Linking thoughts to flows - Fuzzy cognitive mapping as tool for integrated landscape modeling

Wildenberg, M. (1,2); Bachhofer, M. (2); Adamescu, M. (2); De Blust, G. (3); Diaz-Delgadod, R. (4); Isak, K.G.Q. (5); Skov F. (5); Riku, V. (6)

(1) Institute of Social Ecology,Vienna, Austria, martin.wildenberg@uni-klu.ac.at

(2) www.FCMappers.net International network for fuzzy cognitive mapping, Austria

(3) Department of System Ecology, University of Bucharest, Romania

(4) Research Institute for Nature and Forest, Belgium

(5) Estación Biológica Doñana-CSIC, Spain

(6) National Environmental Research Institute, Aarhus University, Denmark

Abstract: This paper presents the results of six European case studies conducted in the frame of ALTER-Net, which all employed fuzzy cognitive mapping in the context of analyzing driving forces and impact of regional environmental change. Fuzzy cognitive mapping (FCM) is a soft systems methodology for analyzing and depicting human perceptions of a given system. It is a procedure to involve stakeholders in a research or management processes and a method to extract and analyze different kinds of knowledge about complex systems and their functioning. It describes the system by showing the central factors and their causal relations, represented by weighted arrows, as a directed graph.

Key-words: Fuzzy cognitive mapping; cause mapping; participative & integrated modeling; regional environmental change; integrated / adaptive management

Introduction

With the growing recognition that complex problems like climate change, biodiversity loss or globalization can be best adressed with inter- or transdiziplinary research the need for integrated models has grown. But integration often makes models over complex so that communicating, and testing them becomes difficult (Voinov this volume). Here we want to present fuzzy cognitive mapping a relatively young but promising method in the field of integrated modeling. The approach, as used in our case studies, offers both: a procedure to involve stakeholders in research or management processes and a method to extract, depict and analyze different kinds of knowledge about complex systems and their functioning. We have used FCM to arrive at stakeholder generated dynamical models of the regions. These models are semi-qualitative in nature which means that they provide information on trends but not on quantitative changes of variables.

This paper reports on the experience and results of six case studies applying fuzzy cognitive mapping to questions of environmental change in long term socio-ecological research (LTSER) platforms. LTSER platforms were set up as research infrastructure for inter- and trans-disciplinary research in the context of the FP 6 network project ALTER-Net. The studies were conducted in Finland, Denmark, Poland, Austria, Romania and Spain.

1. Integrated modeling and FCM

Integrated modeling requires not only the consideration of the bio-physical system functions but also human behavior which is influenced by human perception and beliefs. What are currently still needed more are methods or tools that support holistic understanding and management of complex social-ecological systems. These tools must fulfill certain set of criteria to be useful. They must be able to deal with situations were the data at hand is often insufficient for a full quantitative description, were uncertainty is high or were a range of non-quantifiable elements, originated in the human sphere of causation, becomes important. Data collection, the representation of complex structures, and a comparison between different systems have to be supported to facilitate management and decision support. The pressing urgency and the irrecoverable consequences of many processes like e.g. biodiversity loss makes methods favorable which allow fast information collection, assessment and planning.

FCM allows the depiction and analysis of complex systems like landscapes or other social ecological systems through the involvement of stakeholders. It structures a process in which the perception of stakeholders on a certain system (or problem) is uncovered and a representation of the system is created by the interviewee. FCM enabled us to do mathematical calculations and simulations on the visual representations of a interviewees perception. Moreover FCM enhances social learning. Understanding of the system between participants is fostered. FCM also offers the possibility to deal with situations were the data at hand is insufficient for a full quantitative description, uncertainty is high, conflicting views are present or a range of non-quantifiable elements becomes important (Wildenberg et al in prep.).

Landscapes as social-ecological systems

Landscapes are organized along spatial and temporal scales. The interaction between SES at different scales leads to the emergence of characteristic structures and patterns in the landscape. The elements in these systems are connected via flows of energy, material and / or information and form an interacting network (Levin 1998). One of the constitutive elements in landscapes are human agents (as individuals and as organized social units) living, dwelling and interacting in it. Information flows (in a broad sense) play a significant role in organizing relations and flows between humans and their human and non-human environments. Human behavior can be approached by understanding it as a reaction on the interpretations of perceived environmental signals. Mind models like cognitive maps can be used to depict the cognitive elements in a mindset influencing human decision making on a certain topic (Axelrod 1976. Mindsets are based on the cumulated knowledge of individuals or groups. In a society it is possible to distinguish between different bodies of knowledge held in different social groups or organizations. The different forms of knowledge reflect the different forms of engagement with the environment or landscape and can provide different perspectives on the same complex issue. Bodies of knowledge considered important for regional and environmental management have been classified e.g. as traditional knowledge, local knowledge or expert knowledge (Wildenberg et al in prep.).

