ReedSim†: Simulating Ecological and Economical Dynamics of Mediterranean Reedbeds

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Abstract: This paper addresses the sustainable management and conservation policies of large Mediterranean reedbeds. These habitats are subject to different human uses (reed harvesting, grazing, hunting, fishing and recreational activities), each associated with a particular water and reed management. Seasonal variations in water levels affect the functioning of the ecosystem, having an impact on the efficiency of conservation projects for endangered species. We combined ecological data on water, reed, and bird monitoring with socio-economic data gathered from interviews with user to describe their interaction and its impact on habitat. We present here the general structure of ReedSim, a multiagent model that integrates system dynamics, scale and cross-scale interactions in both human and natural systems. Using the CORMAS software, we built a model based on a hydro-ecological submodel (reedbed, water level and bird populations), and a socio-economic submodel (reed market and management). The model integrates data from a GIS to create a virtual reedbed similar to the studied wetland. As water management involves processes of collective decision-making, we put emphasis on the coalitional dimension of the users' interactions, including public agencies. The model is designed to be used in environmental planning, and to support collective decision-making, especially when involving negotiations between users or stakeholders and public agencies.

Keywords: *Reedbed; Mediterranean wetlands; Multi-agent based simulation; Conservation policies*

† *Resilience and Ecological Economic Dynamics Simulator*

1. INTRODUCTION

If the causal relationships of biodiversity losses are difficult to demonstrate (Forester & Machlis, 1996; Stern, 1993), several studies have shown the usefulness of modeling tools in term of prospective and theory (Bousquet, 2001; Grant, 1998; Grossmann, 1994; Jorgensen, 1994). The need for developing multi-field approaches to reconnect the environmental degradation to their socio-economic causes has also been recognized (Perrings, 1999; Stern, 1993; Soulé & Wilcox, 1980; Primack, 1993). Non-protected areas often hold various human uses, which constitute the critical point of any conservation strategy for biodiversity (Blockstein, 1995). Wetlands further contribute importantly to the maintenance of biodiversity (Blondel and Aronson, 1999). Within Mediterranean wetlands, large reedbeds are typically exploited, with multiple stakeholders. Grazing, reed harvesting, waterfowl hunting, and nature conservation projects, are each associated with specific management practices that interact at multiple scales and hierarchies, with potentially long-run damaging consequences on uses and conservation issues (Mathevet & Mesléard, 2002). Thus, understanding and predicting how reedbeds and bird populations respond to natural and anthropogenic changes represents a major challenge for Mediterranean wetland conservation. Our assumption is that the conflicting needs among users for a common resource and its management (water, fish, reed, waterfowl) lead actors to minimize their interactions, causes specialization of space, resulting in compartimentalization, loss of specificity and biodiversity dynamics (Hudson, 1991). In this context, the management of hydraulic installations for water control constitutes an element of strategic importance in the confrontation of the uses. They foster the issues of collective action and strategic interactions in the management of a common resource (Ostrom, 1990).

A multidisciplinary research project was developed for the period 1996-2005 to document the politico-economic processes operating over space and time, as well as the ecological processes among plants and birds occurring at the Charnier-Scamandre site. This reedbed covers 2270 ha in the Rhone River delta on the Mediterranean Sea coast, southern France (43°30'N, 4°30'E; Figure 1).

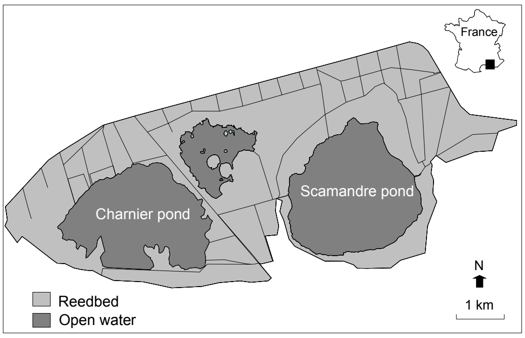


Figure 1. Location of the Charnier-Scamandre reedbeds in Southern France.

The main issue raised is how can we cope with human interactions in order to establish a water management scheme that is compatible with social and individual needs while preserving habitat integrity? The coupling of ecological and socio-economical data into a multi-agent model, will allow us to understand better the relationships between ecological and social resiliences.

2. RESILIENCE OF SOCIAL AND ECOLOGICAL SYSTEMS

In 1973, Holling introduced the concept of ecosystem resilience as the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures (Holling, 1973). Otherwise stated, the resilience is the property that mediates transition among multiple stable states (Gunderson, 2000). Empirical evidence supports the assumption that ecosystem dynamic is generally human-dominated, and hence coupling ecological and social modeling is the only promising approach to understand and predict ecosystem dynamic. Moreover, ecosystem response to human uses is non-linear, exhibiting marked thresholds (Folke, et al., 2002). This last argument has been used to legitimise the use of the concept of resilience in ecosystems management.

