Value based Agents for Social Simulation of Fishery Management

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Abstract. Although there have been many simulations of ecological systems that include social aspects of the persons involved, very little have considered the social aspects of the communities themselves as a separate system. In this paper we will integrate social, economic and ecological models in order to simulate a more realistic fishery community. We need this type of integrated model when we want to explore the effects of new fishing policies on these communities. We argue that a value based approach for the agents is essential and show how this can be used to integrate the different systems.

1 Introduction

There is quite some research about the complexity of ecological, economical, and social systems (Arthur, 1999; Marceau & Wu, 2002; Bryne, 1998). In complex systems there are feedback loops which cause the cause and effects of actions to be interdependent and thus small changes can lead to big effects that are difficult to predict. Such feedback loops have been regarded in combination of models, such as social-ecological systems, social-economical systems, and ecological-economic systems (An, 2012; Steinworth, Wang, & Zhang, 2010; Mayer, Donovan, & Pawlowski, 2014; Valbuena, Verburg, Veldkamp, Bregt, & Ligtenberg, 2010; Akopov, Beklaryan, & Saghatelyan, 2017; Lemoy, Raux, & Jensen, 2017). However, the feedback loop is usually on one of the ecological or economical systems and social factors are only taken into account to study ecological or economical decisions. In other words, despite the fact that these systems are called socio-ecological, they are ecological models with some social factors added to them.

In order to really account for both social and ecological phenomena we should take both systems as being full fledged complex systems with their own feedback loops, plus the connections between them. In this paper we argue that models of fishing communities need to have three subsystems: social, ecological and economical. The ecological model represents the interaction of the humans with the physical environment that influences their life most. The social model is needed to model the relations and interactions between the people in the community. The economical model is needed to represent the relation of the community with the outside world (if communities would have a closed economical system this could be incorporated in the social model). The dynamics of such a complex system is driven by feedback loops between these subsystems and within them. The combinations of these subsystems are modeled in many research efforts, whereas only a few of them considered the dynamic interactions and feedback loops between the subsystems.

In this study, we consider the full combination of feedback loops, feedbacks within each subsystem (social, ecological, and economical system) and feedbacks between each two of them (social and ecological, social and economic, and ecological and economic systems). In what follows we demonstrate the feedback loops within the social system, ecological system, and economical systems by giving some examples.

People have interactions, they influence each other's behavior, decision, and way of thinking. Waste sorting is a good example. Many people voluntarily contribute to waste sorting by separating their household garbage and help to recycle. It means that they do not get paid for their efforts. One intuitive reason of such a behavior is the desire of being accepted in the community where recycling is an accepted environmentally friendly action (Carlson, 2001). Thus, one recycles mainly because it is the norm and everyone does it. In a fishing community, a fisher may decide to fish at least as much as his neighbors, because he feels he has to win the competition and get a high status as a good fisher. In a similar way, a fisherman might feel he needs to invest in a new boat when all the other fishers in the community are doing so. He does not want to be seen as less modern than the rest.

In addition, people have interaction with the environment. For instance, they use the facilities provided by the environment (i.e. water and food). They affect the environment through over-using or misusing of the resources and dumping of industrial wastes in the ocean. They will react to the environmental changes.

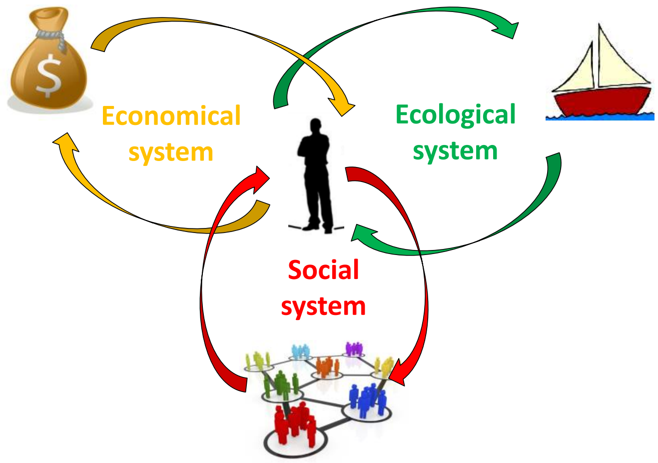

Fig. 1: Feedback loop in a social, ecological, and economic system

There is previous research modeling socio-ecological systems in various fields, such as fishery, land-use, and agriculture. Hunt et. al (Hunt, Sutton, & Arlinghaus, 2013) present a socio-ecological framework and illustrate the connection between the fishers' actions and the environment with several examples. One of the main impacts of the fishers' actions is changing the fish population. According to (Hunt et al., 2013) the management challenge is to consider fishers' desires and fish population at the same time .

Furthermore, general economic conditions and decisions affect the financial situation of all units of a society (companies, families, individuals, etc.). The financial situation is one of the important factors that plays a role in people's decisions. As an example, fishing companies that make a high profit can increase their quota by buying more from fishers. High demand for buying quotas can increase the price of quota. Thus, it could be more profitable for fishers to sell their quota and move to a cheaper country to enjoy a comfortable life.

The result of the system as a whole evolves based on the feedback loops and interaction between all subsystems and people as shown in figure 1. We discuss how values can be used to link the decisions of people in the different subsystems 2 by making them concrete in each context. Such a context needs to be appropriate to study the importance of taking into account all the subsystems and their interaction in a good balance. The basis of our simulations is fishery (Teh, Hotte, & Sumaila, 2017; Gordon, 2000).

