Proceedings of the 54th Conference of the International Simulation and Gaming Association

ISAGA 2023

SIMULATION AND GAMING FOR SOCIAL AND ENVIRONMENTAL TRANSITIONS

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EDITED BY **NICOLAS BECU**

La Rochelle, 2023

LIENSs UMR 7266 LIttoral ENvironnement et Sociétés

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La Rochelle Université

Harnessing the complexity of socio-ecosystems to design games as "viable metaphors": lessons from a case study in the lower Amazon floodplain fisheries

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Abstract. In the Amazonian floodplains, artisanal fishing is a historic activity of high socioeconomic and cultural importance. In the last decades, fishing and fishermen have been suffering from numerous socio-environmental threats, compromising the ecosystem and its biodiversity, and local population livelihoods. Since the end of the last century, fishing communities have pressured the government, civil society, and other social actors to assume and support a sustainable co-management of fisheries in the region based on fishing agreements. It is in this context that we have been developing the construction of a role-playing game called 'PescaViva'. Based on a companion modeling approach, the game has been built collaboratively, involving local fishermen/farmers leaders and environmental agencies representatives. Our aim is to develop a game that would meet not only the wishes of the research team but mainly the fishermen and people from the government. This paper describes how researchers, together with local actors, have worked on the challenges of the 'PescaViva' co-construction, considering the complexity of artisanal fishing in the Amazon and the scarcity of scientific knowledge about the activity. In some test sessions in the fishing communities, the game was understood, well-received, and associated with the local reality. It remains to be seen whether gaming sessions could be organized at the initiative of the local stakeholders themselves with the support of local facilitators in order to revitalize the dialogue and stimulate the construction and review of local fishing agreements.

Keywords: Fishing Agreements, Companion Modelling, Floodplains.

1 Introduction

Fisheries co-management is a difficult process worldwide [1] and artisanal fisheries in the Amazon floodplain are no exception. Floodplains are the periodically inundated margins of the rivers of the Amazon watershed. Because of the river's level variations along the year, the landscape is drastically transformed, between the low- and high-water periods, impacting both ecological and socio-economic dimensions. Floodplains have been occupied by the human population before the colonial period, relying on rich soils for agriculture and highly productive waters for fishing [2]. Fishing remains the main source of animal protein and income for Amazonian populations living in floodplain regions, [3-4]. Until the 1960s, fishing was a seasonal activity. From the 1960s onwards, technological innovation and the increase of urban population transformed fishing practices and favored large-scale fishing whose production is exported to cities and other regions of Brazil. Large-scale fisheries in the last decades have been exerting tremendous pressure on fisheries stocks [3,5] associated with freshwater ecosystem degradation leading to signals of overexploitation of some fish species and fisheries stock depletion [6-7]. The perception of fish stocks declining and the entrance of large-scale fishing boats in floodplain

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environments, considered communal properties, motivated populations living along the rivers to organize themselves to limit, or even prohibit, access to the flooded lakes, leading to significant conflicts in the region. This mobilization formed the basis for fisheries co-management on the Lower Amazon floodplain at the beginning of the 2000s [8]. However, only in 2021, *Pará* state issued a decree setting out the criteria for the formalization of community agreements and tasked representatives of artisanal fishermen (unions, fisheries council) and the municipal and state environment secretariats of *Pará* to accompany the process. From this, the communities felt motivated by the perspective of fisheries co-management evolution in the region.

