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Modeling fleet response in regulated fisheries: An agent-based approach

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Abstract:

Understanding the dynamics of fishing effort plays a key role in predicting the impacts of regulatory measures on fisheries. In recent years, there has been a growing interest in the use of bio-economic models to represent and analyze the short-term dynamics of fishing effort in response to regulation in the fisheries management literature. In this literature, fishing firms are usually modeled as autonomous decision-making units determining their harvest strategies so as to maximize profit, given technical and institutional constraints. The overall dynamics of a fishery is modeled as the result of these individual choices, and of interactions between individual choices due to the impacts of harvesting on the fish stock and/or problems of congestion. Applications have, for example, been related to the discussion of closed areas as fisheries management tools. A multi-agent model of a fishery targeting different species in different areas was developed to analyze the implications of taking into account the response of fishing fleets to such regulatory controls. The model is based on the Cormas platform developed for the simulation of the dynamics of common resource systems. An advantage of the multi-agent approach is that it allows a greater degree of complexity than standard bio-economic modeling tools, by focusing on local, rather than global, interactions. Simulation results are presented to illustrate how the model can be used to analyze the consequences of regulatory measures such as temporary fishing bans on the allocation of fishing effort between target species and areas, and the ensuing economic impacts of these measures.

Keywords: Bio-economic modeling; Multi-agent simulation; Short-run fisheries dynamics

1 Introduction

In recent years, there has been a growing interest within the fisheries management literature in the use of bio-economic models to represent and analyze the short-term dynamics of fishing effort in response to regulation. In particular, greater attention has been devoted to the explicit representation of the spatial and temporal evolution of harvesting, and of its determinants, where fleets can change fishing techniques and move across different areas. This interest has largely arisen from the debate on the potential impacts of fishing bans on the economic and ecological status of fisheries (see *e.g.* [1]).

An implication for modeling is the greater degree of complexity that needs to be taken into account in the formal representation and analysis of the biological and economic dynamics of fisheries. Various modeling techniques have been used in these studies. Both optimization and system dynamics simulation techniques have been applied to fairly simple descriptions of the spatial and temporal evolution of fishing effort: *e.g.* single-species, single-fleet, multi-zone models (see *e.g.* [2], [3], and [4]), or multi-species, single-fleet, multi-zone models (see *e.g.* [5]). Optimization techniques have also been used in more complex bio-economic models involving several species caught by several fleets in several different zones [6], [7].

By focusing on local, rather than global interactions, agent-based modeling appears as an interesting approach to this type of modeling. In particular, it allows the modeling of relatively complex systems while keeping with a simulation approach, making possible the explicit representation and analysis of the dynamics of these systems, both globally and with a fairly high degree of detail.

In what follows, a multi-agent model of a fishery in which a single fleet targets different species in different areas, with different types of gear is presented. The model was developed in continuity with recent bio-economic models of the short-term dynamics of fisheries. In particular, we use the simulation approach developed by [3] to represent the evolution of a fishery harvesting a fish population allocated into biologically interdependent patches. Following [6], [7], we add the possibility for fishing fleets to target different species. However, the modeling technique is different to the one used by these authors, and allows to explicitly represent the technical constraints which may affect the process of effort reallocation. This allows the model to be used for the analysis of imperfect adjustment of fishing effort to changes in fishing conditions. The numerical application presented is similar to those recently used in the literature. The modeling framework created however allows the possibility to easily implement more complex cases, including a larger number of zones and species, and greater heterogeneity in fishing tactics and local fishing conditions.

2 From a theoretical model…

The fishery is composed of a fleet of mobile vessels targeting multiple species (*e.g.* polyvalent), operating over an area A, divided into j zones. The harvested resource is composed of a set of i target species, with no biological interactions. Each species is distributed over the entire area, in local stocks, characterized by:

- Their biomass X_{ij};
- An intrinsic natural growth rate r_{ij} that can vary according to the zone considered;
- A spatial mobility coefficient $d_{ijj'}$, depending on the species and the biological connectivity between zones;

- A carrying capacity $X_{ij}^{\max}$ for each species in each zone.

The concept of métier is introduced to describe the set of fishing options available to the fleet. A métier is defined as the choice to target a particular species in a particular zone, with a given level of productivity. The following notations are used to describe the nominal fishing effort allocated to each métier at each time step, and the associated technical, cost and price parameters:

- E_{ij} is the standard nominal fishing effort targeting species i in zone j;
- q_{ij} is a capturability coefficient for species i in zone j per unit of standard nominal effort;
- c_i is the unit harvesting cost of species i in zone j;
- p_i is the fixed unit price per species.

2.1 Stock dynamics

The dynamics of stocks is modeled as follows:

$$\frac{dX_{ij}}{dt} = f_{ij}\left(X_{ij}\right)X_{ij} + T_{ijj'} - Y_{ij} \tag{1}$$

where $f_{ij}\left(X_{ij}\right)$ measures the instantaneous growth per unit of biomass of species i in zone j, $T_{ijj'}$ measures the migration of biomass of species i between zone j and $j'\left(j \neq j'\right)$, and Y_{ij} measures the instantaneous catch of species i in zone j.

A logistic growth function is assumed for the stock:

$$f_{ij}\left(X_{ij}\right) = r_{ij}\left(1 - \frac{X_{ij}}{X_{ij}^{\max}}\right) \tag{2}$$

Instantaneous catch per unit of effort in each zone is considered as directly proportional to nominal fishing effort E_{ij} and to the local abundance of the target species:

$$Y_{ij} = q_{ij}E_{ij}X_{ij} \tag{3}$$

The net transfer of biomass of species i between zone j and a connective zone j' is assumed to be density-dependent. It is represented as a function of the difference between the ratio of biomass of the species to its carrying capacity in zone j and the ratio of biomass to its carrying capacity in zone j':

$$T_{ijj'} = d_{ijj'}\left(\frac{X_{ij}}{X_{ij}^{\max}} - \frac{X_{ij'}}{X_{ij'}^{\max}}\right) \tag{4}$$

2.2 Fishing effort dynamics

As the aim of the model is to simulate the short term dynamics of fishing activity, the global fishing effort available in the system is fixed. The focus is on how this effort is allocated between the different métiers at each time step.

