Environmental Modelling & Software 25 (2010) 1334–1344

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

A companion modeling approach applied to fishery management

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ARTICLE INFO

Article history:
Received 9 April 2009
Received in revised form
25 November 2009
Accepted 4 March 2010

Keywords:
Agent-based simulation
Companion modelling approach
Razor clam (*Solen regularis*)
Fishery
Role-playing games

ABSTRACT

Don Hoi Lord, a coastal wetland in the upper gulf of Thailand, is famous for the razor clam (*Solen regularis*), which is a source of food and income for local fishermen. However, the razor clam population is significantly decreasing so the aim of this study was to analyze the razor clam fishery and develop a management plan engaging the different stakeholders in collective discussions. A participatory modelling approach was used, including (a) agent-based modelling (ABM) and (b) role-playing games (RPG). First, an individual-state distribution model of the razor clam population was designed and calibrated to synthesise knowledge. Two RPG sessions supported by this biological model were organised to initiate collective learning and promote discussion among stakeholders. After playing with the baseline scenario showing the actual harvesting situation, discussions led to the definition of alternative scenarios for clam management such as establishment and rotation of zones closed for harvesting, and quota systems. These scenarios developed during the RPG sessions were more deeply investigated with an agent-based model that included fishermen agents and the individual-state distribution model of the razor clam population. Simulations of different scenarios (reserve, quota and combination of reserve and quota) were produced to enable better informed discussion between different stakeholders. Stakeholders have acknowledged that management through rotating reserves is not efficient if the duration of reserves is too short. They have realised that the efficiency of reserves is hard to assess without better data on clam recruitment. They have also explored another management option which is the quota system. In the final stage, the local participatory process was endorsed by the incumbent regional policy-making actor. Unfortunately, because of rapid administrative rotation the project abruptly lost support. This unexpected event emphasises the need for continuous monitoring of all actors entering and/or leaving the system, which can radically change the interactions among them and, therefore, the whole management context.

1. Introduction

The evaluation of fisheries sustainability in coastal areas presents a significant challenge given the range of issues that must be taken into account (Inglis et al., 2000; ICES, 2005), the interactions between natural and social components, and the coupling between watershed and coastal zone (Whitall et al., 2007). As in many countries, Thailand's coastal fisheries are a subject of controversy involving local fishermen who want to harvest the resource to improve their livelihood, and government agencies and non-governmental organizations (Crawford et al., 2003; Gibbs, 2004) that want to protect the resource. These conflicting viewpoints give rise to the ever more urgent need for practical and feasible fishery management plans in the light of decreasing fishery populations.

The area studied in this paper is the coastal wetland Don Hoi Lord, literally in Thai the "*sand bar of razor clams*". Hoi Lord is the vernacular name for the razor clam *Solen regularis*, a bivalve that is a very popular delicacy. The area is located in the province of Samut Songkhram, about 100 km West of Bangkok, in the upper Gulf of Thailand (see Fig. 1).

The mudflats located in the Mae Klong river estuary, are formed by the accumulation of sediments and are, therefore, rich in nutrients and represent an attractive site for numerous animal species. Don Hoi Lord is of high ecological value, as attested by its registration in 2001 in the Ramsar International Wetlands Treaty (Ramsar, 2007). During low tide, the sand bar attracts local fishermen who harvest

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doi:10.1016/j.envsoft.2010.03.012

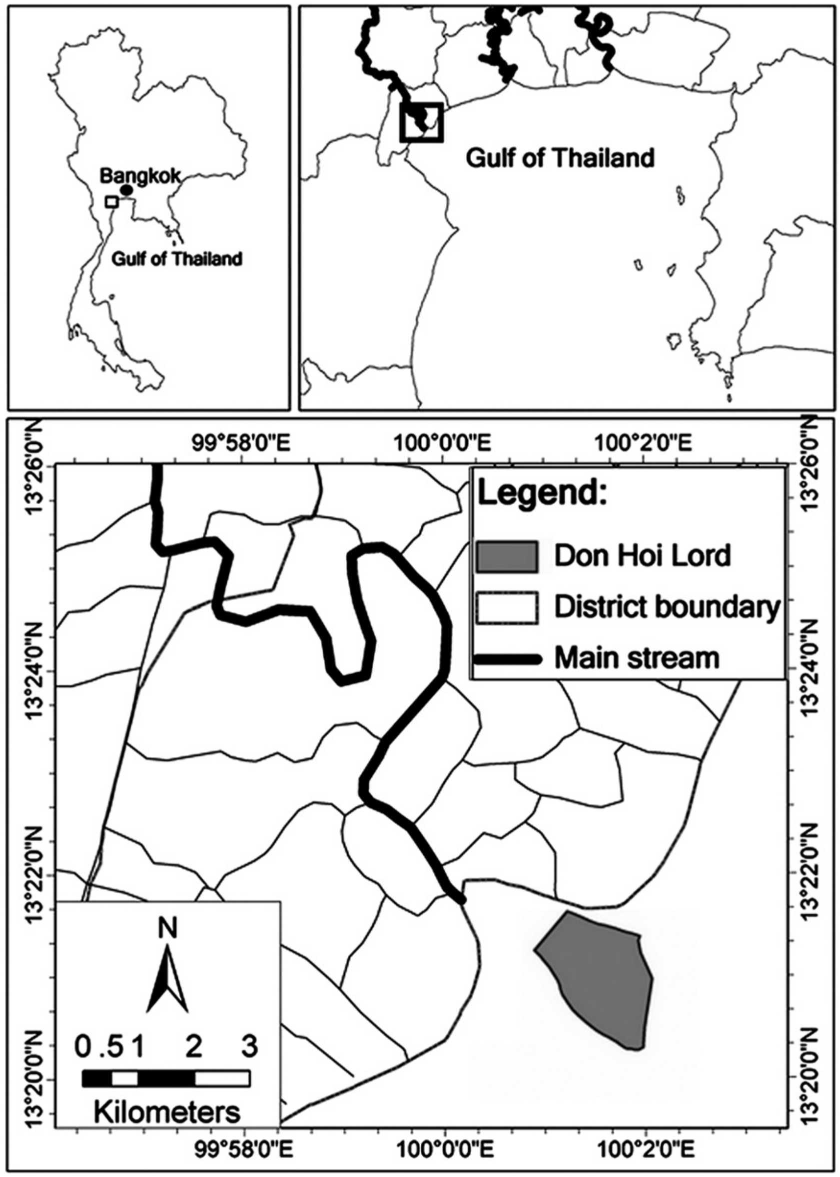

Fig. 1. Don Hoi Lord upper Gulf of Thailand.

the razor clams. Don Hoi Lord is nowadays also a popular tourist destination being close to Bangkok with many city dwellers enjoying seafood delicacies and visiting the natural site. Ruffolo et al. (1999) considers that this increasing demand for razor clams combined with heavier harvesting pressure caused by other regional developments is threatening the sustainability of this ecosystem. Consequently, there is a crucial need to develop scientific research on this ecosystem and promote collective discussion among stakeholders for better management of the fishery.