2. The Fuzzy Cognitive Map - a model of causal relations

Fuzzy cognitive mapping is based on the cognitive mapping approaches described by Axelrod (1976) and on fuzzy logic (Zadeh 1965). It was first used by Bart Kosko (1986) who also developed the mathematical basis for running simulations. In a fuzzy cognitive map a system is represented as a network depicting the directed causal relations between its elements through arrows. It, graphically represents the beliefs and perceptions a person holds about a specific question or system and is created during an interview.

In a fuzzy cognitive map a factor or node in the network stands for a key-factor of the system (Stylios and Groumpos 2000). The directed links show positive or negative causal relations between factors. A positive casual relation indicates that an increase in one factor will lead to an increase in the connected factor. A negative relation indicates that an increase in one factor will lead to a decrease in the other factor. The strength of the relations are expressed with fuzzy values usually numerically represented in the interval between 0 – 1. A map can include a diversity of factors representing abstract values like the beauty of a landscape, as well as quantifiable factors related to institutions and physical structures like infrastructure, ecosystems, landscape elements, individual species etc. According the logic of a fuzzy cognitive map it has to clear what an increase or decrease in the factors connotes. Fuzzy cognitive maps are digraphs so they can be transposed into adjacency matrices which can be computed and mathematically analyzed using graph theory. The matrix representations of FCMs also give the possibility to easily merge several FCMs into a single augmented representation that reflects the knowledge from a number of experts (e.g. (Özesmi and Özesmi 2004). Doing this, the maps tend to show emergent behavior – that is when dynamically analyzed the augmented maps show a different behavior then just the sum of the single maps would expect. Through the capability of fuzzy cognitive maps to incorporate feedback processes it can also be used to simulate changes of a system over time (Kok 2009).

2.1. Fuzzy cognitive mapping

The FCM approach we adopted is based on Özesmi and Özesmi (2004). This approach consists of two distinctive steps: the interview, where the actual mapping takes place, and the processing of the maps which consists of, digitizing, analyzing, visualizing and interpreting the maps

FCM can be applied in group sessions with mixed or homogeneous stakeholder groups or in interviews with single persons, depending on the requirements of the study. In sessions with mixed groups, the stakeholders can be challenged to produce a common model of the system. This will enhances social learning and may contribute to conflict resolution. In sessions with homogeneous groups, the participants can discuss difficult issues and thus create a common problem understanding. Issues which are highly uncertain or to which conflicting views exist can be easily detected. When conducting group interviews, group dynamics, which can lead to the exclusion of certain elements, have to be considered.

Single maps may concentrate on different aspects or scales of a system. They can also vary significantly in there complexity, according to the number of elements and connections mentioned. If the aim is an exploration of the system, the complexity of the maps should not be restricted. As mentioned above, maps covering different aspects of the systems can be aggregated to arrive at a more complete causal model. Aggregation can also be used to reduce the complexity of large maps (with many elements and connections) to arrive at a more comprehensible or focused map (Isak et al in prep.).

The complexity and focus of the fuzzy cognitive maps can also be influenced by the facilitator during the interview. For example by restricting the number of elements which can be used to draw the map or by guiding the interviewee to concentrate on certain topics. This however, requires that the facilitator is familiar with the basic concepts of systems modeling and has knowledge about the interview topic himself. During the process of FCM, it is important to use proper tools for interviewing and facilitating the process such as interview techniques (e.g. Kvale and Brinkmann 2008) and group facilitation (e.g. Kaner et al 1996). Similar to other qualitative interview techniques it may be difficult to compare maps produced by different facilitators. Preparing elaborate interview guidelines and compiling a list containing all mentioned elements and their meaning to which all facilitators can relate to can be used to obtain comparable maps (Isak et al 2009).

