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Developing social-ecological system indicators using group model building

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A B S T R A C T

In many coastal regions, activities of multiple users present a growing strain on the ecological state of the area. The necessity of using integrative system approaches to understand and solve coastal problems has become obvious in the last decades. Integrated management strategies for social-ecological systems (SESs) call for the development of SES indicators that help (i) to identify and link the states and processes of social, economic and ecological subsystems and (ii) to balance different stakeholder objectives over the long-term within natural limits. Here we use a system dynamics modeling approach called group model building (GMB) as a diagnostic participative tool for understanding the determinants of characteristic SES issues in the Dutch Wadden Sea region and exploring salient SES indicators for management. We used GMB in two separate workshops for two distinct cases: sustainable mussel fisheries and tourism development. Follow-up online questionnaires elicited relevant variables for deriving SES indicators. In both modeling cases participants identified and connected the variables that expressed fundamental SES dynamics driving each issue. In the mussel fisheries model the central part of the structure was the interaction between the model variables 'extent of mussel habitat with high natural value', 'mussel cultivation efficiency', and 'market supply'. In the tourism model a key driving force for explaining tourist development was the reciprocal relation between the model variables 'natural value', 'experience value', and 'number of tourists'. Application of GMB revealed SES issue complexity and explicitly identified key linkages and potential SES indicators for policy and management in the Dutch Wadden Sea area. As a tool for stakeholder involvement in integrated coastal management the approach enables the joint building of system understanding and the exchange of individual perspectives. Participants agreed with the jointly created models and highly appreciated the way the structured approach facilitated communication and learning about complex and contested issues.

1. Introduction

The necessity of using integrative system approaches to understand and solve environmental problems has become obvious in the last decades. The development of knowledge for Integrated Coastal Management (ICM) requires identification of the components, both natural and human, of the ecosystem, and understanding their relationships to manage them in an integrated context (Turner, 2000; De Jonge et al., 2012). The framework of *social-ecological systems* (SESs; Ostrom, 2009; McGinnis and Ostrom, 2014) highlights the complex feedback loops between humans and nature that can create unsustainable dynamics and undesirable outcomes such as degraded ecosystems and negatively affected ecosystem users (Glaser et al., 2012). The integrative demands of the SES concept call for the development of human-

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environmental indicator sets that help to identify and link the states and processes of ecological, social and economic subsystems (Jørgensen et al., 2013). But although the importance of suitable information infrastructures for ICM is widely accepted, there is an increasing awareness of the complexities in identifying, monitoring and evaluating relevant interactions (Glaeser et al., 2009).

Modeling is a widely applied instrument for integrating and structuring social and ecological complexity, as well as for facilitating communication and understanding between scientific disciplines and between science and management (Den Exter, 2004). Models have historically been used in support of natural resource management and policymaking, often in a quantitative and highly formalized (i.e. computerized) form (Mirchi et al., 2012; Laniak et al., 2013). But although formal models are used in many resource management applications, there is increased recognition that the role and impact of human systems have often been overlooked or at least underrepresented in many models (Schlüter et al., 2014; Voinov and Bousquet, 2010). While greatly improved computer capabilities are driving a growing use of the systems approach for complex issues in other research fields, the application to SESs lags behind (Hopkins et al., 2012). A possible reason for this is the difficulty of integrating knowledge on variables and their relationships from both the social and the ecological domains (Schlüter et al., 2014).

Increasing our insight into complex socio-ecological systems helps to understand environmental problems better, but is not sufficient for solving them. We also need to motivate stakeholders to take action. There is increasing demand for participation of stakeholders in ICM not only as sources of information but as active and involved actors in decision-making as well (Stringer et al., 2006; Hanssen et al., 2009). There is evidence (Korsgaard et al., 1995; Nutt, 2002) that stakeholders are more likely to implement proposed actions if they participated in a joint process of building understanding and developing indicators and management scenarios of the issue at stake.

Model building is used more and more as a tool to structure discussion and debate about issues, and to create a learning environment that allows assumptions to be tested. Participative and stakeholder based policy designs can be organized around a model in which diverse interests are brought together to build a shared level of understanding and consensus (De Jonge and Giebels, 2015; Voinov and Bousquet, 2010). In this view, models are not only valued for providing solutions; in addition, they offer a way to understand and learn more about the system being modeled (Vennix, 1996; Cockerill et al., 2009).