It is in this context that we conducted our research in the region of the Great Lake of *Curuai* (*Lago Grande do Curuai*). A companion modeling (ComMod) approach was used to engage local fishermen in tackling the issues of sustainable fishing in the context of socio-economic pressures and hydroclimatic changes. Supporting decision-making processes is not the core objective of the co-design and implementation of a model, but there are demonstrated cases in which the ComMod methodology was able to foster agreements to common-pool resources sustainable management [9]. The ComMod approach [10] encompasses a large panel from computer-free games to autonomous agent-based models to explore solutions to a sustainable future. This paper presents a current experience with ComMod for fisheries co-management in the Lower Amazon floodplain and, in particular, the challenges we faced in developing a version of the game that would prove useful and be easily adopted by the local stakeholders involved in its co-design. Indeed, in some experiments, the game is only useful for researchers. Once the game has been designed, local actors and decision-makers cannot deal with it on their own. To address this, [11] argues that a game 'must function as a viable metaphor'. In other words, it must be recognizable, playable, and appropriate, making the game relevant to its target audience. Therefore, our aim in this paper is not to present the process that led the participants (including the researchers) to better understand the functioning of the system, but rather to relate the different steps with the actors involved that made it possible to represent the complexity of the system while keeping the game useful to users and managers as a tool to address issues about fisheries management.

2 The Lago Grande do Curuai floodplain

The floodplain of the *Lago Grande do Curuai* (Fig. 1) extends for one hundred kilometers (bounded rectangle -01°50′16″N - 02°15′12″S and -55°00′51″E - 56°05′00″W) along the right bank of the Amazon River in front of the city of *Óbidos* in *Pará* state. It consists of numerous lakes connected by channels. The flooded area varies roughly between 2200 and 600 km², depending on high and low water levels. Most of the municipalities in the region are administratively attached to the district of *Santarém*, but to the west, they are attached to the district of *Juruti* and to the north to the district of *Óbidos*. Under the auspices of the National Institute for Colonisation and Agrarian Reform (INCRA), most of the communities in the region have been consolidated through agro-extractivist settlement plans (PAE). *Lago Grande* PAE covers about 250,000 hectares and includes more than 128 communities. In this area, the land is shared collectively, and the use of renewable resources and the development of economic activities are regulated by a plan of use drawn up by representatives of the Federation of community associations, FEAGLE [12]. According to local fishermen, fish production in the *Lago Grande do Curuai* floodplain, which was historically very high, is now much lower. Fishing is regulated locally by community or inter-community agreements. However, invasions by large-scale fishing boats from other communities or regions are common. Agreements are not necessarily systematically respected within the communities themselves.

