DEVELOPING A SUSTAINABILITY ASSESSMENT TOOL FOR SOCIO-ENVIRONMENTAL SYSTEMS: A CASE STUDY OF SYSTEMS SIMULATION AND PARTICIPATORY MODELLING

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ABSTRACT

Assessing the sustainability of socio-environmental outcomes, created through wetland restoration, requires a systemic approach. The aim of this paper is to develop a participatory modelling procedure for understanding sustainability in complex socio-environmental systems by combining participatory modelling and systems simulation. This study uses the wetland restoration program at Winton Wetlands (Benalla, Victoria, Australia) as a case study. The systems simulation component, which includes system dynamics and agent-based modelling techniques, is used to identify: i) the main elements and relationships of the system, ii) plausible scenarios for sustainable development, and iii) sustainability indicators for the Winton Wetland socio-environmental system (WWSeS). In addition, the process includes the participation of stakeholders for model validation and better understanding of the system. A nature-based tourism simulation model is developed as an example for the systems simulation method. This novel approach is thought to provide new insights into and guidance for assessing sustainability of complex socio-environmental systems around the world.

Keywords: sustainability, complex socio-environmental systems, simulation modelling, agent-based modelling, system dynamics, wetlands

1. INTRODUCTION

1.1. Sustainability and complex socio-environmental systems

Since it was first introduced, sustainability has been defined and conceptualized on many occasions (Gibson, 2006; Lozano, 2008). This presents difficulty for undertaking assessments of sustainability and ascertaining whether or not it is a practical concept and if it represents more than just good intentions and promises. It has been argued that assessments of sustainability need to consider whether an initiative is: i) based on the underlying principles of sustainability (Table 1), ii) is viewed in the context of the complex system in which it is embedded, iii) is systematic and traceable (Phillis & Andriantiatsaholiniaina, 2001) and iv) includes stakeholders in the decision-making process (Gibson, Hassan, Holtz, Tansey, & Whitelaw, 2005). Many assessments, in particular those which claim to address sustainability systemically, have neglected to truly address these requirements. In particular, they either fail to account for the complexity of the socio-environmental system (SES) of interest or do not include stakeholder participation in the modelling process (Bagheri & Hjorth, 2007a, 2007b).

Table 1: Principles of Sustainability

1. The resources of the system, in terms of sinks and sources, are not deteriorated. a. Substances produced by society must not accumulate in the ecosphere. b. Substances extracted from the Earth´s crust must not systematically increase in nature.
2. The physical basis for productivity and diversity of nature must not be deteriorated.
3. All people should have their basic needs satisfied so that they can live in dignity and in healthy communities.
4. Have a systemic perspective of the world in terms of the social, environmental and economic implications of sustainability.
5. Build collective responsibility through open and informed deliberations.

In the context of assessing sustainability, SESs are acknowledged as complex, however their characteristics have often not been fully taken into account. A common misconception is that complex systems are characterized by having a combination of social, economic and environmental aspects. However, this ignores the important features of complex systems, such as being constantly changing, tightly coupled, history dependent, having emergent phenomena and being governed by feedback (Bagheri & Hjorth, 2005; Borshchev & Filippov, 2004; Sterman, 2000). Efficiently accounting for these features enables the sustainability of complex SESs to be addressed in a more thorough and systemic manner.

It is because of the complexity of SESs that the assessment of sustainability should focus on understanding the processes and dynamics that shape the physical, social and economic environments and establish measures to keep the system working in perpetuity (Bagheri & Hjorth, 2005). However, because complex systems contain a large number of objects (e.g. people, businesses, vehicles, animals, etc.), which interact with each other, building a complete picture of such a system is extremely difficult without the use of systems simulation modelling (Sterman, 2000). Moreover, the unique characteristics of every SES together with the difficulty of gathering all the information necessary to describe it, requires the incorporation of stakeholder participation in the modelling process.

All these previous factors open the field for an integrative study of sustainability, which focuses on the complexity of SES. Because of this, the aim of this study is to develop a participatory modelling procedure for understanding sustainability in complex socio-environmental systems by combining participatory modelling and systems simulation. The case study for this project is the Winton Wetlands site at Benalla, Victoria in south-east Australia.

1.2. The Winton Wetlands as a complex socio-environmental system

The Winton Wetlands is an 8,750 ha transformed wetland site, located in the Goulburn-Broken Catchment in North-East Victoria, approximately 200 km north of Melbourne, Australia. In 1970, it was transformed into an artificial irrigation reservoir, Lake Mokoan, with the construction of a dam. Due to its inefficiency as an irrigation reservoir (increasing turbidity, algal blooms, and water losses), the State Government decommissioned the dam in 2004 (Goulburn Broken Catchment Management Authority, 2012).

