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Transdisciplinary Conceptual Modeling of Socio-Ecological System

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Abstract: Management of natural resources is a complex issue. Human history shows the need for sustainable management of natural resources and one of the premises for this is knowledge integration. Nevertheless the need to integrate different types of knowledge poses a challenge. This paper proposes Conceptual Modeling as a tool to improve deliberation processes and research. Praia da Vitoria Bay in Terceira Island, part of Azores archipelago is the case study for Conceptual Modeling in a transdisciplinary setting towards system definition. During a three hour workshop, 18 stakeholders worked together to produce Conceptual Models describing Praia da Vitória Bay socio-ecological system. Participants included scientist of Azores University, local government with management responsibilities, private institutions that explore the area and local non-governmental institutions. The process, models obtained and stakeholder feedback are discussed. The exercise reveals that conceptual modeling is a challenging task for non-scientists. Nevertheless participants agree that this was a profitable moment of discussion and sharing visions, while cooperating to finalize the task. Information derived from the workshop includes not only variables and processes but, also scenarios. The overall result shows that during the 3 hour workshop data identification and integration has been achieved. The conclusion of this application is that collective Conceptual Modeling will not serve all purposes but, can be an important step towards integrated management.

***Keywords**:* Conceptual Modeling, Systems Thinking, Participatory approach.

1.INTRODUCTION

A transdisciplinary approach enables researchers from different disciplines to work together with practitioners to solve real world problems (Klein, 2004). Nevertheless, environmental and management research show that integration of science-policy and society are necessary but, difficult to achieve (Checkland, 2000; Heemskerk et al., 2003; Klein, 2004; Reed, 2008; Tett et al., 2011).

Rapid advance in science and technology have proved insufficient to solve some of the problems affecting socio-ecological systems (Tett et al., 2011). The complexity of socio-ecological systems makes them exceptionally challenging to characterize and to develop suitable methodologies (Checkland, 2000; Klein, 2004; Tett et al., 2011). “Hard” and “Soft” systems thinking can be used to produce

an output that is useful for management and that allows the system to be explored. Conceptual models are one tool that can be used in “hard” and “soft” modeling. Models are a simplification of the real world and are geared for a particular purpose. However, models can be inflexible and hinder the necessary tradeoffs between conflicting interests (Checkland, 2000; Heemskerk et al., 2003; Reed, 2008; Voinov, 2008).

The coastal environment provides a setting for the study of complex socio-ecological systems. This was achieved at 18 EU coastal sites from 2007 to 2011 in the context of European research project accessing science and policy integration for coastal assessment (SPICOSA). The project defined a Systems Approach Framework (SAF) that includes a sequence of steps towards an output that can be useful to policy makers by allowing a holistic appreciation of the impact of a decision in the coastal system (fig. 1). This article explains how conceptual modeling can be used to model a socio-ecological system - taking into account processes of Soft Systems Modeling (SSM) and Hard Systems Modeling (HSM). By using this technique in a transdisciplinary setting we also discuss the benefits, limitations and challenges of using this tool.

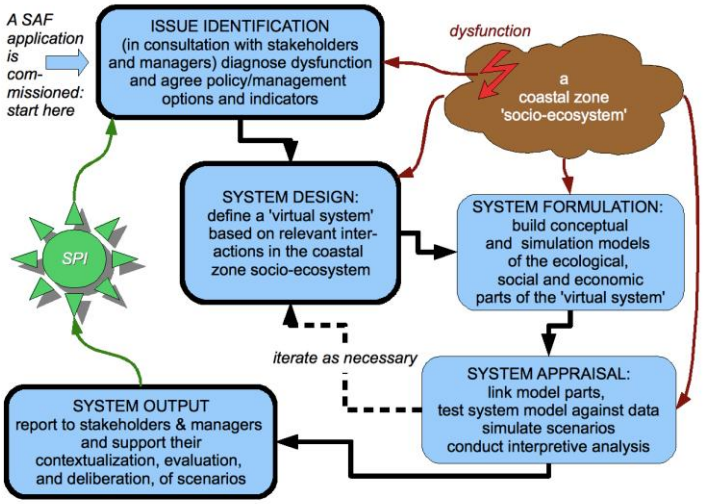

Figure 1: The step of SPICOSA Systems Approach Framework (from Tett et al., 2011). The issue is a dysfunction in the social-ecological system (including its economy) involving human activity’s impact on ecosystem goods and services. The symbol SPI stands for Science – Policy Interface.