It is now widely recognised that ecosystem studies require a holistic interdisciplinary approach in order to integrate biological, environmental and social components within a research framework (Turner and Carpenter, 1999). Advancing the present-day concept of “integrated renewable resource management”, the challenge is now to develop a new “integrative science for resilience and sustainability”. This should focus on the interactions between ecological and social components and take into account the heterogeneity and interdependent dynamics of these components (Costanza et al., 1993; Funtowicz and Ravetz, 1994; Berkes and Folke, 1998).

At the same time, modelling has become an essential tool for the study of ecological systems as it provides an opportunity to explore ideas and scenarios, which for logistical, political, or financial reasons would not be possible under practical field study conditions (Jackson et al., 2000). As a result there is now a wider spectrum of objectives for how models are being designed and applied, in addition to their standard role as decision-support tools.

Models should ideally be flexible, user-friendly for all the participants and easily adaptable for unforeseen situations and new ideas. It could be said that models are no longer mainly intended for predicting outcomes, but rather for promoting and encouraging creativity, facilitating discussion, clarifying communication, and thereby contributing to the collective understanding of problems and potential solutions among involved stakeholders through the exploration of simulation scenarios (Carpenter et al., 1999). In this context, the term “companion modelling” (ComMod) has been proposed (Bousquet et al., 1999; Barreteau et al., 2003) to underline the new role for simulation models.

The goal of this study was facilitate the development of management plans for razor clam fishery by using the ComMod approach as a platform for communication and stakeholder engagement. When this research started the minimum objective was to develop understanding between scientists and fishermen for the socio-ecological processes at stake (the fishery), and explore collectively possible management scenarios.

In the first section, the paper describes the Don Hoi Lord. Different methodological aspects regarding the implementation of ComMod in Doi Hoi Lord are then presented and the two main modelling tools – the agent-based model (ABM) and the role-playing game (RPG) – are described. The main results from the several steps of the companion modelling process are analyzed. Finally, we discuss several future challenges for razor clam management and conservation in Don Hoi Lord.

2. The Don Hoi Lord fishery

According to local people, fishermen have been harvesting razor clams at low tide for more than 80 years using one of the following traditional methods.

(i) Dipping lime: fishermen search for razor clam holes with fingers knocking on sand surface. If a razor clam responds, it ejects water from a siphon through the hole, revealing its presence. Then a small bamboo stick dipped in lime is poked into the hole forcing the clam to react and emerge from its hole.
(ii) Applying lime: lime is directly applied on sand surface (approx. 1 m^2) with most razor clams reacting and emerging from their holes.
(iii) Applying lime solution: 1–2 kg of lime is dissolved in water and applied as in method (ii), directly on the sand surface (approx. 2 m^2).
(iv) Applying acetylene solution: similar to methods (ii) and (iii), this method is much more effective but it also has observable harmful effects on other species.
(v) Digging out the clams: no chemicals are applied but it takes more time and effort, which leads to lower harvesting rates.

In 1987, the provincial government released a regulation on harvesting methods prohibiting the direct application of chemicals on the sand (as in (ii)–(iv)). As a result, the first method described above is now used by all fishermen. In 1998, the provincial government mandated a closed, reserve area as a breeding site for razor clams. In practice, only the harvesting regulation has been implemented which is still a controversial topic among fishermen. However, all the fishermen agree on one point: the density of the razor clam population is continuously decreasing as is the clams mean size.

The razor clam resource in Don Hoi Lord is a common-pool resource (Suwanna, 2003) with an estimated 1300 people from 10 villages harvesting razor clams. However, surveys have shown that less than one-fourth of the population considered themselves as full-time clam harvesters (Oiamsomboon, 2000; Worrapimphong, 2005). The daily average number of fishermen harvesting clams is variable (in August 2004 the maximum observed in one day was almost 200), depending on several conditions such as the tide schedule but also on the income earning opportunities from other activities. The clams are sold either to middlemen or, less frequently, directly to tourists.

Previous research on Don Hoi Lord focused on the life history of the clams (Tuycharoean and Worra-In, 1991), on the environmental conditions at Don Hoi Lord (Pradatsundarasar, 1982), or on the social awareness of the importance of razor clam for the local community (Oiamsomboon, 2000). These existing studies were oriented towards conservation from either a biological or a social perspective, but none of them provided an integrated approach to improve management options.

3. The companion modelling approach

The ComMod approach is based on a series of iterative stages including field studies and participatory modelling activities (ComMod Group, 2003). ComMod involves stakeholders in all these steps to support two complementary objectives: to produce knowledge about the system and to support collective decision making (Bousquet et al., 1999). Scientists as other stakeholders, including both resource users and managers, are collectively learning by actively participating in the process. The two main tools generally used in companion modelling are based on multi-agent systems (MAS) principles, a metaphoric representation of complex systems: the dynamics and patterns observed at a global level are due to interacting autonomous local entities (agents) that can perceive and modify their environment, communicate among themselves, and refer to specific goals and representations to make their decisions.

From this organizational framework, two concrete tools can be implemented: agent-based computer models (ABM) that describe the agents in terms of computer programs, and role-playing games (RPG) that require the participation of human players to represent the agents (Barreteau et al., 2007). The combination of tools to be used in companion modelling depends on the context and specific objectives of the study.

Companion modelling has already been used to deal with many renewable resource management issues such as (i) water sharing in Tunisia (Feuillette et al., 2003) where ABM proved to be a useful tool for negotiating the integrated management of the water table system, (ii) wild life in a forest village in eastern Cameroon (Bousquet et al., 2001) where coordination among groups of hunters appeared to contribute to the viability of the system, (iii) diversification in upper paddy area of northern Thailand relating to the organization of the sugarcane supply chain (Suphanchaimart et al., 2005) and (iv) water sharing in Bhutan (Gurung et al., 2006) where a watershed committee management has been established.

According to Robinson et al. (2007), ComMod's main strength is that it provides a platform for communication and collective learning that helps to elicit tacit knowledge and to build a shared representation. On the other hand, it is generally implemented at the local level, and consequently its impact is limited and the findings are difficult to generalise for wider applications.