One can see that the people are the connecting pin of the systems (figure 1). It is important for people to keep the overall system in a good balance. Symes and Phillipson (Symes & Phillipson, 2009) claim that many small scale fishing communities may not be viable in the long term; lack of balance between all the subsystems of their life is one of the key reasons. They suffer from lack of local facilities, such as school, hospital, housing, and limited access to public transport (Symes & Phillipson, 2009). These facilities cannot be provided for small communities due to the economies of scale. In this case, people have to leave the village, even though they have strong social connections and they experience a healthy environment. For individuals with a lot of money but no social relations the choice to leave becomes even easier. They will move based on economic reasons and build up new social relations in another community. (This might happen to fishers who sell their quota and are seen as traitors of the community). We claim that the way that people balance the different aspects of their life (the aforementioned subsystems) and make consistent decisions over all subsystems is through the use of abstract values that underlie all decisions in the end. Thus we need to model these values in the agents of our simulations if we take more than one aspect of life into account.

We will discuss the use of values in the next section. In section 3 we discuss the model that we build using value based decisions. In the section after we discuss the different types of influences that can be modeled based on our value based agent model. We show the first results of our simulation that indeed show some of

Value	Definition
Benevolence	: preserving and enhancing the welfare of those with whom one is in frequent personal contact (the 'in-group')
Universalism	: understanding, appreciation, tolerance, and protection for the welfare of all people and for nature
Tradition	: respect, commitment, and acceptance of the customs and ideas that one's culture or religion provides
Hedonism	: pleasure or sensuous gratification for oneself
Self-Direction	: independent thought and action;choosing, creating, exploring
Achievement	: personal success through demonstrating competence according to social standards
Power	: social status and prestige, control or dominance over people and resources
Conformity	: restraint of actions, inclinations, and impulses likely to upset or harm others and violate social expectations or norms
Security	: safety, harmony, and stability of society, of relationships, and of self
Stimulation	: excitement, novelty, and challenge in life

Table 1: A brief definition of the Schwartz' values

these influences and how they affect the balance of the complete system. We conclude with some conclusions and directions for future research.

2 Values

In order to connect the social system with economic and ecological systems, we propose to use agents with values. These values are defined in line with the Schwartz' value model (Schwartz, 2012). Values are criteria to evaluate actions and events (Dechesne, Di Tosto, Dignum, & Dignum, 2013). In our model, we use this definition and let the agents have a different ordering of values (priorities) which are considered into their decisions.

Each value has a different concretization in different situations for each agent (Weide, 2011). For example, universalism in Schwartz' value model can be made more concrete when it motivates the importance of protecting human life or even more concrete supporting refugees. It can also be made more concrete into respecting the environment (Rawluk, Ford, Neolaka, & Williams, 2017). In other words, the concrete effect of values is context dependent.

Agents have their own private priorities of values. They will decide what is the best action in each situation based on their value ordering. For example, if a fisher prefers hedonism over universalism, he might decide to fish more expensive species even if it is a threatened species.

It is worth mentioning that, the salience of a value depends on the situation, while the value ordering for each agent does not change over time. As an example, consider a situation where there is plenty of fish. The universalism value is not very salient for a fisher in that case. No matter how much he fishes the environment will not suffer. This changes drastically when there is not enough fish. In that case, the fisher has to balance between catching enough fish to survive himself and not too much in order for the fish to survive.

In accordance with Schwartz's theory of basic values (Schwartz, 2012), agents in our model have the following values: power, self-enhancement, universalism, benevolence, hedonism, tradition/conformity, and achievement which are the most relevant to the ecology and economy. Furthermore, these values can show the incompatibility of satisfying values simultaneously. The definitions of each value provided by Schwartz are mentioned in table 1.

In order to use these values in the simulation we decide upon the use of a set of more concrete values that are kept as minimal as possible while still covering all subsystems. Each adult agent that has family takes care of them (hedonism and benevolence). Having an income is important for each adult agent and promotes social status (power), but also can promote the financial support of family members (hedonism and benevolence), etc. Continue fishing against adversities, which is happening in many small fishing communities, promotes tradition and conformity. Adult agents prefer to work in a job according to their education and skills, as this promotes achievement. Taking care of the environment and engaging in public benefit activities are two other concrete values that agents have and which promote universalism and benevolence. Adult agents want to be financially independent as this promotes self-direction. The above indicates the set of values that all agents will in principle consider (when salient) in their decisions. Which decision is taken depends on the priority of the values.

For example, all the agents want to have income. But some will also prefer more income over a healthy environment. In the fishery environment, fishers try to catch fish as much as possible (based on their available facilities). In the case that there are some species which are in danger of extinction, those fishers who prefer the value of "taking care of the environment" more than "making more profit" will choose to catch fish from other species. Fishers with the value preference of the environment more than money, check the environment advocacy NGOs suggestion, advisory rules, and observe the environment before making a decision.

In the next section we will describe the role of values in our model.

3 Model description

We develop a multi-agent model that includes different types of agents and an environment (i.e. common resources, market, and facilities). This simulation includes human agents, fish species, a market place, a factory (that buys and preserves fish), and a university. The agents and their interactions with the common resources, market, and each other makes a socio-ecological-economical complex system. In this section we only describe the main characteristics of the model as space does not permit describing all variables.

Human agents grow up, give birth to children, work, are being retired, and die. The status of an agent in each time tick is an element of the set $\{child, retired, fisher, factory\ employee, jobless, employee\ outside\ the\ community\}$. We will discuss the actions of the agents in a separate section later on.

For the sake of simplification, we followed Bousquet approach(Bousquet & Le Page, 2004) and consider three types of fish species. *Small* species eats plankton, *Big* species eats *Small* and plankton, and *Predator* species is predator and eats *Small* and *Big* species. All fish species grow up, create offspring, eat, swim, and migrate.

In order to introduce sustainable behavior we introduce an agent that plays the role of adviser. This agent observes the whole ecological environment and determines which species need to be taken care of, which species are forbidden to catch, and which species are allowed to catch. Having this agent means that we do not need every agent to calculate the consequences of catching fish, but only distinguish agents in whether they follow the advise or not.

The Market is a place to buy and sell fish species. Based on the availability of fish species in the market and in the environment, the market price of each species will change according to supply and demand.

