Multi-scale Integrated Modelling for Sustainable Adaptive Systems

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Abstract
This paper presents a theoretical expansion of the 3-step modelling approach (Costanza & Ruth, 1998), which proposes an incremental progress from "scoping "models to "research" and "management" models. The trade off for increased detail and resolution in model building is a decrease in transparency. This paper aims to provide a context for Mediated Modelling (which happens at the "scoping" level) and similar system dynamics based participatory modelling approaches, as a missing link toward Adaptive Management. An emphasis is placed on reflective capacity among relevant stakeholders to evaluate the behaviour of systems at various scales and integrated dimensions. A theoretical Multi-Scale Integrated Modelling for Sustainable Adaptive Systems (MIMSAS) framework is discussed as a foundation for three, 6-year research programmes on (1) urban systems, (2) energy systems and (3) watershed and coastal ecosystem services.

Key words: Mediated Modelling, Adaptive Management, Sustainability, Integration.

Background
With global biophysical systems at a "tipping point", ecosystem degradation, a financial crisis and a global economic recession, the trans-disciplinary approach of Ecological Economics (EE) is gaining increased relevance. This approach is trans-disciplinary, integrative and "solution-oriented". For example, its practitioners are interested in well-being and Genuine Progress Indicators, rather than economic growth and Gross domestic Products. Inherently, the focus is broad and includes integration of social, economic and ecological systems and their underlying structure and dynamics. EE highlights synthesis in balance with analysis. The integration of socio-economics and ecological systems is inherently complex and sensitive to issues of scale; add the human factor of governance (fairness of distribution and efficient allocation) and it becomes clear that humanity is facing a daunting task to "get it right". To support decision making in a transition toward a more sustainable world I propose a framework that highlights Adaptive Management (AM) and the need for reflective and collaborative learning. I focus on the "Assessment" component of an Adaptive Management cycle and the use of model building to support integrated

assessments. In particular, I believe that Systems Thinking (ST) and its quantitative form System Dynamics (SD) are particularly well-suited to be used in integrated assessments and increasing levels of detail. However, I have concerns about a common drive to develop System Dynamics models at "management" level when not solidly grounded in a participatory process. With "grounded" I mean that key stakeholders understand the actual workings of a management model, i.e its merits, limitation and assumptions, beyond a role-play or gaming situation. Without a broad (as opposed to expert) understanding, the impact and relevance of any model (whether rooted in SD or any other approach) is questionable. ST and SD provide important tools in pursuit of an integrated perspective of socio-economic and ecological systems and is therefore an essential tool in the tool kit of an ecological economist. Partly in response to the inaugural speech by Jim Lyneis, I offer this paper as contribution to the conversation of "what the role of SD should be". With this paper I argue for a broader application and perspective of "System Dynamics" and particularly the role of "Participatory/Mediated Modelling" while finding synergies with other inquiries of thought rather than taking a more narrowly defined perspective of SD.

SD tends to explore dynamics in a "horizontal" plane, focusing on dynamics within a system for management purposes. On the other hand, Complex Systems (CS) and hierarchy theory tends to be interested in scale issues and "vertical integration" and appreciates the complexity that arises from scaling; how do new properties of a system emerge and impact a system at a different scale? Where as SD tends to be applied in manageable situations, CS practitioners observe rather than aim to manage; in part because the complexity is deemed too high. The emerging field of Complex Adaptive Systems is concerned with the emerging, self-organizing properties of complex systems and remains theoretical. Yet, people make decisions; sometimes with far reaching consequences, as in the case of energy systems, urban planning and ecosystem management. These are complex decision-making situations, which require appropriate tools and processes. Humans and their societies are learning, adaptive entities. Rather than mere observation, we aim to actively manage our environment. Adaptive Management (AM) is sometimes described as "decision making as an experiment" (Riley et al, 2003). AM is, in principle, the acknowledgement of a "feedback loop and time lag" in a policy making context. As such, AM is potentially of interest to the SD community. AM can benefit from various forms of model-based assessments and I emphasize Mediated Modelling (MM) and similar approaches. I propose to explore SD tools and management approach in a hierarchical, CS environment and apply the cyclical foundation of AM to organize such evolution (figure 1).