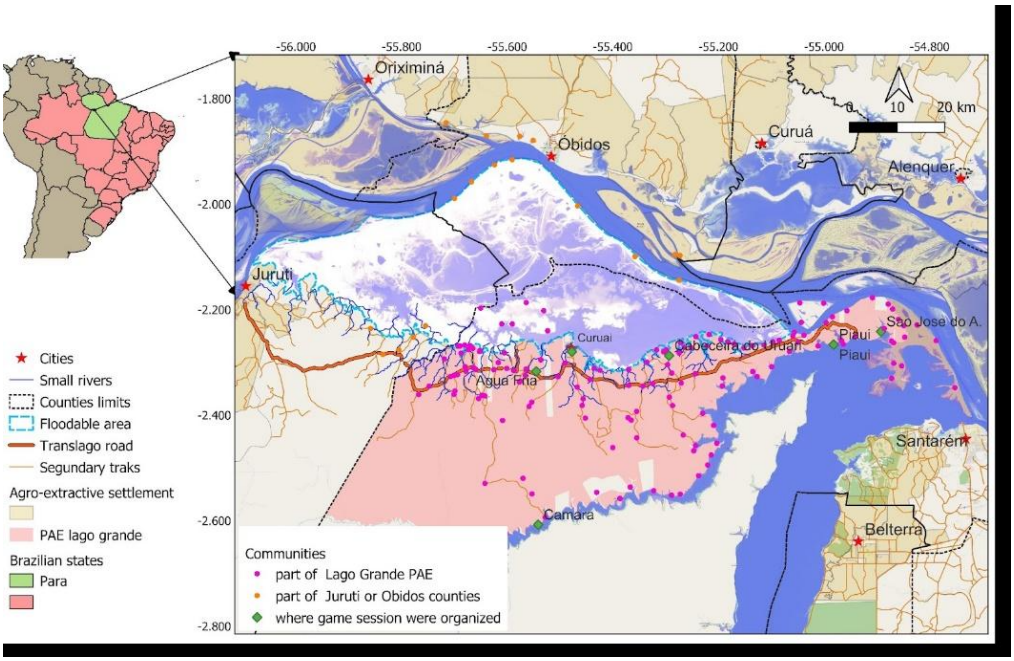

Fig. 1. Study site. The administration of the floodplain of *Lago grande do Curuai* is the responsibility of three counties: *Jurutí* for the western end, *Óbidos* for the northern part, *Santarém* which covers most of the floodplain and adjacent uplands. The *Lago Grande* PAE extends south over upland to the *Arapiuns* River and encompasses communities in the *Arapixuna* to the east. It includes only a part of the communities of the floodplain, those that depend on the county of *Santarém*.

3 Mobilization process for the *PescaViva* game design

We started the mobilization process in October 2019. However, the Covid epidemic forced us to interrupt our interactions with stakeholders for almost two years. During this time, we built a prototype of the game based on our knowledge and the literature. The challenge here was to make a game that would attract the interest of the stakeholders while remaining very simple, as we wanted to rebuild it entirely with them. Once the interaction with stakeholders was back on track, the state of *Pará* reopened the process of the revision of the fishing agreements by decree. In November 2021, we met with representatives of the fishermen' and farmers' unions of *Santarém* and neighboring districts (*Óbidos*, *Jurutí*). We also met with MOPEBAM (the Lower Amazon Fishermen's Movement, made up of 14 unions along the Amazon and *Tapajós* rivers) and FEAGLE. During the meeting, the representatives expressed their willingness to work together to revise the region's fishing agreements and, more generally, to develop an integrated management plan for the area. The co-construction process was thus carried out through monthly meetings with this regional focus group from January to December 2022. In the end, 10 meetings were held. Feedback on the game, testimonies on the daily life of the fishermen, and proposals for changes were collected at the local level, represented by the communities of *Lago Grande do Curuai*, and then presented to the focus group.

4 A role-playing game called *PescaViva*

4.1 Description of *PescaViva* game

The current version of *PescaViva* was designed to be played by four players/teams. The maximum number of participants is not strictly defined but should be between 20 and 30.

The game board

It depicts a floodplain with five fishing sites around which four communities are located. Two boards are used to represent the seasonal changes in the landscape throughout the year: 1) the *inverno* (winter) board represents high water, and 2) the *verão* (summer) board represents low water. On the *inverno* board, all the fishing spots are larger and connected. On the *verão* board, they are smaller and one of them is isolated (see Fig. 2). The fishing spots are materialized by jars placed under the board. Holes of the same size as the jars allow the players to "fish" with different fishing equipment. Each jar contains a certain number of small seeds, corresponding to a volume of water for each season, in order to reflect the variation in water levels between winter and summer.

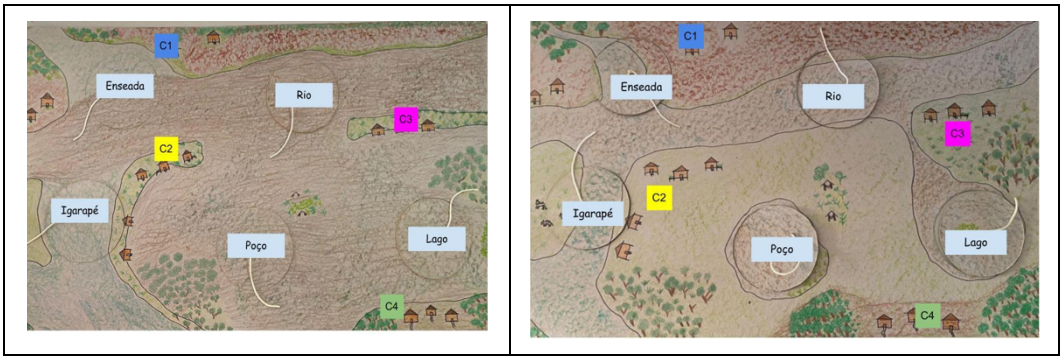

Fig. 2. On the left: *inverno* game board; on the right: *verão* game board. C1 to C4 indicate communities 1 to 4. Here the holes under which the jars are located are covered by round cardboard pieces.