2.CASE STUDY

2.1. Praia da Vitória Bay, Terceira Island, Azores

The case study is part of Terceira Island; one of the nine islands that constitute the Azores archipelago (fig. 2) that is located in the North Atlantic Ocean about, 1,400 km west of mainland Europe.

Figure 2: Azores and Terceira island location, followed by a satellite image of Praia da Vitória Bay with indication of the main elements. Blue arrow indicates the location of the wetlands: Paul da Praia, Belo Jardim and Cabo da Praia (source: Lima, 1999 and Google Earth)

Praia da Vitória town is situated in one of the basins adjacent to the Terceira Rift, bounded to the northeast by the Lajes fault that marks another uplift zone. This basin is a zone of sediment accumulation that gave rise to one of the longest beaches of the Azores (3 km long) and the only shore once fringed by a 300 meter-wide dune system (Bannerman and Bannerman, 1966; Morton et al., 1998). The low-lying nature of the shoreline, the protection afforded by former dunes, and the incursion of seawater through porous sediments, result in a natural setting for the development of a coastal wetland and, prior to human settlement, this was the largest natural wetland in the Azores. The wetland and dune system has been altered since 1929 by human occupation (Bannerman & Bannerman, 1996).

Human activities in Praia da Vitória date back to human settlement; however, the prevailing interests have been related to its strategic location, sheltered provision, soil quality and fishing grounds. These activities have intensified and nowadays the bay is an urban center of more than 6 200 habitants (statistical data from 2001) that includes the biggest fishing harbor of the island, port harbor, military harbor, a marina, dairy and agriculture industry, agricultural fields and dairy farms. The bay has been partially closed by 2 big jetties for port activities that dramatically changed the hydrodynamics and sediment transport. Problems of erosion were solved by the construction of groynes along the bay to trap the sediment while also dividing the beach into 6 parts.

2.2. Paul da Praia and Belo Jardim – remainders of the natural wetland

Today, the dune system can only be observed in the Belo Jardim area (Total area = +/- 3000m^2). The Belo Jardim system was probably part of an ecological continuum with Paul da Praia (Morton et al., 1998; Morton et al., 1997; Agostinho in Bannerman & Bannerman, 1966). Paul da Praia (Total area = 40000 m^2) is the only remaining natural marsh, due to a recent restoration project promoted by the local municipality. Belo Jardim has not been the focus of such a restoration project and is only detectable by the presence of a *Juncus* community of around 100 m^2 surrounded by agricultural fields, livestock farms and a diked stream.

The management of these wetlands is debated; while some consider their recovery to be beneficial, others consider it of little importance and a waste of public funds. This is a multi-institutional decision making process since management is shared by the local municipality while stakeholders include sectors such as transportation, port, military and industrial activities. Since Azores is an autonomous region, the regional government is also part of the process.

2.3. Cabo da Praia - artificial wetland

The discussion has intensified since the creation in 1983 of the Cabo da Praia artificial wetland (Total area = 150000m^2). This artificial wetland was developed from a quarry that provided large quantities of rocks for construction. The quarry was dug too deep, reaching the coastal water table so that tides pump water into the base of the quarry, partially filling depressions therein (Morton et al., 1997). On spring tides, the entire floor of the southeastern end of the quarry floods to form a shallow seawater lake. Over the years, the Cabo da Praia Quarry has gained fine sediments and been colonized by vegetation and several species of zoo benthos. Cabo da Praia Quarry has thus become one of the most famous places in the Azores to observe occasional and rare birds. A community of around 200 birdwatchers, national and international, share data on observations in the Terceira Island since 2005 (data from *Birding Azores* website).