Holling (1994) further incorporated resilience in the theory of dissipative structures so as to provide a complete description of the different phases of ecosystem dynamics. He completed the two classical stages of exploitation and conservation, with two additional stages: creative destruction and renewal (Holling, 1994). While stability and productivity are at stake during the exploitation and the conservation stages, resilience and recovery are important in the release (creative destruction) and renewal sequence. Following Holling’s framework, numerous studies were carried out in several human-dominated ecosystems such as lakes, coral reefs, forests, semi-arid and temperate rangelands (Gunderson, 2000).

Gunderson (2000) introduced a new term, adaptive capacity, to describe the process of modifying ecological resilience. Adaptive cycles link resilience and sustainability hence defined as the capacity to create, test, and maintain adaptive capability” (Holling, 2001). Following their general character, adaptive cycles were readily applied to human societies. Adger et al. (2002) defined social resilience as “the ability to cope with and adapt to environmental and social changes mediated through appropriate institutions.” In addition, he distinguished institutional resilience from dependency of social systems on the environment (Adger, 2000). Peterson (2000) presented a range a problems arising when coping with the dynamics of human-ecological systems. In adaptive cycles, the time is being kept implicit, and the recovery phase can incompass the scale of human life. The question of whether ecological and institutional resiliences are related is yet under review and scrutiny.

3. THE SYSTEM UNDER STUDY

An ecological submodel (hydrology, reed and bird dynamics) was combined with a socio-economic submodel (reed market and management by social agents who have diverse objectives, beliefs and access to information).

The relationships amongst the main biophysical and socio-economical variables are presented in figure 2. The lowest level of organization of our model was that of the functional hydro-unit as an individual decisional unit. At the landscape level, we simulated the dynamics of the reedbed and associated birds resulting from the individual management of hydraulic units in interaction with other units.

Our model was constructed using CORMAS (Common-pool Resources and Multi-Agent Systems), a simulation tool based on the VisualWorks® programming environment software used for programming in Smalltalk® object-oriented language (Bousquet et al., 1998). The two entities represented in our model were: (1) the elementary spatial unit, the patch, which inherits the predefined generic entity "Cell"; (2) the social entities which inherit the class "Communicant/Agent", allowing them to exchange messages.

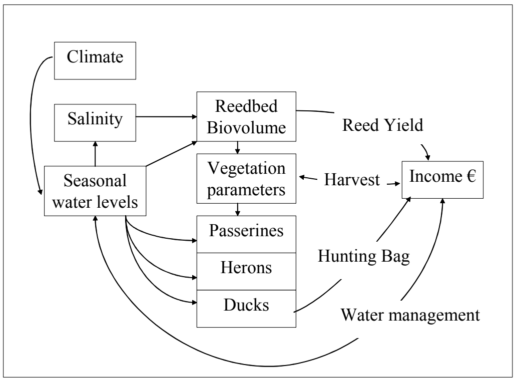


Figure 2. Relationships amongst the main variables in ReedSim ecological system

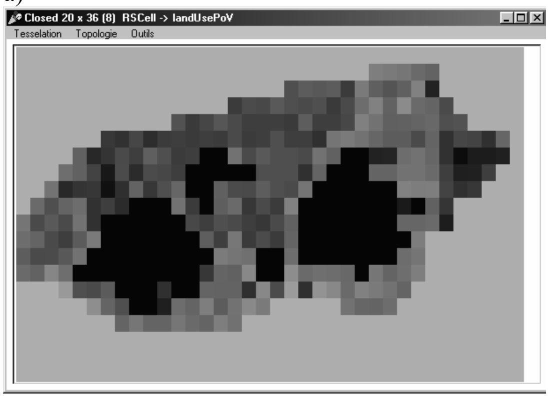
3.1. The virtual wetland

The landscape was represented by a space-grid of 720 squared cells (20 x 36). Each cell corresponded to 10 ha and was connected to eight neighbouring cells. They had closed boundaries and were internally uniform. Each cell was assigned a type of land use (reedbed, open water, open land), a topography (-150 to +50 cm at 10 cm intervals), and belonged to one of the 43 hydro-functional units presented on the site. Twelve estates of variable sizes, including public land were included in the model (figure 3). The spatial configuration, size and number of hydro-units and estates reflect the current situation at the Charnier Scamandre.

