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SPECIAL FEATURE

Squaring the Circle? Combining Models, Indicators, Experts and End-Users in Integrated Land-Use Management Support Tools

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Abstract The most important challenges faced in the field of integrated land-use management are (i) harmonizing and integrating different datasets, (ii) selecting appropriate indicators, (iii) fitting suitable models to adequate scales, and finally (iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility with the adaptation to a variety of questions and applications. The articles of this special issue "Squaring the Circle? Combining Models, Indicators, Experts and End-Users in Integrated Land-Use Management Support Tools" demonstrate the challenges that are related to this topic. The case studies present examples of such integrated systems in order to recommend best practices to support land-use management and to reveal existing shortcomings. As a conclusion, seven features of a successful applicable integrated land-use management support system are derived: (1) ability to deal with discontinuity in information and datasets, (2) contribution to solve the problem of indicator diversity, (3) structuring the decision-making process, (4) support of participation processes in generating decisions, (5) development, comparison and evaluation of land-use alternatives, (6) assessment of the efficiency and trade-offs of management options, and (7) assistance of stakeholders in group communication processes.

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Introduction

Land-use management is a multidisciplinary field that is confronted by an increasing level of complexity. Issues such as cross-sectoral policy making (e.g. agriculture, forestry), land-use planning and integrated ecosystem service management (e.g. water management, nature protection, tourism) make it necessary to involve multiple stakeholders (Sterk and others 2009). Increasing demands from a public that is scrutinizing decision-making regarding land-use management and its effects on environmental conditions and ecosystem services add additional complexity (Messner and others 2006; Newham and others 2006; Milligan and others 2009). In a society characterized by globalization effects, large scale interactions between agencies and institutions at an international level influence decision-making even at a local level.

As a consequence of such multiple and sometimes confusing interactions, land-use management decision-makers are being confronted with an increasing number and diversity of rules, regulations and directives. This circumstance often poses problems with the application at different spatial scale levels—from the global to the continental level and from the continental to the national, regional and local level, respectively. This means that the scale of integrated land-use management (including analysis, modeling and assessment) is not restricted to the global level, but includes local and regional models of ecosystems and environmental processes (Parker and others 2002). Sectoral models at the local and regional level

(e.g. agriculture and forestry) generally neglect interactions with other land-use types, and oftentimes ignore landscape structure aspects and spatial interactions of different land-use types, which are critical for a proper understanding of environmental processes; such models are often not compatible in their temporal and spatial resolution (Parker and others 2008; Baskent and Keles 2005; Botequilha Leitao and Ahern 2002).

Another well-known reason for an increase in the complexity of land-use decisions is the dynamic nature of the environmental parameters (climate, site conditions, etc.), which leads to uncertainties regarding their interactions (e.g. interactions between climate change and changes in ecosystem processes), and the rate and extent of change (Matthies and others 2007). Moreover, environmental data are officially available, access is often difficult (Allan and others 2006; Volk and others 2008), and data bases focused on different scale levels and land use categories are often incompatible.

Furthermore, the selection and interpretation of suites of sustainability indicators, some of which are focused on aspects of land-use change, can send ambiguous signals to land-use managers. There is an excessive number and variety of indicators to assess the impact of human activities on the environment at different scales—which leads to problems with the interpretation and harmonization of these indicators and oftentimes limits their usefulness in support of land-use management decisions (see e.g. Wijewardana 2008).

Another problem relates to the impact of the growing diversity of regulations with increasing temporal dimensions in management planning. An example is forest management planning with its division into strategic (long term = at least one rotation period) planning, tactical (mid-term = up to 30 years) planning and operational (short term = up to 10 years) planning (Baskent and Keles 2005). Strategic planning in forestry must necessarily respect development, resource provision or protection targets from politics and society. Once a strategic decision such as conversion of coniferous into deciduous forest stands is made, tactical and operational planning are forced to translate this decision into concrete planning measures and operations. In case, a strategic decision must be revised due to new, complementary or competing regulations, managing the tree species composition and stand structure according to a new strategy is difficult or takes at least several decades.

Challenges

Integrated land-use management assimilates in a comprehensive manner methodological approaches in management and evaluation from different land-use sectors. Appropriate management requires (i) harmonizing and integrating different datasets, (ii) selecting the right indicators, (iii) fitting the right models to the right scale, and (iv) integrating data, indicators and models into systems that allow both a high level of participation and flexibility in application to different questions. This seems to be comparable to the challenge of "squaring a circle". Squaring a circle is used here as a metaphor for doing something logically or intuitively impossible as it was in the ancient world the construction of a square with the same area as a given circle by using only a finite number of steps with compass and straightedge (see e.g. Hobson 1913).