3.METHODS

3.1. Conceptual Modeling Workshop

The SAF includes a sequence of steps that explore the dynamics of socio-ecological systems and provide information about the consequences of policy alternatives (fig.1). The first step for the workshop preparation was the definition of the policy issue in discussion. A policy issue is defined as a question of a political nature perceived as coastal environmental problems and concern social-ecological dysfunctions (Tett et al., 2011). This was done in a previous stage of the present work, using participatory methodologies (Guimarães et al., working paper). The second step of the process is System Design, in which a model that includes the essential features of the social-ecological system behaviour involved in the policy issue is draft. The springboard of the workshop was: *Wetlands along Praia da Vitória Bay – definition of the system.*

3.2. Workshop proceedings

The structure of the workshop was tested previously and necessary adjustments were made. Thirty stakeholders were invited to participate in the workshop and more than half of them participated (60%). Table 1 provides information on the stakeholders involved, including their stake in the policy issue. Groups were defined before the workshop and participants were distributed in combinations to assure heterogeneity in background, stakes and perspectives. All stakeholders that could not participate justified their absence with other reasons rather than lack of interest. Taking into account the institutions with stakes around the issue only one was not represented- the Regional Directorate of Environment. Nevertheless, this institution participated in the previous stages of the SAF (fig. 1: issue identification) and in the following stages (fig. 1: system appraisal and system output).

Table 1: Participants in the workshop

Institution	Stakeholder category	Stake related to the policy issue
History Museum	Public – Governmental	Promoter of the recovery project of Paúl da Praia. Defender of cultural heritage.
Azorean Biodiversity Group		Research in biodiversity issues.
Municipality		Management of the area.
Tourism Office		Promotion of the tourism sector.
Mathematics		User of the area but, with no

Research		particle stake, just curiosity due to the modeling component (observer)
National Guard		Competence of control of illegal activities in the area, like garbage deposition.
Port Activity		Development of industrial activities.
Climate, Weather and Changes		Research on the area
Ecoteca		Environmental education
Industrial sector	Semi-private	Development of industrial activities.
Praia em Movimento		Promotion of the tourism sector in the municipality.
Nature guide	Private	Potential do promote guided nature tours
Nautical Activities		Promoter of recreational activities.
Surf Association of Terceira	Public - Non Governmental	User of the zone with stake related to the possible construction of new infrastructures.
Gê- Questa NGO		Environmental education and environmental protection actions

The workshop started with a presentation of the program, overall goal and guidelines for the first task that involved an individual reflection about the definition of variables (fig 3). Variables were written down on cards of different colors. Each color represented a component of the system ecological (green), socioeconomic (grey), cultural (orange) and regulation (blue). The use of different colors representing distinct components of the system was used to assist the identification of the variables while taking into account all the components of the system. The individual reflection took about 15 minutes and, during this time, all participants were silently identifying variables and choosing the adequate color.

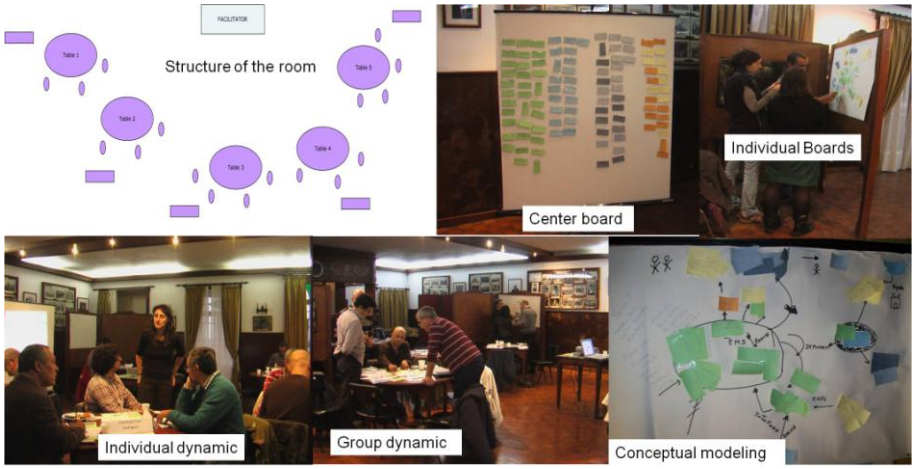

Figure 3: Structure of the room and workshop dynamic (personal pictures).

A brainstorming technique was used to generate a list of ideas/concepts related to the predetermined issue (Hogan, 2002; Marin et al., 2008; Osborn, 1963). The participants chose from a set of previously identified variable the ones that they would share with the rest of the participants. The variable was explained and given to the facilitator who placed it on the central board (fig. 3). After variable *x* was identified by participant *y*; the exercise was repeated by the next participant. All participants had a chance to share their identified variables and this exercise was

only concluded when no more new variables existed to include on the central board.