After the decommissioning, the state Minister of Water established the Winton Wetlands Committee of Management (WWCoM). This community-based organization was charged with the preparation and implementation of two projects aiming to return the Winton Wetlands to its natural state as an important wetland system (approximately 2,900 ha of Red Gum woodland were destroyed with the construction of the dam) and develop the site as a sustainable nature-based touristic wetland. These are the Winton Wetlands Restoration and Monitoring Plan and the Winton Wetlands Master Plan, respectively (Goulburn Broken Catchment Management Authority, 2012; Taylor Cullity Lethlean et al., 2012). In both documents, sustainable development with the participation of stakeholders is considered a main objective and guiding principle of the restoration project (Taylor Cullity Lethlean, et al., 2012). This makes the Winton Wetlands an ideal case study for the development of a sustainability assessment method such as the one proposed in this paper.

It is recognized that there are many actors and issues involved in the Winton Wetlands SES. These actors have different agendas, interests and knowledge of the system (Taylor Cullity Lethlean, et al., 2012), all of which need to be taken into account in the construction of the system. Some actors have been identified such as, graziers, tourist operators, indigenous communities and local residents in the neighbourhood of the wetland.

In addition to the actors, the main issues identified for the Winton Wetlands socio-environmental system SES include water availability, water quality, biodiversity, economic revenue and the creation of a Winton Wetland tourism brand. Regardless of the different levels of acceptance of the overall restoration project, stakeholders agree that whatever is done, needs to be done well. The interactions among the actors and the environment comprise the Winton Wetlands SES and need to be included in the simulation process.

The Winton Wetlands restoration project is an ideal case for this study because it is currently in the beginning stages of restoration and development of nature-based tourism. Furthermore, sustainable development and inclusion of stakeholders is deemed as important and the community has shown significant interest in taking part in the decision-making process.

2. SYSTEMS SIMULATION TECHNIQUES AND STAKEHOLDER PARTICIPATION IN SUSTAINABILITY ASSESSMENTS

SESs are dynamic, multi-scalar systems, which are so complex that a full description is impossible, prediction of changes is difficult and unexpected changes are likely (Gibson 2006). To overcome these difficulties, systems simulation processes, utilizing qualitative and quantitative methods, are used to incorporate stakeholder participation and approach the study of sustainability along two main axes. First, they address sustainability through the development of a simulation model of the socio-environmental system (Bagheri & Hjorth, 2005; Cockerill, Passell, & Tidwell, 2006). This takes into account the features of complex systems such as feedbacks and non-linear interactions. Second, they make use of a participatory method to include direct input of stakeholders throughout the modelling process

(Andersson, Olsson, Arheimer, & Jonsson, 2008; Stave, 2002; Voinov, 2008).

2.1. Systems simulation modeling

Systems simulation approaches interpret reality through the construction of representative models of a system. These simulation models can be considered as a set of rules (equations or logical rules) that define how the modeled system will change in the future, given its present state (Borshchev & Filipov, 2004). Systems simulation modelling approaches, such as Systems Dynamics (SD) and Agent-Based Modelling (ABM), have been adapted for the study of complex SESs (Borshchev & Filippov, 2004). These approaches not only address the features of complex systems, but also allow the main elements of the system and their relationships to be depicted rigorously and unambiguously, thus making the modelling process traceable (Scholl, 2001).

SD was originally developed for the analysis of complex systems in other areas, such as engineering and business management, while ABM has been applied to fields such as social sciences (Scholl, 2001).

The differences between SD and ABM simulation modelling come from the approach of their respective simulation procedures. SD is a 'top-down' simulation in which the overall structure and interdependencies of the system determines the behaviour of the particular elements. In SD, real world processes are represented in terms of aggregate variables (stocks and flows between stocks) and their interconnections, through feedback loops. Feedback loops represent circular causation among the elements of a system and are the fundamental building blocks of a SD model.

As SD uses differential equations for the modelling process, the modeler has to think in terms of global structural dependencies and has to provide values for them. This makes SD a confirmatory approach. In addition, by working with aggregate variables, the items in each aggregate are indistinguishable from one another.

In contrast, ABM is a 'bottom-up process' where emergent phenomena are derived from behavioural rules of individual agents (Scholl, 200). Emergence, in complexity theory, is understood as the property of complex systems where "much comes from little". Said in other words, complex patterns arise from simple behavioural rules. Compared to SD, the aim of ABM is to look at the global consequences of local interactions in a given space. Therefore global behavior is established at the individual level, and emerges as a result of many individuals following their own behavioral rules. These rules include interactions with other individuals and the environment. ABM, as opposed to SD, therefore has an exploratory nature.

Despite the differences between both modelling techniques, SD and ABM are underpinned by a set of universal principles that support the behaviour of all complex systems and can be modelled over time (Bonabeau, 2002). This is the main reason why recent studies have established that they can be complementary as each technique can potentially account for weaknesses in the other (Borshchev & Filippov, 2004; Scholl, 2001). For example, the exploratory nature of ABM counteracts the confirmatory nature of SD. This is particularly important for the study of complex SES where little is known about the overall dependencies and the modelling team (and in this case the stakeholder group) does not intuitively need to know the specific globalized dependencies of the system (Bonabeau, 2002). Thus, modelling the individual agents in terms of their individual rules, which help them interact with other agents and the environment, results in the emergence of the behaviour of the system (Borshchev & Filippov, 2004). In contrast, certain tools within SD, such as Causal Loop Diagrams (CLD) may be helpful in the qualitative conceptualization of the model, particularly with stakeholders, as they show the relationships among the elements of the system under discussion (Coyle, 2000).