A comparative assessment of stakeholder involved modelling methods

Model building in a group setting has been a recognized sub-component of the SD community for some time now. Advances in computing capabilities have opened possibilities for facilitated, computer-assisted processes with stakeholder involvement. Several networks have, often in isolation of each other, developed approaches to support decision-making related to complex problems through a form of group model building. Currently, there are a host of names for similar approaches: Mediated Modelling (van den Belt, 2004; van den Belt et al 2006, 2007a,b,c; Antunes et al 2006, Videira et al 2006), Anticipatory Modelling (Sendzimir et al, 2007); Collaborative Modelling (Selin and Chavez, 1995; Beall and Zeoli, in press 2008), Cooperative Modelling (Cockrill et al 2006, 2007; Tidwell and v.d. Brink, 2008),

Participative or Group Model Building (Vennix 1996, 1999; Andersen et al 1997; Andersen and Richardson, 1997), Strategic Forum (Richmond, B., 1991), Participatory Modelling (Brown Gaddis et al, 2007, Jones et al, 2008); Participatory Scoping Modelling (Sandker et al, 2007, 2008) and Scoping Modelling (Costanza and Ruth, 1998).

Beall and Zeoli (in press, 2008) summarize the components that these approaches have in common as:

1) based on systems thinking at least in their conceptual, qualitative stage.
2) including some form of stakeholder involvement;
3) producing models that may or may not "qualify" as quantitative system dynamics (SD) models.
4) sometimes initiated by one organization with additional stakeholder participation and sometimes constructed to scope out dynamics for internal use.

Beall and Ford (2007) provide a categorized overview of ten case studies. All of the approaches mentioned are, for the purpose of this paper, summarized as "scoping" models, as they tend to be broad-brush attempts to synthesize learning among various stakeholers involved.

In addition, other modelling approaches, such as agent-based modelling (Montes de Oca Munguia, 2009) and multi-criteria decision making (Antunes et al, 2006) are becoming more participatory, either through role-playing (Barreteau & Bousquet, 2000) or by involving stakeholders in the model building process (d'Aquino et al, 2003).

The current development of "how to use models" is shifting away from individual modelling techniques toward finding the synergies between modelling techniques and combining them, to solve real world problems (Smajgl et al, 2009).

Even within the System Dynamics community, there are some apparent (but no hard-lined) differences between Systems Thinking / System Dynamic based participatory approaches:

1) Participatory modelling tends to focus on the resulting model and content through participation, while mediated, cooperative and collaborative modelling tends to focus on the group learning to provide a framework for content and learning, rather than focusing on the resulting model. In addition, participatory modelling doesn't necessarily refer to systems thinking-based modelling tools and may refer to modelling as Group Role Play, Geographic Information System mapping or various forms of agent-based modelling.
2) Group Model Building tends to refer to qualitative models rather than computer generated simulation models. Scenario or Vision Planning are also among the more narrative-based approaches.
3) While some see MM as potentially useful for stimulating a dialogue or the development of community planning (Tidwell et all, 2004; Sandker et al 2007, 2008; Forgie & Richardson, 2007). A hesitation to use MM stems from rigid system dynamics (SD) modelling evaluation requirements and a concern that the topic under consideration is too complex for a system dynamics model (Dudley et al, 2008) or; SD and group model building "fail to deal with constitutional change" (van den Smagt, 2006).

4) Vriens and Achterbergh (2006) make a considerable contribution by clarifying the social dimensions of SD modelling as (1) models *of* social systems; (2) models built *in* social systems and (3) models built *for* social systems. The examples of MM and similar modelling approaches focus on dimension 2 and 3.
5) While the traditional System Dynamics (SD) community tends to place stronger emphasis on systemic explanations of the past to draw lessons from, the participatory inclined users of SD tend to focus on the future and embrace complexity.
6) SD tends to focuses on decision support and not on implementation (Grossler, 2007), while MM practitioners are inclined to trade off SD purism to make a process work toward implementation.

Costanza and Ruth (1998) proposed a sequence of model building from "scoping" models (which is where most MM and similar models fit) to more detailed "research" models and finally "management" models for frequent and accurate decision-making. The progression indicates an increase in precision while trading off communicability of the structure, parameters and data quality of a computer model.

MIMSAS – taking scoping models to the next level

The stakeholder involved modelling processes mentioned above are a basis for multi-scale integrated modelling for sustainable adaptive systems and includes the following key elements:

Multi-scale - refers to vertical integration of global, national, regional and local perspectives.

Integration - refers to environmental, social, economic technology, policy and political perspectives. Synchronization of expert and visionary thinking that maintains the bigger picture while going in ever greater detail.