After the brainstorming, a second presentation provided the guidelines for building the conceptual model (fig.4). This presentation also provided explanations concerning the procedure as well as examples of conceptual models. Processes in the model were identified between two variables and represented by an arrow with a verbal identification. The following hour was devoted to the conceptual modeling process. This occurred in small groups of 3 and 4 members that had an individual board to create their model (fig. 3). All participants could go to the central board to review the variables identified during the brainstorming and select the ones to use.

When all groups finalized the process of model building, each group selected a spokesperson to present their model. Discussion followed each presentation and continued after all presentations. This stage took about 1h30.

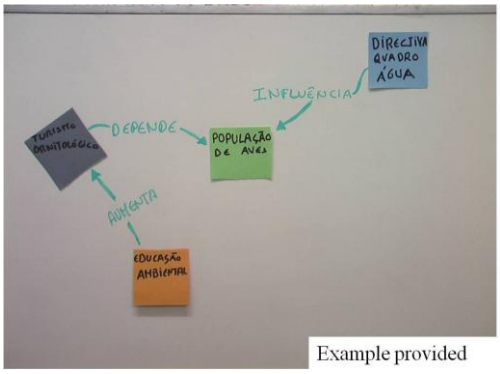

Figure 4: Example given during the presentation concerning the conceptual modeling and process identification..

Finally, the participants were asked to reply to an individual questionnaire. The goal of this questionnaire was to evaluate the workshop as well as the approach used. Most questions included a structured component using the *likert scale* and unstructured components were participants could justify their choice.

3.3. After the workshop – comparing and accommodating towards action

The research team developed a final conceptual model by analyzing and comparing the results of the workshop. This comparison led to the definition of the following action towards the improvement of the perceived real-world problem situation. The following step of the SAF is system formulation. This step implies the search of appropriate mathematical formulae to transform a conceptual understanding of the system to a quantitative simulation model, useful to explore the different effects of policy options.

4.RESULTS

4.1. During the workshop

During the brainstorming activity, 97 cards were placed on the center board (fig.3). At the beginning of the exercise, the concept of variable and a limitation of one word per card were established; however the participant's didn´t fully respect the rule and added more information than required. Hence, around 30% of the cards did not identify a single variable or process.

Although participants were asked to define variables that characterize the current system, in some cases these variables represented perspectives about the future of the bay. So, at the end of the first task of the workshop we obtained additional information about variables (e.g. employment), processes (e.g. deposition) and scenarios (e.g. biodiversity and business).

The ecological component included the highest number of cards. Nevertheless, the interpretation of the content of the cards shows that some of them were actually representatives of the socio-economic component (e.g. light pollution, bathing water quality). In the modeling exercise, all groups reached the final goals and 5 conceptual models were constructed. Again none of the participants group strictly followed the guidelines provided; some variables were grouped in bigger groups and some process were not fully identified (e.g. arrows without identifying the process). All models included feedback processes.
Before the end of the workshop, all participants, except one, replied to the questionnaire (fig.5). Most participants considered the approach innovative mainly because of the chance to share ideas concerning the study area. This denotes the scarcity of public participation and interactions between stakeholders, as well as the possible contributions towards the social learning process. A social learning process is where stakeholders - and the wider society in which they live - learn from each other through the development of new relationships, building on existing relationships and transforming adversarial relationships as individuals learn about each others' trustworthiness and learn to appreciate the legitimacy of others (in Reed, 2008). Some stakeholders referred to the link between science and empirical knowledge as a good result of the workshop as well as the possibility of having demonstrated their perspective to others. Although most participants were previously concerned with the amount of time spent in the workshop some subsequently indicated that a longer workshop would be appropriate.