For the case presented here the challenge was to bring together different stakeholders who have different sources of knowledge, to establish a shared understanding of the system and envision management scenarios. Biologists' strategies for resource management are associated with population dynamics models which are not understood by the fishermen. On the other hand fishermen have various strategies and adaptations to resource dynamics in the economic context. It is necessary to share these strategies and adaptations as part of negotiations on resource management. From a methodological point of view the challenge was to craft a combination of computer simulation models and role-playing games, based on the same conceptual model of resource dynamics and fishermen activities.

4. How ComMod was implemented

Like other types of integrated modelling approaches, companion modelling needs to assemble different sets of knowledge. For this study, the existing biological and ecological clam population data as well as the harvesting behaviour of fishermen were investigated. For both components, specific field studies were conducted to collect additional knowledge.

The field study was conducted on a monthly basis during one year (from March 2004 until February 2005). Data on razor clams were collected for the same sand bars as in previous studies. Line transects and a quadrant sampling method (Krebs, 1989) were used to collect data on razor clam population. There were 81 sampling plots of 1 m^2 from 27 stations following 4 line transects from which mean values of razor clams population density and individual clam weight and size were calculated. At the same time, local fishermen, razor clams traders and local government officers were interviewed to understand their decision-making process, and their direct and indirect actions regarding the clam population dynamics.

The overview of the ComMod process implemented in Don Hoi Lord is showed in Fig. 2.

To integrate existing knowledge about razor clams population biology in Don Hoi Lord, a model of razor clams population dynamics was first developed. This model computes population density as a result of various biological processes (growth, reproduction, mortality) producing a vector of numbers for individual clams in a number of discrete size classes. This individual-state distribution model (Caswell and John, 1992) was constructed from secondary data, expert knowledge and additional field data. This model was used in two different configurations: as a tool to simulate the dynamics of a population of clams during RPG sessions, and as a module of an ABM that included fishermen agents to simulate management scenarios (see Fig. 2). Even though the spatial and temporal scales are different for these two configurations, the biological functions could be considered as similar and the values of parameters were the same. Therefore, we considered that the razor clams i-state distribution model is a common component shared by both simulation tools involving real (RPG) or virtual (ABM) fishermen.

Two sessions of the RPG were organised. The first one aimed at facilitating knowledge sharing and collective discussions on fishery management among stakeholders, while the second one aimed at presenting the results of the first RPG and extending the process to new stakeholders. In between sessions, the model was used to run computer simulations with computerised agents, with the objective of exploring scenarios discussed during the first RPG. The same process was repeated after the second RPG. Finally the results of these processes were presented to the then incumbent provincial governor, the deciding policy maker.

5. Modelling choices

We present here the methodological issues dealing with the implementation of the modelling process. First, we describe how

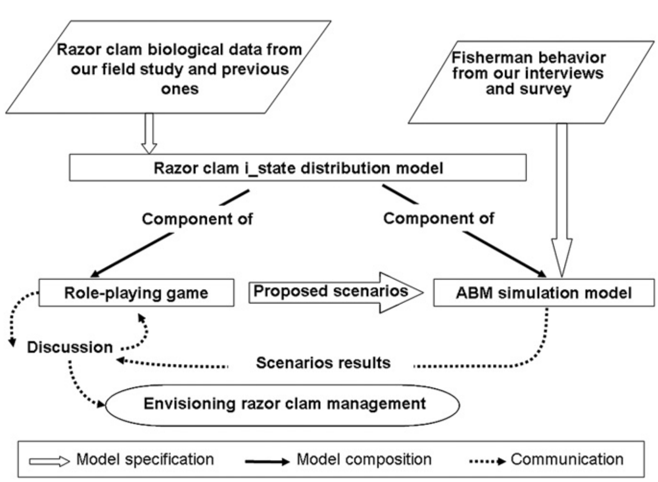

Fig. 2. Schematic representation of the ComMod process in Don Hoi Lord.

the razor clams i-state distribution model was designed, calibrated and applied to synthesise knowledge. Next, we clarify adjustments we have done in order to use the model in two different ways: as a virtual common-pool resource harvested by fishermen players (humans) during RPG, and as a virtual common-pool resource for artificial agents modelled to explore various scenarios at finer temporal and spatial scales.

The model was implemented within the Cormas platform (Bousquet et al., 1998). Cormas is a software for modelling multi-agent systems. It includes interfaces and primitives to simulate agents, which may communicate among themselves and move on a spatial grid on which resources can be located. (Cormas is freely available from the Internet: http://cormas.cirad.fr). The model code to be imported into Cormas is available at: http://cormas.cirad.fr/logiciel/DHL.zip.

5.1. *A razor clam dynamics model for knowledge integration*

A population dynamics model was constructed by integrating razor clams population biology data from literature and field studies done from 1981to 2003 (the monitoring was not continuous) and as part of the present study.

Clams are represented in the model as a subpopulation divided into size classes with distribution ranges from 3 to 7 cm. The width of a size class was set to 1 mm. The population dynamics is driven by three biological functions: growth, natural mortality and reproduction, which depend on the carrying capacity of the sand bar.

5.1.1. *Growth and mortality rates*

Constant (size-independent) rates have been defined for growth and mortality. The growth rate was set to 1 cm/month from the study by Ruffolo et al. (1999). The natural mortality was set as a daily probability to die equal to 2% for all size classes. This value was also suggested by Ruffolo et al. (1999), but the authors mentioned a higher level of uncertainty for this parameter than for the growth rate. Therefore, we decided to test the sensitivity of the model to 5 different values (0.01–0.05 incremented by 0.01) of the natural mortality rate (see Section 5.2 on calibration).

5.1.2. *Carrying capacity*

The carrying capacity of the sand bar is unknown as there is no data for unexploited razor clam populations in Thailand; furthermore the existing data on razor clams densities are extremely variable. The maximum observed density, of over 200 individual clams per m^2, was reported by Pradatsundarasar et al. (1989). A cluster analysis made from the data we collected (clam density) revealed that the suitability of the habitat is related to the sand grain size (Worrapimphong, 2005). In the model, we defined three categories of sand grain sizes (fine, medium, coarse) and associated a population threshold (respectively, set to $x = 30$, $2 \times x = 60$ and $3 \times x = 90$ individuals/sq.m). When the population exceeds this threshold (a kind of carrying capacity) the recruitment is lowered. Different values for the carrying capacity parameter ($x = 30$; 40; 50) were also included in the sensitivity analysis of the model.

