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Semi-quantitative actor-based modelling as a tool to assess the drivers of change and physical variables in participatory integrated assessments

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ABSTRACT

Integrated assessments that aim to support sustainable natural resources management require analysing how biophysical systems are impacted by human actions. These analyses are often performed by modelling the physical system, while human actions are prescribed as scenarios and introduced into the physical models by varying the model input. To achieve a more thorough analysis of the human system component in participatory integrated assessments, we developed a semi-quantitative approach for actor-based modelling which focuses on modelling actions of societal actors based on their problem perceptions but also computes the resulting changes of physical system variables. Our approach is intended to support transdisciplinary research and identification of sustainable development options in problem fields with high levels of uncertainty or ignorance, together with the actors that are being modelled. Actor-based modelling is done using an enhanced version of the DANA software. DANA allows modelling the actors in a specific problem field by representing the perception of each actor by directed graphs, and by computing optimal actions from the perspective of each actor. These perception graphs are semi-quantitative causal maps, which can easily be discussed among stakeholders in a participatory process. DANA was extended to support, in addition to actor modelling, the other two steps in actor-based modelling, modelling of actions and modelling of factors. Modelling of actions refers to determining the actions of each actor under certain scenario assumptions, taking into account the diverse problem perceptions of the individual actors in the problem field, the action of the other actors and exogenous changes. Modelling of factors refers to calculating, in a semi-quantitative way, the resulting changes of physical variables (e.g. pollutant emissions), which may serve as input to physical models. We applied actor-based modelling in an integrated assessment of mobile organic xenobiotics in rivers. Our study shows that actor-based modelling allows generating scientifically better founded and more transparent scenarios of the drivers of change in integrated assessments, in particular because they are based on a structured analysis of the actors' problem perceptions.

Software availability

The software for Dynamic Actor Network Analysis (DANA) is available free of charge at the DANA web site: http://dana.actoranalysis.com

1. Introduction

To support sustainable management of natural resources, it is in most cases not sufficient to provide decision makers with a decision support system that represents the technical and natural system components only. Sustainable management depends on human actions, and it is therefore helpful to include the human system component into assessments that aim to support sustainable development. Integrated assessment (IA) is an appropriate approach to achieve not only the necessary cross-linking of disciplinary scientific results, but also the participation of stakeholders (actors) that is assumed to lead to social learning and increased acceptance of management strategies (Van Asselt and Rijkens-Klomp, 2002; Pahl-Wostl and Hare, 2004; Rotmans, 2006; Pahl-Wostl et al., 2008a; Van Delden et al., 2011; Laniak et al., 2013). "Integrated assessment implies that not only is the science exemplary but that it is now being done in the context of the social and economic forces at work in society." (Harris, 2002: 201).

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IA comprises the use of different methods from natural and social sciences, and, by generating scenarios of the future, puts a particular focus on evaluating the consequences of actions (Bailey et al., 1996; Gough et al., 1998). Consequences of actions on the physical environment are computed by (bio)physical models that are driven by input that represents the outcome of human actions, e.g. pollutant emissions scenarios. A more advanced modelling approach in IA is the development and application of an integrated model of the human–(technology)–environment system (e.g. Döll and Krol, 2002; Bendahan et al., 2004; Carmichael et al., 2004). Still, human actions and the resulting input to (bio)physical models are mostly prescribed, as scenarios, in an ad-hoc manner, without thorough analysis of the drivers of change, i.e. actors and their actions (e.g. see the IPCC scenarios as discussed in Moss, 2002). In some assessments in support of natural resources management, the human system component is represented by economic models (Vriend, 1996; Jaeger et al., 2001; Binder, 2007). However, economic theories are often criticised for being based on the problematic assumptions of rational choice and complete information. Besides, the economic models commonly used in IA (e.g. Ribaudo et al., 2001; Bazzani et al., 2005) need large empirical datasets for their calibration and validation. Thus data availability or structural uncertainty (Walker et al., 2003) often prohibits the construction of quantitative computational models of the socio-economic system.

An alternative way of integrating human and environment systems (Scholz et al., 2011) is to elicit and analyse the often diverse problem perceptions and social relations of the actors that are relevant in the human–environment system under consideration. A thorough and well-structured analysis of the actors in a problem field provides insights that may be translated into quantitative inputs for computational models of the biophysical system. "It is a guiding principle (…) of actor based analysis and modelling to capture the subjective perspectives of the actors and to combine them in a process with factual knowledge to determine solutions that are both feasible and desirable" (Pahl-Wostl, 2005). According to Pahl-Wostl (2002, 2005), agent-based modelling is a possible method for actor-based analysis and modelling within a participatory process. Moss (2002), for example, performed "participatory agent based social simulation" in the framework of an integrated assessment project on water demand and its management.