Representation of the dynamics of fishing effort is based on the assumption that the fleet allocates its activity between métiers based on the anticipated margin over variable costs associated with each métier.

The decision tree on the basis of which anticipations are constructed is represented in Figure 1.

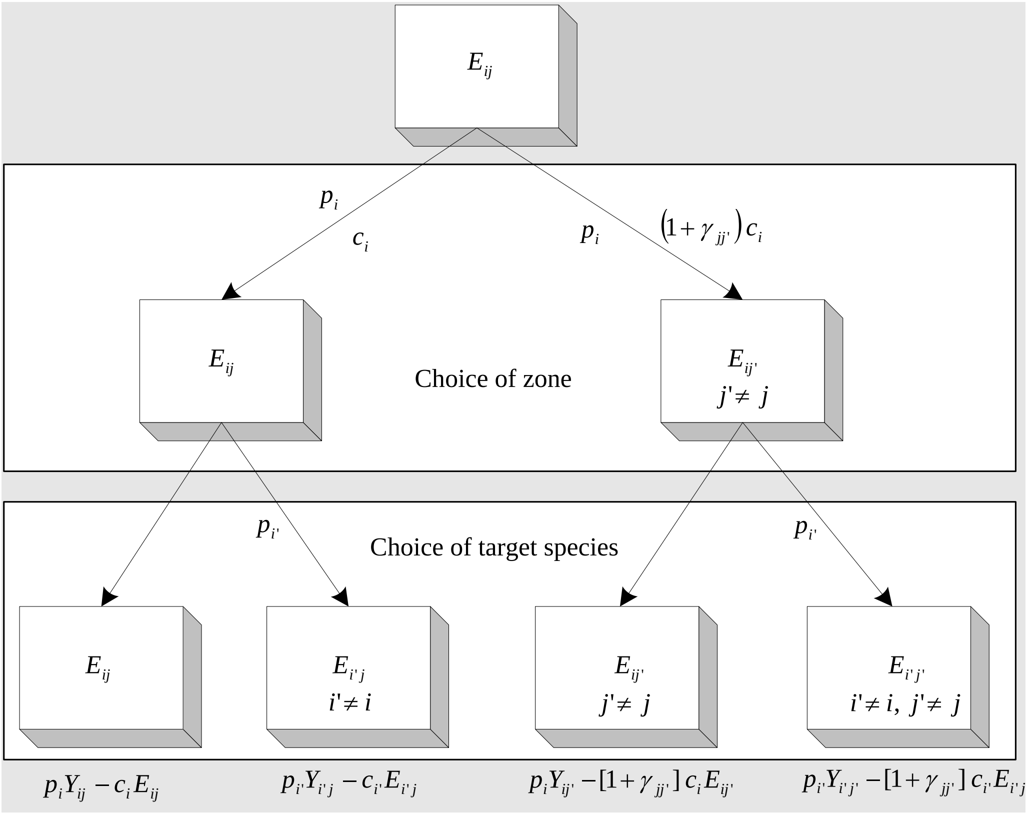

Figure 1. Basic decision tree used for anticipated margins

Units of nominal effort will be reallocated to métiers different from their current métier if this allows an increase in the anticipated margin per unit of effort. In all other cases, no effort reallocation will occur (and some units of effort may remain inactive where only negative anticipated margins prevail).

The capacity for fishing effort to transfer from one zone and/or species to another is described by the following coefficients:

- n, a polyvalence coefficient describing the capacity of fishing units to transfer from one target species to another;
- m, a spatial mobility coefficient describing the capacity of fishing units to transfer from one zone to another.

Where effort reallocation is justified, based on the comparison of margins per unit of effort for the different métiers, it is modeled as follows:

$$\frac{dE_{ij}}{dt} = m\left(g_{ij} - g_{ij'}\right) + n\left(g_{ij} - g_{i'j}\right) + mn\left(g_{ij} - g_{i'j'}\right) \tag{5}$$

Where g is the anticipated value (at t) of the margin per unit of effort associated with each métier.

An adaptive anticipations framework with perfect information is used to model the calculation of anticipated margins and allocated effort. Myopic behavior of the fleet is assumed: anticipated margins per métier are supposed equal to the margins observed at the previous time step, corrected by the additional costs associated with the selection of a new fishing zone. Hence,

$g_t = \frac{M_{ij}^{\exp}}{E_{ij,t-1}}$ and $M_{ij}^{\exp} = p_i Y_{ij} - \left[1 + \gamma_{jj'}\right] c_i E_{ij}$ with $0 \le \gamma_{ij} \le 1$ depending on the distance between zones.

3 …To an agent based model

The model was developed using the CORMAS modeling platform (see [8], [9]). It is based on the three types of entities available in CORMAS: spatial entities (entities that define the environment used for the simulation, *e.g.* cellular automata, grid …), passive entities (entities used in the simulation such as date or time manager, message encapsulating information …), and social entities (entities that represent the agents, *e.g.* situated agents, communicating agents …).

3.1 Spatial entities

Two spatial entities are modeled:

- The *Sea* entity represents an area of the ocean decomposed into cells defining a homogeneous grid. Individual cells are the smallest elementary units defining the spatial grid, and act similarly to the cells of a cellular automata. This allows for the simulation of the fishery (fish biomass, fishing effort, fish catches, and observed and anticipated costs and earnings) at a fine scale. In the first version of the model presented here, this functionality is not used as the fishery simulated is purely theoretical and described at a coarser level. It will be used in applied versions of the model. Harbors are associated with certain cells of the *Sea* entity.

- The *Zone* entity represents a set of cells having the same type. In the version of the model presented here, the type is a zone number. This allows to define distinct zones and to simulate the evolution of the fishery at the coarse scale of these zones. Description of the fish species, their characteristics (biomass, local carrying capacity, intrinsic growth rate, migration rate) and their instantaneous dynamics (migration to and from neighboring zones, mortalities, natural growth) are stored at the level of each *Zone*, as well as an identification of the harbors it contains, and a description of the status of the zone in terms of regulatory controls applying to fishing.