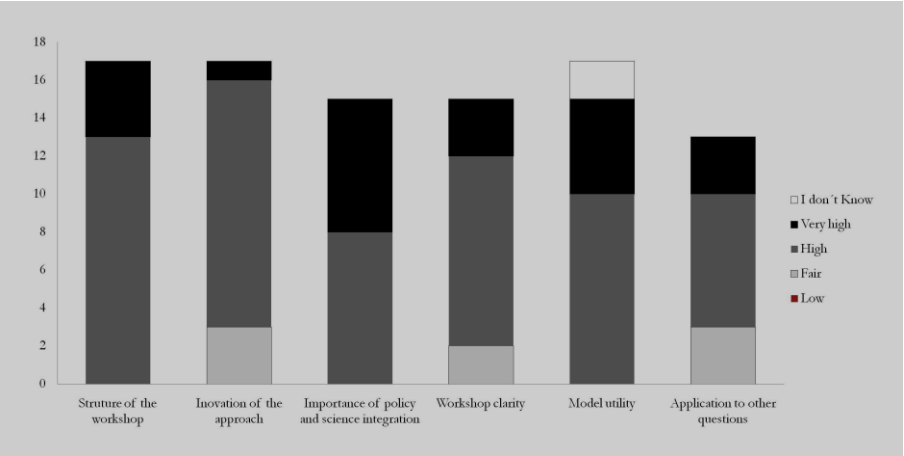

Figure 5: Indicators obtained by the final individual questionnaire.

4.2. After the workshop

The researchers used the 5 conceptual models and additional sources of information (Chekland, 2000; Tett et al., 2011, Ballé-Béganton et al, 2010; Mongruel et al., 2011) to develop the final model (fig. 6). The model includes the most relevant information gathered during the workshop and addresses 3 fundamental questions "what, how and why". It´s divided three layers (governance, uses and resources) and provides information about what will be the actions of the future development of SAF. The final conceptual model was made available to all stakeholders by the blog of the project: http://forumnapraia.blogspot.pt/. It was also present several times and no disapproval was ever registered.

The definition of governance in Tett et al. (2011) comprises the steering and ruling of society and the ways in which citizens and groups articulate their interests, mediate their differences, and exercise their legal rights and obligations. The main topics of discussion were how to manage without defining who had the role of manager. This lack of definition is related to the variety of uses occurring within the bay which is a resource *per se* and explains why its development was intense after settlement. The variety of uses results in several overlapping spatial planning regulations that make it more difficult to understand who should do what. For this reason, the conceptual model includes an arrow pointing at the public institutions. There is a need to clarify how and who may put into practice the possible management actions.

Within the governance layer it was also recognized that citizens -mainly residents need to understand management benefits; since any management action requires public support to be successful. This again was highlighted using a “take action” arrow; since residents are not fully aware of the diversity of values within the bay. Most uses in the bay are quite visible, and participants did not have difficulties in identifying socioeconomic indicators such as employment and link them with the uses within the bay. However, it was clear that not all activities represent the same impact on the bay. In addition, not all activities are taken into consideration in the management actions; for example the bird watching activity. Bird watching is therefore highlighted with an arrow, as a sub-component of the system that requires a closer look. Questions about the activity economic relevance were to and opinions diverged.

Problems are identified in the governance and use levels of the conceptual model, and therefore conservation measures are needed in the resource level.