In line with the ideas exposed by Pahl-Wostl (2005), the semi-quantitative method for actor-based modelling that we present here aims at supporting participatory integrated assessments of human–environment systems, by not only eliciting and analysing problem perceptions of actors but also by estimating the consequences of these perceptions for future actions and states of (bio) physical variables. Our approach is based on modelling the problem perceptions of societal actors with the software DANA (http://dana.actoranalysis.com, Bots et al., 2000; Bots, 2007a). In DANA, actor perceptions are represented as causal maps (Axelrod, 1976; Chaibdraa and Desharnais, 1998; Eden, 2004; Montibeller and Belton, 2006) that show relations between goals, actions and external influences. Assuming rational choice, the actors' preferred strategies can be automatically inferred from these maps. Confrontation of perceptions and strategies can reveal actor relations such as awareness, resource dependency, conflict and coalition potential. Originally, the DANA software tool has been applied for "actor modelling", i.e. for the representation, analysis and comparison of actor perceptions as part of an in-depth stakeholder analysis (Hermans, 2004, 2008; Kastens, 2006), and for assessing resource dependency and finding win–win strategies (Bots, 2007b). In the research work presented here, DANA was extended to perform not only "actor modelling" but also semi-quantitative modelling of the actions of these actors under given scenario conditions as well as of the resulting changes of factors, i.e. variables that can be used as input to (bio)physical models.

Actor-based modelling with DANA can be considered as a type of agent-based modelling approach. In agent-based modelling, an agent individually assesses its situation and makes decisions on the basis of a set of rules (Bonabeau, 2002), which is also the case in our modelling approach. In terms of the characteristics of agent-based simulation models proposed by Hare and Deadman (2004), DANA has the following characteristics:

- It considers a small number of actors (approximately 10–20)
- Actors are not individuals but institutions or groups (e.g. "water suppliers" or "consumers")
- Characterisation of the specific problem perception of each agent (societal actor) is detailed (using semi-quantitative graphs)
- Social interaction is modelled in a simple manner
- Different from most agent-based modelling approaches, DANA does not simulate the influence of the change of physical variables on actions but only the influence of the actions of other actors.

We prefer to call our modelling approach "actor-based" instead of "agent-based" because we want to emphasise that it simulates the behaviour of societal actors that also participate in model development within the participatory process, and not the behaviour of more general "autonomous agents" (a term more common in computer science than in the social sciences, Bolte et al., 2007). Besides, we want to stress the link to actor analysis.

In this paper, we present a semi-quantitative actor-based modelling method that is implemented by an extended version of the software DANA. The goal of this type of modelling effort is to support transdisciplinary knowledge integration (Siew and Döll, 2012) as well as identification, within a participatory process, of implementable management strategies in problem fields with high levels of uncertainty or ignorance. Clearly, the goal of actor-based modelling is not to provide predictions of the future but to help actors understand better 1) the problem perceptions of the other relevant actors and 2) the dynamic human–environment system.

In the next section, we describe our case study on mobile organic xenobiotics (MOX) in surface waters. In Section 3, we explain how the problem perceptions of different actors are represented and subsequently used to infer potential future actions under certain scenario conditions, and how the change of physical variables (factors) that result from these actions are determined. We show how temporal developments of actions and factors are approximated. In Section 4, modelling results are presented for the problem field of MOX in surface waters. In Section 5, the usefulness and limitations of our modelling approach are discussed, and in Section 6, conclusions are drawn.

2. Case study

We developed our semi-quantitative method of actor-based modelling within an integrated assessment of MOX in surface waters (INTAFERE, 2007; http://www.intafere.de), in which representatives of the most important actors in the problem field participated. A goal of this project was to investigate how integrated assessment could become an innovative risk evaluation method for MOX. In the European Union, more than 100,000 chemical substances are used, of which 30,000 are produced in amounts larger than 1 ton per year and 2700 in amounts larger than 1000 tons per year (BfR, 2007). The approximately 3000 substances that were newly introduced into the market after 1981 have been tested with respect to toxicity for humans and aquatic ecosystems, but of the