The Factory represents all industry in the community that is fish dependent. It buys fish from fishers, processes them, and sells it to the market. The factory employs people. There are limited vacancies for higher educated people as well (10% of regular vacancies). The factory increases or decreases the number of vacancies based on the available fish (caught fish by fishers) and its profit. The factory makes money from selling fish to the market and spends money for paying its employees' salary and utility costs. The factory has to accomplish maintenance periodically. If it cannot make enough profit, it gets subsidized with the public savings. If the savings cannot cover the deficits, it starts firing its employees until it reaches the minimum required number of employees. If using the public savings and firing employees do not save the factory it declares bankruptcy.

In this model, agents have all the values mentioned in section 2 including power, self-enhancement, universalism, benevolence, hedonism, tradition/conformity, and achievement. However, the priority of each value is different for different agents. For example, for male agents the importance of "making money" is higher than women (in average) due to the fact that most of the time men are responsible for financial support of the family (an empirical fact in these communities, not a desired one!).

Adult agents decide about their action in each time tick. Adult agents can continue their education at the university. They decide to continue or change their job status. The job can be inside or outside of the community. The jobs inside the community include $\{fishing, factory\ employed, retired, jobless\}$. There are two types of $factory\ employee$s, high ranked and regular. Without loss of generality, we consider only one type of job outside of the community with a fixed range of salary.

3.1 Agents' action

In each simulation time tick, each human agent acts as follows:

– Step 1. Working to earn money for agents aged between 18 (child) and 70 (retired);
– Step 2. Deciding to change or continue the current status that is only possible for agents aged between 18 (child) and 70 (retired);
– Step 3. Giving birth to a child that is only possible for agents aged between 18 (child) and 70 (retired);
– Step 4. Calculating the current time tick living cost;
– Step 5. Calculating the current time tick profit;
– Step 6. Deciding whether to invest in public benefits.

Except fishing, a fixed amount of salary is assigned to each job before starting the simulation. High ranked factory employees need to be higher educated and their salary is higher than regular employees.

Fishers need to fish and sell the fish to the factory or market in order to earn money. Fishers decide how much fish to catch, what are the target species, and which gears to use. To make such a decision, they take into account the ecological situation (advisory rules and their observations) and their personal values. Each agent has a parameter, called survival intention (SI), that shows how much is its intention to protect the environment. SI is a random number between 0 and 100 assigned to each agent when it is created. Maximum capacity of catching fish of each agent is determined according to its gear and physical power. Each fisher agent detects all the available fish according to its gear. Fishers check the market price and the advisory rules of all species at the start of each time tick.

If $SI = 0$, the agent starts catching fish from the most expensive available fish species that are not forbidden to catch. It continues catching fish until it has no more capacity. If $SI > 0$, the agent cares about the environment. Thus, it takes into account the advisor agent and its observations. Starting from the most expensive specie, the fisher agent hunts fish if the agent does not consider a significant decline in the population of that species and if that species is allowed to be fished. If that species is allowed to be fished, but their population decreases based on the agent experience, the fisher agent catches at most $(100 - SI)\%$ of them. In addition, if that species needs to be taken care of based on the advisory rules, the fisher catches at most $(100 - SI)\%$ of them.

In the second step, each agent checks whether it earned enough money (at least their living cost) out of the current status in the previous time tick. If the current status does not satisfy the basic living requirements, the agent decides to change the current status as described in Algorithm 1.

To change the current status, first the agent decides whether leaving the community or staying in is more preferable. This selection occurs based on the agent's personal value of intention to stay inside the community(ISI), where ISI is a real number between 0 and 100.

Algorithm 1 Changing status of an agent based on its personal values

```
set A ← {}
rand ← random real number between 0 and 100
if rand < ISI then
    set A ← {jobless}
    if  fishing is thriving & there is a vacancy for a new fisher then
        A ← A ∪ {fishing}
    if I am higher educated & factory has a vacancy for a higher educated person then
        A ← A ∪ {factory employee}
    if I am not higher educated & factory has a vacancy for a regular person then
        A ← A ∪ {factory employee}
else
    A ← A ∪ {employee outside community}
new status ← select an element of the set A
```

When an agent is born, the maximum number of children, in its lifetime is assigned to it. In each time tick, each adult agent with the probability of 50% gives birth to a child if its number of children does not exceed its maximum number of children.

Personal living expenses for each agent is represented by a number which is assigned based on its age and status. Each adult agent takes the responsibility of supporting its underage children, its university student