The players can see the game board, the location of the communities, and the five fishing spots. However, they cannot see the fish stocks located in these spots. They can only estimate the stocks based on their catches when fishing.

The fish stocks

There are two types of fish in the game: Scaly fish and Flatfish, each represented by a sought-after species (e.g. *tambaqui* for Scaly fish, *surubim* for Flatfish), which is subject to a fishing ban (*defeso* period) during its breeding season, and a base species of lesser value. The four types of fish are identified by different colored pearls. The varying density of fish in each site and in both seasons is represented by the "amount of water" (weight of seeds) contained in each jar. The pearl fishes are thus "diluted" in the jars, which leads to different catch probabilities due to the dilution, but also due to the fishing gear used by the players.
The initial number of fish is chosen in such a way that the stocks are partially depleted quickly. Fish reproduction and migration are represented by a simple law. The resulting updates are made at the beginning of the summer season. Some predators are also introduced in the jars: the '*boto*' (pink dolphin), the *jacaré* (cayman), or the *piranha* (a carnivorous fish). While fishing, players may accidentally catch predators. These predators will not only eat the fish (thus reducing some of the fish catch) but will also damage the fishing gear.

The fishermen

Each player (or team) takes on the role of a fisherman in a floodplain region. If the game is played as a team, one of the team members will also take on the role of president of the community association and will be involved later in the game in the process of negotiating a fishing agreement. Each player belongs to one of the four communities (C1 to C4, see Figure 2) and is given a profile card containing information about the size of their family, two fishing gears: *miqueira* and *malhadeira*, two types of gill nets that differ in mesh size, fishing capacity, and material; and an initial amount of money ($15).

Other roles in the game

These roles can be played by the research team or by participants who already know the game.
- The " salesman " buys the fish. The price varies according to the type of fish and the fishing gear used. He also sells food (to feed the family) and two types of gill nets, and a cast net (*tarrafa*), which is usually used in the summer. It allows the fisherman to throw back any unwanted catches. The seller pays the *seguro defeso*, a subsidy set by the State as compensation for the prohibition on selling certain sought-after species during their breeding season.
- The Environmental Agency Patrol (SEMAS) can inspect the fish to be sold during the fishing ban and, in the event of non-compliance, confiscate the fishing equipment and/or impose a fine.
- The *geleiro* is a fisherman. His boat has a large cooling capacity. He arrives before the banned period ends. He has access to all the fishing spots. He uses his hands to catch fish to "simulate" his large fishing capacity.

The formal description of the model

The following UML class diagram (Figure 3) gives an overview of the game elements, their attributes, and their relationships. The colored boxes refer to the tangible elements of the game that can be manipulated by the players. Their names were kept in Portuguese because the game was co-designed during participatory workshops with Brazilian colleagues. The four types of fish are Scaly Fish (*Escama*) and Flat Fish (*Liso*), which in turn are divided into desirable (*Valioso*) or basic (*Básico*) species. The five fishing spots have names: *Enseada* = Creek, *Poço* = Well, *Igarapé* = Stream, *Lago* = Lake, and *Rio* = River.