Numerous approaches have been developed and are still being developed to promote an integrated land-use management. Originally developed to support business managers, decision support systems (DSS) have attracted much interest in the field of environmental management. Environmental decision support systems and procedures that combine multicriteria analysis (MCA) or optimization tools with models usually involve the integration of a broad information base. They are becoming increasing user-friendly, through careful user-needs analysis in the development phase and through the use of sophisticated stakeholder participation approaches in their application. Agent-based modeling and participatory approaches in the generation of tools and systems reflect the rising complexity of land-use management and the objective of arriving at integrated instead of segregated management concepts (Becu and others 2008; D'Aquino and others 2003; Parker and others 2003). Various integrated assessment and landscape modeling techniques are increasingly being applied as tools in support of land-use management or environmental and river basin management (see e.g. Janssen and others and Volk and others in this issue; Giupponi 2007; Newham and others 2006; Volk and others 2008). The complexity inherent in socio-biophysical systems and the various sources of uncertainty add further complications to such management, which faces a trade-off between the attempt to simplify the intrinsic complexity of such management planning, the need for scientifically robust approaches and detailed high quality data. Provision of transparent communication interfaces whenever public participation is considered, is a common challenge in DSS development (Matthies and others 2007).

Integrated landscape management tools that address this complexity pose the risk of getting too complicated for the end-user or even for the expert, and thus of never being used in practice. Giupponi (2007) states that despite the many DSSs developed in the field of environmental management, the risk of such systems failing to meet the challenge of real-world problems is reported to be high, and even the criteria for judging whether a DSS has been

successful or not are often a matter for discussion (e.g. Newman and others 1999; Zapatero 1996; Uran and Janssen 2003). Giupponi (2007) emphasized that there is a widely recognized need to develop new support tools for decision-making in this field, with greater attention to the needs of potential users and to identification of the application context. The typical rationale behind the development of these tools is to increase the overall benefit of land-use through improved planning and prioritization of objectives. However, a predominantly scientific focus on the development of these techniques has the potential to obscure the practical realities of land-use management and to result in a lack of acceptance and adoption of both the systems and their output (Diez and McIntosh 2009; McIntosh and others 2007; Malczewski 2003). This can result in management tools having minimal impact on decision-making and management support.

In the process of integrated assessment and modeling, participation of stakeholders involved in land-use management is a crucial element for success. Stakeholders need to be able to provide feedback throughout the entire integrated assessment and modeling process to ensure tools to support decision making and land-use management and the results thereof are suitable for their needs. Likewise, researchers, including model developers, need to be able to acquire knowledge from communities and organizations with statutory responsibilities through participatory approaches.

Aim and Scope of the Special Issue

The Special Issue addresses the challenges of integrated land-use management supported by multidisciplinary landscape modeling and the use of suitable indicators and upscaling techniques. Several examples with different foci are presented by the authors. Challenges are described and conclusions are drawn about best practices for use in land-use management support. The articles focus on forest landscapes in Europe and highlight participation processes that aim to link scientifically-oriented models, stakeholders and an interested public at different planning and management scales. This is illustrated with the generic land-use management support system presented by *Fürst and others* in the last article of the Special Issue. This system can be used to combine multiple indicators, model output and end-user needs in a flexible way.

The first article by *Volk and others* deals with the progress with decision support systems in landscape and river basin management. They analyzed the benefits and shortcomings of the recently developed decision support systems (DSS) FLUMAGIS, Elbe-DSS, CatchMODS, and MedAction. The analysis focuses on (i) application area/ decision problem, (ii) stakeholder interaction/users involved, (iii) structure of DSS/ model structure, (iv) usage of the DSS, and (v) the most important shortcomings. On the basis of this analysis, they formulate four criteria that they consider essential for successful use of DSS in landscape and river basin management. The efficiency and applicability of these approaches is discussed and suggestions are presented to overcome existing problems. *Wolfslehner and Seidl* review the state of the art in forest ecosystem modeling and multicriteria decision analysis in the context of forest management planning. They identify two major challenges in a harmonized application of forest ecosystem models and multicriteria decision analysis (i) the design and implementation of an indicator-based analysis framework capturing ecological and social aspects and their interactions relevant for the decision process, and (ii) holistic information management that supports consistent use of different information sources, provides meta-information as well as information on uncertainties throughout the planning process. *Janssen and others* present a generic, integrated bio-economic farm model with its linkage to other models at field, regional and market scales. They assess with their models the socio-economic and environmental effects of policies on farm management and production.