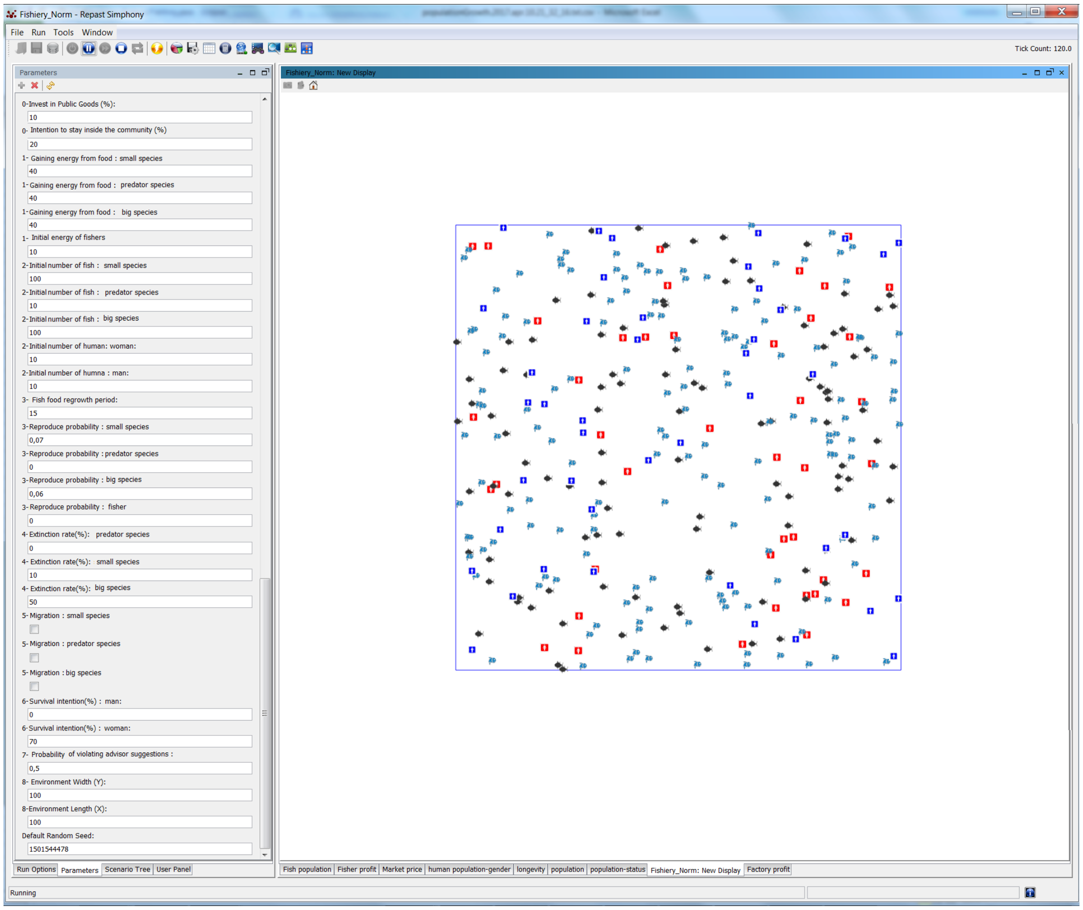

Fig. 2: Screenshot of the fishing simulation

children, and its jobless children. Therefore, the agent's living expenses are calculated by adding its children living expenses that are under its guardianship and its personal living expenses.

The current time tick profit of each agent is the amount of income that remains after living expenses and additions to public savings. Each agent may donate to the public savings from its profit according to a donation rat. The donation rate is a fixed real number between 0 and 100. Its value is determined before starting the simulation. The agent adds the current time tick profit to its saving. If the agent will become jobless or retired, it will use its saving money.

In figure 2 one can see some of the model parameters that can be set (Parameters tab), define output data and charts (Scenario Tree tab), and control the running options (Run Options tab). The main window shows the fishermen at sea and the different types of fish. In the next section we will show some of the results of the simulations.

4 Simulation experiments

In this section we discuss why considering feedback loops between all of the three aforementioned subsystems (social, ecology, and economy) is important. We design several simulation experiments in order to study the dynamicity of the feedback loops within and between those subsystems.

We model the complex system, that includes all subsystems, using Repast (North et al., 2013). As shown in figure 2, this model contains a lot of parameters that allows users to control the model.

We perform our simulation experiments for value based agents as mentioned before. For these agents some values have high priority. The concrete values with high priority include supporting family members, having income, and finding a job according to education. The other values change in the simulation experiments to

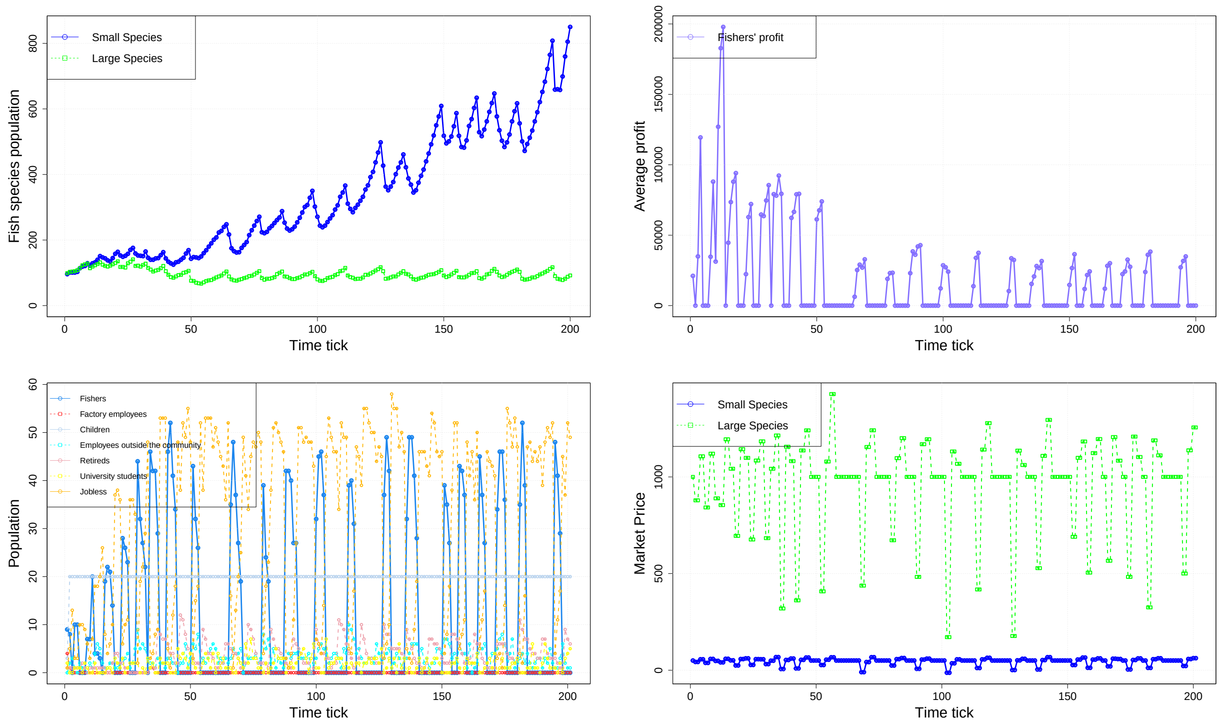

Fig. 3: The conditions of this experiment are population of the fish species is low (initial population, the amount of available food, and offspring rate are low); universalism and benevolence values have low priorities ($SI = 0$, no body donates); and tradition has a high priority ($ISI = 90$).

study their impacts on the whole system. We make changes in social variables (intention to stay inside the fishing community, care the environment, and donate for public benefit), ecological variables (fish species population by changing the offspring rate and available amount of food for fish), and economic variables (sensitivity of the market price of fish pieces to fish population and available amount of fish).