5.1.3. *Reproduction*

Razor clams, as most shellfish, have complex life cycles with the process of physical transport of planktonic larval stages to appropriate recruitment habitats leading to unclear relationships between the number of recruited new clams (size between 3 and 4 cm) and the existing abundance of the reproducing clam population (size over 4 cm) (Freire and Garcia-Allut, 2000). The recruitment of small clams was represented in the model as a stochastic process related to the population of female adults and related to the space left available by resident clams (defined as the difference between the local carrying capacity related to the grain size and the actual local density). In addition, it seems apparent from the literature as well as from our own field results that some months are better than others for small razor clam recruitment. To account for this seasonal modulation, a seasonal pattern has been included in the model as a set of monthly coefficients: (1, 1, 1.5, 1.5, 1, 1, 1.5, 1.5, 1, 1, 1, 1). This implies that March and April, then July and August, are providing 50% more recruits than the other months of the year. This reproduces the pattern observed in our field data. Several values (25; 35; 45) giving the number of recruited clams produced by each adult female were also tested to calibrate the model.

5.2. Calibration and validation of the model

Because of the abovementioned high level of uncertainty for three major parameters (natural mortality rate, carrying capacity and number of recruits per female), we conducted a sensitivity analysis to identify which combination of parameters lead to a simulated population dynamics that could be considered as realistic. This realism was assessed according to three criteria proposed by Pradatsundarasar et al. (1989), namely (i) the maximum density of clams should remain lower than 200 individuals/m^2; (ii) the density of clams should not reach values close to zero; (iii) two peaks of higher density should be visible in each year, to represent the two breeding seasons. Out of the 45 combinations of the three parameters that were tested by running the model, one set of values which was found to provide the best fit for the three criteria was selected (mortality rate = 0.01; carrying capacity = 30 and number of recruits = 25). With these parameters, the mean density of the simulated razor clam population is around 120 individuals/m^2.

Additionally, to check the size structure of the simulated razor clams population, the distribution of size classes obtained after 10 years of simulation without fishermen and with five fishermen was plotted and compared to the distribution observed in Don Hoi Lord (Worrapimphong, 2005). The shape of the two distributions is similar (see Fig. 3). The similarity of distributions was tested with a Kolmogorov–Smirnov test, the differences being non-significant ($p = 0.463$, 0.358, 0.194). However, it is difficult to further compare the two distributions as the real population of clams was harvested over many years and, therefore, its distribution is distorted by the effects of this long term harvesting.

With fishermen agents added to the biological model (see Section 5.4), the simulated distribution (gray-colored bars in Fig. 3) is accounting for such effects: the abundance of big size classes is less, thus being closer to the real data.

5.3. A model to support RPG sessions with real fishermen

The spatial setting of the role-playing game considers only 4 zones, in a configuration covering the sand bar of Don Hoi Lord (see Fig. 4A). The number of zones was set to 4 after interactions with the fishermen on their perception of dune's zones heterogeneity. The sand grain size was considered as medium in all the 4 zones. Accordingly, only 4 independent local populations of clams were created, one in each of the 4 zones (connections between the zones are closed for larvae migrations).

Participants to the RPG sessions who were playing the role of fishermen were asked to indicate for each month (i) if they went fishing; (ii) if so, in which of the 4 zones. They had to fill out a sheet given to the game facilitator. Their choices (12 harvest locations for 12 months) were then entered in the simulation. The location of players was displayed, allowing the players to know the spatial distribution of the overall harvesting pressure (the number of harvesters but not their identity) for the 12 steps. For each fisherman, the computer model then assigned a random (uniformly distributed between 30 and 100% as observed in the field) harvest rate (proportion of clams harvested) for each month and updated the clams population by combining fishing with the natural processes described in Section 5.1. At the end of each round, the game facilitator returned the sheets to the players showing monthly and yearly harvests. Each scenario was played during 3 rounds representing 3 years.

5.4. A model with virtual fishermen to run agent-based simulations

The objective of designing an agent-based model was to run the scenarios identified during the RPG sessions by releasing the simplifications imposed by the format of the game. With the ABM, each simulation scenario was run for 5 years and the time step was set to one day. As explained below, information about fishermen practices was integrated and the spatial setting was also refined.

5.4.1. Spatial setting of the ABM

A spatial grid consisting of 141 × 141 regular 1 m^2 cells, was defined (see Fig. 4B). The justification for choosing 1 m^2 as the elementary spatial unit of the ABM is related to our observations of the fishing activity: when a fisherman makes a stop on the sand bar to apply lime into what is seen as a razor clam's hole, she/he will systematically also scan the immediate surroundings (approximately 1 m^2). The extent of the spatial grid (141 × 141) was chosen as it realistically represents the area which one fisherman can cover (between 100 and 200 m length) in one day (the chosen time step). This is not related to the actual size of the dune nor is it related to the 4 spatial units represented in the RPG. The topological properties of the spatial grid are defined by von-Neumann neighborhoods (each cell has neighbors in 4 cardinal directions) and closed boundaries. To be able to simulate scenarios referring to the 4 management units discussed during the RPG sessions, four zones were also defined splitting the whole spatial grid into quarters. To account for spatial heterogeneity, each quarter was divided into 3 patches of grain size (see Fig. 4B, the darker the coarser).

5.4.2. Virtual fishermen

According to the principles of Agent-Based Modelling, virtual fishermen were designated as computer agents. All behavioural characteristics (number of cells harvested, harvest rate) have been defined from the interviews and direct observations of local fishermen. In addition, special sampling was undertaken such as systematic digging of a 1 m^2 areas of the sand bar after a fisherman had finished harvesting that specific location, thus evaluating the proportion of clams harvested (Worrapimphong, 2005).

The daily step of a fisherman agent is specified as follows: first the decision to harvest clams is made with a probability of 2/3. The number of cells visited by a fisherman agent in one day is set between 100 and 200, the actual number being randomly determined (uniform distribution) for each fisherman, for each day. For each visited cell, the proportion of clams (size gt; 4 cm) harvested is then randomly (uniform distribution) set between 0.3 and 1. Finally, a fisherman agent is able to detect the neighboring cell with the highest razor clams density, and moves from one harvested cell to the next one.