3.2 Passive entities

Two passive entities are modeled:

- The *Fish* entity represents the biomasses of fish in the system. A *Fish* entity is associated with each species, and is distributed in the coarser spatial grid defined by the Zones (with their associated carrying capacity for each species). Each *Fish* entity is defined by its name, an intrinsic growth rate, a spatial mobility coefficient, and a level of biomass.

- The *Boat* entity represents the nominal fishing effort in the system. Each *Boat* entity is attached to a unique Harbor, and can thus be indirectly located on the spatial grid, with only one *Boat* entity being associated with each Zone. *Boat* entities have access to the following information concerning each species: fish prices, available fishing effort, catchability, catches, costs and earnings. Each *Boat* entity embeds a polyvalence rate representing its capacity to change target species, and a spatial diffusion coefficient representing its capacity to move from one zone to another.

3.3 Social entity

The only social entity (*i.e.* agent) used in this version of the model is the Harbor entity. This is the entity that manages the portion of fishing effort over which it has control at each time step. Each Harbor entity embeds a Boat entity, with one Harbor entity in each Zone. The key role played by this entity is to re-allocate the nominal effort of the fishing fleet in its zone according to the expected costs and benefits of the various options available, at each time step in the simulation.

3.4 Model structure and dynamic

Structure

Figure 2 presents a Unified Modeling Language (UML) diagram of the model structure [10].

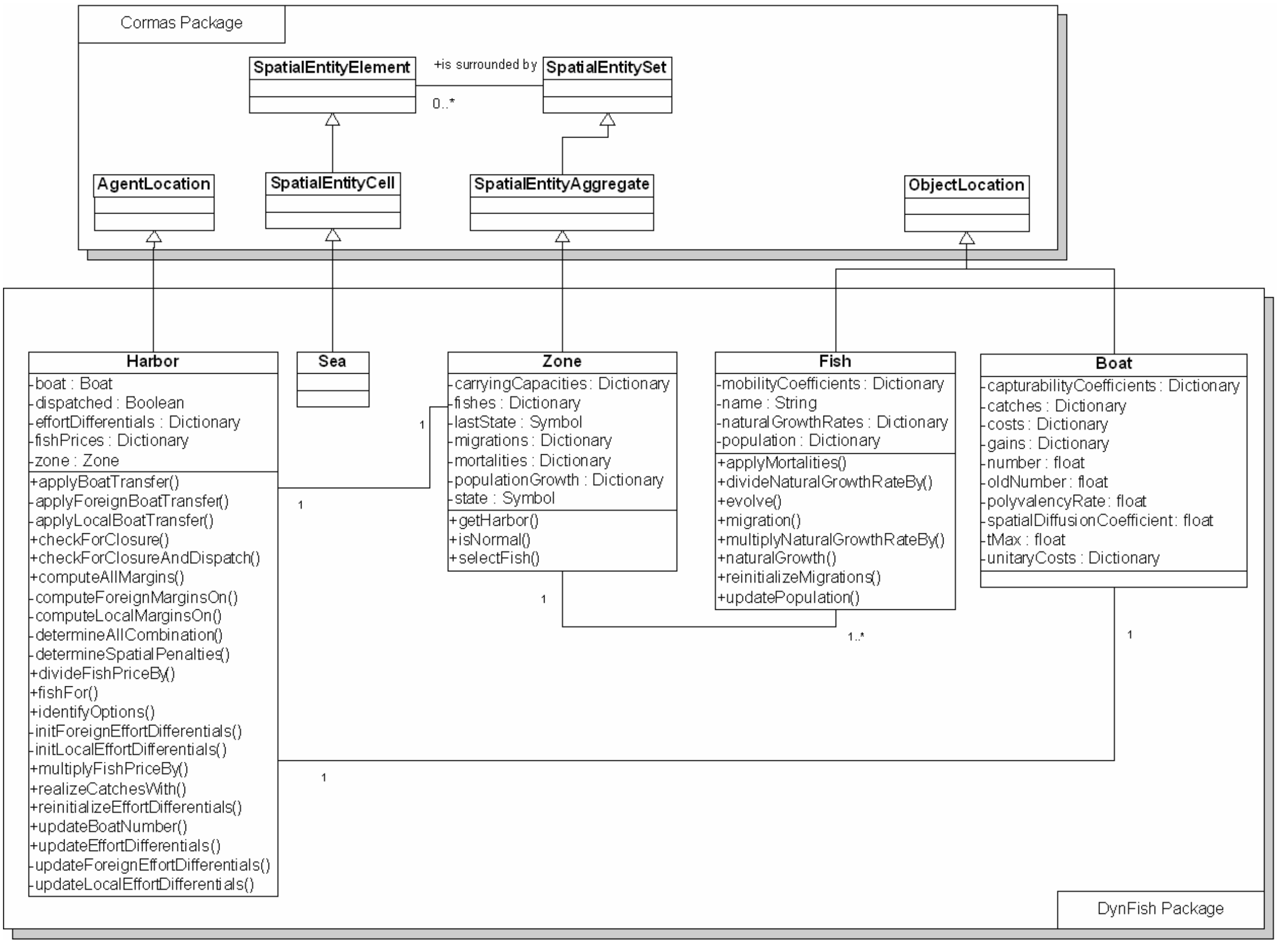

Figure 2. UML description of the model

Dynamics

The dynamics of the model operate at two levels: biomass dynamics and fishing effort re-allocation.

- **Biomass dynamics.** The sequence of biomass evolution at a given time t is defined as follows:
    1. Decrease of the biomass due to fishing mortalities at time step $t-1$. These mortalities are defined for each species and stored in a dictionary for each zone.
    2. Natural evolution of the biomass. This operates in two stages: natural growth and migration. Natural growth is computed from a logistic growth function (see above). Migration is computed as a function of the differences between zones in the density

of local biomass to the local carrying capacity for each species, and of a species specific mobility coefficient. The computed migration values are stored in a dictionary for each zone. Figure 3 illustrates the process of fish migration as it is modeled in a four-zone application of the model.