We start with calibrating the operation of each subsystem. In order to isolate one subsystem, the other two subsystems are considered in the extreme conditions that their changes are ignorable and have no effect. The extreme conditions contain infinite fish, infinite job vacancies, infinite money, fixed market price, and no human agent in the environment. However, it is not possible to completely isolate each subsystem from the others in this special model. For instance, the economic variable, market price, is connected to the available amount of fish in the market and estimation of fish population in the environment.

Figures 3 to 8 represent contribution of the three subsystems (social, ecology, and economy) to emerge the whole system situation over time. In addition, those figures clarify the feedback loops occur between all the subsystems. In each of the following simulation experiments, one parameter changes and the other parameters remain fixed in order to make it possible to compare the simulation results. The parameters involve fish population (that is controlled by offspring rate, the available amount of food, and initial fish species population), tradition value (ISI), universalism value (SI), and benevolence value (donation). The market price of each fish species is a function of two elements; the amount of available fish in the market; and the estimation of the available fish in the environment. There is a sensitivity rate that defines how much the market price is sensitive to the changes in those elements. The sensitivity rate is set to a high value in all of the experiments.

Figure 3 illustrates the situation that there is not much fish. Additionally, most of the agents do not care about the environment and do not donate to public benefits. Staying in the community has a high priority for most of the agents. As the fish population is not high, there is less opportunity for being a fisher. All of this makes it difficult for the factory to survive because it cannot buy enough fish and there is no external source of money (i.e. subsidy from the public savings). Thus, the number of jobless agents increases. Also, fishers catch the most expensive species that causes decreasing its population. Decreasing the population of the species results increasing its market price. As universalism has a low priority for most of the agents, the

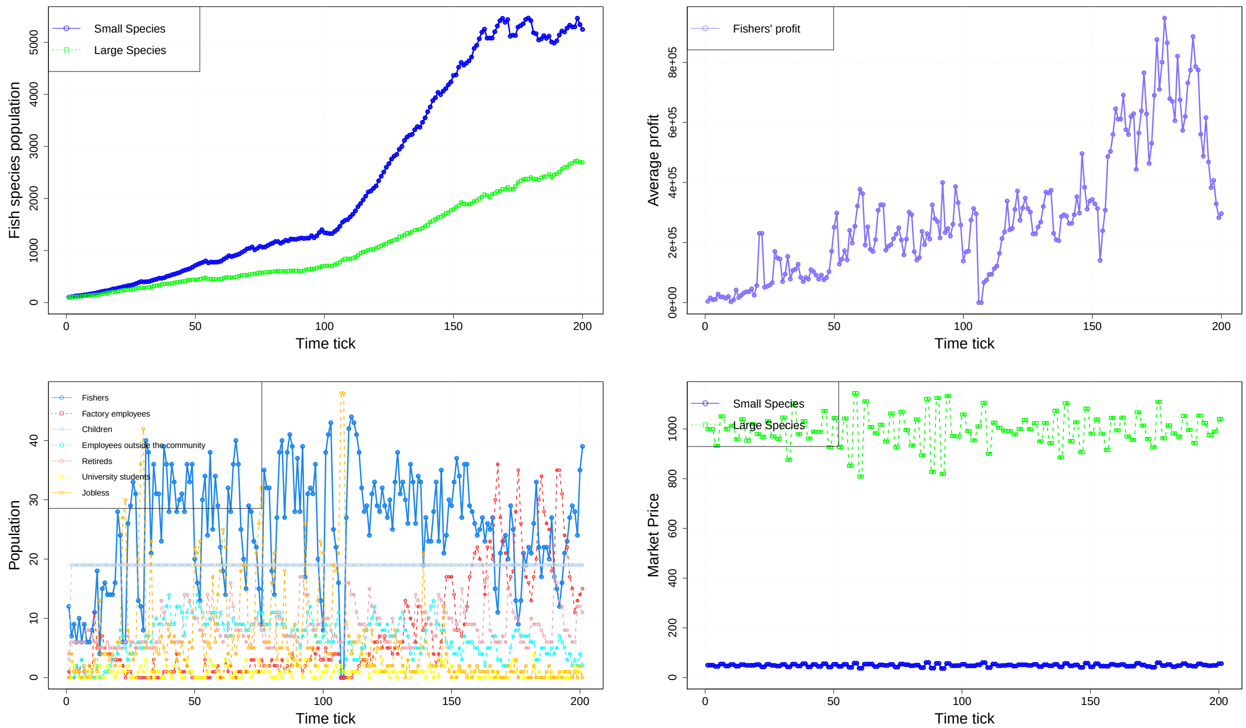

Fig. 4: The conditions of this experiment are a low fish species population (initial population, the amount of available food, and offspring rate are low); universalism and benevolence have high priorities ($SI = 100$, every agent donates to public savings);and tradition has a high priority ($ISI = 90$).

number of the most expensive fish species gradually decreases over time. Fisher agents do not fish cheaper species because there is not enough of them in the environment to satisfy the cost of fishing and living. In addition, fisher agents have to take their caught fish to the market (if the factory is bankrupt). In other words, they have to spend some time off-boat in order to sell their products. During this time period, they are jobless. When there are fewer fishers, there will be less fish in the market that results in increasing market price. This situation is a reason for making the fishing marketable, even if the amount of caught fish is not high. The feedback loops continue like this ever after.

