-based Simulator, with the aim of helping to investigate and understand sustainability in the exploitation of fishery resources. The simulator has capabilities for exploring different fishing scenarios, focusing on the case study of the common sole (Solea solea) stock in the Northern Adriatic Sea (Mediterranean Sea). In order to assess and predict the availability of the fish stock under different fishing efforts, the simulator allows the user to specify fishing mortality rates (F) on a monthly basis. We present some preliminary results simulating different scenarios.

1 Introduction

The World Summit on Sustainable Development (WSSD) [1], held in August 2002, laid the foundation for a radical shift about how marine ecosystems and fisheries are to be managed in the future. In particular WSSD agreed to restore the worlds depleted fish stocks to levels that can produce the maximum sustainable yield (MSY) on an urgent basis where possible no later than 2015. After 10 years from the adoption of WSSD, Europe is still far from achieving these objectives [2] especially in the Mediterranean area [3]. Most of the fish stocks in European waters, 88%, are estimated as being overfished and 30% of them are outside safe biological limits, which means they may not be able to replenish [4]. To reach an healthy state of the resources it is important to know their population dynamics, which is often difficult to estimate [5]. Thus, a big effort of the scientific community has been directed towards the development of modelling approaches and techniques (e.g. maximum likelihood methods and Bayesian analysis) as new kinds of toolkit for understanding the dynamic of fishery exploited marine resources [6]. Within this framework, the use of agent-based techniques represents - as in the present study - a new powerful tool in order to

use the little pieces of information coming from scientific survey at sea in order to assure faithful modelling, towards sustainable exploitation of the stocks.

In this work, the simulator is used for the assessment of the common sole stock of the northern Adriatic Sea (Mediterranean sea). Only fishery-independent data, coming from a specific scientific survey (SoleMon survey) [7], were used. The case of Solea solea in the Northern Adriatic Sea is exemplary because the management of fishery resources, despite the results of the studies, has been defective. This is especially true for the young portion of the stock that continues to be exploited at unsustainably high levels [8], particularly in juveniles aggregation areas and periods [9]. Using the simulator it will be possible to understand the correct exploitation pressure on the stock. This can provide long-term high yields and low risk of stock/fishery collapse and can ensure that the sole stock is restored at least at levels that could produce the maximum sustainable yield.

2 Model of a Sole Behaviour

In [10] an automata-based formalism, extended probabilistic discrete timed automata (EPDTA), was introduced with the aim of modelling the essential behaviour of an individual of a fish population. An EPDTA is able to express time passing in a discrete domain - using special clock variables - and to specify constraints on the transitions from a state to another state of the individual. Such constraints depend on the values of clock variables or of other variables. Transitions can reset clocks and/or update the values of non-clock variables. The target state of any transition is determined probabilistically using a discrete probability distribution on the state space. We refer to [10] for the full definition of the EPDTA model. In Fig. 1 the simplified model (without breeding) of the sole behaviour is shown. The clock t measures absolute time, in months, since the starting of the system. The clock x is used for updating the sole on a monthly base. As common in their biological study, the sole population is partitioned in six classes, characterised by ranges of length. From state "class i", the invariant $x \leq 1$ combined with the transition guard $x = 1$ forces to go (with probability 1) to state "chkM i" while the age (in months) of the sole is increased by 1 and the new length is calculated using the function fVB. This function uses the The von Bertalanffy growth function [11] to estimate the length of the sole at its age and at the particular time t. This permits to model a different growth rate at different absolute times due to, for instance, abundance or scarcity of food. In state "chkM i" ("chkF i") the sole can die for natural causes with a certain probability $\mathrm{PrM}(i, t)$ (can be fished with probability $\mathrm{PrF}(i, t)$, respectively). The probabilities are inferred from real survey data and are distributed along the year with different weights, in such a way that, for instance, a temporary protection period of fishing can be modelled. If the sole does not die and is not fished, then it enjoys another month of life in the same class (returns in state "class i") or in the next class (goes to state"class $i + 1$") if, in the meantime, its length has been increased to the next class range. In both cases the clock x is reset to zero in order to let another month pass in state "class i" (or "class $i + 1$").
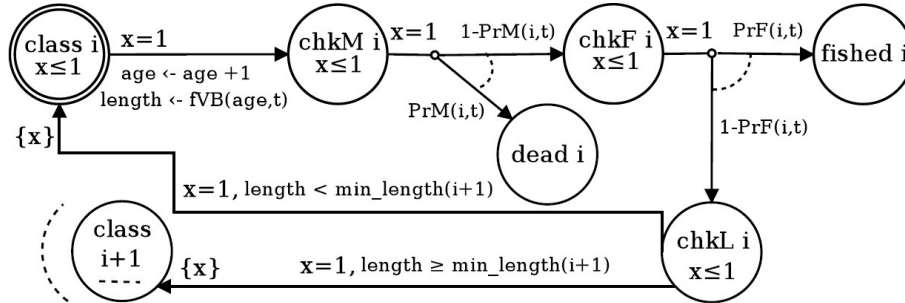
Fig. 1. Part of an EPDTA representing the behaviour of a sole in class i. The double circled state is the initial one when $i = 0$. From state chkL i the automaton goes to the next class $i + 1$ if the length of the sole is sufficient to be considered in the new class.