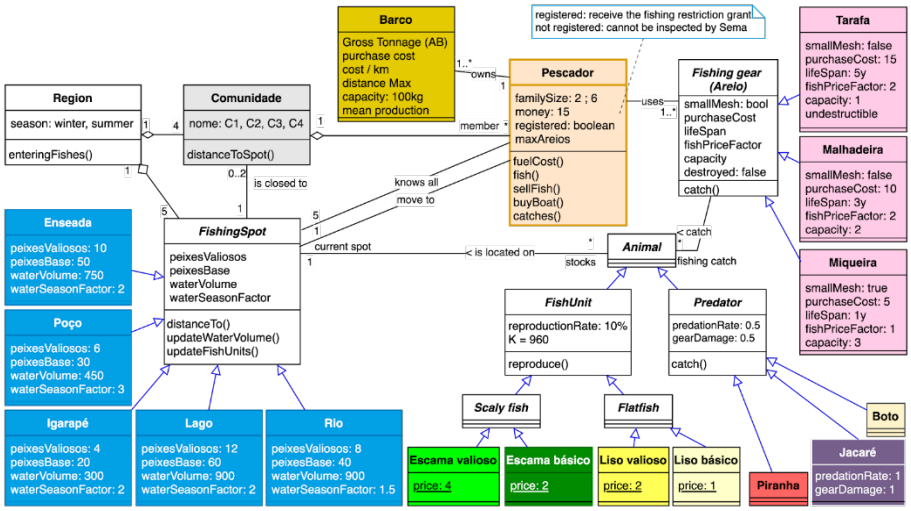

Fig. 3. UML class diagram representing the structure of the model behind the game.

4.2 Game sequence

A round of the game (1 year) is divided into three stages. The first is played on the *inverno* board (March to June), the second (July to October), and the third (November to February) on the *verão* board. The last step is called *defeso*. During this period, the sale of sought-after species is forbidden. The Environmental Agency (SEMAS) can carry out some controls.

Each player is invited to fish in turn at each stage. Each gear can be used once in each location. After the selection of the fishing spots, the selection of the fishing gear, and the payment of the fuel (the further the fishing spot is from the location of the community, the higher the fuel costs), the player can fish. To do this, the facilitator gives the player a small cup (the size

of which varies according to the fishing gear). The player puts the cup in the chosen fishing spot and tries to catch fish (Fig. 4).

Fig. 4. The action of fishing in the PescaViva game board.

Before and in between fishing actions, players can visit the Fishing Market, where they can buy new equipment, sell fish and buy food and consumer goods. During the third stage, if the player is not fined by the SEMAS, he will receive the *seguro defeso* from the salesman.

4.3 Organization of a session

In its current version, a session of *PescaViva* covers 10 years of fishing. We combine pure role-playing with agent-based simulation. After the first year (three steps), which is played on the game board, the next four years of fishing are simulated using the agent-based model (ABM) of *PescaViva*, implemented on the Gama platform [13]. For this purpose, the recorded decisions of the players are read by the simulator, which generates the results by copying the behavior (fishing location and gear used) of the players. The results are shared and discussed with the participants after 5 simulated years. At this point, the four presidents of the associations are invited to set up - in 15 minutes - a fishing agreement within and/or between the communities. Then, in the sixth year of the game, the players return to the game board to fish. No instructions are given as to whether the fishing agreement is to be respected or not. Based on the fishing decisions in year 6, the ABM simulates the next 4 years as in the first cycle. Finally, the results of the 10 simulated years are shared and discussed with the participants.

The debriefing starts by asking for feedback from the players on the game itself. Then we question the choices made by the players during the game and the reasons for their decisions. Finally, there is a discussion on the realism of the game: relevance and suggestions for improvement or modification.

4.4 Examples of two sessions of the *PescaViva* game

In July 2022, two sessions were organized in *Lago Grande do Curuai*, the first one in *Agua Fria* and the second one in *Curuai* (see the locations in Figure 1 and the audience in Figure 5).

Fig. 5. Left: Game session in *Agua Fria*, 25/07/22: players selling their fish at the market. Right: Game session in *Curuaí*, 26/07/22: players fishing on the board game.

