7. SYSTEMS THINKING – LANGUAGE OF COMPLEXITY FOR SCIENTISTS AND MANAGERS

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Land managers are regularly faced with the prospect of having to anticipate the consequences of their actions, and avoid unintended consequences, without comprehensive information about the system surrounding their management activities, for a number of reasons. First, natural systems are complex and while information may be available to assist managers in decision-making, it is often uncertain. Second, relevant information is often fragmented and scattered throughout scientific publications, reports, databases and in the heads of experienced people, making it difficult for managers to utilise. Third, people can have divergent views about management because pieces of information often relate to different management objectives (e.g. conservation vs. production) and different people hold different opinions about how management systems operate. This uncertain, fragmented and conflicting picture of natural resource management can result in managers continually dealing with symptoms rather than the underlying causes of management problems. Thus, there is a need to integrate information surrounding land management issues in a systematic way. This paper provides an insight into how systems thinking can be used as a mechanism for developing an understanding of the issues under consideration. It briefly explores the requirements for dealing with complex systems and demonstrates the application of three examples of Systems Thinking tools to help achieve some of the desired outcomes toward sustainability. The paper concludes by highlighting the need for a paradigm shift (a new way of thinking about the world and relationships). For this, Systems Thinking not only offers a language for understanding complexity and dynamic change, but also provides sophisticated and unsophisticated modelling technology and associated collaborative learning environments.

INTRODUCTION

Despite most impressive advances in sciences and technology, the prevailing worldview and the way researchers and managers work and approach problems are deeply rooted in the thinking that emerged during the Renaissance of the 17th century! This thinking was influenced by the sciences of that era and in particular by Newtonian physics. Newton viewed the world as a *machine* that was created to serve its master –God, (Ackoff *et al*. 2007). The machine metaphor and the associated mechanistic (positivist) worldview, which was later extended to the economy, society and the organisation, have persisted until today and are evident in current thinking and vocabulary. As the futurist Alvin Toffler declared, 'the Age of the Machine is screeching to a halt' (Maani and Cavana 2007).

In the early part of the 20th century, a new breed of scientists, in particular quantum physicists, began to challenge the Newtonian precepts. Bertalanffy's seminal text 'General Systems Theory' (1968) became a major milestone of the systems theory. Later, Jay Forrester of MIT introduced and demonstrated the applications of feedback control theory in simulation models of organizations. Forrester's pioneering work led to the scientific discipline of Systems Dynamics. Systems Dynamics is concerned with applications of systems theory and computer modelling in business, economics, and the environment (Maani and Cavana 2007).

Systems Thinking (ST) is a discipline for understanding the complexity underlying business, economic, scientific and social systems (Maani and Cavana 2007). The prevailing approach in dealing with complexity is analysis. That is, in order to understand a complex situation (e.g. an organization, a policy, a biological system (such as the human body) – we break it into pieces and study the pieces *separately* (Ackoff *et al*. 2006). This approach tends to overlook the interdependencies and interactions between the constituent parts, which are the very causes of complexity and dynamic behaviour in systems.

Systems Thinking has three distinct but related dimensions: Paradigm, Language, and Methodology as outlined below (from Maani and Cavana 2007):

- *Paradigm*: Systems Thinking is a way of thinking about the world and relationships. This paradigm relates to the dynamic relationships that influence the behaviour of complex systems. It is the ability to see the tree and forest.
- *Language*: Systems Thinking provides a tool for understanding complexity and dynamic change. The Systems Thinking language unravels underlying cause and effect relationships and makes divergent mental models transparent.
- *Methodology*: Systems Thinking provides a sophisticated computer modelling technology and associated learning environments for group interactions and learning.

This paper briefly explores the requirements for dealing with complex systems and demonstrates the application of three examples of systems thinking tools to help achieving some of the desired outcomes toward sustainability of natural systems.