In the following articles, some examples and case studies are presented, which analyze and discuss options and restrictions in land-use management support. To support management decisions, a set of suitable indicators is required and local information must furthermore be upscaled to a landscape level. *Zirlewagen and v. Wilpert* demonstrate how to scale up ecological processes in order to better supporting their integration in forest management decision-making processes. The issue of which indicators can be considered as relevant for management support under changing environmental decisions is raised by *Fürst and others*. They introduce a screening method for better integrating the state and impact of environmental pollution in sensitive forest management decision-making processes. *Moravčík and others* discuss a model for the assessment of forests according to the degree of their naturalness. They considered the degree of forest naturalness as a basic criterion for the determination of the nature-conservation value of forest ecosystems. They identified the (i) possibility to restore and (ii) the possibility to improve the naturalness of less natural forest ecosystems, (iii) the occurrence of the endangered species, and (iv) the occurrence of other natural values as further decision-making criteria.

Three contributions by *Lorz and others*, *Vuletic and others* and *Fürst and others* illustrate, for a case study in Central and South-Eastern Europe, how environmental and societal parameters and dynamic development of landscapes, environment and society can be integrated into adaptive management support tools required by planning.

Natural and socio-economic conditions are compared for Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Germany, Serbia and Slovenia as a basis to interpret differences and similarities in stakeholder preferences for decision and management support tools. Results from surveys of forest management relevant stakeholders are used to define a common understanding in best practices in management support. Conclusions and recommendations are made for country-specific policies that consider international policy processes and experiences of other countries.

One of the greatest challenges in land-use management decision support is the integration of locally or regionally specific information. Such knowledge has to be integrated into a generic framework, where the input delivered by sectoral models, statistical data, monitoring information or expert knowledge has to be compatible to the information needs on the landscape level. A precondition for this procedure is a hierarchical evaluation and interpretation approach, which moderates between different levels of detailedness and complexity of information for decision making. *Fürst and others* present a system that combines a cellular automaton based modeling approach for simulating land-use changes with GIS functionalities for integrating different land-use change scenarios and a multicriteria evaluation approach. Model outcomes, statistical data and monitoring information are used as a knowledge base to describe the impact of different land-use types and land-use practices on a set of selected ecosystem services. Knowledge gaps are filled by a stepwise integration of regional expert knowledge and stakeholder perception. An exemplary application case in developing a regional climate change mitigation strategy leads to the conclusion that the evaluation process and results have high regional acceptance and that the results of simulated different land-use scenarios are considered as reliable by the planning actors.

Conclusions

The articles presented in this special issue cover a broad variety of integrated land-use management support tools on different scales, from DSS development and application in river basin and landscape management, to integrated bio-economic farm management tools, to forest ecosystem analysis, modeling and management, and regionally specific adaptive land-management tools. Concluding from these articles, and several other studies (Alkemade and others 1998; Harremoës and others 2001; McCown 2002; Parker and others 2002; Uran and Janssen 2003; Giupponi 2007; Van Delden and others 2007; Van der Sluijs 2007; Voinov and Gaddis 2008; De Kok and others 2008; Hewett and others 2009), an integrated land-management system that is able to cope with the present and future multifaceted challenges should fulfill the following preconditions. It should:

- be able to deal with discontinuity in information and datasets and bridge information gaps through active integration of scale-appropriate (local, regional) experience from experts and stakeholders;
- create a standardized list of indicators, which supports customizable indicators applicable on local to regional level that are consistent with the generic list in the sense of a nested approach;
- support the user on structuring the decision-making process and apply an appropriate conceptual approach (modeling vs. expert systems);
- support participation processes in generating decisions, management options and system understanding by means of user-friendly communication approaches such as visualization instead of simply presenting tables or parameter values;
- help to develop, compare and evaluate alternative management options (on the basis of a pool of options);
- help to assess the efficiency and trade-offs of possible management strategies on the basis of available information (data and experience);
- assist different stakeholders or stakeholder groups to balance and estimate their preferences.

One single tool that fulfils all these preconditions might not yet exist and remain a vision. But the articles presented in this special issue showed that there are already tools available that bundle some of these features. They force the development in this direction and revealed still existing shortcomings. This might improve the acceptance of such tools in land-use management planning and decision processes. The main objective of this process has to be the support of sustainable land-use management to overcome the still valid findings of FAO (1999):

"Planning and management of land resources are integral parts of any rural development programme as well as many development programmes with both rural and urban components. Land use does not consider agricultural uses only but also encompasses natural areas, forests, watercourses and urban areas among others. Land-use planning has often had negative connotations because it was traditionally associated with top-down procedures. […] Conventional land-use planning has frequently failed to produce a substantial improvement in land management, or to satisfy the priority objectives of the land users. As a result, rural development programmes have had mixed success in meeting production and conservation aims."

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