Observing the socioeconomic conditions, *Agua Fria* is representative of a community lifestyle whereas in *Curuai*, the fishermen, more numerous and more diversified than in *Agua Fria*, follow more individualized trajectories. We wanted to assess to what extent the participants would jump into the game and found it somehow related to their reality. Table 1 displays the results in terms of variations in total fishing effort.

Table 1. Total numbers of fishing gears (Mi = *Miqueira*; Ma=*Malhadeira*; Ta=*Tarrafa*) used by players in *Agua Fria* (left) and *Curuai* (right) in each step of years 1 and 6.

Session	Agua Fria								Curuai							
Year	1				6				1				6			
Fishing gear	Mi	Ma	Ta	Tot	Mi	Ma	Ta	Tot	Mi	Ma	Ta	Tot	Mi	Ma	Ta	Tot
Inverno	6	3		9		5		5	6	6	1	13	4	7	3	14
Verão	3	4	3	10		5	3	8	8	8	1	17	5	6	3	14
Defeso	4	5	2	11			4	4	9	13	3	25	1	5	3	9
Ano				**30**				**17**				**55**				**37**

In *Curuai*, the participants increased their fishing capacity during the first 3 steps of the first year, while in *Agua Fria* the total number of gears remained almost the same. Faced with the results of the computer simulation in terms of poor catches at the end of year 5, it was decided in both sessions to reduce the intensity of fishing effort during the *defeso* period substantially (by 64%). In addition, the *Agua Fria* participants took the radical decision to ban the most destructive fishing gear (*miqueira*). The differences and similarities in the participants' basic attitudes and responses to the onset of the crisis seemed to us to be consistent with the way the fishery operated in the two places where we tested the game. More importantly, we received positive feedback from the majority of participants about the game's ability to allow them to project themselves into real-life situations.

5 Challenges in designing a game as a "viable metaphor"

Cleland (2017) suggests that games are "viable metaphors" when they are playable, recognizable, and suitable for the targeted stakeholders. The game is recognizable if the intended stakeholders can identify elements of their reality in the game. It has to correspond to the intended audience representation. By suitability, she means that the issues and scales (time, space) of the game must be in line with those that participants may have leverage over in their real lives. Finally, the playable principle refers to the balance between the freedom and structure of a game/model. A highly structured game/model can make the game very mechanical without much freedom and creativity for decision-making by the players. On the other hand, a highly open game can result in very random decisions, making analysis and discussions based on the game/model results

unfeasible. Finding the right balance between the different elements of the game to make it both attractive and interesting for the target stakeholders is therefore quite complex. We present here some lessons learned from the development of *PescaViva* and try to draw some guidelines.

The game's design is recurrently confronted with the complexity of the studied system. Too much complexity in a game often leads to too many rules, which are sometimes difficult to remember and can limit interaction between participants and their creativity. Complexity is therefore very much related to the playability of the game. However, a balance has to be found. Too much simplicity can make a game unrecognizable and participants will find it difficult to embody their role.

The way *PescaViva* presents fisheries in the Amazon is the first example of the balance between complexity and simplicity. Literature suggests that the catch composition varies between 29 and 45 fish species, which represents a large diversity of exploited fish compared to other fisheries [14-16]. Each species has its own biological and ecological characteristics, which influence its population and stock dynamics. The fishermen of the region use a great diversity of fishing gear, fishing is usually done with more than one fishing gear and the use of each depends on the variation of the river level [16-18]. What is the minimal structure of the game adopted in these conditions to keep a credible representation while keeping the game playable? Keeping in mind the central objective of the game "to discuss fishing agreements", discussions with the focus group led to the adoption of a description based on local categories of fish, each represented by two species, one called "basic" and the other called "valuable". This last distinction was important to be able to introduce the *defeso* period into the game and to bring into the debates, elements on the regulation of fishing and the role of the environmental agency. A similar approach was adopted in the Fish Banks model [19] for example, in which only two fish stocks are considered to mimic the deep ocean and coastal fisheries. The two fish "stocks" only differ by the parameters used in the law used to describe the fish population dynamics. Fish Banks game has been applied with students, researchers, and fishermen and was judged sufficient to bring discussion upon renewable resources management.