2.2. Stakeholder participation

There is growing consensus that every socio-environmental system is unique within its context (Gibson, 2006). When it comes to studying sustainability of SES, this implies that in order to have all the information necessary to depict a particular system, a large amount of data needs to be collected, and even then, there would still be gaps in knowledge and margins of error (Stave, 2002). In addition, systems that involve human sub-systems are characterized by uncertainties, conflicts of interests and value judgments, making it difficult to find a single "optimal" representation of the system (Stave, 2002). As a result, instead of constructing a socio-environmental system after months or years of exhaustive data collection, a mixture of available data and stakeholder knowledge of the system could be used to understand the main elements and relations within the SES.

Stakeholder participation is often called upon as a means of tackling challenging problems, such as sustainability in natural resource management. Yet, there is much discussion that participation is not a homogenous concept and about the most appropriate form of participation for different contexts and situations. Beginning with Arnstein (1969), the argument has been that not all processes of participation are equal. Using the metaphor of a ladder, participation can range from nonparticipation to full community control along levels of manipulation, therapy, informing, consultation, placation, partnership, and delegated power (Arnstein 1969). Collins and Ison (2006) suggest that community participation is too manipulable and misused, and call for participation as a reflection of social learning. Parkins and Mitchell (2005) suggest that a new direction for public participation is a deliberative democratic approach. Rodela (2012) argues that participation is exercised through learning a deliberation among stakeholders with competing discourses. Drawing on this literature, we are engaging participation from the perspective that it encourages discussion among stakeholders for the understanding of the SES.

Even if participation of stakeholders has been widely used when building models, there is a need to have a more structured way of deliberation and communication between stakeholders and the modelling team (Luna-Reyes & Andersen, 2003). According to Stave (2002), most of the time, public involvement does not involve the use of formal models. At the most basic level, hearings are held to solicit public comment, sometimes with an expert panel to respond to questions, but with the primary purpose of collecting input to be summarized and addressed at a later time. New planning approaches involve cooperative simulation models in which scientists and stakeholders work together to develop a computer simulation model to assist in planning efforts (Cockerill, et al., 2006).

Protocols are available for including stakeholders' knowledge in the modelling process for SD and focus on the use of participation throughout certain stages of the modeling process. Elias & Cavana (2000) consider that participation is important during two stages of the simulation: the qualitative structuring of the system and the scenario planning. In this regard, stakeholders are only expected to provide information on the scope of the system and their vision of plausible scenarios of the future that is validating the results of the model. There is a lack of inclusion of stakeholders in other important stages of the modeling process, such as establishing the interactions of the elements of the system and providing value parameters to feed the model (Stave, 2002). Moreover, there are few studies in the literature that present protocols to incorporate qualitative data derived from stakeholders into the modelling process (Luna-Reyes & Andersen, 2003). This is particularly important because although simulation models are mathematical representations of problems, it is recognized that most of the information available is not numerical in nature and there is a need to establish techniques to record, analyse and incorporate this kind of qualitative data into the model (Luna-Reyes & Andersen, 2003).

In contrast, for ABM, stakeholders have a more active role in the development of the modelling process. They are responsible for the establishment of the behavioural rules of the individual components. This is because people directly tell the modeler what they would do under certain conditions (Purnomo, Mendoza, Prabhu, & Yasmi, 2005), thus allowing the inclusion of on-site decision making (An, 2012).

In terms of sustainability assessments, ABM and SD simulation techniques have been used in combination with stakeholder participation for the study of complex SES. Berman *et al.* (2004) studied the adaptation and sustainability of a small artic community. They modelled, through research and local knowledge, how people interact with each other and adapt to changing economic and environmental conditions. The model outcomes assess how scenarios associated with economic and climate change might affect the local economy, resource harvest, as well as the well-being of the community. As far as SD is concerned, Bagheri & Hjorth (2005, 2007a; 2006) have developed the concept of Viability Loops to address the sustainability of complex SES. They identified different dynamic structures governing real world ecosystems, including human ones. To them, the world can be explained by means of reinforcing and balancing loops. While reinforcing loop are sources of growth and decline, which can bring the system into collapse, balancing loop hamper the reinforcing loops, keeping the system in balance (Bagheri & Hjorth, 2005). Sustainability therefore means to recognize the balancing loops (viability loops) that allow the system to work everlastingly and keep them functional (Hjorth & Bagheri, 2006).

3. MODELLING PROCESS

The modeling process requires the parallel development of the Winton Wetlands Socio-Environmental System (WWSES) through systems simulation techniques (SD and ABM) and the rigorous inclusion of stakeholder participation in the modeling process.

3.1. Modelling procedure

The modelling procedure consists of seven stages, each of which has different levels of input from stakeholders.