To become familiar with the method and to be aware of their own mind models, it is advisable for the facilitator to create a map showing his / her perception of the problem/system before starting with the interviews (Özesmi and Özesmi 2004).

2.2. Dynamic analysis

To receive information on the dynamic behavior of a FCM we have to calculate the influence one factor has on others over a number of iterations, so that the feedbacks between the concepts can play out. The value of a factor is calculated by summing up its positive and negative incoming links multiplied with the value of the connected concepts:

Equ. 1:

$$A_i^{(k+1)} = \left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} w_{ji} \right)$$

Where $A_i^{(k+1)}$ is the value of factor F_i at iteration step k+1. $A_i^{(k)}$ is the value of factor F1 at iteration step k, $A_j^{(k)}$ is the value of factor F_j at iteration step k w_{ji} is the weight of the link between F_i and F_j (Stylios et al 2008). In each step a threshold function is used to normalize the values. If the value A_i of factor F_i is increasing, we say that factor f_i shows a positive trend. After a number of iterations FCMs will either converge to a state where the values of the factors stabilize, implode (all factor values converge to zero), explode (all factor values increase / decrease continuously) or show a cyclic stabilization. The starting values for the factors (the activation vector) can either be set to one (unit-vector) or set according to assumptions about the current state of the concept (Mendoza and Prabhu 2006). We consider the first approach more practicable and have used a unit vector to calculate the base-line scenario of the FCM.

To calculate scenarios, values of some factors are fixed. That is if we assume that factor F_i is constantly high in a scenario e.g. through management measures or external drivers, the value A_i of the factors is fixed to 1 throughout all iterations. We compare the outputs of the management scenarios with the outputs of the base-line scenario. Positive deviations indicate a positive change compared to the baseline, negative deviations a negative trend. It has been suggested that iteration steps can be used to approximate time steps (i.e. one iteration = one time step), under the condition that all factors operate at the same time scale (Kok 2009). As this is hardly achievable under the participative mapping method we employed, this is not applicable in our case.

2.3. Software and Visualization

To facilitate analysis we developed an easy to use tool: FCMapper, based on excel and VBA, which is freely available for non commercial use on the inter-net (www.FCMappers.net). With FCMapper we calculated all indices, performed the dynamic simulations and transformed the matrix coded FCMs into files that can be displayed and further analyzed with network-analysis software.

To visualize our maps we have used FCMapper, Pajek (http://pajek.imfm.si/doku.php)and Visone (http://visone.info/). As an example, figure 1 shows graphic representations of the similarities (in terms of common factors) between the case studies and between single maps. The circles represent aggregated or single maps, their size and the number of factors in the case study or map. The width of the connecting line shows the number of same factors found in both maps. The graphic was obtained by using the Fruchterman – Reingold algorithm. This is a force directed algorithm which places topologically near nodes close to each other and far nodes far from each other (Fruchterman and Reingold 1991). If maps show more overlap with each other than with maps of other case studies, then they are placed closer to each other.

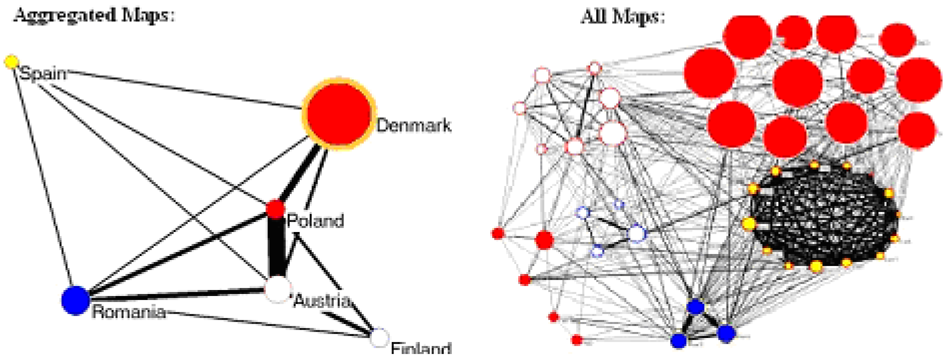

Figure 1: Graphic representation of the similarities (in terms of overlapping factors) between the case studies. The map on the left shwos one node per casestudy the map on the left one node per map. The size of the nodse represents the number of unique concepts mentioned, the width of the line the number of overlapping concepts. (Wildeneberg et al in prep.).