When designing *PescaViva* an important feature to be considered was the dynamics of the river in the floodplain. In the prototype, the hydrological fluctuation was defined according to the scientists' categories of rising, flooding, receding, and low water. This resulted in four game boards. In addition to the fact that in this version four rounds of the game had to be played per year, with the amount of water being updated in each round, which slowed down the game considerably and reduced its playability, the players did not recognize this division of time. They explained that there were two seasons that they considered when deciding how to fish: 1) summer, a time of low water with few rainy days; and 2) winter, a time of high water with many rainy days. Although the four periods were not unfamiliar, we decided to have two game boards instead of four: one for winter and one for summer. By including the *defeso* period, a year unfolds in three rounds.

On the other hand, too much simplicity may limit the recognizable features of a game. Literature suggests that lakes are the main places to fish in the region [16-17]. The prototype game board exclusively represented lakes, the river was represented but it was not considered as a fishing location. In the first few sessions of the game, however, participants had difficulty understanding why they could not fish in the river. We also noticed that some players had difficulty recognizing water or land, with water in the prototype being represented in blue, and land in brown. Specific drawing activities with the stakeholders (Fig. 6) allowed us to list the different important fishing sites in the region. From the many fishing locations drawn during these activities, we selected five that seemed most important to the focus group and adopted their color code (the water is brown and the land is a mixture of brown and green) to completely revise the game board. Using participatory mapping to collectively design the game board is therefore important, and is often used by game developers [9].

Fig. 6. - On the left: initial gameboard drawn by the research team. On the right: a drawing of the fishing spots made by some participants of the workshops

Another important aspect of game design concerns the elements that influence the time needed to play the game. In the area of common pool resource use, it is necessary to play several rounds of the game in order to identify trends, as system responses are generally not immediate (e.g. declining fish stocks, gradual water degradation, etc.). Even if an attempt is made to simplify as much as possible the various actions to be taken during a game round, it is sometimes difficult to reduce the length of the game round. In the current version of *PescaViva*, for example, one year is represented by three rounds. With 4 players, this means about 30 to 40 minutes. However, it is difficult to mobilize participants for long game sessions, especially since the game is only one part of the organized workshops. A debate is systematically organized after the game. In *PescaViva* we chose a computer-based game to overcome this problem. The ABM reproduces the behavior of the players (fishing grounds, fishing gear used) for the next 4 years. This period is close to the duration of the fishing agreements in the communities where we work. Of course, the identical reproduction of the players' behavior over several consecutive years does not allow the game to be faithful to reality. However, it does provide sufficient elements for the debates that follow the actual game session. This computer-based support was also used in the *VárzeaViva* game [21]. The player fills in a decision sheet every 4 years. Again, this duration was chosen to match the growing cycle of the fields in the area being studied. However, speeding up the time with the help of a computer can lead to other difficulties: For example, it may not be acceptable for players to be able to change their decisions despite the conditions (e.g., continuing to use a type of net when fish stocks are already very low). The choice of the duration of the "projection" must be discussed with the participants. It must make sense in relation to their reality.

It is difficult to find the right balance between the "serious" aspects of the game and the elements that make the game fun. In some cases, these elements are intentionally detached from reality (e.g. drawing a lucky card: you have won the lottery) and, although fun, may not fit very well into the dynamics of the game. In *PescaViva*, fishing itself is an element of fun. Although the equipment for each type of net is the same for all, the players have more or less luck. Some fish a lot, while others catch little or nothing at all, and a "competition" quickly develops between the players. The game also includes predators. This was suggested by the focus group. When fishing, players are worried about encountering one of these predators. These playful elements in the game (predation, inequalities in catches) are often commented on in discussions because they correspond to real situations and cause sadness and anger among fishermen when they happen. Fun is considered a non-explicit goal of participatory game design [20]. In our experience with local actors facing serious socio-environmental problems and conflicting interests, the tensions generated by these problems can create a negative atmosphere during the game. Therefore, fun is

an important dimension to consider in order to reduce some of these tensions. In addition, the recognition principle of the game is also related to the elements of surprise mentioned above. Because it happened in their reality, the players accepted the loss of their catch and equipment when encountering predators.