3.1.1. System's boundaries

The first step in the process is to determine, through stakeholder involvement and revision of relevant documentation, the spatial and temporal boundaries of the system, which will help delimitate the entire modeling process (Bagheri & Hjorth, 2005; Musters, de Graaf, & ter Keurs, 1998). As the main interest is to define and develop the socio-environmental system surrounding the Winton Wetlands, the spatial boundaries are intended to cover more than the extension of the wetlands and include neighbouring towns, which will influence and be influenced, directly and indirectly, by the restoration project. The temporal boundary of the system will establish the time span in which the model will be simulated. This is particularly important and is a principal deficiency in many "mental models" of the world where the tendency is to think of cause and effects as local and immediate (Sterman, 2000). Therefore, the choice of time horizon dramatically influences our perception of the system.

3.1.2. Main elements and interactions (Factors-Actors-Sectors framework)

The next stage in the modelling process is the identification of the main social, environmental and economic elements of the Winton Wetlands socio-environmental system.

This is achieved through the implementation of the Factors-Actors-Sectors framework (FAS) used to develop participatory-based scenarios in Southern European countries (Kok, Patel, Rothman, & Quaranta, 2006; Kok, Rothman, & Patel, 2006). Within the FAS framework, a factor represents a component of a socio-environmental system around which there are broad issues of concern. An actor represents an individual or organization of individuals with the capacity to affect and/or influence the factors. A sector characterizes a sub-component of a natural or social system, such as agriculture or tourism. For the Winton Wetlands SES, some examples of factors, actors and sectors are water quality of the wetlands, neighbouring households and agriculture, respectively.

During the focus groups, stakeholders will be ask to identify between 3 and 5 of these elements and record them on "post-it notes", which will be later pasted onto a white board. During group discussion these elements will be clustered in similar topics and relations will be indicated among them. The information obtained from stakeholders' will be complemented with published and unpublished documentation about the Winton Wetlands.

3.1.3. Model Formulation I: Causal Loop Diagrams

The next step is to qualitatively capture the interactions among the variables previously established during the discussion of the Factors-Actors-Sectors through the use of Causal Loop Diagrams (CLD).

A Causal Loop Diagram is a graphical tool borrowed from System Dynamics, which shows the relationships among elements in a system (Ford, 2010). It is a helpful reminder during discussions, not only because they explicitly depict the interactions among elements but also because they can help identify the wider context of the modelling task. A correctly drawn Causal Loop Diagram is the basis for a quantified model and is easily transformed into mathematical expressions (Coyle, 2000).

The CLD, as applied in this study, consists of variables, which represent the Factors, Actors or Sectors identified by the stakeholders, and arrows that denote the interactions among the elements (Ford, 2010). In System Dynamics, CLD are used to characterize the feedback processes that determine the dynamics of the system. These dynamics arise for the interaction of two types of feedback loops, reinforcing (or positive) and balancing (or negative) (Sterman, 2000). In a reinforcing loop, an action influences other variables in a way that the result is more of the same action. In contrast, a balancing loop causes change in the current state of a variable, which is affected at the moment that an external or internal input is introduced into a reinforcing loop (Sterman, 2000).

For the construction of the Winton Wetlands SES, the CLD is divided into subsystems, which can be arranged hierarchically in the overall system. Some examples of these subsystems are wetland hydrology, woodland restoration and nature-based tourism.

An example of these subsystems is a model of the dynamics of nature-based tourism (Figure 1), adapted from the work of Lacitignola *et al.* (2007). In this model, tourists visit a site depending on its attractiveness. For nature-based tourism this attractiveness depends on the ecological quality of the site as well as the infrastructure, such as road access, accommodation and facilities. In this sense, if tourists perceive that the ecosystem quality and infrastructure are low (by previous experiences or word of mouth) they will choice another destination to spend their holidays. In contrast, if the ecological quality and infrastructure are above certain threshold, tourists will be more inclined to visit the site. Ecological quality and touristic infrastructure are also affected by the arrival of tourists. This model assumes that even if nature-based tourism differs from mass tourism in its care for the environment, there are certain pressures to the ecological quality such as, generation of waste and use of resources like water and space (Buckley, 2004). In addition, the arrival of tourists also implies that pressures are exerted on the system, which require maintenance of existing and construction of additional infrastructure, such as roads, visitor facilities, accommodation, amenities and essential services. Finally, the arrival of tourists also assumes that there is an increase in capital through tourism revenue. This capital is in turned use for the maintenance and construction of new infrastructure and the restoration of ecological quality of the wetland itself.

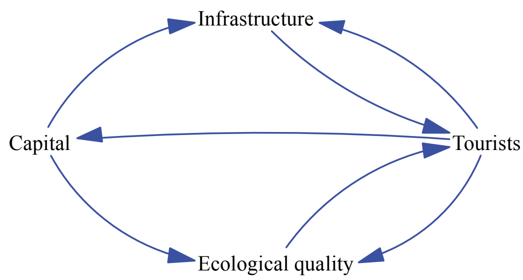

Figure 1. CLD of subsystem nature-based tourism

3.1.4. Model formulation II: Agent-Based-Modeling

Using the Causal Loop Diagrams with the main elements and relation within the SES, the next stage is to translate such relations to an Agent-Based Model. This is achieved through mapping the decision rules of the agents, using a flow chart, and entering them as commands into the ABM software Netlogo.