3 From Model to Simulator

A population of virtual soles has been instructed, each with its individual behaviour, and they have been monitored along a (simulated) period of time of 10 years. Following the MAS (Multi-Agent System) paradigm, an environment has been created in which sole agents (about 500 in a simulated square kilometre) behave accordingly to the EPDTA model in Sec. 2.

We employed Repast Simphony, Recursive Porous Agent Simulation Toolkit [12], an agent-based modelling and simulation toolkit used in various application fields like biological systems, ecology, animal population, food chains, economy and financial markets. The initial configuration is stored in a file containing initial population, growth index, length-weight relationship, death index, and so on. Hence, the user can change the simulation parameters according to the target fish survey-based real data. In Repast Simphony one can change the properties of the scheduler. We used this feature for forcing all the agents to be updated simultaneously at discrete time points corresponding to months.

Accordingly to the species real habit, every year in June (i.e. months 6, 18, 30 and so on, in the simulation) the new born are added. For the first 7 years (2005-2011), which correspond to the period of the SoleMon survey, the number of the new born to add come from survey data. After 2011 they are added by randomly choosing a number taken from a normal distribution whose mean and standard deviation are calculated form the new born of the last 3 years.

Table 1 shows the probability of natural death and of being fished, related to fish length classes (0-5+). At each step (1 month) the probabilities $\mathrm{PrM}(i,t)$ and $\mathrm{PrF}(i,t)$ are read from the configuration file. $\mathrm{PrM}(i,t)$ remains fixed for the whole duration of the simulation while $\mathrm{PrF}(i,t)$ varies for each year.

In the first 7 years we derived $\mathrm{PrM}(i,t)$ and $\mathrm{PrF}(i,t)$ from surveys made by marine biologists. Afterwards, we used the values of $\mathrm{PrF}(i,t)$ of the last year available. Future scenarios can be created by modifying $\mathrm{PrF}(i,t)$ or other parameters. At each step the total biomass is calculated as the total weight of live

Class	PrM	PrF						
		2005	2006	2007	2008	2009	2010	2011
0	0.041	0	0	0	0	0	0	0
1	0.024	0.122	0.121	0.131	0.100	0.171	0.084	0.115
2	0.020	0.115	0.114	0.155	0.087	0.093	0.144	0.117
3	0.017	0.152	0.153	0.178	0.080	0.195	0.280	0.182
4	0.017	0.129	0.129	0.158	0.080	0.159	0.177	0.139
5+	0.027	0.129	0.129	0.158	0.080	0.159	0.177	0.139

Table 1. $PrM(i, t)$ and $PrF(i, t)$, related to Sole length classes (0-5+) derived by the SoleMon scientific survey data.

agents. During the run it is possible to visualise, in real time, the charts about the evolution of the population (divided by age class) and of total biomass, as well as the 2D and 3D scenarios of the population. Furthermore, data are saved into external files in order to be processed with external tools. In the following, some results obtained using DISPAS are shown and commented.

Biomass trend. In Fig. 2, the red solid line shows the mean of total biomass computed by 50 runs. Dotted lines represent maximum and minimum values, while vertical bars show the confidence interval of 5%. $PrM(i, t)$, $PrF(i, t)$ and other parameters come from the SoleMon survey data. Note that the total biomass tends to a mean level of almost 15,000 grams over square kilometre.

Varying F. We fixed $PrM(i, t)$ and other parameters according to the SoleMon data. $PrF(i, t)$ is set differently to create different scenarios: virgin stock (PrF=0); PrF taken form SoleMon data; half of SoleMon PrF; and twice SoleMon PrF. Results are shown again in Fig. 2. The blue line (scale is on right axis) represents the biomass trend of the virgin stock, i.e. a sort of null model that indicates the ideal population dynamics. Other trends clearly denote the impact fishing on the total biomass.

Varying F after the survey period (2005-2011). In this scenario we used the same $PrF(i, t)$ as before, but we applied them after the period of the SoleMon scientific survey (2011).