1.1. Modeling of complex systems

Many approaches to developing models of complex systems have been pursued such as Bayesian networks, couple component-, agent-based or knowledge-based models, and system dynamics. Bayesian networks use probabilistic rather than deterministic relationships to describe the connections among system variables. The approach of coupling component models involves combining models from different disciplines or sectors to come up with an integrated outcome. Agent-based models describe the observed world in terms of factors (agents) that are characterized by certain rules (behavior) whereas in knowledge-based models knowledge is encoded into a knowledge base and then an inference engine uses logic to infer conclusions. Finally, system dynamics (SD) is concerned with understanding how the behavior of systems changes over time and is gaining in popularity because of its flexibility and structural focus (Kelly et al., 2013). The premise underlying the approach is that the dynamic behavior of complex systems is a consequence of system structure. Building SD models can help to systematically understand the time lags, nonlinearities, accumulation and feedbacks that characterize the relationships among system components (Sterman, 1994; Groesser and Schaffernicht, 2012). There are two mutually reinforcing sides to the SD modeling process (Kelly et al., 2013). First the process is directed at eliciting the causal assumptions that experts and end users have about the system (known as mental models), and testing the validity of these assumptions. Secondly SD applications engage experts and end users in the modeling process, fostering values of openness, diversity, and self-reflection (i.e. social learning purpose).

SD modeling has been applied in various environmental studies (Stave, 2002; Den Exter, 2004; Van den Belt, 2004) and more specifically in sustainable development (Kelly, 1998; Antunes et al., 2006; Hjorth and Bagheri, 2006), and water resources problems (Winz et al., 2009; Mirchi et al., 2012) amongst others.

SD modeling can help to identify critical information about structures and feedback loops underlying SES issues within a particular system. The formulation of concrete cause-effect-chains or webs of relations between variables can provide a foundation for the development of relevant SES indicators in decision making (Kandziora et al., 2013). By facilitating the exploration of salient social-ecological feedbacks an SD model can provide fundamental understanding of leverage points for sustainable solutions (Kelly, 1998; Mirchi et al., 2012). Empirical case studies in applying the SD approach in SES issues in ICM are limited. Exceptions are the use of SD to identify sets of indicators (Sanò and Medina, 2012) and for artisanal fisheries analysis (Camanho et al., 2011).

1.2. Group model building as a tool for understanding SES issues

In this study we want to explore the SD methodology as a tool for ICM and indicator development. Specifically, we apply a form of participatory modeling (Voinov and Bousquet, 2010), namely group model building (GMB; Vennix, 1999) as a conceptualization and learning method that helps to understand SES issues and develop indicators for ICM in the Dutch Wadden Sea region. This coastal region represents a typical social-ecological system, i.e. a system that is a continuously changing and coevolving through interactions between users, institutions, and natural components (Holling, 2001; Liu et al., 2007; Ostrom, 2009; Schlüter et al., 2014).

As is the case for many coastal areas around the world, management issues in the Wadden Sea region can be considered as “wicked”, “unstructured” or “messy” (Kabat et al., 2012). Such issues are not of a technical nature and do not have a definite formulation nor a well-described set of potential solutions. Their definition depends on the perspective taken by the observer, i.e. on how the problem is looked upon by each of the stakeholders involved (Head and Alford, 2013; Jentoft and Chuenpagdee, 2009; Sanò et al., 2014). Conditions for “messiness” are present in the Wadden Sea region as its governance is characterized by the involvement of many institutions, overlapping jurisdictions, and multiple users with different backgrounds, bringing their own vocabularies, knowledge, and ways of operating in the governance arena (Hanssen et al., 2009; Giebels et al., 2013; Puente-Rodríguez et al., 2014). Because of their wicked nature, coastal problems can only be managed on the basis of a joint understanding of the situation and of stakeholder goals.

We apply GMB in two case studies in the Dutch Wadden Sea region to document how stakeholders perceive the development of two sectoral issues, i.e. sustainable mussel fisheries and tourism. The cases – sustainable mussel fisheries and tourism – present two major issues in current policy and management. Both cases concern multiple stakeholders with different interests and involve issues with important system knowledge uncertainties (Vugteveen et al.,