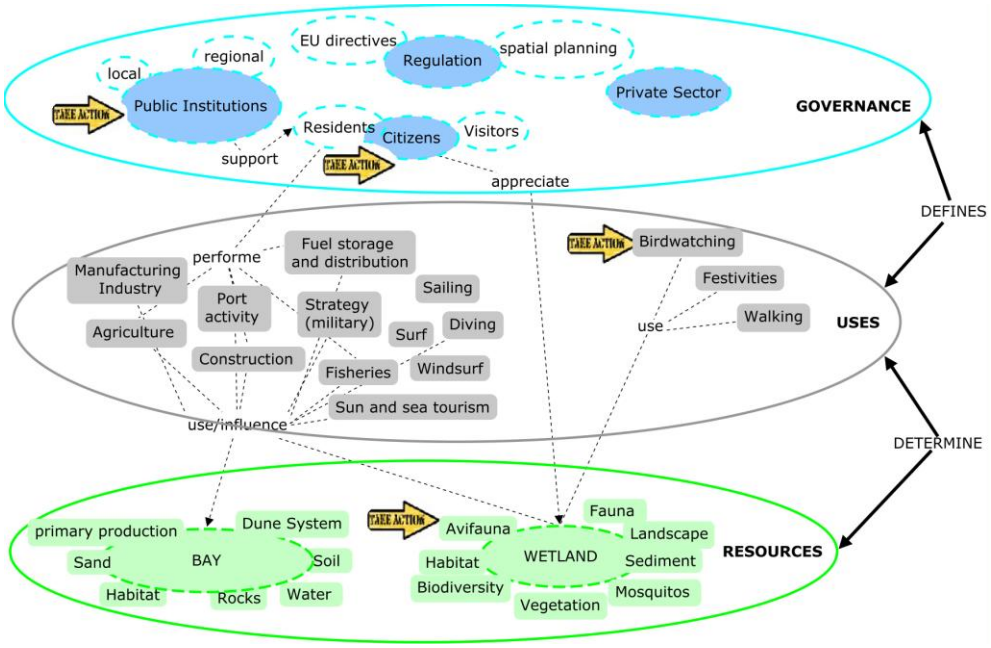

Figure 6: Final conceptual model and identification of action define.

5.DISCUSSION

More complex conceptual models are described in the literature (Heemskerk et al., 2003; Jones et al., 2011) but, the selection requires a trade-off between complexity, results needed, participation, clarity of the procedures and motivation. The work by Reed (2008), shows that planning for stakeholders participation implies several principles, including the avoidance of loss of interest which results from badly delineated procedures, that promises something and fails to deliver.

Since the SAF is a procedure that can imply several moments of interaction it should be simple, efficient and fruitful for all. The modeling exercise took into consideration the lack of familiarity of the participants with this procedure, some suspicion about SAF results and time limitation. Conceptual models were constructed simply using boxes (= variables) and arrows (= processes). The issues discussed in the workshop are complex and require coherent methodologies. However, during a participatory process clarity should be the first principle. After the modeling workshop, the work of the researcher doesn´t stop and all the information needs to be synthesized and used, including that not expressed on a card or in the model (e.g. confusion in governance, tensions, power).

Although time limitation is a real issue, we consider it is also closely related with the goals of a participative process. The most promising result obtained was the participants' expression of interest in future sessions and indication of the need for longer workshops. This shows the utility of the workshop at the participant level and can be an open window for the possibility of using other approaches and increasing the expectations of the workshops. Stakeholders may find time and resources to promote the use of this methodology to increase productivity, efficiency and sustainability of their decisions.

A transdisciplinary approach is useful for scientists to develop functional links with society (Sagoff, 2011; Ostrom et al., 2010). A workshop for Conceptual Modeling can help researchers to better understand reality and how to bring their work to a useful end but, it does not substitute the work towards an efficient conceptual model. Heemskerk et al. (2003) explains how conceptual modeling in interdisciplinary settings can be a tool for communication across disciplines, we agree on this and broaden the conclusion to the transdisciplinarity arena were scientist and other stakeholders need to find ways to communicate so that together they find a way to solve a real-world problem. Nevertheless, discussions among scientists from different disciplines and discussions of scientists with other stakeholders are quite distinct and impose different challenges.

6.CONCLUSIONS AND RECOMENDATIONS

Conceptual modeling has proved to be a good tool to communicate in a transdisciplinary setting. Using Conceptual modeling provides participants with directions and a final objective that promotes constructive discussion. Conceptual modeling is useful within different settings: interdisciplinary, practitioners and transdisciplinary deliberation processes. We found that the process of model building is, in itself, a valuable step towards science-policy and society integration. The need to promote communication and understatement among stakeholders underlines the necessity to promote a gradual learning process. Every one with a stake for a certain policy issue needs to understand the system in its various components so that a deliberation process can occur and tradeoffs can be defined. Hence, collaborative Conceptual modeling can also be a relevant tool for a demanding learning process.

In transdisciplinary settings conceptual modeling should be planned taking into account the different levels of practice in systems thinking, the different stakes and backgrounds present and the need to create a long lasting relation of respect and utility. Considering future conceptual modeling exercises in transdisciplinary settings we consider that priority should be given to simple and productive methodologies that don´t make participants feel exhausted (too long workshops) or less capable then others, feedback of the obtained results should always be provided to all.

Finally, going forward with a SAF application in Praia da Vitória Bay, we are still to conclude about what has more impact and importance, the final product or the process itself.

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