3. Final update of the new biomass. This is computed by adding the instantaneous natural growth to the existing biomass, and by subtracting the mortalities and migrations.

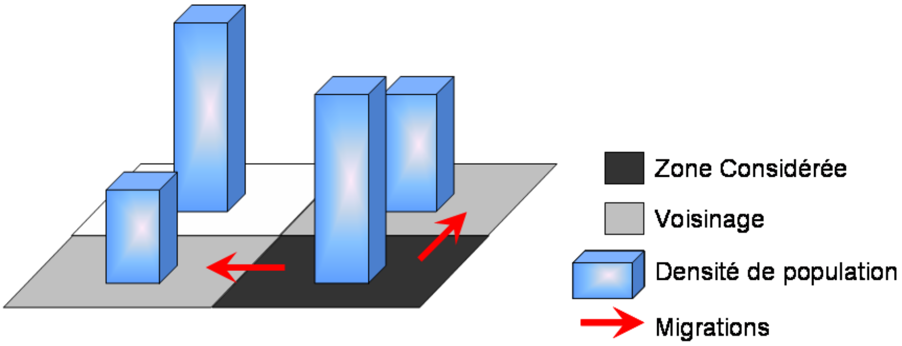

Figure 3. Illustration of the process of fish migration

- **Fishing effort re-allocation.** The sequence of fishing effort reallocation at a given time t is defined as follows:
  1. The harbor builds a dictionary representing all the possible métiers available for fishing. At each time step, four options must be compared (see Figure 1): (i) status quo (keep the target species in the same zone); (ii) change target species in the same zone; (iii) keep target species but change zone; and (iv) change target species and change zone. The dictionary is built in two stages: definition of local possibilities, followed by the definition of `foreign' possibilities.
  2. The harbor computes the observed margin over variable costs for each métier, taking into account spatial penalties associated with a potential change of harvesting zone. As before, this operation is performed in two stages: local margins are calculated first, and `foreign' margins second.
  3. The harbor compares the margins associated with the status quo with margins associated with all the other métiers. Where the latter are lower than or equal to the former, the options are ignored in the following simulation stage for the current time step (as there is no interest in changing activities). As before, this operation is performed in two stages: local differences are calculated first and “foreign” differences second.
  4. Based on equation 5, the harbor determines the reallocation of effort which will take place in the current time step and performs the transfer of effort. Following this reallocation, fishing units perform their respective catches.

4 Application to the simulation of a temporary fishing ban on a 4 zone – 2 species fishery

A first application of the model was developed for a simple case of a theoretical “multi-métier” fishery in order to simulate the consequences of a temporary fishing ban.

The fishery develops on four zones, targeting two independent species, both having density-dependent diffusion processes as described above. Global nominal fishing effort is considered as fixed. The initial allocations of effort between métiers, as well as the initial biomass levels for the two species in each zone, are determined so that the fishery is in equilibrium, with no effort reallocation taking place.

At each time step, nominal fishing effort in each métier (species-zone combination) can be reallocated to any of the seven other métiers. Additional costs associated with the change of zone vary with the zone towards which movement is being considered. In this case, costs of moving horizontally or vertically are lower than costs of moving along the diagonal (see Figure 4 and parameters values below).

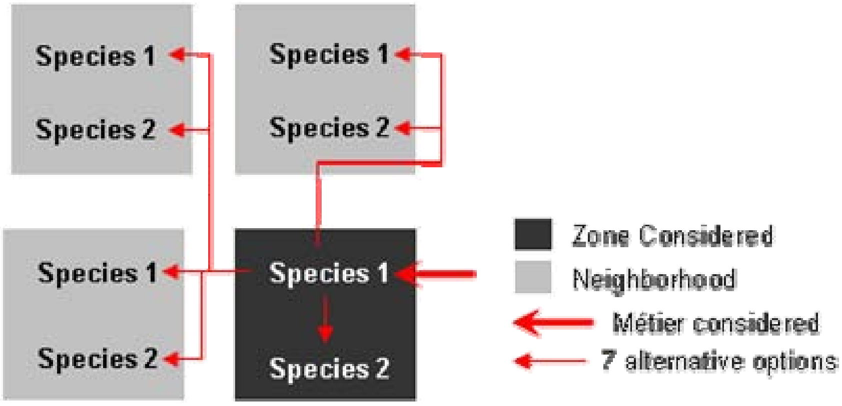

Figure 4. Effort reallocations possibilities

4.1 Experimental design

First, a sensitivity analysis of the model to the level of fishing effort allocated to the different species and areas was carried out, in order to determine the steady state equilibrium of the fishery with and without area closures, given a mobile and polyvalent fishing fleet. Simulations were run for 300 time steps. A first run was carried out without a fishing ban. A second run was carried out assuming that a fishing ban occurs for one of the species on one of the areas between time steps 10 and 100. A third run was carried out assuming that a fishing ban occurs for the two species in one of the areas between time steps 10 and 100. Results are presented in terms of the levels of short-term equilibrium profits obtained for variable levels of fishing effort, given the parameter values (see Table 1 and Section 4.2).

Second, nominal fishing effort was fixed at a level allowing positive (although less than optimal) margins over variables costs throughout the fishery (initial effort $E = 0.75$). Simulations were run for 300 time steps, and it was assumed that a fishing ban occurs for one of the species only, in one of the areas, between time steps 10 and 100. The simulations were carried out for fleets with different technical capacities to change métiers, i.e. for different values of the mobility and polyvalence parameters. Scenarios tested include a mobile, single métier fleet; a sedentary but polyvalent fleet; and a mobile and polyvalent fleet. Results are presented in terms of the dynamic response of fishing effort to the fishing ban where reallocation occurs. The overall economic consequences of the ban over simulation time are also presented for the scenario in which the fleet is both mobile and polyvalent, allowing a discussion of the consequences of effort reallocation in this fishery.