3. The case studies

Six case studies using fuzzy cognitive mapping were conducted in the framework of ALTER-Net. The Danish case study was concerned with the planning of Mols Bjerge National Park one of the first Danish national parks (Isaak 2008). The Polish maps were produced during a workshop in the Polesia Biosphere Reserve with the aim to provide a hands-on example for the participating scientists and to reach at a common basic design for the other case studies. The Spanish case study was designed to extract expert-knowledge on the drivers of biodiversity loss around the Doñana LTSER-site. The results were used for the development of a conceptual DPSIR[1]-model (Haberl et al 2008). The Austrian FCM exercise served as a tool to gather data for the development of an agent based land-use model covering the Austrian LTSER-site Eisenwurzen (Gaube et al 2009a). The Finish FCMs were conducted to inform an ongoing process of water shed management planning for Lake Karvianjärvi in South-West Finland. Four mapping sessions were conducted with experts and local stakeholders. The Romanian FCM focused on the Small Island of Braila Nature Park in the inner Danube Delta. Three group FCM were conducted. There specific settings are shortly described in table 1. In total 45 maps were obtained and analyzed. In the Austrian case we could compare the trends predicted by the fuzzy

[1] DPSIR = **D**river – **P**ressure – **S**tate –**I**mpact - **R**esponse

cognitive model of the Eisenwurzen (FCM-EW) with the results of an integrated agent based model which simulated a municipality in the same region.

Table 1: Overview over the six case studies conducted in the frame of ALTER-Net

	Austria	Denmark	Spain	Finland	Poland	Romania
Region covered	LTSER Eisenwurzen	The core area of National Park Mols Bjerge	Donnana National Park / LTSER	Lake Karvianjärvi in South-West Finland	West Polesie Biosphere Reserve	Small Island of Braila LTSER
Interview Partners & approach	Experts living and working in the region (regional development agencies, National and Nature Park employees, municipality administration)	12 stakeholders each created maps for 6 locations in the area. The 6 maps from each stakeholder were subsequently aggregated into one map	Scientists / Experts working in or with the National Park on biodiversity issues	Local managers and stakeholders; group interview with experts	Two maps were made with scientists participating at a workshop - three maps were made with local stakeholders	Three stakeholder groups: scientists and representative persons of the administration of the Natural Park and farmers & fisherman;
Central Questions	What factors or agents / institutions influence the development of your region?	What is important for you at this place?	What are the main drivers effecting biodiversity (pos. or neg.) in Donnana?	What issues/things comes to your mind when you think of the lake Karvianjärvi?	What influences the uniqueness and richness of the nature?	What are the characteristics that make this area unique / special? What are the most important things in your area? This area has changed in the last years, how did that effect the uniqueness of the area and what were the causes of change?

4. Results

All case studies reported that the goal of engaging stakeholders in discussions was achieved. The majority of the interviewees had a good experience while conducting the FCM exercise. They were enthusiastic, each telling her or his point of view. Some explicitly emphasized that they had developed a broader or new view on the region through the FCM-exercise. The FCM exercise also permitted to identify potential conflicts existing in the areas, while at the same time pointing at possible ways to resolve them through local stakeholders. In the individual sessions, FCM was helpful in understanding common or diverging priorities and perceptions of different social groups and institutions. Working with FCM required thinking about how topics or elements influence each other and thus took the discussion about the issue a step further than purely naming important aspects of a region. As FCM focuses on causality between factors it naturally directed the thinking towards a problem solving approach. Example maps from the case studies can be found in figure 2.

In the Finnish case-study it could be shown that FCM can contribute to the goal of detecting knowledge needs in the different stakeholder groups. Also in Romania FCM contributed to the election of knowledge-needs, in this case for conservation management In the Austrian study the information gathered through the FCM sessions proved to be very helpful in assisting with the construction of an agent based land-use model of the LTSER Eisenwurzen platform, especially in assisting the construction of the agent's decision rules.