Continuing with the example of the nature-based tourism subsystem, after the CLD is established, the behaviour of tourists is translated into decision rules (Figure 2). The potential tourists start their journey in the city or hometown. Every turn, they randomly decide if they wish to go to on a holiday or not (based on a probability of recreation). Once they decide to take a holiday, they can choose to go to the wetland or to another destination, (e.g. the beach) depending on their previous experiences of the wetland (experience), as well as the experiences of other visitors of the wetland (word of mouth). The previous experience of the wetland for each tourist is determined by the fulfillment of their expectations of the wetland touristic site in terms of the ecological quality and infrastructure during their previous visit. While some tourists value more the ecological quality of the wetland, others value more that the infrastructure (facilities, restaurants and hotels). If during their visit of the wetland their expectations are met, their experience will be satisfactory. In contrast, if their expectations are not fully met, their experience will decrease. Once the tourists finish their visit to the wetland, they return to the city and exchange experiences with other potential tourists.

While the tourists are in the wetland, they impact environment in one hand and leave revenue for the touristic site on the other hand. As explained in the previous section, because their presence in the wetland and the activities related with nature-based tourism, the ecological quality decreases as well as the infrastructure. In addition to these impacts, tourists bring economic revenue to the site, which in turn can be used for more infrastructure or restoration efforts. Every time a tourists interacts with an ranger of the wetland (builder for infrastructure and ecologists for restoration) they give resources to them in order to improve the overall quality of the wetland.

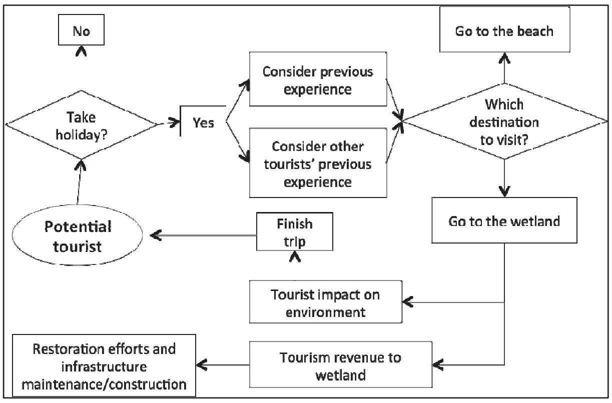

Figure 2. Behavioural rules flow chart of tourists

The agent-based model constructed in Netlogo shows the movement of the tourists from the city to the wetland depending on their travelling decisions (Figure 3). It contains sliders which are used to establish initial conditions, such as the number of tourists, rangers (builders and ecologists), tourist revenue and probability of recreation. The model has three plots, which show the average experience of tourism in the wetland, the average ecological quality and the number of tourists in the wetland at any given time (Figure 4).
The implementation of the decision rules depends on the agent in the model (tourists, ecologists and builders). The ecologist and builders move randomly across the wetland and are able to undertake their activities if they have available resources. These are a result of encountering tourists in the wetland, therefore if a park ranger never gets in touch with a tourist, he would not have enough resources to build new or maintain old infrastructure and to restore the wetlands. In addition, every time he finds himself in a patch of the wetland that could be improved, *i.e.,* where ecological quality and infrastructure could be increased, he allocates part of the resources to that patch.

The other agents in the model are the tourists, which transition from different states depending on their decision rules. Every potential tourist (city residents for this model) has a preference for ecology or infrastructure when it comes to choosing to undertake a nature-based touristic experience. Some people value more the environmental traits of the site and some people value more the infrastructure (restaurants, facilities, etc.). In addition, this model takes into account that there are certain circumstances that diminish the chances of taking a holiday by establishing a random probability of recreation within a range previously established by the modeler. Once they decide to go on a holiday, they base their decision to go to the wetland or another destination (beach) based on their previous experiences and the experiences of other people that have visited the wetland. Those decisions are based on the following rules:

$$E=\left[\left(1-E_d\times E_{t-1}\right)+\left(E_d\times\left(\frac{100}{M}\right)\times\left(P_{ec}+P_i\right)\right)\right] \quad (1)$$

where: E is the experience of each tourist after visiting the wetland; E_d is the experience decay (proportion of the experience that decreases every turn that the tourist does not go to the wetland); E_{t-1} is the previous experience of the tourist; M is the maximum resources that a patch can have (divided into infrastructure and ecology for each patch) and; P_{ec} and P_i are the product of the patch value for ecology and infrastructure and the individual preferences of the tourists for ecology and infrastructure, respectively.