According to figure 4, if a lot of agents are committed to their tradition value as well as universalism and benevolence, the system is in a balance. Agents take care of the environment while satisfying other requirements. Higher priority of universalism and tradition values mean that sustainability of the environment and the community are important for the agents. When the fish population is low, fisher agents do not fish more than they need and fish less than the amount that is harmful for the environment. Such a decision minimizes the risk of fish species population collapse. There is not a considerable change in the available fish species in the market and the environment in each two consecutive time slots. Therefore, the market price does not fluctuate a lot. Comparing figures 4 and 7, agents earn money a bit less out of fishing in this experiment (figure 4). However, fishers can fish permanently as fish keeps plenty. The factory keeps operating and gets subsidized when needed. Although most of the agents stay in the community, there is not a lot of jobless agents. The whole system is stable; the market price does not fluctuate a lot, the factory stays active, fish species population normally grows, and people stay and work in the community upon their personal values.

Low amount of fish in the environment does not necessarily lead to destroying the fishing community (figure 5). If the universalism and benevolence values have a high priority for the agents, there is a chance that the environment will be stable. Tradition value is one of the factors that influences attractiveness of fishing for the agents. When tradition value has a low priority, fishing is not an interesting job for many agents because fishing is a hard work with low income. Consequently, agents prefer leaving the community to look for a higher paid job. Fewer fishers stay in the community that are committed to the tradition value.

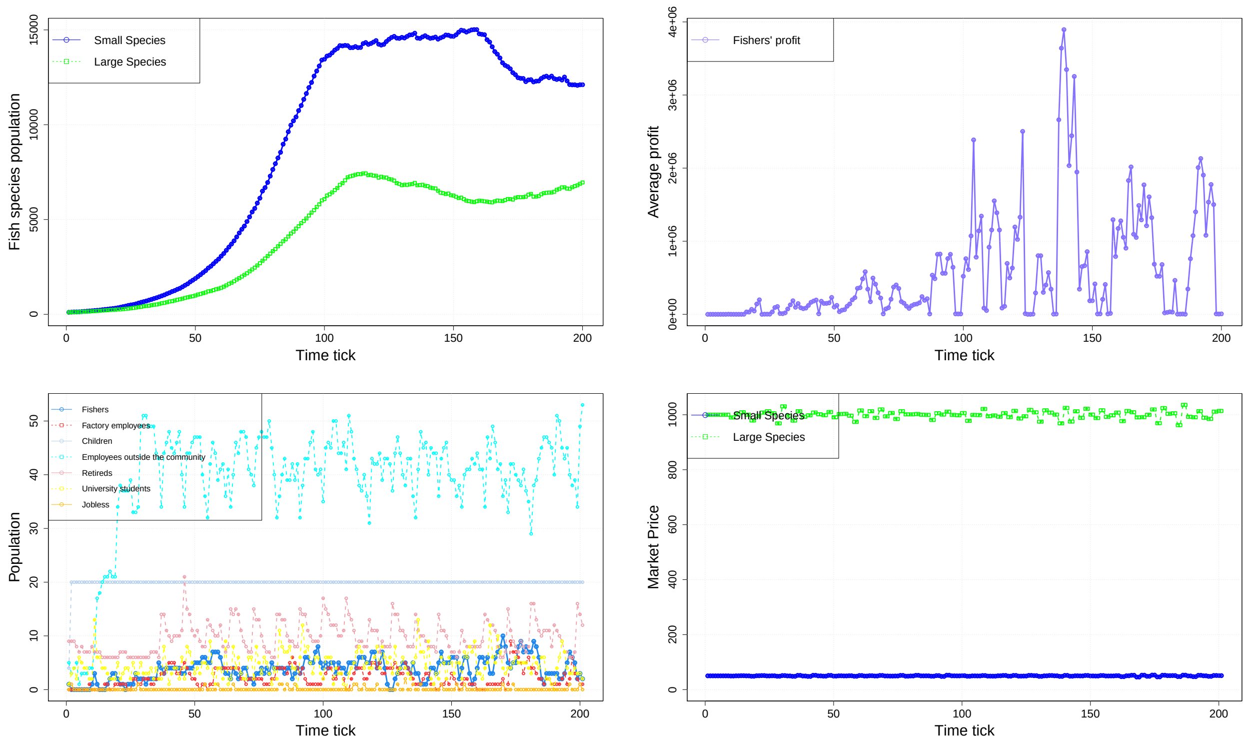

Fig. 5: The conditions of this experiment are a low fish species population (initial population, the amount of available food, and offspring rate are low); universalism and benevolence have high priorities ($SI = 100$, every agent donates); and tradition has a low priority ($ISI = 10$).