Modelling - refers to any assessment tools at scoping, research and management level, including databases, but for my purposes focuses on system dynamics and complex systems models

Adaptive - refers to the capacity to manage iterative cycles of complexity and resolution while maintaining flexibility. Building the capacity to see the big picture in increasing detail without loosing the overview (i.e. provided by vision, assessment, planning, implementation, monitoring etc). Policy-making as a deliberate "experiment".

Sustainable - refers to socio-economic and ecological systems being in tact to support well-being for current and future generations.

There are two possible tracks to pursue the enhancement and uptake of models as tools for decision support through integration by:

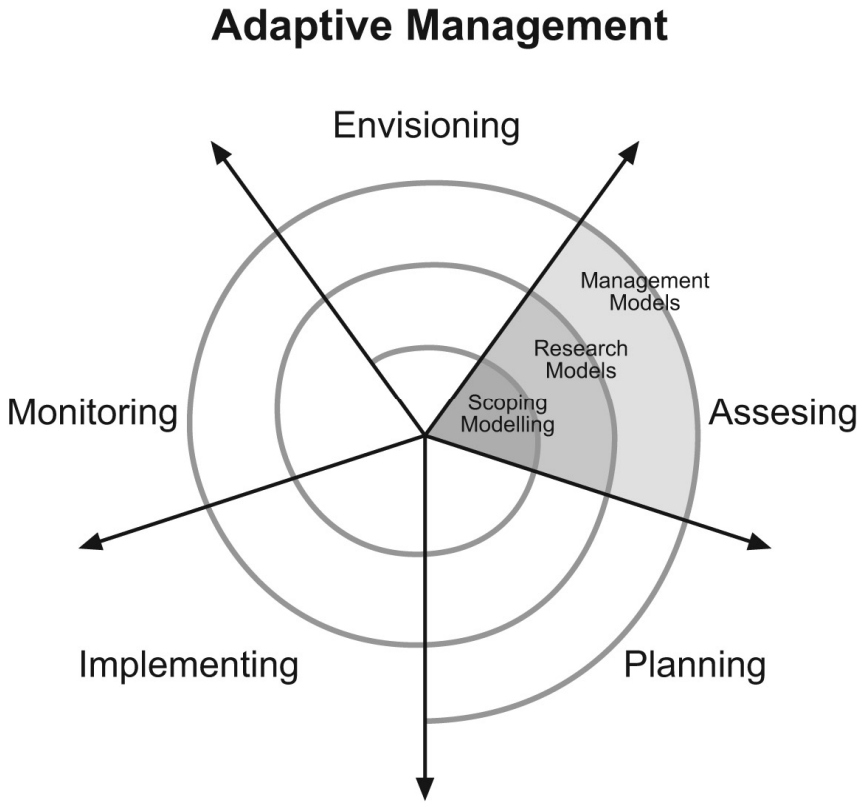
1) Linking existing "legacy" models and databases or,
2) Integrative (scoping) assessments in areas where models haven't been linked combined with the collection of relevant data.

Both approaches have their costs and benefits. Therefore, it is important to find the appropriate mix through careful evaluation and criteria to ensure that a desirable next step, relevant to the context, takes into account both the reality of "what is" and the vision of "what's desired".

Our MIMSAS framework is the evolving foundation of three programs that aim to develop the methodology and tools for adaptive capacity among stakeholders and decision makers in the design process of models as assessment tools, but also follow the process through implementation, monitoring and refining a vision. Figure 1 is a schematic overview and conveys the elements of Adaptive Management on outward pointing axis. These axes signify an increasing level of detail and resolution of time frame. In the past, modelling has often been used to generate extensive "management models" of high resolution and detail, often with limited impact. At the core of such model building projects, stakeholder involvement and specifically the capacity to use system thinking/dynamics is lacking.

In this view, reflective (feedback) capacity does not only apply at a time scale of multiple years, as is the case in planning cycles and adaptive management. Reflective capacity is also observed through the use of "listening cycles" (Conklin, 2006) during Mediated Modelling sessions at a time scale of minutes and hours, as well as in between MM session, at a time scale of days and weeks, as well as over the course of a MM project at time scales of months to years (van den Belt, 2004). Hence the issue of reflective-ness and adaptive-ness gain relevance on a scale of time and is dependent on implementation and monitoring before desirable progress can be achieved.