Third, sensitivity analysis of these results to the value of the polyvalence and the mobility parameters was carried out. Again, simulations were run for 300 time steps, and it was assumed that a fishing ban occurs for one of the species in one of the areas between time steps 10 and 100. Sensitivity runs were carried out for different initial equilibrium levels of fishing effort and fish biomass, identified based on stage 1 simulation results. Results are presented in terms of the global economic costs of the fishing ban as compared to a situation without a ban.

Table 1. Common parameters used in simulations

Biological parameters	**Species 1**	**Species 2**
Carrying capacities	10	10
Growth rates	0.8	0.8
Mobility coefficients	0.2	0.2
Economic parameters		
Fish prices	10	10
Catch costs per unit	3	3
Technical parameters		
Polyvalence rates	Varying according to simulation scenario	
Spatial mobility coefficients	Varying according to simulation scenario	
Spatial penalties	0.1 in the direct neighborhood of a zone, 0.2 in the other zones	

4.2 Simulation results

4.2.1 Stage 1: Steady-state equilibrium short-term profits as a function of fishing effort, with and without a fishing ban

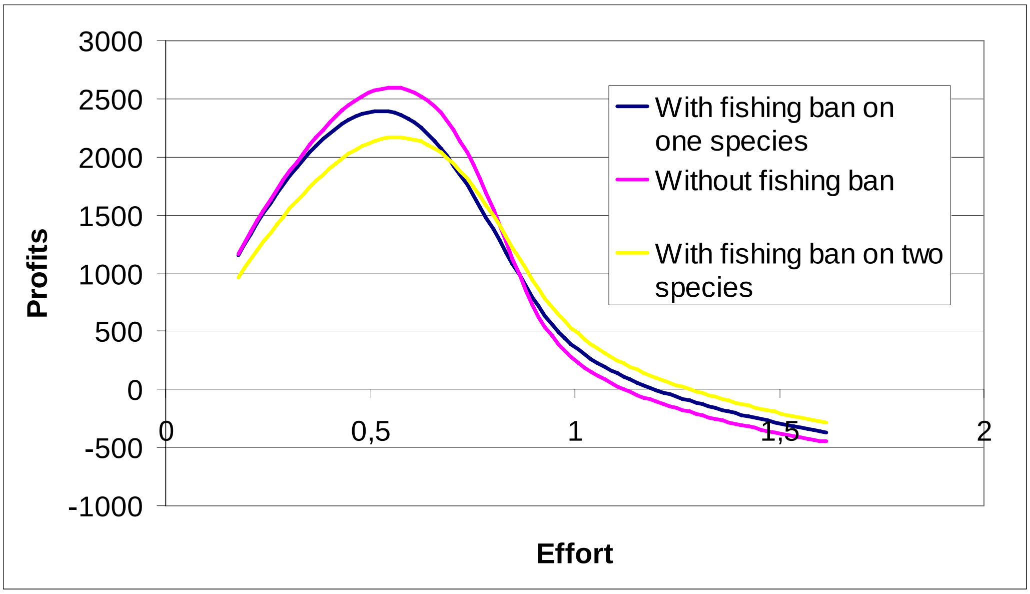

Figure 5. Profit evolution for a given effort level

Simulation results obtained for this stage replicate the conclusion of recent work concerning the bio-economic impacts of closed areas ([1]). As expected, the fishing ban entails a reduction of the equilibrium short-term profits derived from the fishery for low to medium levels of fishing effort (see Figure 5). This reduction is more important where the fishing closure affects the two species targeted in a zone, rather than only one. Both types of closures (partial and total) reduce the maximum equilibrium level of short-term profit which the fishery can achieve. As another expected effect of the area closure, the fishery may remain profitable for high effort levels, due to the "reserve" effect resulting from the protection of the stock in the closed area, and to the diffusion of biomass from that area to the rest of the fishery. The extent of the reserve effect in this particular scenario however appears fairly limited, due to the temporary nature of the fishing ban that is being simulated. The Figure 5 illustrates this evolution.

4.2.2 Stage 2: Dynamic response to a fishing ban

Scenario 1: Mobile, single métier fleet (mobility coefficient $m = 0.0004$*; polyvalence rate* $n = 0$*; initial effort level per métier* $E = 0.75$*)*

In the first scenario tested, the fleet is assumed to be mobile with no possibility to change target species. The dynamic response of the fishery to the fishing ban is presented in Figure 6. Effort devoted to the capture of species 1 remains unaffected by the ban. Effort devoted to the capture of species 2 drops to zero in zone 1 during the ban, but some of the idle fishing effort is re-allocated to the neighboring zones. The effect of the ban is a rapid build-up of biomass of species 2 in zone 1, and an associated export of biomass to neighboring zones, making these increasingly attractive. Following the lift of the ban, the idle fishing units remaining in zone 1 resume fishing. High levels of biomass in zone 1 and associated high levels of catch per unit of effort lead to a transfer of effort towards this area, leading to a reduction in biomass and catch per unit of effort. Effort then exits the area and the fishery returns to equilibrium.