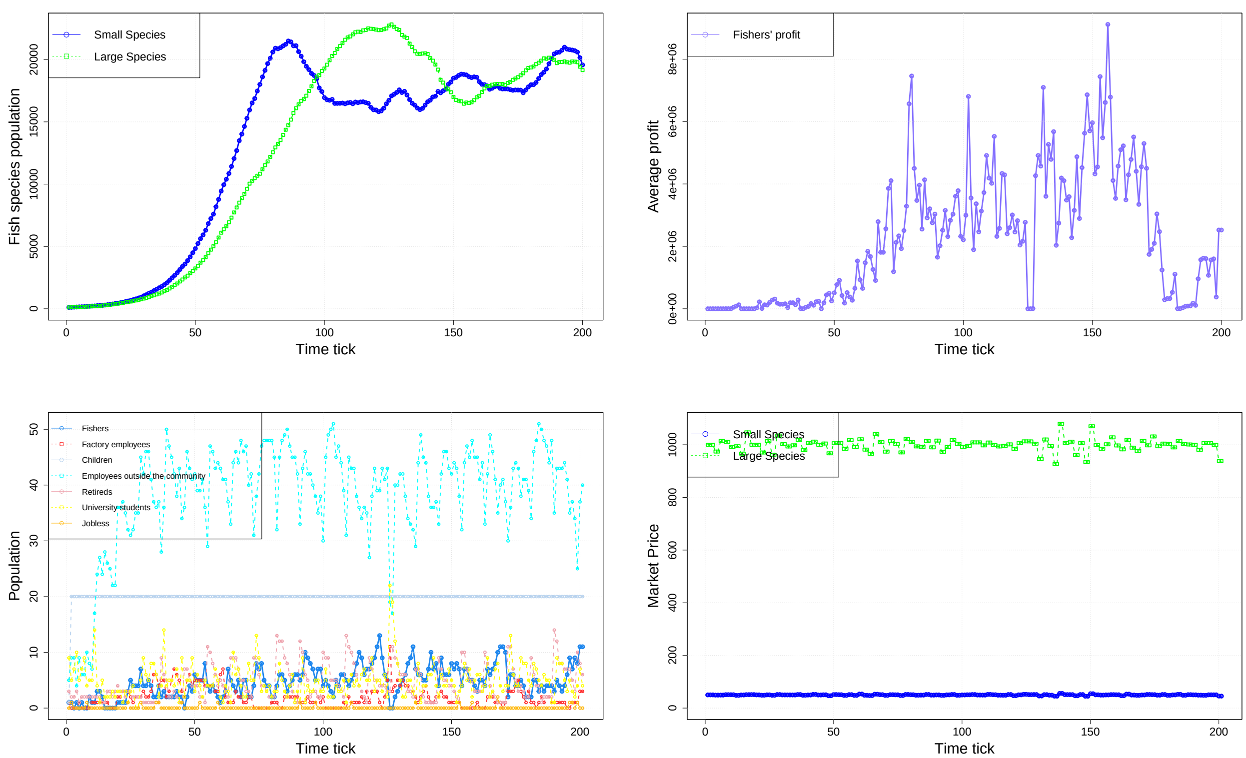

Fig. 6: The conditions of this experiment are a high fish species population (initial population, the amount of available food, and offspring rate are high); universalism and benevolence have high priorities ($SI = 100$, every agent donates); and tradition has a low priority ($SI = 10$).

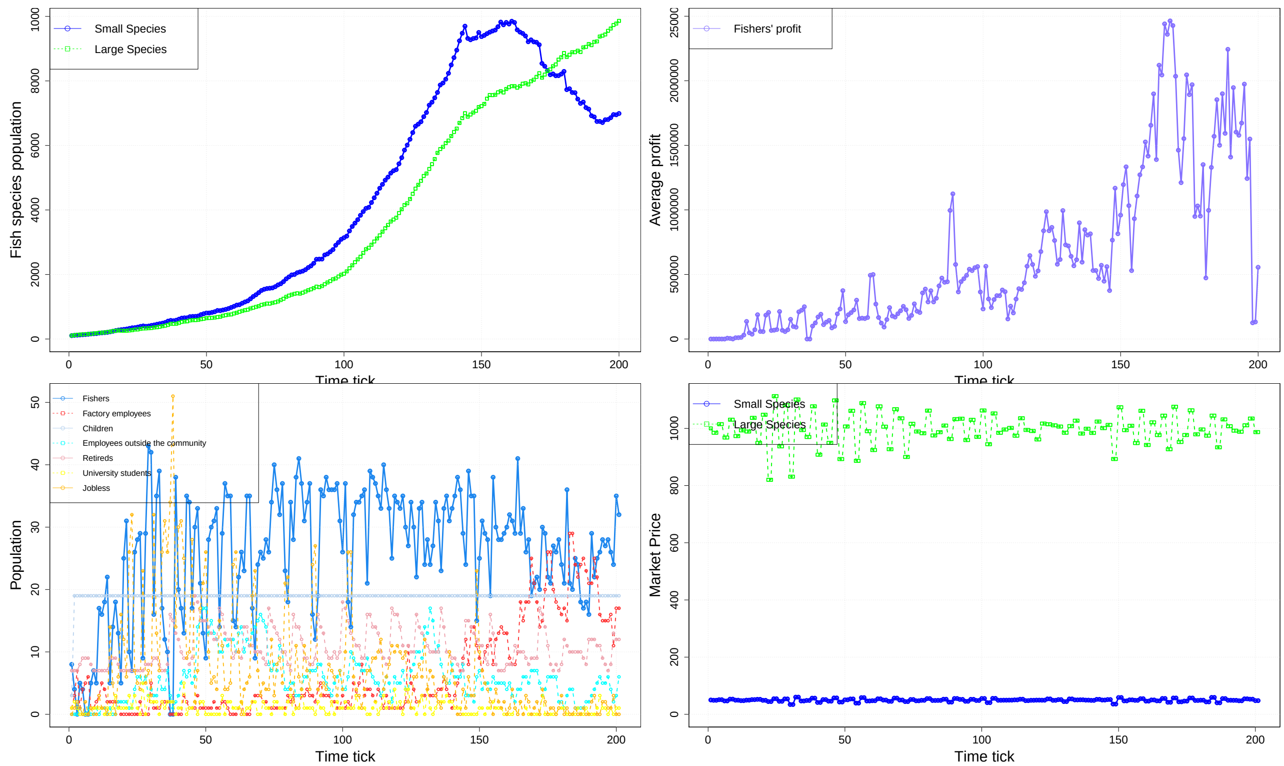

Fig. 7: The conditions of this experiment are the fish species population is high (initial population, the amount of available food, and offspring rate are high); universalism and benevolence have high priorities ($SI = 100$, every agent donates); and tradition has a high priority as well.

Some of them that do fishing can make enough profit. Also, the fishing factory continues its activity with the minimum number of employees. The amount of available fish in the market and the environment does not change a lot. Therefore, the market price fluctuation is not high. During the time that fishing is slack, the factory uses the public savings to survive. In a nut shell, the community is small but remains viable in this experiment. Comparing figures 6 and 5 demonstrates that fish population is not the only significant factor that impacts the whole system situation. The only difference between these two simulation experiments is the fish population, though the trend of the whole system is almost the same. The community, the factory, and the market are stable in both simulation experiments.