4 Future work

In order to validate our model, we plan to use SURBA (SURvey-Based Assessments) [13], a well-established model in the context of marine biology. In particular, SURBA will be fed with the simulation outputs from DISPAS and we will compare the results with the ones obtained feeding SURBA with real data from SoleMon. Moreover, we plan to devise a technique for calculating the optimal protection period of fishery in order to maximise the replenishing of the stock. Finally, we plan also to define a scenario for calculating the recovery time after overfishing, i.e. the time that the fish stock takes to reach again a sustainable level after simulating a period of strong fishing effort.
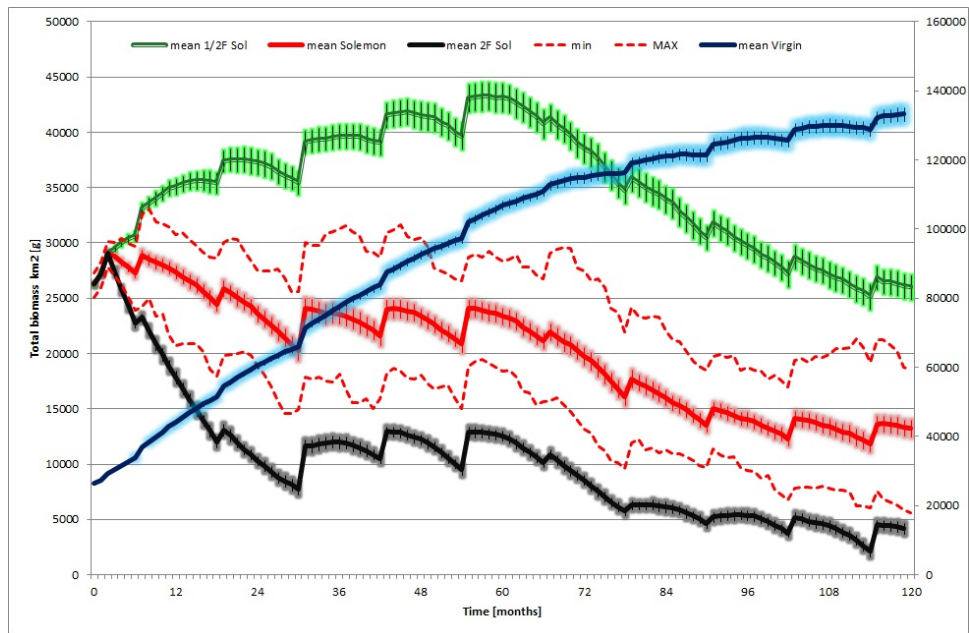
Fig. 2. Results of 50 simulations using SoleMon data (red), virgin stock (blue) and different fishing scenarios (green and black).
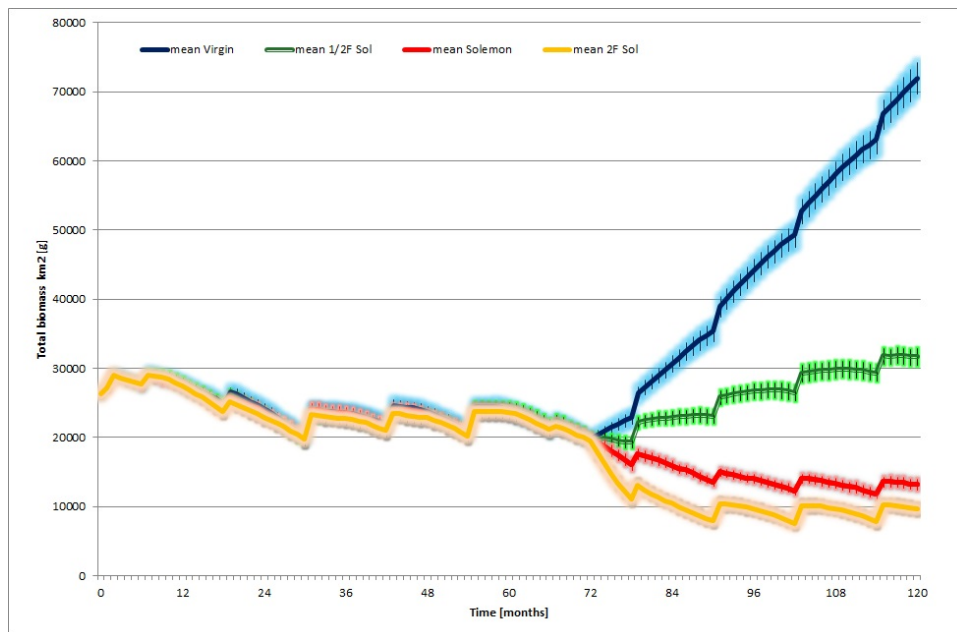
Fig. 3. Prediction in different fishing scenarios after 2011 (84 step/month).

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