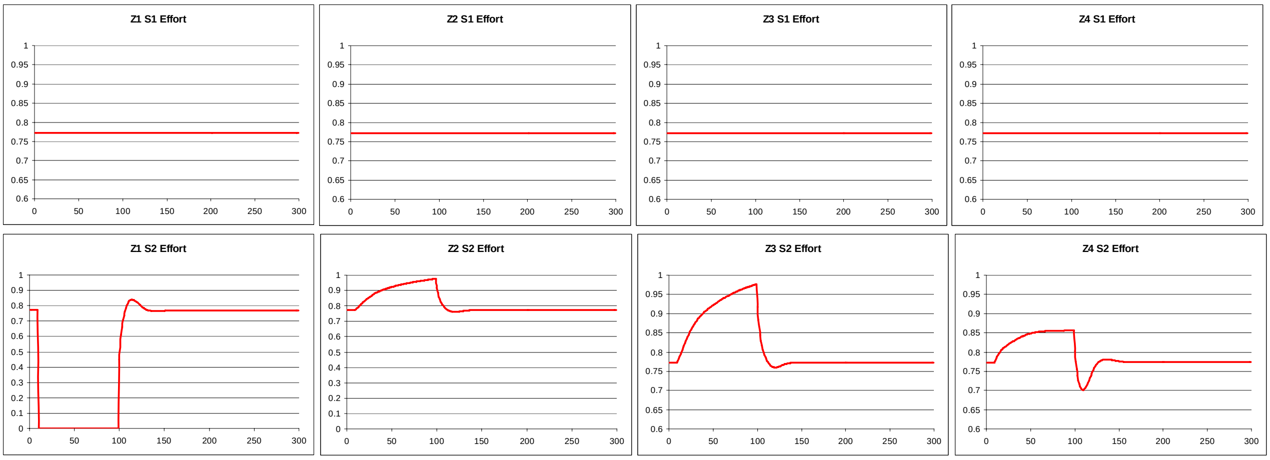

Figure 6. Response of the fishery to a ban on the capture of species 2 in zone 1 (mobile single métier fleet) – Z1S1 means Zone 1 Species1, Z1S2 means Zone 1 Species 2 …

Scenario 2: Fixed multi métier fleet (mobility coefficient $m = 0$*; polyvalence coefficient* $n = 0.0004$*; initial effort level per métier* $E = 0.75$*)*

In the second scenario, the fleet is assumed to be fixed, with a capacity to shift only from one target species to another. Figure 7 illustrates the response of the fishery in this scenario. The first impact of the ban on the catch of species 2 in zone 1 is a reallocation of fishing effort towards the capture of species 1 in this zone. The reserve effect and associated export of biomass of species 2 from zone 1 to neighboring zones leads to an increase in catch per unit of effort of species 2 in these zones, making this species relatively attractive for boats operating in these zones in comparison to species 1. At the same time, a shift to species 1 as the target in zone 1 leads to the depletion of its biomass in this zone, and favors migration of biomass from neighboring zones towards zone 1, with associated reductions in catch per unit of effort in these zones. As a result, a shift from species 1 to species 2 is observed in neighboring zones. Following the lift of the ban, the fishery returns to equilibrium following a small oscillation linked to a transfer of effort towards species 1. The Figure 7 illustrates such scenario.

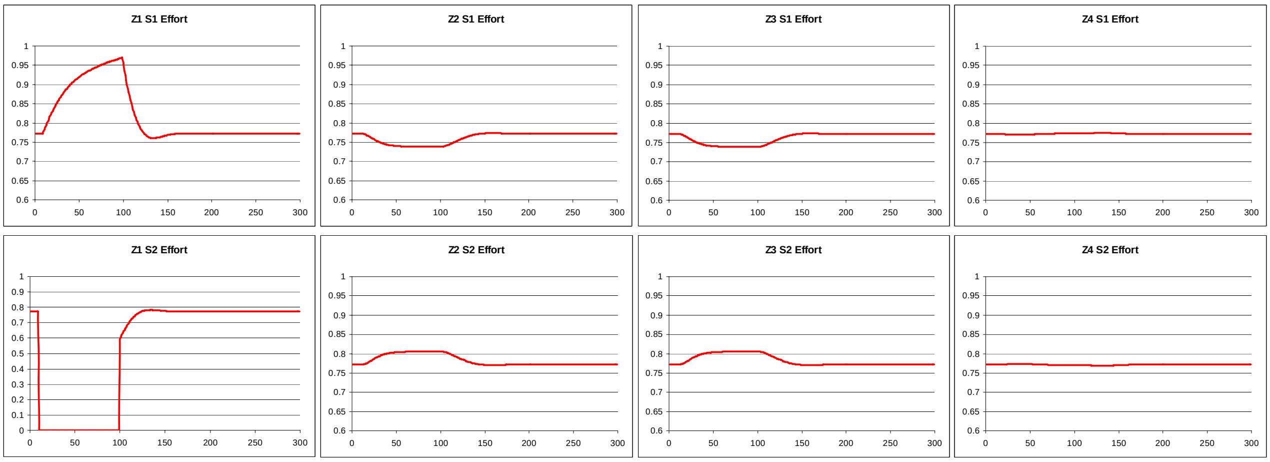

Figure 7. Response of the fishery to a ban on the capture of species 2 in zone 1 (fixed multi métier fleet) – Z1S1 means Zone 1 Species1, Z1S2 means Zone 1 Species 2 …

Scenario 3: Mobile multi métier fleet (mobility coefficient $m = 0.0004$*; polyvalence coefficient* $n = 0.0004$*; initial effort level per métier* $E = 0.75$*)*

The response of the fishery to the fishing ban when the fleet is both mobile and polyvalent is more complex, as re-allocation of effort occurs both between zones and between areas at each time step. Oscillations following re-opening of the fishery for species 2 in zone 1 are also greater, with greater time needed to achieve equilibrium. The Figure 8 illustrates the response of the fishery under this scenario.

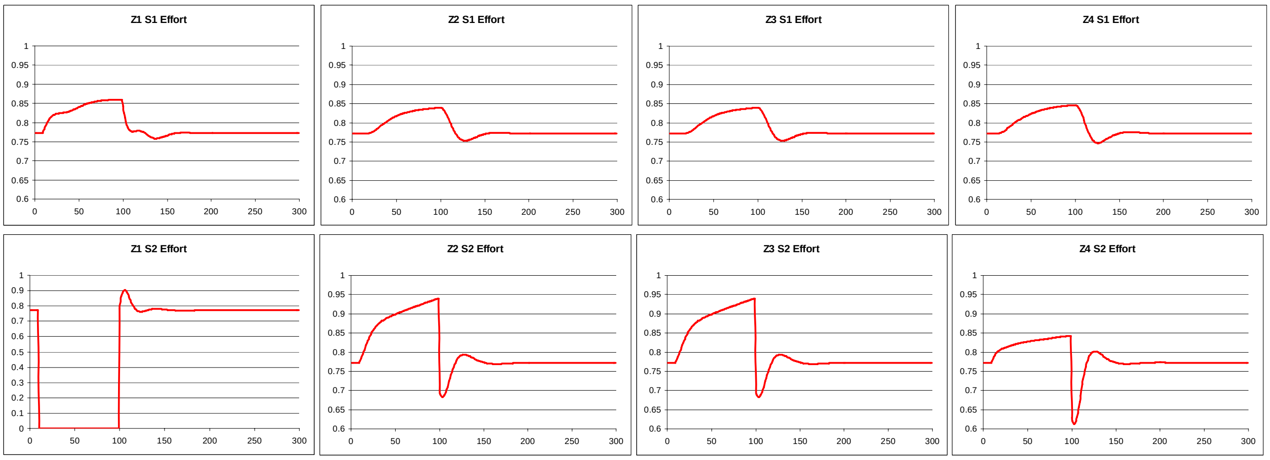

Figure 8. Response of the fishery to a ban on the capture of species 2 in zone 1 (mobile multi métier fleet) – Z1S1 means Zone 1 Species1, Z1S2 means Zone 1 Species 2 …