6. Results

The results are presented for each of the successive steps for the implementation of the ComMod methodology in Don Hoi Lord, namely (1) the first RPG session; (2) the integration of artificial fishermen agents and the exploration with the ABM of the

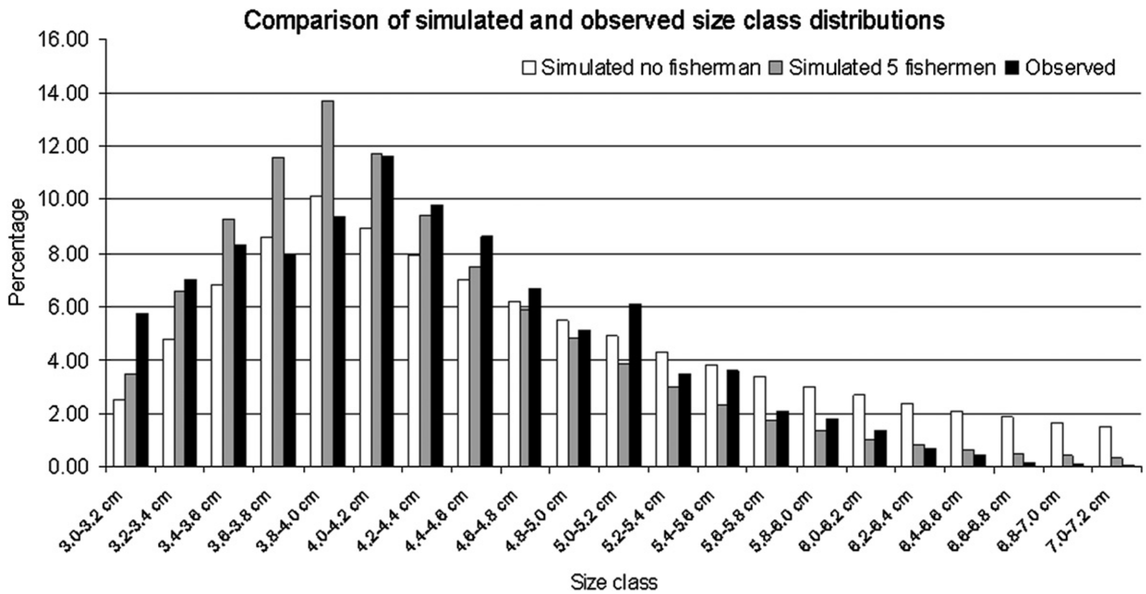

Fig. 3. Comparison of simulated and observed (Worrapimphong, 2005) razor clams size class distributions.

scenarios discussed during the first RPG session; (3) the second RPG session; (4) the exploration with the ABM of the scenarios discussed during the second RPG session; and (5) discussion about management options with the policy makers.

6.1. First RPG session

The first role-playing session in the study was organised at Chu Chi village, which is located near Don Hoi Lord. The participants were 12 local fishermen from the same village. Officers from the local government (Tambon (District) Administrative Organization or TAO) participated as observers. Four scientists were acting as game facilitators during the game (during the final discussion they took their role of scientists, providing scientific knowledge and debating about this knowledge). The session was separated into 2 periods (morning and afternoon). In the morning the game was played and then followed by free discussion. In the afternoon, several scenarios that emerged from the discussion were played.

Four scenarios were played in this game: the baseline scenario (scenario *B*) represents the current situation (harvesting by dipping lime, no regulations) and the three other scenarios with closing access to one zone (reserve) with rotation of the preserved zone. The effect of the duration of the rotation was tested by looking at 3 options: (1) 3 months/zone closing (scenario *Rsr* for Reserve short rotation), (2) permanent closing for one zone (scenario *Rnr* for Reserve no rotation), and (3) 1 year/zone closing (scenario *Rlr* for Reserve long rotation).

The results obtained by playing these four scenarios during the first RPG are synthesised and presented in Fig. 5.

The 3 alternative scenarios were then discussed. The fishermen were asked to comment on the realism of the scenarios and the lessons drawn. Comments were based on one single game for each scenario. Statistically we cannot conclude that there was any difference between scenario's results. However, the perception of the players was that the scenario *Rsr* was better (in terms of harvest) than the other scenarios, presumably because the rotation

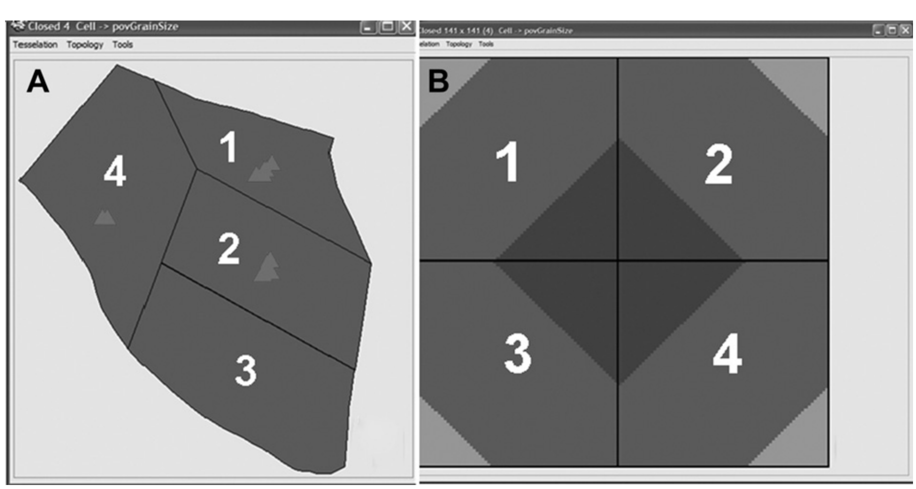

Fig. 4. (A). Spatial setting of the RPG: based on the actual topology of the sand bar, the 4 zones to be used as management units are based on fishermen representation. The triangles are the location of the players. (B) Spatial setting of the ABM: a regular grid made of 141×141 cells representing each 1 m^2. The types of grain size are indicated by different colors (the darker the better). The 4 zones are management units just as in (A).

among the zones being closed was set with the appropriate timing. During the collective discussion (see Fig. 6), it appeared that local fishermen did not like the fact that an area remained closed for too long. All participants indicated that they would prefer to consider scenario *Rsr* as a regulation to be implemented in the future.

The overall result was that all participants identified that the duration of the rotation was an important factor to explore. This suggests a process of learning by testing through simulation.

Finally, some players and local government officers suggested that the game should be organised again, but with a wider audience including players from another village, who are also harvesting razor clams in Don Hoi Lord. One important outcome was the opportunity for participants to stress the importance of going beyond the boundaries of their village to tackle the problem.

6.2. ABM simulations related to the first RPG session

The baseline (*B*) and short rotation (*Rsr*) scenarios, formulated with the stakeholders during the first RPG session, were implemented and run with the ABM. The simulation was carried out for 5 years with different numbers of fishermen agents, as we had no information on the harvest pressure (density of fishermen). The results showed that there was little difference between scenarios, both regarding the razor clam density (Fig. 7), the mean size of the razor clams (Fig. 8) and the weight harvested (Fig. 9). We see in Fig. 9 that the weight harvested is dependent on the number of fishermen while the razor clam density is not. These are different because the fishermen harvest only clams which are larger than 4 cm.

The reserve is not efficient because, as soon as it is opened to harvest it is very rapidly depleted. These results underline the fact that, in absence of reliable information on the diffusion of larvae from the reserve, the efficiency of reserve management option is difficult to assess and other management approaches should be explored.