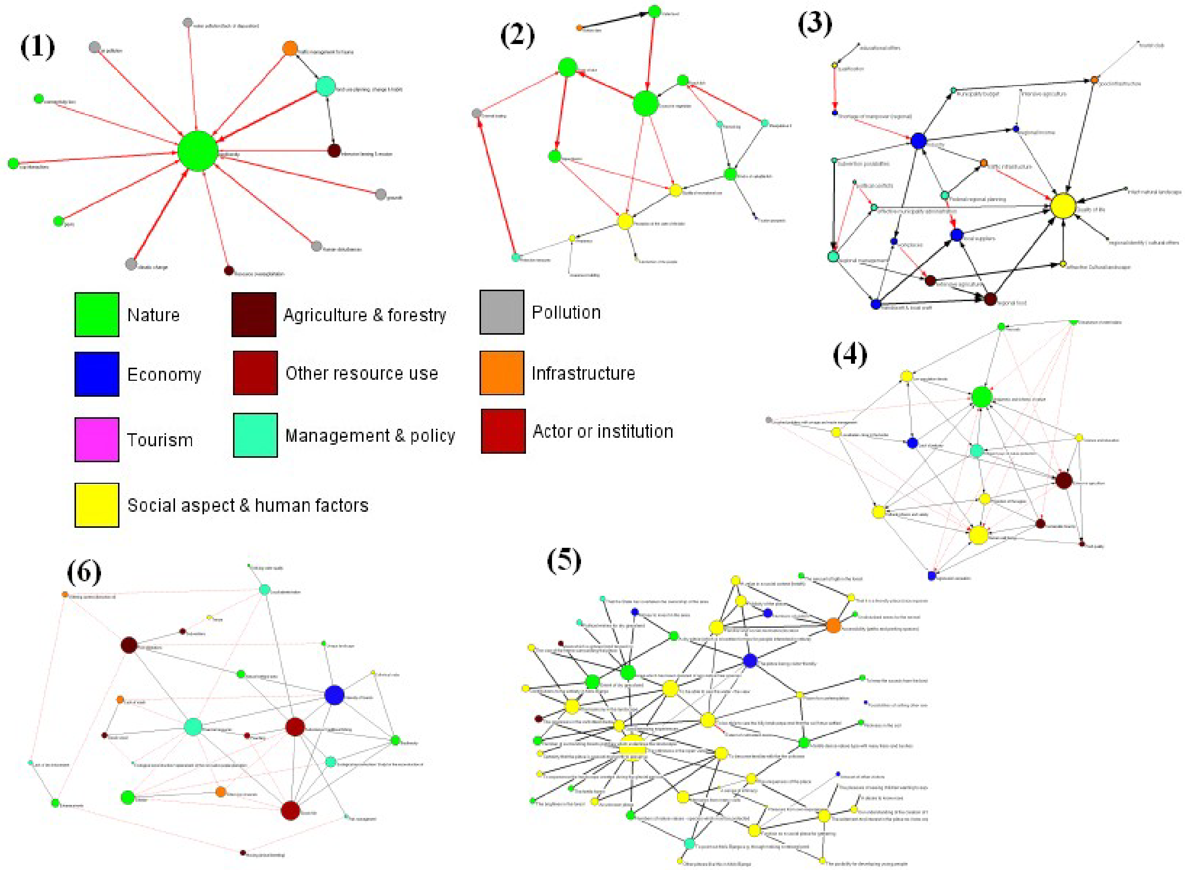

Figure 2: Six FCMs with different structural patterns. FCM 1 is taken from the Spanish case study, FCM 2 from the finish, FCM 3 from the Austrian, FCM4 from the Polnish, FCM 5 from the Danish and FCM 6 from the Romanian casestudy (Wildenberg et al in prep.)

Trends for the Eisenwurzen

The six expert maps of the Eisenwurzen case study were aggregated to reach at a comprehensive picture of the region. This social map consisted of 111 factors and 245 edges and was the starting point of our dynamical analysis. We replicated the scenario assumptions of the agent based model '*Simulation of Ecological Compatibility of Regional Development*' (SERD) model (Gaube et al 2009b) with the FCM-EW and compared the resulting trends. The SERD model is a spatially explicit agent based model of the municipality of Reichramming situated in the central parts of the Eisenwurzen. The model includes agents representing farmers, tourism companies, municipality and households. In contrast to the SERD model the FCM-model does not give quantitative information and does not work with discrete time steps. It gives information about the trends (increase or decrease) of factors. Three scenarios were simulated: 1.) Trend scenario extrapolating trends observed from 2006-2008; 2.) GLOB-Scenario assuming strong glottalization and no mitigation; 3.) LOC-Scenario assuming strong glottalization with local mitigation.