Global costs

Following [7], the bio-economic consequences of effort reallocation processes in the fishery can be analyzed by comparing the case where such reallocation takes place, conditional upon the technical ability of the fleet to changes métiers, to a situation in which the units of effort affected by the ban would not be allowed to change métier, and would therefore remain inactive during the ban.

The top quadrants of Figure 9 show the global cost and the cost per zone of the fishing ban simulated in the third scenario above, assuming that effort reallocation is not possible. Costs of the fishing ban are calculated as the difference between profits achieved with the ban, over simulation time, and profits that would have prevailed without the ban. In this case, the cost of the fishing ban is fully supported by the métier on which it is implemented. Métiers in neighboring zones may even benefit from the area closure, due to the reserve effect already mentioned. This reserve effect may operate in a cascade fashion as illustrated in this case, where the more distant zone also benefits from the ban, although to a lesser extent than the immediate neighbors.

The lower quadrants of Figure 9 show the global cost and the cost per zone of the fishing ban under the same scenario, assuming effort reallocation between métiers. In this case, the cost of the ban is spread throughout the fishery, with all métiers affected to a variable degree. While the métier targeted by the ban is the most strongly affected, the results show that, given the parameter values used for these simulations, métiers in the more distant zone may be more affected than those in the vicinity of the protected area. This is a consequence of the effort reallocation process: the increase of effort in zones 2 and 3 due to reallocation from zone 1 entails a reduction in catches per unit of effort in these zones, making zone 4 attractive, and entailing a migration of fishing effort towards zone 4. The reopening of fishing for all species in zone 1 attracts fishing effort back from zones 2 and 3 more rapidly than from zone 4, due to the differential of spatial penalties, leaving the latter area with excess fishing effort for a longer period of time.

The comparison of the top and bottom quadrants of Figure 9 with regard to the global cost of the fishing ban shows that, under the assumptions made for this scenario, the possibility for the fleet to reallocate its effort between métiers as a response to the area closure will significantly increase the cost of the regulatory measure to the fishery.

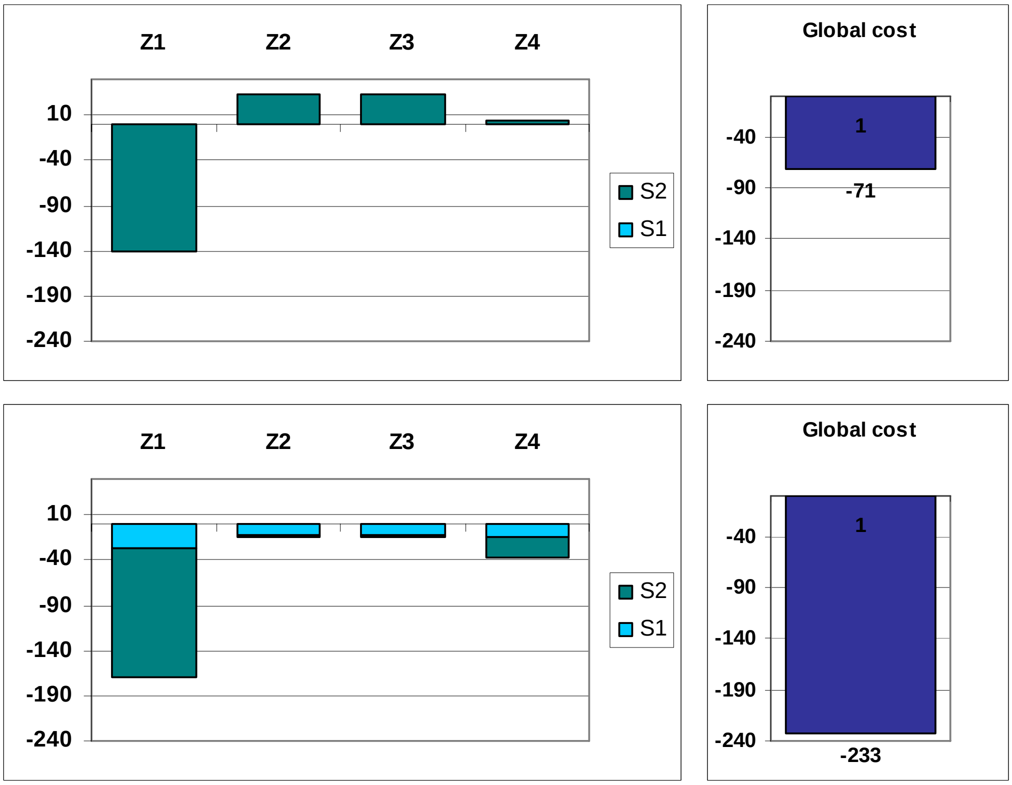

Figure 9. Costs of the fishing ban per zone and globally

4.2.3 Sensitivity analysis

As already stressed, the above results are obtained for a fishery which derives positive yet sub-optimal profits given the fixed level of effort used in simulations (the fishery being in a situation of excess capacity). Sensitivity analysis of these results to both the status of the fishery and the technical ability of the fleet to change métiers provides more general conclusions on the impacts of effort reallocation in this numerical application of the model. Results of this sensitivity analysis are presented in Figure 10, in terms of the global cost of the fishing ban for different values of the mobility and polyvalence parameters, and for three different cases regarding the status of the fishery.