6.3. Second RPG session

Following a suggestion made during the first RPG session, 10 fishermen from 2 villages, and 1 trader who directly buys razor clams from fishermen were invited to participate in this game. In addition, local government officers from 2 TAO (Tambon Administrative Organization), and a fishery officer participated as observers. Before the beginning of the game, the results of simulation runs were presented to the stakeholders who participated in the first RPG session. The gaming session started with the same

Fig. 6. Discussion among stakeholders during a role-playing game session.

baseline scenario (scenario B) played during the first RPG session. Discussions led to the selection of additional scenarios to be played. Scenario Rsr, defined during the first RPG session and explored with the ABM, and was selected again. Additionally, two new scenarios were identified. Some participants claimed that the harvesting method formerly used in Don Hoi Lord (applying lime directly on the sand, which has been prohibited for the past 20 years, as reported in Section 2), would ensure better harvest. To check this statement, a scenario (called HM for Harvesting Method) assuming absolute efficiency for the harvesting method (no clams left in the sand after a location has been harvested) was defined. Other participants proposed to test a scenario that would impose individual quotas (IQ) with a maximum of 3 kg per harvester per day.

The results of this second RPG session are presented in Fig. 10. The highest razor clams harvest occurred for scenario *HM* but at the same time this scenario was shown to be unsustainable.

Free discussions led to preference given to scenario *IQ*. A new issue emerged during the discussion: if more clams are sold to the trader, the buying price is likely to decrease. Fishermen requested a guarantee on razor clam price if this scenario was to be applied in the future. Local government officers who participated in collective discussion were also in favor of the quota system.

6.4. ABM simulations related to the second RPG session

After the second RPG session, the individual quota (*IQ*) scenario was implemented and run with the ABM, and then compared to the reserve (*Rsr*) scenario. We also implemented a scenario which

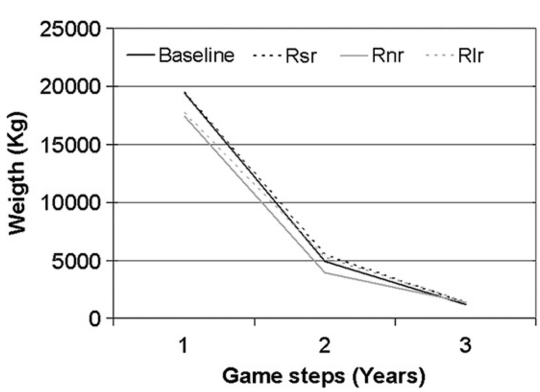

Fig. 5. Results from the first RPG session. Total harvested razor clams from all scenarios through out the 3 steps of each game. Baseline scenario; Rsr: reserve (prohibited zone) with short rotation (3 months) among zones; Rnr: reserve without rotation (permanent prohibited zone); and Rlr: reserve (prohibited zone) with long rotation (1 year) among zones.

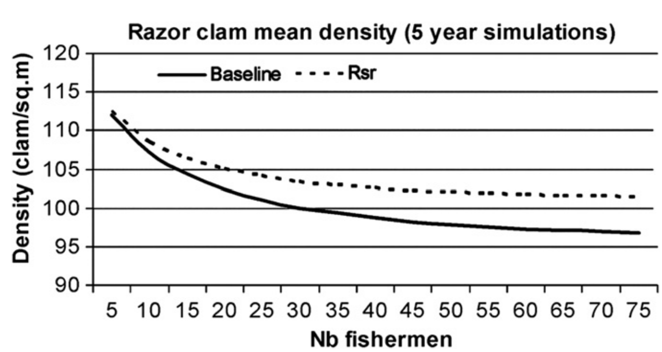

Fig. 7. Results from the ABM simulation. Razor clams mean density (clam/m^2) for baseline scenario (B) and reserve short rotation (Rsr) over 5 years.

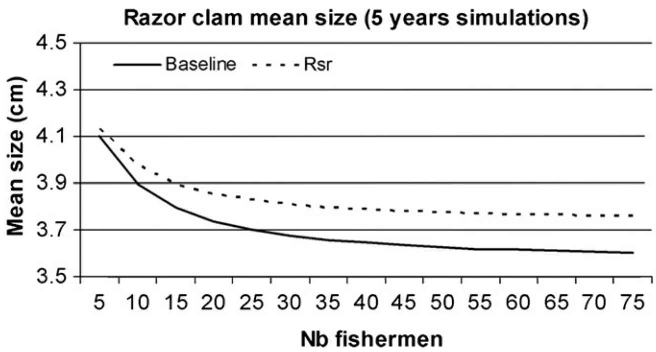

Fig. 8. Results from the ABM simulation. Razor clams mean size (cm) for baseline scenario (B) and reserve short rotation (Rsr) over 5 years.

combines reserves and individual quotas (Figs. 11 and 12). Qualitatively we observe that the IQ scenario produces better results for both indicators, however, when the fishermen number is very high, the quota has no more effect (fishermen harvest less than the quota), but the reserve scenario still has a small effect.

6.5. Discussion about management options with the policy makers

A few months after the second RPG session, the local government invited the research team to present the results of the ComMod process to the provincial administrative organization in charge of resource management in Don Hoi Lord. The governor of the Province expressed his interest and commitment to implement various regulations as part of conservation and management policy in the future. He was keen to follow the suggestions coming from the ComMod study: to set up a razor clam individual harvesting quota and to guarantee the buying price to local fishermen by using provincial funding support. Unfortunately, a few months later, this governor was removed and as a result his plan remained unimplemented. His successor was less interested in the conservation aspects but more motivated in promoting Don Hoi Lord as a popular destination for domestic and international tourists.

7. Discussion

7.1. ComMod process

The ComMod process in Don Hoi Lord is still ongoing. This paper describes a cycle of participatory workshops where the main achievement was involving the stakeholders in building a shared representation of the razor clams fishery. By taking part in this process, in particular by collectively discussing the simulated effects

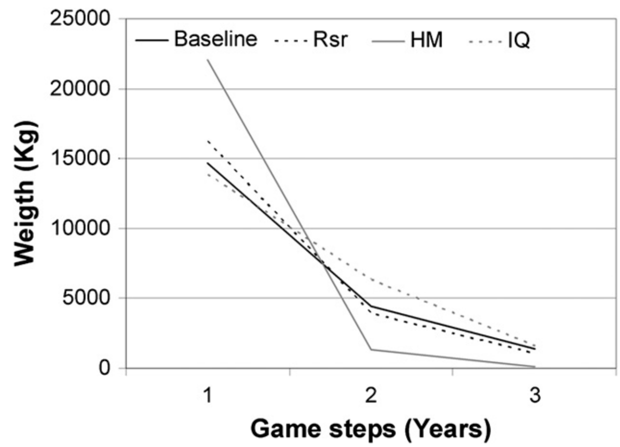

Fig. 10. Results from the second RPG session. Total harvested razor clams from all scenarios through out the 3 steps of each game. Baseline scenario; Rsr: reserve (prohibited zone) with short rotation (3 months) among zones; HM: previous harvesting method resulting in 100% catchability; IQ: individual quota system.

of some management options they had suggested, stakeholders have improved their understanding of the system, which is a key step towards setting-up institutional and policy support for natural resource management plans. This kind of opportunity to convey the research results and thereby convince the governor to pay serious attention would not have occurred if the team and the local authority, such as the village head, had not had developed consensus and a firm belief in conserving the razor clam fishery. This also underlines the importance of the close and lasting relationship between the researchers and the villagers, which in this case was developing over 20 years. This long lasting relationship raised the level of trust, friendship and participation that lead to the successful implementation of natural resource management options.