The results of the FCM-EW model for the base-run show a downwards trend for most important variables (figure 3). Agriculture and other economic activities decrease leading to increasing forestation, less available working places, out-migration and population loss for the region. The TREND scenario leads to positive changes in some of the most important factors like "Workplaces" and "Nr of farms", due to the higher demand for wood as an energy carrier and the increases in agricultural prices. Most other relevant factors stay unchanged and "Quality of life" even shows a slightly negative trend. The setting of the GLOB scenario causes even more negative changes. "Quality of life" as well as most of the other central factors shows negative trends. The positive trends of the factors "natural landscape" and "national park Gesäuse" are caused by an increase in forestation due to loss of farmers and associated cultural landscapes. Through the internal mitigation measures set in the LOC-scenario most of the negative trends caused by glottalization can be anticipated. Only the "Nr of farms" and the "Protected natural property" still show negative trends which points to their high dependency on external subsidies. The results of the dynamic analysis show that the region has a potential to mitigate negative external effects through internal action. Both models the FCM-EW and the SERD show a large concordance in the predicted trends.

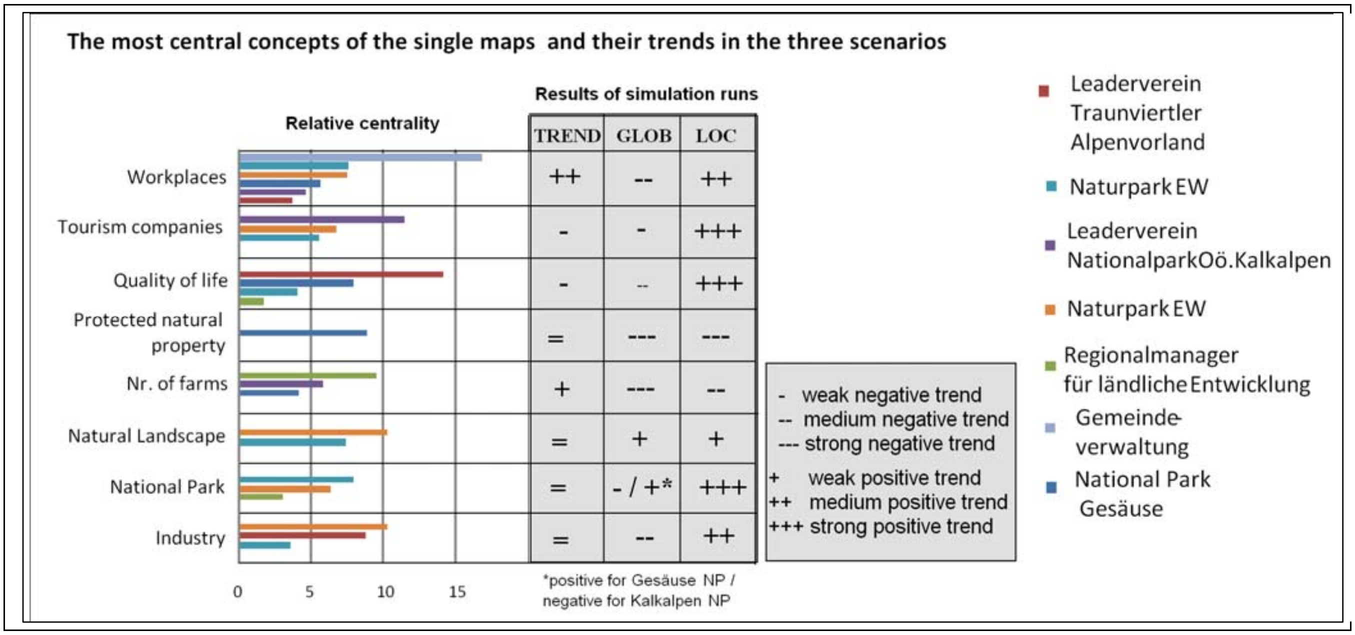

Figure 3: The results of the dynamic analysis for the most central concepts of the FCM-EW. The bars indicate the relative centrality of the factors for each map – if it occurred in the map. The higher the centrality the more importance the interviewee has assigned to the factor.