3.2. The ecological model

Reedbeds refer to marshes with emergent vegetation dominated by common reed *Phragmites australis*. The main ecological variables and their interactions considered in the model were seasonal water levels, vegetation structure, and density of various bird species (figure 2). Although common reed is a flood-tolerant plant, a summer drawdown every 5-10 years improves nutrient uptake, rhizome growth, and the overall stability of the plant formation. Permanent flooding results in anoxic conditions favoring the formation of reed tussocks before they completely disappear to open water. Likewise, reed can tolerate salt concentration of 20 g/l, but grow thinner and shorter above 5-10 g/l. The combination of salt and permanent flooding speed up the degradation processes. Winter cutting, by eliminating the dry stalks and litter, is rather beneficial to reed growth by favoring photosynthesis. Cut reedbeds typically have a higher density of reed stems which are also thinner and shorter. Winter cutting is detrimental if carried out with heavy machinery on soft waterlogged ground because it breaks the rhizome system leading to a fast degradation of the reedbed. Occurrence of five reed passerine species, and two heron species were simulated based on correlative analysis drawn from our field surveys (Poulin & Lefebvre, 2002; Poulin et al., 2002; Barbraud & Mathevet, 2000, and unpublished data). The carrying capacity for wintering ducks is from Tamisier & Dehorter (1999). The hydrological model is seasonally-based. The salinity model was derived from Heurteaux (1979). In the model, flooding of a cell depends on the water management by the agent, the condition of the adjacent cells, and the climate.

a)



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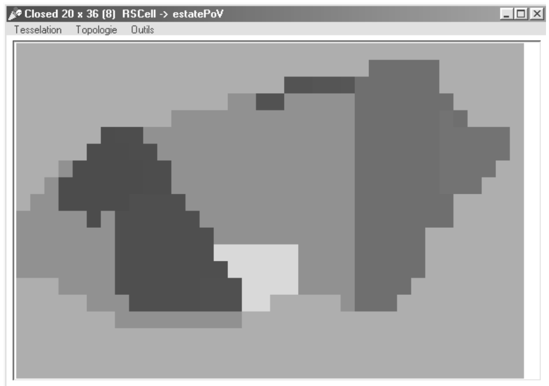

Figure 3. (a) The virtual landscape. Different grey cells represent different values of the biovolume (l/m²) of the reedbed. Cells with water are dark. (b) Location of the 12 estates on the model's spatial grid

3.3. The socio-economic model

Five types of social agents were modeled (figure 4):

- The landowners have different economic means and objectives (leasing of hunting or grazing rights; Mathevet & Mesléard, 2002), which affect the type of reedbed management and the resulting quality of reeds for birds and commercial purposes;
- The harvesters' aim is to increase reed harvesting and they use different machines (i.e. different yields and costs). They may have other incomes besides reed harvest and can work for the collector agents;
- The collectors provide reed to the national and international reed market for thatching. They rent the access to the reedbeds from the landowner agents. They can subcontract the harvest and management to harvester agents;
- The fishermen rent seasonal fishing rights to the landlord agents. They have other incomes than fishing.
- The public hunters need reasonable hunting bag and hence try to increase the carrying capacity of reedbeds for ducks on public lands.

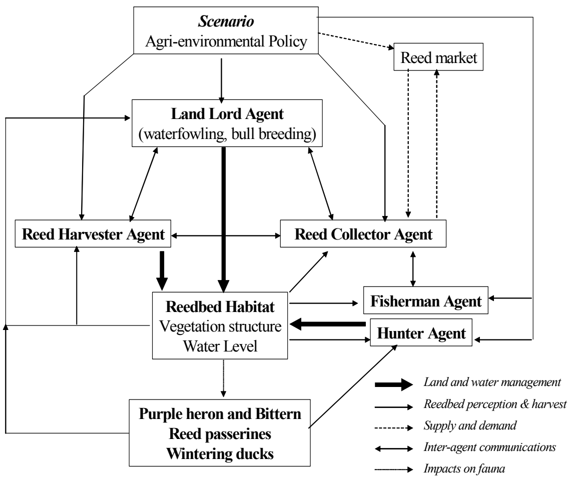

Figure 4. Model description

These agents exploit a defined space corresponding to one or several hydro-functional units. They can communicate with each other. Each agent has different attributes (satisfaction, cash amount, estates etc.) and is related to natural resources having their own dynamics. The seasonal water levels determine not only the reed production of the current year but also of the following years. The behavior of the agents depends on their utility function. The decision rules were established from field surveys and literature (Mathevet et al., *in press*; Gilbert & Conte, 1995; Ostrom, 1990; Gardner & Ostrom, 1991). The interactions between agents rely on the communication and financial flux (figure 4). The choice of strategies was established based on the proportions observed in real life.

The cost of the access to the reedbed and its evaluation by the agents determine its management and exploitation. The ecological and socio-economic consequences of individual management decisions go beyond the estates, and relate to the whole system on a different time scale.