One very important result of this process is that new stakeholders were identified during the first RPG and were invited to attend the second RPG. It was clear that playing the management role with a restricted set of stakeholders was not productive. The challenge was to support the negotiations with all the harvesters represented. The strength of the iterative Commod methodology is that the importance of other stakeholders was revealed by the stakeholders themselves and their presence was requested by the main village fishermen as soon as the discussion got focused on management. The scale (several villages instead of one) at which this issue should be tackled was collectively identified. In general the Commod process (mainly through RPG) reveals the interactions between stakeholders involved in a decision-making process. In the second step, after the stakeholders had come to a collective

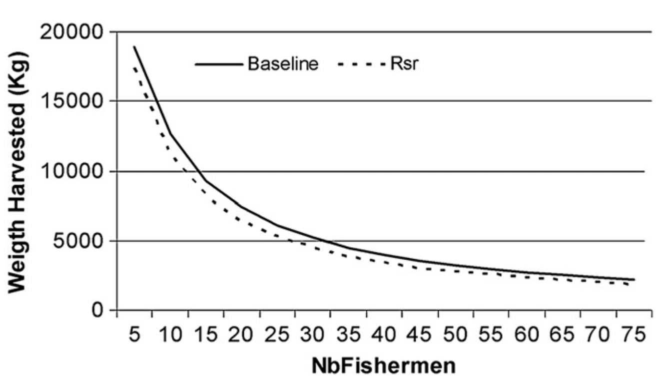

Fig. 9. Results from the ABM simulation. Harvested clams (Kg) for baseline scenario (B) and reserve short rotation (Rsr) over 5 years.

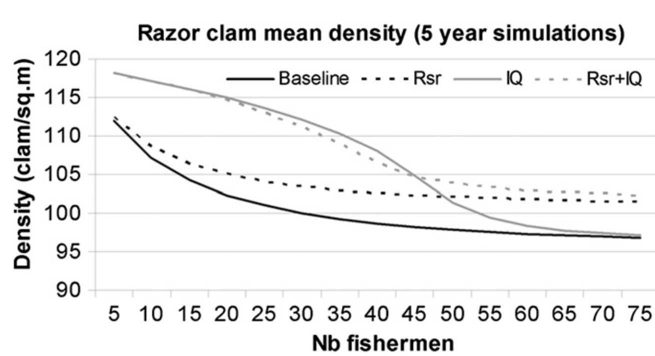

Fig. 11. Results from the ABM simulation. Razor clams mean density (clam/m^2) for 4 scenarios: reserve short rotation (Rsr), individual quota (IQ) and reserve short rotation plus individual quota (Rsr + IQ) over 5 years.

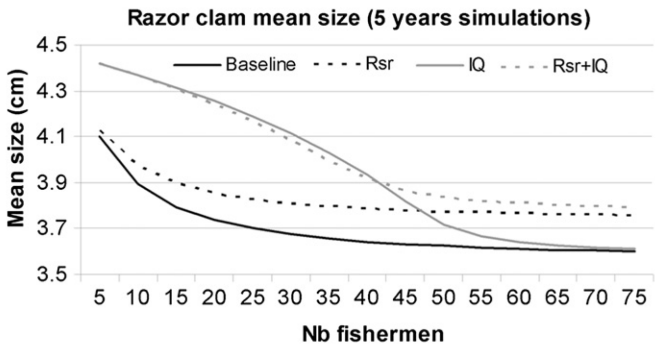

Fig. 12. Results from the ABM simulation. Razor clams mean size (cm) for 4 scenarios: reserve short rotation (Rsr), individual quota (IQ) and reserve short rotation plus individual quota (Rsr + IQ) over 5 years.

agreement (expressed collectively in open discussions and later on expressed by several individuals during informal discussions), the case was brought to the upper level (see Table 1).

Personal interviews after the second RPG session indicated that the companion modelling process implemented in Don Hoi Lord helped stakeholders to better understand the resource problem (including the uncertainties and gaps in knowledge) and also to effectively conduct collective discussions. Options for the management of the razor clam fishery emerged from the successive RPG sessions and were collectively assessed. During this process, knowledge was shared between researchers and stakeholders concerning the different perceptions of razor clam population dynamics, the evolution of razor clam harvesting and management by stakeholders. It also underlined the lack of certain scientific knowledge and allowed us to identify new research. For the fishermen, the process is also ongoing as those who had experienced the ComMod process start to share the information with other fishermen.

In this study we experienced the limits of participatory modelling when limited to the local level without the endorsement of decision-makers (the governor) at a policy-making level. The fact that the previous governor, who endorsed the process, was replaced by another governor with different objectives stresses the fact that management of renewable resources is a continuous process, with surprises and unexpected changes. The companion modelling process was conceived to be adaptive enough to cope with such dynamic aspects. But in Don Hoi Lord, we had no time and resources to invest in a new round of mediated interactions with the new governor and the associated government offices.

7.2. Modelling tools

While RPG is more efficient in sharing knowledge, ABM is more efficient at quickly exploring scenarios and integrating scientific knowledge. Running in parallel RPG and ABM is an original set up compared to other participatory experiments (Barreteau, 2002). In some cases the computerised model is developed first, and serves to synthesise knowledge with the objective to support a RPG. Sometimes, once the process with the stakeholders is started and the scientific model is no longer needed for the following interactions (Barreteau et al., 2001; Barnaud et al., 2007). In other cases, the RPG is set up first and serves as an elicitation tool for a model which is used at the end of the process (Becu et al., 2003; Promburom, 2004). Here the model was first used to assemble information and data about the fishery. Then the RPG was used to share the scientific information from the scientists to the stakeholders. This knowledge was shared and management scenarios were identified. Agent-based simulations were conducted to explore the scenarios identified and prepare a second RPG, which focused on a new management system. The similarity between the two tools (RPG and ABM) allowed maintenance of a consistency between workshops with stakeholders and laboratory simulations.