5. Experience with FCM as tool for integrated landscape modeling

Together with the case-study leaders we conducted a SWOT analysis summarizing the strengths, weaknesses, opportunities and threats of fuzzy cognitive mapping (Isak et al in prep.) The strength of FCM showed to be its potential to include all elements and their linkages in the landscape, independently of the details of knowledge about the elements and their exact interactions. FCM facilitated discussions of the specific landscape through outlining the important elements in the landscape and their interactions. Some were related directly to specific ecosystems, such as water quality, number of alien species, area with forest, overgrazing, and the area covered by agricultural land. Others were related to the socio-economic system, such as urbanization, population size, quality of recreation, price of fertilizers, and funding for management. Lastly, some elements related to more personal aspects such as the experience of peace, the personal feeling for the area, the awareness towards nature protection, and perceptions of conflict in the area were included. In all case studies the process of depicting the landscape was experienced as positive and engaging, with a constructive atmosphere which provided interesting settings for social learning processes. Working with mixed stakeholder groups enhanced the appreciation between groups holding different views on the system. In the individual sessions, FCM was helpful in understanding common or diverging priorities and perceptions of different social groups and institutions. Working with FCM required thinking about how topics or elements influences each other and thus took the discussion about the landscape a step further than purely naming important elements found in the landscape. As FCM focuses on causality between the topics in the landscape, it naturally directed the thinking towards a problem solving approach.

Through its close relation to conventional causal modeling approaches, and its ability to extract and represent the perceptions of different actors, FCM has a high potential to inform other land-use and land-cover change models especially agent based modeling approaches. FCM can be easily linked to other modeling techniques. Its way of representing complex systems is closely related to system dynamic approaches, the focus on the perception of stakeholders allows linking it conceptually to agent based modeling and its affinity to graph theory naturally connects it to network based approaches. Additionally, FCM can present the complexity and dynamics of a system (e.g. a landscape) in an intuitive and graphic way which opens up new possibilities to communicate knowledge about those systems.

Besides the positive aspects of the method there are also some weaknesses connected to fuzzy cognitive mapping. A FCM requires a simplified representation of the elements in order to generate a model of the system under investigation. In some instances the simplification of the landscape showed to be too extensive. This resulted in elements being imprecise, unidentified and not reflecting the reality, which lead to cognitive maps, partly losing their meaning, Furthermore, as the maps described the perception of a current situation, it was difficult to work with future effects between the elements i.e. to include what people expected to happen in the future. Another threat is that very uncertain and/or preliminary thoughts can be presented in an apparently systematic and credible, scientific looking way, as the content of the maps may be taken as “the truth”, and not as the participant’s perception. Like in many other participative approaches, the role of the facilitator and the design of the process are critical (Cook and Kothari 2001). The influence of the interviewer/facilitator on the process and possible lack of interview and facilitation skills may also heavily impact the quality of the results. Especially in group interviews, this may result in an incomplete representation of ideas and perceptions. Another problem can be that the facilitator does not find the right balance between supporting the interviewee in creating the map and at the same time not exerting influence on him/her/them.

Hobbs et al (2002) remind that the conclusions based on FCM should be viewed together with existing scientific knowledge. Conclusions based on an analysis and/or simulations of FCM can be counter-intuitive or against scientific results. If such are encountered, one must further study the assumptions depicted in fuzzy cognitive maps, but also be open to insights gained from a systemic approach to problem analysis that FCM is. It may well be the case that previous scientific studies were not based on systemic approach, e.g. ecosystem approach, and thus have missed the unexpected linkages and feedbacks in the system. Cognitive mapping methods are especially designed for systemic approaches and can thus make visible previously unknown and surprising effects of the system (Isak et al 2009).

Conclusion

Detecting knowledge gaps and at the same time creating a common basis on which the stakeholders can discuss and try to resolve them is an important contribution of FCM to integrated or adaptive management approaches. The capability of FCM to capture the perception of stakeholders in a structured way is a valuable contribution to the design of ABMs. Additionally the FCM results can help to focus model design on issues which are of importance for the stakeholder. The main advantage of FCM is that it offers a relative quick and easy way to involve stakeholders in participatory modeling or scenario projects. It can be used as a stand-alone tool to develop scenarios or as a very useful complementary tool for quantitative modeling approaches e.g. as a bridge between narrative story-lines and quantitative model development (see also Kok 2009).FCM showed to be able to combine different types of knowledge and to cover a broad and diverse set of issues. It thereby provides us with a comprehensive and more thoroughly understanding of a landscape or socio-ecological system. Not only of the elements and their cause-effect and feed back relations, but also how these are perceived and interpreted by human actors.

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