The left Figure represents the case of an under-exploited fishery. In this case, the cost of the fishing ban will be higher if no reallocation of effort can take place. Because, in such a fishery, there are potential benefits to be made from increases in effort in the different métiers, the cost of the ban, while relatively low, can be partially reduced by the extra benefits derived from such increases due to shifts in effort.

The right Figure represents the case of a fishery exploited at its steady state optimum. The cost of the fishing ban is always much higher in this case than in the latter. Effort reallocation will increase the global cost of the ban, but only to a limited extent if the fleet is both mobile and polyvalent. On the other hand, effort reallocation will entail an increase in the cost of the ban if the fleet is only mobile or only polyvalent (see previous section). This is due to the fact that transitional effects due to the reallocation process will not be captured where the fleet's ability to change métiers is partially constrained.

The bottom Figure represents the case of a fishery with excess fishing capacity. In this case, effort reallocation will always entail an increase in the global cost of the fishing ban. While lower than in the two other scenarios if no reallocation occurs, this cost may become the highest of all three scenarios with reallocation, and a highly mobile and polyvalent fleet. The influence of polyvalence on these results is however lower than that of mobility, in this simulated fishery. This is due to the existence of spatial penalties for changes of zones; while no equivalent penalty was assumed for a change of target species (see Table 1).

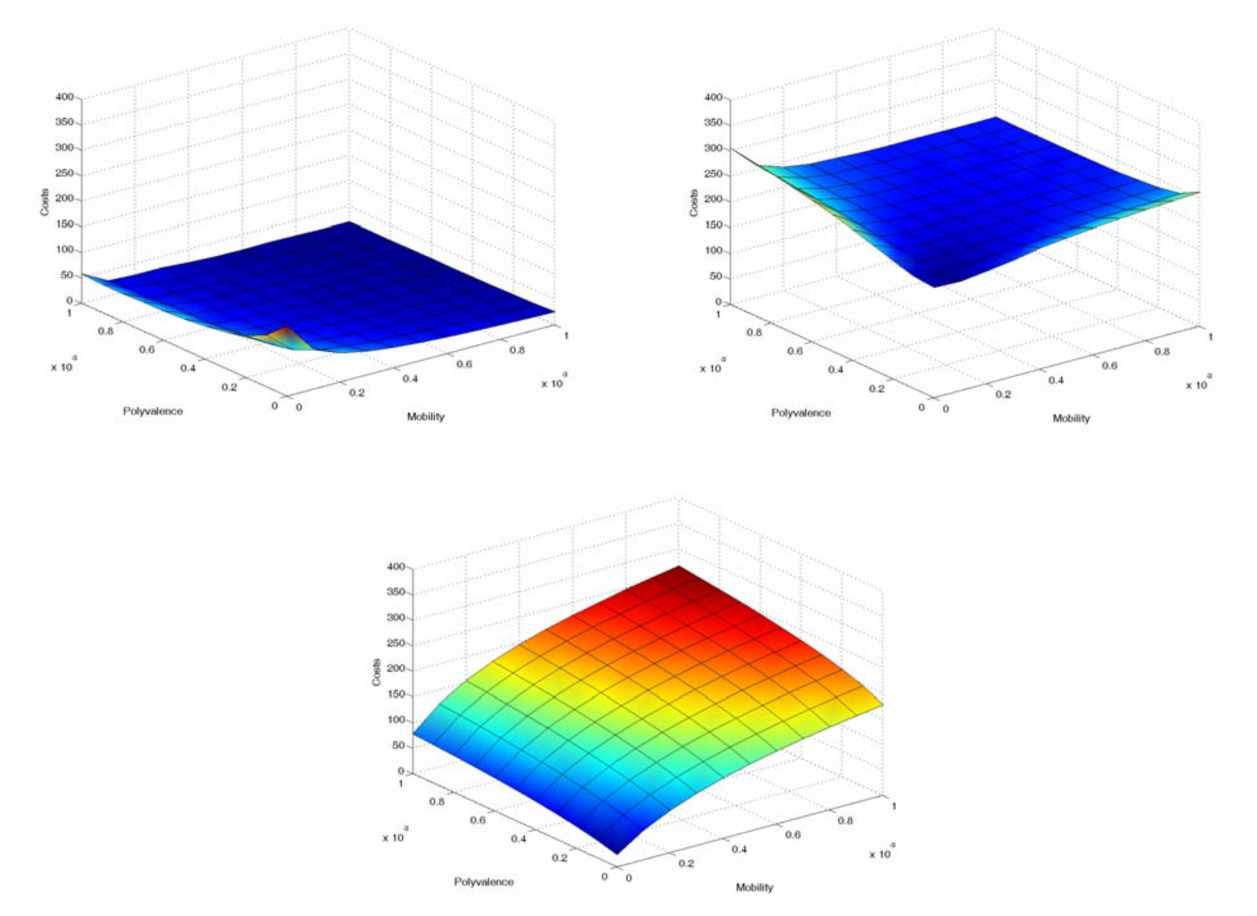

Figure 10. Area covered by the costs when mobility and polyvalence increase at a given effort level

5 Conclusion

The main purpose of this exercise was to develop a multi-agent system to simulate the dynamics of fisheries from a short-term, bio economic point of view. The fishery presented in this paper is purely theoretical.

The modeling approach used for this purpose, based on the multi-agent platform CORMAS, allows studying explicitly the nature and the consequences of the response of a fishing fleet to changes in regulation, given the assumptions made on the behavior of fishing units. Being initialized by an XML file ([11]), the model allows fairly rapidly building and simulating various scenarios of interest, from the fully mobile fleet harvesting relatively sedentary resources to the sedentary fleets harvesting highly migratory stocks.

The application to a simple case presented here shows the great complexity of such dynamics, with the response of fishing effort and of fish biomasses combining with cascade effects between zones, and leading to complicated adjustments to a measure such as a partial fishing ban. Overall evaluation of the economic impacts of the ban as a function of the capacity for the fleet to adapt itself shows the importance of taking such dynamics into account in the analysis of the consequences to expect from a regulatory measure.

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