Ensuring the suitability of the game has implications for the scales of space and time considered in the game. In *PescaViva*, this principle is evidenced when participants are invited to establish fishing agreements within the community and between communities which is a form of regulating fishing in the region. These scales (community and region) are the ones users deal with in reality to propose their agreements. Moreover, the game board incorporates "generic" fishing spots in the region. During the game sessions with the focus group, the participants tended to project themselves at the "regional" scale of the *Curuai* floodplain and stressed the importance of having agreements between the fishing unions of the municipalities of *Juruti*, *Óbidos,* and *Santarém*. During the community play sessions, players had no difficulty establishing "community" agreements to preserve fishing spots near their communities represented on the board. The time scales considered (5-10 years) correspond to those used to define the validity of these agreements. During the game sessions and discussions, however, participants stressed the importance of involving the environmental agency to enforce agreements and tax violators. The environmental agency is responsible for enforcing the *defeso* period, and given the evolution of legislation in the *Pará* state will also have to enforce the fisheries agreements. Introducing this role in the game and inviting representatives of these institutions to participate in the workshops of the focus group was important to make the game "suitable". By inviting the environmental institutions of the region to participate in the workshops, we allowed the fishermen to discuss and articulate their claims. Thus, the suitability of the game involves not only the scales of time and space represented in the game but also the composition of the group of participants engaged in its design.

6 Conclusion

Playability, recognisability, and adaptability are important principles to take into account when designing a game/model if it is to be useful and easily adopted by users and managers of socio-ecological systems. An indicator that we have achieved this with *PescaViva* was the report of the agents of the Environmental Agency of *Óbidos* who participated in the focus group. They used *PescaViva* in one of their activities in a fishing community in *Óbidos*. They did this without the help of the research team and made some adaptations to better suit their activity. They indicated that the results obtained with *PescaViva* were very positive in relation to their awareness-raising activities with the community.

The collaborative process with the actors of *Lago Grande do Curua*i and also being open to changes while designing the game was significant to develop *PescaViva* as a 'viable metaphor'. However, some challenges still remain. We intend that *PescaViva* can be a generic game for the lower Amazon floodplain. To validate it on a regional scale, which means to know if the game is representative of any fisheries on the Lower Amazon, sessions in different fishing communities are necessary. That is the current stage of the collaborative process. Some sessions have already been held and participants pointed out *PescaViva* as a game really related to their reality.

Another ongoing challenge that emerged in the last *PescaViva* sessions with the focus group was how to represent the social system of fisheries. The game barely explores this dimension. Indeed, the community is not used except for the initial distribution of players. Yet the social dimension obviously plays an extremely important role in fisheries management and by doing that, the game would be more recognizable. One way to address this dimension is to consider various Fishermen's profiles, which should significantly change the playability of the game. Thus, these changes could further strengthen the mediating role

of the game around fisheries agreements and, therefore, be more attractive to fishermen, organizations, and government leaders.

From this experience and to make the game useful for local actors and decision-makers, we conclude the need to engage in a longer participatory process. If, as initially planned, 10 workshops were carried out, we recognize that additional sessions with the focal group and other fishing communities will be necessary.

Acknowledgments:

This research is conducted within the framework of two research projects, the BONDS project (Biodiversa-Belmont Forum) with funding from the ANR, and the SABERES project funded by the BNP Paribas foundation. The first author thanks the INCT ODISSEIA (UnB/IRD) for the funding of his post-doctoral fellowship

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