The decision rule upon which a tourist decides to visit a wetland depends not only on each tourists' own experience, but also the degree of influence that others tourists' opinions have on the weight of their previous experience. This decision is represented by the following equation:

$$E_w=\left(1-G_w\right)E_{wt-1}+\left(G_x\times E_o\right) \quad (2)$$

where: E_w is the weighted average experience of each tourist; G_w is the gossip weight (weight of other tourists' opinion); E_{wt-1} is the previous experience of other tourists and; E_o is the average experience of other tourists.

Two different scenarios were constructed, A and B (Figure 3), depending on the amount of resources left by tourists upon their arrival to the wetland and the limit for ecological quality and infrastructure improvement. Limit for ecological quality and infrastructure improvement mean that for each patch, there is a maximum degree of restoration that can be achieved and a maximum amount of infrastructure can be developed or maintained. In Scenario A, the number of rangers (builders and ecologists), the payment of tourists and the maximum resources of patch is set to low values. In scenario B, all those parameters are set to higher values. For both scenarios, the number of tourists, the weight of gossip from other tourists and the probability of recreation stayed the same.

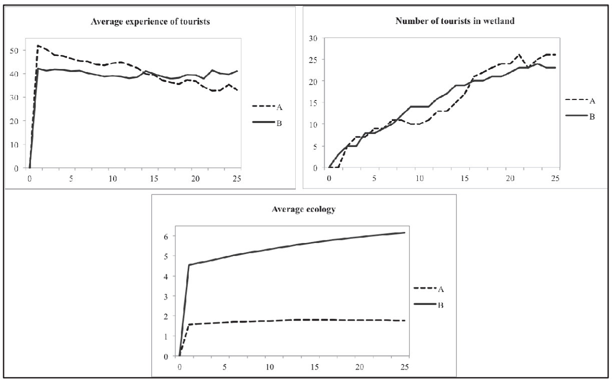

Figure 3. Average Experience of tourists, average ecology of wetland and number of tourists in wetlands in two different scenarios: A and B.

The average experience of tourists for scenario A decreased as opposed to scenario B, which stayed unchanged through out the simulation. Because the number of tourists was the same for both scenarios, the number of tourists in the wetland was the same in both scenarios. Finally, the average levels of ecology of the wetland differ between scenarios. When there are more rangers in the wetland, tourists leave more revenue that is translated into restoration and construction efforts and type of activities undertaken by the rangers are appropriate for the wetland in terms improving the ecological quality of the site, the average experience of tourists does not increase and the average quality of the wetlands increases.

An ABM is constructed for each of the subsystems of the Winton Wetlands SES to represent the interactions of main elements of the SES. Each subsystem is represented in a netlogo interface, with sliders, agents and plots (Figure 4).

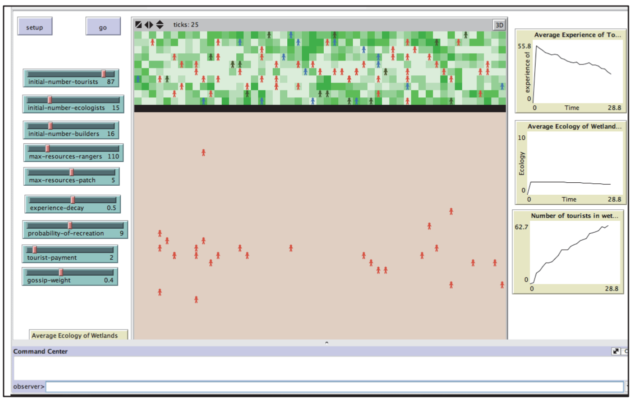

Figure 4: Window screen of Netlogo showing the tourists moving in and out the city (bottom) to the wetland (top); the sliders which modify the initial conditions of the simulation (left) and the response plots of each simulation (right).

3.1.5. Sustainability principles and questions

During this step, the stakeholder group is introduced to principles of sustainability adapted from several analyses of those principles by (Bagheri & Hjorth, 2005; Gibson, 2006; Holmberg, Robert, & Eriksson, 1996; Peet & Bossel, 2000; Robert, Daly, Hawken, & Holmberg, 1997). In combination with the main elements and relations within the system, these principles are then translated into sustainability questions (Bagheri & Hjorth, 2005). They represent a set core of values that any project, which deems itself to be sustainable, should address (Table 1). These questions assert the general conditions under which the system is considered to be sustainable by the stakeholders. It does not mean that specific indicators are established at this point. Instead, general questions such as “Is the water quality of our system decreasing” are asked.

3.1.6. Parameter estimation

The next step is to estimate the parameters of the model using the best available information. This stage of the process can start at the beginning of the modelling procedure and can continuously be increased. The information can come from numerical, written or mental databases (Forrester, 1991). The range of information is portrayed along the information spectrum from hard sources to soft sources: physical laws, controlled experiments, uncontrolled experiments, statistical information, case studies, expert judgment, stakeholder knowledge, personal intuition. Statistical information such as time series data or cross-sectional data, are common sources of information. Stakeholder knowledge is also gaining in importance as it can take the form of knowledge accumulated in a community (Cockerill, et al., 2006; Stave, 2002).