7.3. Coping with the ecological complexity of the recruitment process and regulatory strategies

During the participatory workshops with the stakeholders in Doi Hon Lord, several regulatory strategies have been collectively derived from the simulations results and discussed. Indirect effort regulation by individual quotas was well accepted by every participant except the clam trader. In theory, a direct effort regulation by creating reserves represents a suitable regulatory tool for species with limited mobility or which aggregate in predictable locations at certain times in their life (Lauck et al., 1998). However, the decision making related to the location, size and time period for the reserve areas is a scientific problem that requires accurate and specific knowledge about the species' biology. The challenge is to ensure that the reserve area will be a metapopulation source (rather than a sink) of larvae (Perry et al., 1999).

In 2008 new research was undertaken and it showed a dramatic decrease of clam population (Fig. 13). Given the fact that the fishing effort has not increased dramatically it may be due to an ecological event or due to the fact that fishermen started to harvest lower size clams. Or it is due to the poor quality of recruitment modelling: the recruitment process in the model is maybe too productive making the population more resilient than it should be. Due to lack of knowledge about the razor clam recruitment in Don Hoi Lord, the recruitment of small clams was represented in the model as a stochastic process depending on the number of females and related to the space left available by resident clams (defined as the difference between the local carrying capacity related to the grain size and the actual local density).

Table 1
Stakeholders involved in the ComMod process at Don Hoi Lord.

	Fisherman	Local gov.	Trader	Fishery officer	Provincial gov.	Total
First RPG	11(1 village)	3 (1 gov.)				**14**
Second RPG	10 (2 villages)	4 (2 gov.)	1	1		**16**
Discussion policy	40 (4 villages)	not counted (3gov.)	not counted	not counted	not counted	**60**

☐ Yes ▤ No

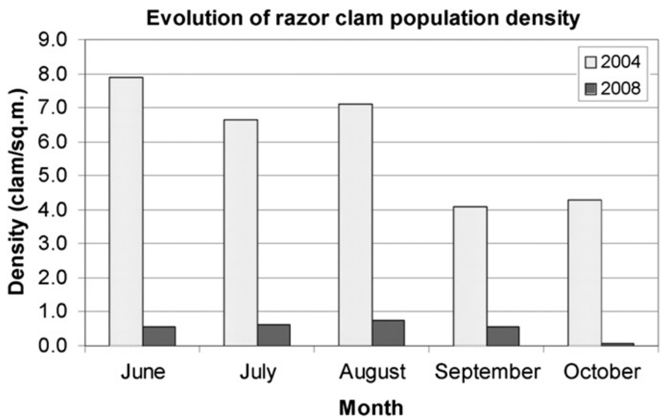

Fig. 13. Observed mean razor clam density at Don Hoi Lord in 2004 and 2008.

It is now widely recognised that the recruitment of benthic invertebrates like razor clams relies on a combination of density-dependent (biological) and density-independent (physical and chemical) factors that all have the potential to influence the settlement of larvae (Andre and Rosenberg, 1991; André et al., 1993; Whitlatch and Osman, 1998). Such a complexity gives rise to the observed spatio-temporal patterns which are characterised by high variability (Raffaelli et al., 2003). Benthic organisms display patchiness at a range of scales, from millimeters to kilometers and from seconds to years (Hall et al., 1994). The interconnection between the local populations of post-larval stages along the coast mainly exists through the planktonic larval stage. This aspect determines a decoupling between the local stocks of adults and the subsequent recruitment in the same local population. In some cases there is even evidence of source–sink dynamics in which only some of the local adult populations contribute reproductively to the next generation (Freire and Garcia-Allut, 2000). In the case of Don Hoi Lord, deeper investigations at both smaller and larger scales may provide key information to better understand how the recruitment is operating.

7.4. Challenges ahead

To continue, we would need to develop a new version of the ABM. To fine-tune specific management options, the model clearly lacks several key components. More field studies are needed for a better estimation of the real razor clam density without harvesting pressure, and also to understand how the environmental conditions may affect the recruitment of razor clams. The harvesting function in the ABM also needs improvement: it would be interesting to investigate certain economic considerations with the model, such as the impact of the marketing and fluctuation of prices according to the season and/or the size of the harvested razor clams.

An important methodological challenge is to get more commitment of stakeholders from higher organizational levels. The objective of companion modelling is to build a bottom-up process of institution development that goes beyond the expert-government decision maker matrimony. When the objective is to develop a common understanding of a resource management problem, a bottom-up process such as the one presented in this paper, is efficient. But if the objective is to modify the management system, other stakeholders should sometimes be involved. One option is to convey the local agreement to the higher levels, as was attempted in our case, but ran into some problems. The other option is to work with the higher-level stakeholders from the very beginning, but the difficulty then is to level the playing field between actors who have very different power.

8. Conclusion

Through this participatory modelling experience we have developed a model which was used in two ways: as the biological module of an agent-based model, to explore and compare management options by running simulations, and as a virtual resource for a fishery role-playing game. Both tools were used in sequence so as to promote progress in the mutual understanding between researchers and fishermen, identification of relevant stakeholders, definition of management scenarios and the identification of lacking scientific information. Modelling was shown to be a process of collectively assessing the available knowledge, sharing the perceptions of the socio-ecological knowledge and collectively brainstorming on management and future research. In short, despite the lack of knowledge and the associated weaknesses of the model, stakeholders have discussed various scenarios, they have acknowledged some emergent facts, such as that management through rotating reserves is not efficient if the duration of reserves is short, they have realised that the lack of knowledge on clam recruitment is a major problem in making conclusions about the usefulness of reserves, they have explored a new management option, which is the quota system, which efficiency is not dependent on missing knowledge about recruitment. The result of the companion modelling presented here is this collective-learning trajectory: the model is used to assemble knowledge, to reveal knowledge gaps and to draw lessons, which take into account the uncertainties. At the final stage, the local participatory process was even endorsed by the incumbent regional policy-making actor. His unfortunate and unexpected removal emphasises the limits of this kind of intervention and proves the need for continuous follow-up of the process and contact with various actors entering and/or leaving the system, which can radically change the interactions in the system and, therefore, the whole context of the intervention.

Acknowledgements

This research was supported by the Biodiversity Research and Training Program (BRT) and Chulalongkorn University graduated school and the French Ministry of Foreign affairs (SCAC-French embassy in Bangkok). The authors would like to acknowledge CU-CIRAD ComMod project at Chulalongkorn University and the stakeholders at Don Hoi Lord area. The authors are grateful to Mr. Jensen Sven for his editing work on a first version of this paper.

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