Increases in the number of fishers does not always lead to a decline in the fish species population (figure 7). If universalism and benevolence have high priority for the agents, they take good care of the environment and their community. Therefore, they are aware of the fish species conditions. They catch fish as long as it does not threaten the environment. As most of the agents have a high priority for tradition value, they prefer to stay in the community. Most of them do fishing and some of them work for the factory. Similar to the experiment shown in figure 4 agents keep working in the town, the number of jobless agents decreases, and the factory operates over time. The only difference is that when the fish population is higher, fishers fish more. The factory earn more profit accordingly which means it has more vacancy to hire more agents.

What will happen if a lot of agents want to stay inside the community and nobody cares about the environment (figure 8). The number of fishers increases and population of the most expensive species declines. Because catching the most expensive fish species is economically justified. Increasing the number of fishers makes more fish available to the market. Therefore, the price decreases. When the price diminished, the fishing is not interesting for many people anymore. Many people leave fishing. Thereafter, the number of available fish in the market decreases which causes the market price to rise. This flipping between fishery becoming an interesting job or not causes high fluctuation in the market price. As there is not always enough fishers (and available fish for selling accordingly), the factory does not survive. Additionally, the fishers in each time slot can be different agents. So, fishing communities are not stable and will not invest in the community.

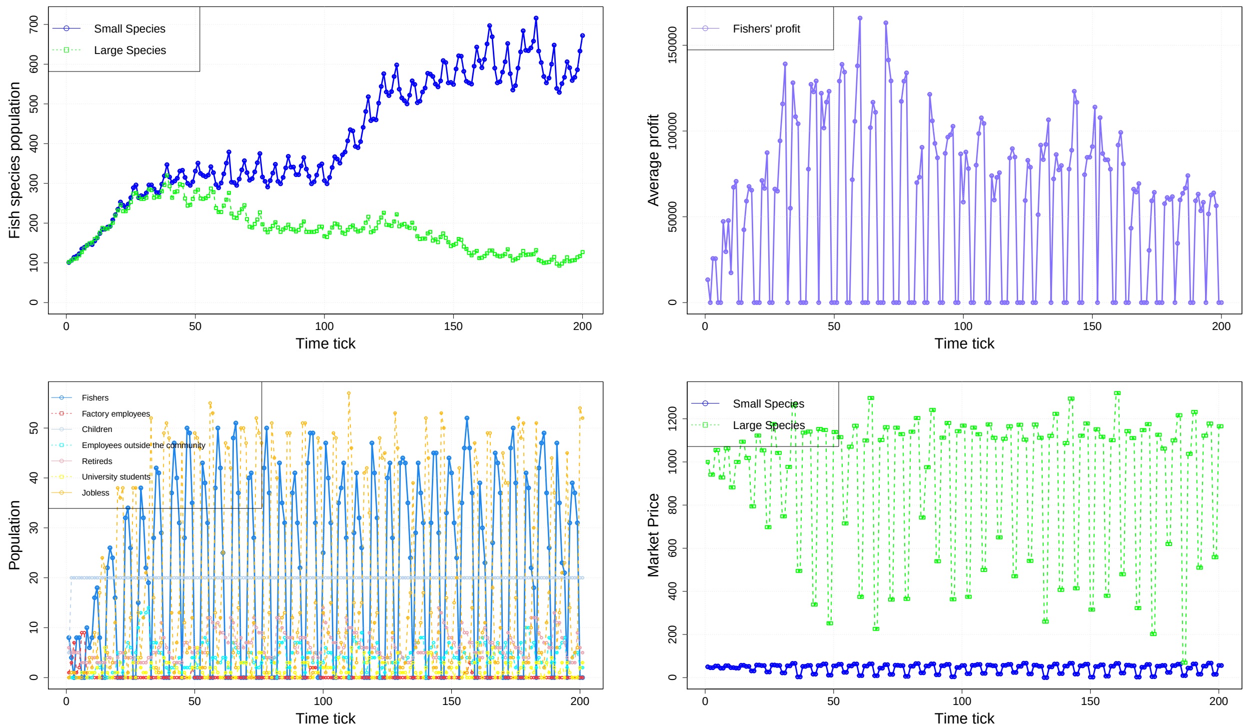

Fig. 8: The conditions of this experiment are a high fish species population (initial population, the amount of available food, and offspring rate are high); universalism and benevolence have low priorities ($SI = 0$, nobody donates); and tradition has a high priority.

Figures 3, 4, 7 and 8 depict the importance of taking care of the environment and community. When agents want to stay in the community, their commitment to the universalism and benevolence values are the main effective factors of the whole system. In such a case, the fish population only plays a role in the market price and the profit that fishers and the factory make. If the universalism value has a high priority for most of the agents, it can cause a sustainable environment, a viable community, and a stable economy. However, the community will collapse if universalism has a low priority for most of the agents. Because in that case the fish species population decreases rapidly and therefore there will be much fewer job opportunities revolving around fishing in the town.

According to the results depicted in figures 6 and 7, the tradition value is a key factor that determines the situation of the community when the environment is in a normal condition (because of the high priority of the universalism value). Agents prefer to leave the community when the tradition value is not important for them, even if there are plenty of fish available in the environment.

5 Conclusion

In this paper we argued that we need to integrate economical, ecological and social systems in order to simulate fishery communities. In order to integrate these complex systems we use value based agents. Using values the agents can make consistent decisions over the three domains and in that way create a balance between all of them. In this paper we have only shown the initial simulations illustrating some of the intuitive dependencies within and between the different systems. It forms a solid basis for more developed simulations that explore the consequences of different priorities between values in a community and also the consequences of new policies that either forbid some behavior or give incentives for certain behavior. These policies will interact with already existing rules and norms in the social system, while also having impacts on the economic system and indirectly on the ecological system.

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