In some cases the measurement of real values may be difficult or even impossible and the value used in the model, legitimately, may be a guess. In this case, such a value cannot be regarded and treated in the same way as other parameters in the model. It must be treated tentatively and its role evaluated using sensitivity analysis (Kitching, 1983).

A database of parameters and assumptions is kept, recording the source of information and the degree of uncertainty.

3.1.7. Sustainability Indicators and scenarios of sustainable development

The indicators of sustainability come as a result of the entire modelling procedure and translation of the sustainability questions into quantifiable indicators. These could be used in the future monitoring of the system and to establish scenarios of development. As sustainability is seen as a process instead of an end state (Bagheri & Hjorth, 2005), preference will be given to process indicators as opposed to performance indicators. For example, if one of the questions of sustainability is; is the water quality decreasing? The indicator could be the rate of change of water quality.

Values of different stakeholders are incorporated through future scenarios of development. This can be achieved using Q-methodology (van Exel and de Graf, 2005) to produce groups of highly correlated opinions. Each group of opinions is representative of different viewpoints within the broader stakeholder group. These viewpoints represent the stakeholders desired visions for the system. Plausible scenarios of development are incorporated into the model by modifying certain parameters based on the desired visions for the Winton Wetlands established earlier.

3.2 Stakeholder participation procedure

The overall goal of the stakeholder participation procedure is to be able to incorporate the knowledge and values of stakeholders at different stages of the simulation process. Stakeholder knowledge and values will be incorporated through the use focus groups with two stakeholder groups: a General Stakeholder Group (GSG) and a Modelling Stakeholder Group (MSG) (Stave, 2002). The MSG is actively included in the different stages of the modelling process while the GSG is included only in the general process of model validation, as well as in the inclusion of stakeholder values in the development of scenarios for the future.

4. SUMMARY

The assessment of sustainability in socio-environmental systems requires the understanding of complex systems as well as the inclusion of stakeholders. The outcomes of this project could be use as guidelines for future decision-making processes in the Winton Wetlands and could also provide a framework to assess the sustainability of initiatives or programs in other parts of the word. In the particular case of modelling nature-based tourism for nature-based tourism, it was found that experience of the tourists and the average ecological quality of the wetlands (in terms of biodiversity, which is attractive to nature-based tourists) depends on the amount of resources allocated to restoration and infrastructure efforts, as well as the type of activities undertaken by the rangers are appropriate for the wetland in terms improving the ecological quality of the site. The current modelling procedure presented in this paper demonstrates the functionality of an approach combining multiple systems simulation paradigms and participatory modelling, which provides a base upon which to develop models of complex SESs. However, this model will be further elaborated upon in terms of complexity of decision rules for the ABM component and number of variables incorporated into the overall model.

REFERENCES

Andriantiatsaholiniaina, L.A., Kouikoglou, V.S., & Phillis, Y. A. (2004). Evaluating strategies for sustainable development: fuzzy logic reasoning and sensitivity analysis. Ecological Economics, 48(2), 149-172.

Arnstein, S.R. (1969). A Ladder Of Citizen Participation. Journal of the American Institute of Planners, 35(4), 216-224.

Bagheri, A., & Hjorth, P. (2005). Monitoring for sustainable development: A systemic framework. International Journal of Sustainable Development, 8(4), 280-301.

Bonabeau, E. (2002). Agent-based modelling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences of the United States of America, 99(Suppl 3), 7280-7287

Borshchev, A., & Filippov, A. (2004). From SD and discrete event to practical AB Modelling: reasons, techniques, tools. Proc. of the 22nd Int. SD Conf.

Gibson, R. B. (2006). Sustainability assessment: basic components of a practical approach. Impact Assessment and Project Appraisal, 24(3), 170-182.

Goulburn Broken Catchment Management Authority. (2012). Lake Mokoan Decommissioning Plan. Available from: http://www.gbcma.vic.gov.au/default.asp?ID=lake_mokoan [accessed 12 September 2012]

Musters, C. J. M., de Graaf, H. J., & ter Keurs, W. J. (1998). Defining socio-environmental systems for sustainable development. Ecological Economics, 26(3), 243-258.

Scholl, H. J. (2001). Agent-based and system dynamics modelling: A call for cross study and joint research. Paper presented at the System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on System Science.

Stave, K. A. (2002). Using system dynamics to improve public participation in environmental decisions. System Dynamics Review, 18(2), 139-167.

Taylor Cullity Lethlean, McKINNA, Sanmor, Design Flow, Prowse Qs & Arup. (2012). The Winton Wetlands and Benalla Master Plan. Benalla.

Voinov, A. (2008). Systems science andmodelling for ecological economics. San Diego: Academic Press.

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. Ecological Modelling, 229(0), 25-36.

Andersson, L., Olsson, J. A., Arheimer, B., & Jonsson, A. (2008). Use of participatory scenario modelling as platforms in stakeholder dialogues. Water SA, 34(4), 439-447.