4. PRELIMINARY RESULTS

In this section we describe a few preliminary simulation experiments.

4.1. Constant water management strategies

We tested different scenarios of water management to evaluate their impact on the habitat and its fauna in the long-term (figure 5).

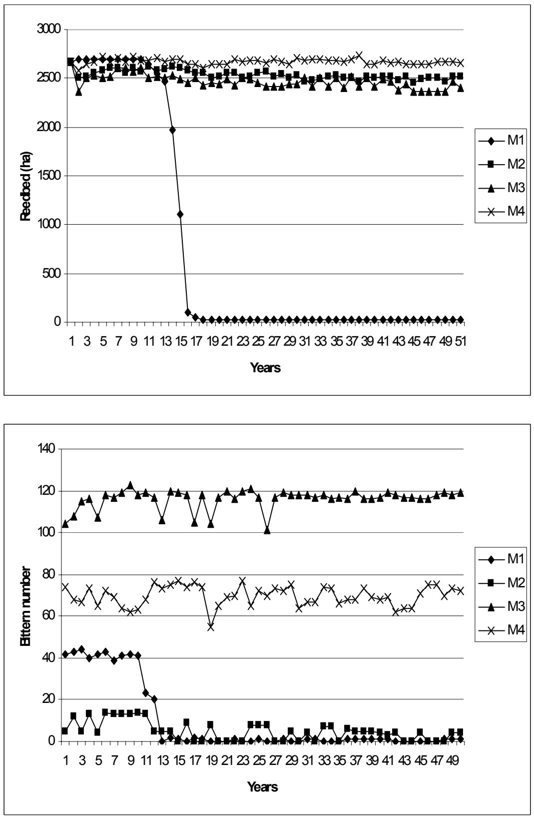

Figure 5. Evolution of reed area and bittern density according to four types of water management (1. permanently flooded, 2. semi-permanently flooded with spring drawdown, 3. semi-permanently flooded with winter and summer drawdowns, 4. semi-permanently flooded with summer drawdown).

These simulations revealed that the water management typical of hunting marshes (permanent high water levels), leads to a complete disappearance of reed within 15 years. On the other hand, water management typical of cut reedbeds (summer and winter drawdown) is good for reed and optimal for the Great bittern, a vulnerable heron species.

4.2. Alternating water management

Given that different users have diverging needs in water levels and that embankment of marshes devoted to different uses is not an option, a possible compromise is to alternate water management practices among years. In the three scenarios tested (figure 6), the annual reed biomass stabilized after five years and an equilibrium strategy could be reach with a tour de role control which would give alternatively water control to hunters and harvesters, with a minimal loss of profit (i.e. M1-3 *vs* M3-4). This kind of agreement may be stable due to the risk to come back to an individual strategy in the case of the free riding of one agent.

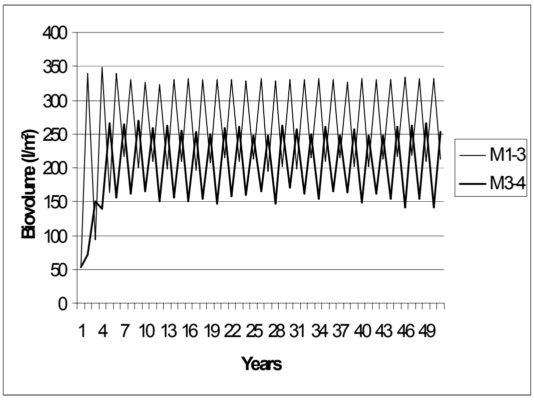

Figure 6. Evolution of the biovolume of the reedbed when water management type changes each year (1, 3, 4 as on fig 5).

5. CONCLUSIONS AND PERSPECTIVE

A large part of the biodiversity is found outside protected areas and cannot be preserved without taking into consideration user behavior and public policies. This approach, however, is complicated by the numerous functional and strategic interactions between actors, the lobbying typically used to solve conflicts, the asymmetric access to information and the high costs of administrating and controlling these policies. In this context, the present project must be regarded as a first stage to provide the empirical and theoretical foundations to a new conservation policy. The next steps will be to run various simulations to test the impact of different economic scenarios and on the mechanisms controlling the access of users to specific reedbeds.

From a sustainable development perspective, our proximate goals are to improve dialogue among users intervening in the private and collective estates to stop the marsh compartmentalization process, and to develop locally an efficient water management policy. The multi-agent model developed here is most useful for the management of natural resources and can be used as a companion modeling approach to help collective decision-making among stakeholders (Bousquet et al., 1999).

6. ACKNOWLEDGEMENTS

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