Figure 1 – Multi-scale Integrated Modelling for Sustainable Adaptive Systems



In theory, the sequence as proposed in the 3-step modelling process (Costanza & Ruth, 1998) can only productively reach a next stage after a full adaptive management cycle is completed (van den Belt, 2004). For example, an AM cycle starts with the recognition of a seeding vision, followed by an assessment of what information is both available and/or required to develop a viable plan. Provided the appropriate

stakeholders are involved and reaching a higher level of understanding, the modelling project can assist in building consensus during the assessment process. A period of implementation and monitoring follows. Monitoring is preferably based on the indicators the stakeholders developed by building "scoping" models. The results are tested against an evolving vision, which can mean a more refined, detailed vision or involving increasingly more people and/or communities.

After a full AM cycle, the scoping model is ideally revisited; its function is now to evaluate "were we right? Does the monitored data mean that we "only" change/narrow a few parameters? Or should the model structure be updated, because we missed major feedback loops or time lags? Can the results from research models be integrated in a meaningful way in the scoping model or is the scoping model obsolete? Research models are more detailed, explicitly targeted models with higher resolution, data requirements, precision and are generally less transparent. In principle, research models are developed by experts. The goal is to develop models with a long "shelf life"; i.e. models that provide a basis or learning and insights for a growing number of people/communities. Applicability of research models increase when based on appropriate questions; again, the broader the perspectives involved during the scoping phase, the higher the likelihood that the "right" questions surface. "Right" or robust in the adaptive context refers to "shelf-life" as the assessment tools and plans are periodically up for review. Not until the next step in planning, implementation, monitoring and envisioning is cycled through, is the stakeholder community ready to construct resource intense management models. Reality is more messy and generally dealt with in a more linear manner than the proposed theory, causing unintended consequences. I advocate embracing cyclical thinking (starting with ST, SD and progressing to CS) at various levels of scale in the dimensions of time, space, complexity as well as social dimensions.

Moving from theory to practice and back to theory

The theory above is based on practical experience with several case studies using Mediated Modelling for scoping purposes in the context of coastal zone management (van den Belt et al, 1998), land use / integrated watershed management (van den Belt, 2004), UV-b radiation and ecosystem services (van den Belt et al, 2005; 2006) and energy planning (van den Belt et al, 2007). None of these models were intended to being re-visited after a time lag of a few years, even though some have spurred "research models" in the form of PhD projects on particular weakly understood links within the scoping model. In addition, summarized research models have been used as input into the scoping models. Even though "scoping" models seem useful in addressing (and often dissipating) a complex and potentially contentious situation, "re-visiting" scoping models could in part be hampered by the fact that a Mediated Modeller is often hired on a consulting basis as a neutral party to facilitate an often contentious area of investigation, bringing together stakeholders that would otherwise be unlikely to put their minds together in a collaborative manner. In addition, public organizations (Boland and Fowler, 2000) often lack the capacity to pursue these tools, because incentives tend to reward short-term, centralized, segmented decisions with a competitive rather than collaborative underpinning.

Western society, science and education tend to reward jumps ahead into areas of ever greater detail without the relevant capacity to synthesize and build the human capital to make a collective rather than individual progress, as adhered to in Eastern and often indigenous societies.

In the past, re-visiting of scoping models has not been an explicit goal; many projects have been undertaken as a "pilot project" to test the use of SD modelling for integrative purposes in a group context without a plan for mid to long term follow up. The proposed framework is the foundation for programs with a duration of 6 years on urban and energy systems, as well as ecosystem services. Throughout these programs, a conscious effort will be made to evaluate progress based on figure 1 and develop result measurements on the various scales and areas mentioned in this paper. However, it is recognized that even a 6-year time perspective is likely too short to develop a MIMSAS as proposes. The use of existing "legacy" models at "management" level will also be evaluated.

Conclusion

System Thinking and System Dynamics has much to contribute to a transition toward a more sustainable society, through its philosophy of interconnectedness, feedback loops, time lags and tradition of model building. From practical experience, I suggest that the relevance of ST and SD increases through the involvement of stakeholders in the process of model building. I propose to deliberately extend the use of Mediated Modelling and similar approaches into long-term development adaptive management capacity. As such, more experimentation is needed to test and develop the suitability of SD models at "scoping", "research" and "management" level, with increasing precision but trading off transparency. Models as assessment tools are only relevant if/when actual planning, implementation and monitoring follow from their assessment capacity. This realization could greatly improve the uptake by end-users and impact of SD models.

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