Bagheri, A., & Hjorth, P. (2005). Monitoring for sustainable development: A systemic framework. International Journal of Sustainable Development, 8(4), 280-301.

Bagheri, A., & Hjorth, P. (2007a). A framework for process indicators to monitor for sustainable development: Practice to an urban water system. Environment, Development and Sustainability, 9(2), 143-161.

Bagheri, A., & Hjorth, P. (2007b). Planning for sustainable development: A paradigm shift towards a process-based approach. Sustainable Development, 15(2), 83-96.
Berman, M., Nicolson, C., Kofinas, G., Tetlichi, J., & Martin, S. (2004). Adaptation and sustainability in a small arctic community: Results of an agent-based simulation model. Arctic, 401-414.
Borshchev, A., & Filippov, A. (2004). From SD and discrete event to practical AB Modeling: reasons, techniques, tools. Proc. of the 22nd Int. SD Conf.
Buckley, R. (2004). Environmental impacts of ecotourism. Wallingford: CABI Publishing.
Cockerill, K., Passell, H., & Tidwell, V. (2006). Cooperative modeling: building bridges between science and the public. JAWRA Journal of the American Water Resources Association, 42(2), 457-471.
Coyle, G. (2000). Qualitative and quantitative modelling in system dynamics: some research questions. System Dynamics Review, 16(3), 225-244.
Elias, A., & Cavana, R. (2000). Stakeholder analysis for systems thinking and modeling. Paper presented at the 35th Annual Conference of the Operational Research Society of New Zealand, Wellington, New Zealand.
Ford, A. (2010). Modeling the Environment (2nd ed.). Washington, D.C.: Island Press.
Forrester, J. (1991). System Dynamics and the Lessons of 35 Years. In K. De Greene (Ed.), The Systemic Basis of Policy Making in the 1990s (pp. 1-35).
Gibson, R. B. (2006). Sustainability assessment: basic components of a practical approach. Impact Assessment and Project Appraisal, 24(3), 170-182.
Gibson, R. B., Hassan, S., Holtz, S., Tansey, J., & Whitelaw, G. (2005). Sustainability Assessment: Criteria and Processes. Virginia: Earthscan.
Hjorth, P., & Bagheri, A. (2006). Navigating towards sustainable development: A system dynamics approach. Futures, 38(1), 74-92.
Holmberg, J., Robert, K., & Eriksson, K. (1996). Socio-ecological principles for a sustainable society-Scientific Background and Swedish Experienc e. In R. Costanza (Ed.), Getting down to Earth: Practical Applications for Ecologica Economics (pp. 17-48). Washington, D.C.: Island Press.
Kitching, R. (1983). Systems ecology: An introduction to ecological modelling. Queensland: university of Queensland press.
Kok, K., Patel, M., Rothman, D., & Quaranta, G. (2006). Multi-scale narratives from IA perspective: part II. Participatory local scenario development. Futures, 38, 285-311.
Kok, K., Rothman, D., & Patel, M. (2006). Multi-scale narratives from IA perspective: part I. European and Mediterranean scenario development. Futures, 38, 261-284.
Lacitignola, D., Petrosillo, I., Cataldi, M., & Zurlini, G. (2007). Modelling socio-ecological tourism-based systems for sustainability. Ecological Modelling, 206, 191-204.
Lozano, R. (2008). Envisioning sustainability three-dimensionally. Journal of Cleaner Production, 16(17), 1838-1846.
Luna-Reyes, L. F., & Andersen, D. L. (2003). Collecting and analyzing qualitative data for system dynamics: methods and models. System Dynamics Review, 19(4), 271-296.
Musters, C. J. M., de Graaf, H. J., & ter Keurs, W. J. (1998). Defining socio-environmental systems for sustainable development. Ecological Economics, 26(3), 243-258.
Peet, J., & Bossel, H. (2000). An ethics-based systems approach to indicators of sustainable development. International Journal of Sustainable Development, 3(3), 221-238.
Phillis, Y., & Andriantiatsaholiniaina, L. (2001). Sustainability: an ill-defined concept and its assessment using fuzzy logic. Ecological Economics, 37(3), 435-456.
Purnomo, H., Mendoza, G. A., Prabhu, R., & Yasmi, Y. (2005). Developing multi-stakeholder forest management scenarios: a multi-agent system simulation approach applied in Indonesia. Forest Policy and Economics, 7(4), 475-491.
Robert, K.-H., Daly, H., Hawken, P., & Holmberg, J. (1997). A compass for sustainable development. International Journal of Sustainable Development & World Ecology, 4(2), 79-92.
Scholl, H. J. (2001). Agent-based and system dynamics modeling: A call for cross study and joint research. Paper presented at the System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on System Sciences.
Stave, K. A. (2002). Using system dynamics to improve public participation in environmental decisions. System Dynamics Review, 18(2), 139-167.
Sterman, J. (2000). Business dynamics: Systems thinking and modeling for a complex world. Boston, Massachusetts: McGraw Hill.
Voinov, A. (2008). Systems science andmodeling for ecological economics. San Diego: Academic Press.