THE SITUATION IN NATURAL SYSTEMS

Natural systems are complex. Resource utilisation is moving beyond commodity production to value chains, sustainable natural resource management, rural community development and transparent governance. Agriculture is an excellent example of how complexity increased over time. It went through successive eras of pioneering, production and productivity (Bawden 1991), and as each successive era built on its predecessors, levels of complexity in the production system increased, and now the added challenges of environmental and social responsibility have come to prominence. Just as fertilizer use and mechanisation propelled production systems from one era to the next, Systems Thinking has arisen as a breakthrough mechanism for analysing complex problems, comprehending inter-relationships at a variety of levels and creating novel management solutions to improve profitability in an era of sustainability.

Knowledge is uncertain and scattered. Land managers are regularly faced with the prospect of having to anticipate the consequences of their actions, and avoid unintended consequences, without comprehensive information about the system surrounding their management activities (Bosch *et al.* 2003). While the information may be available to assist managers in decision-making, it is often uncertain, fragmented and scattered throughout scientific publications, reports, databases and in people's heads, making it difficult for managers to utilise an interdisciplinary approach as the only way to deal with complex management problems to help build a more sustainable future.

Biophysical scientists spend most of their efforts in finding management solutions to issues of ecological sustainability, at all different scales, through developing a better understanding of ecosystem functioning under various disturbance regimes – from minimum disturbance (conservation) to all different kinds of disturbances such as grazing, fire, deforestation, mining, and tourism. Social scientists, on the other hand, strive to provide valuable information on understanding the underlying social and institutional causes of patterns of sustainable development, known to contribute to decisions about natural resource management (Dovers and Mobbs 1997). Biophysical processes are set in train by human managers (Ross and Abel 2000), hence the need to understand the human managers and the rationales for their actions. However, to transform these research findings into useable knowledge remains a problem. Without *integrating* the ecological, social and economic dimensions, the development of new pathways for sustainable futures will continue to be inhibited.

Community-based knowledge comes in diverse forms, since managers themselves are diverse and manage for quite different purposes at different scales (see *Divergent views* below). These multiple forms of natural resource knowledge and the human dimensions are in many cases not integrated. This results in the input from all stakeholders not being maximised, which makes it difficult to design the best solutions to sustainability challenges, and to ensure ownership/uptake of solutions.

Divergent views exist. There is a focus on working within system boundaries, especially when people are working within levels of system organization. Different stakeholders hold different mental models about how a system works. They also have different objectives, resulting from different *driving forces* at different scales – globalisation of economies versus the bank account of individual land managers; long-term planning (e.g. for climate change, biodiversity) versus how will that help the land manager to pay their bills; production of quantity and quality versus value-added products; demand for systems management based on catchments, landscapes, management of bioregions versus at the property level; tourism growth versus growth in use of protected areas; public versus private goods; economic rationalism versus developing social capital; national funding priorities versus having a telephone that works; and public priorities versus personal desires.

Not understanding the mental models of each other makes it difficult to communicate and thus to share the enterprise of improving management and knowledge together. This leads to differences in the *consequences* of natural resource management decisions for different types of people, especially those who make a direct living from the land (agriculture, forestry, tourism), and those who play a management role but are not dependent directly on the management outcomes for their livelihoods. Within each group there is diversity with regard to attitudes, values, priorities, people's perspectives of the systems in which they operate, lifestyles and locations.

This uncertain, fragmented and conflicting picture of resource management can result in managers continuing to deal with symptoms rather than underlying causes of management problems.

REQUIREMENTS FOR DEALING WITH COMPLEXITY

There appears to be no easy solution to improving information access, utilisation and management. The *application of Systems Thinking* to understand and manage the 'natural' and 'people' systems associated with resource problems and solutions is a 'new way of thinking' to manage the complex problems associated with sustaining and enhancing the natural resources. Although the range of methods and methodologies are extensive, many of these new ways of thinking have emerged from or embrace the concepts inherent in Systems Thinking (Bosch *et al*. 2007).

Four Levels of Thinking

Human interactions with the world occur at four levels (Maani and Cavana 2007). The first is the *events* level where people become aware of things in the world − through a noticeable change at home, workplace, city, the nation or in the world. This could be a power failure, a car accident, a major crime, or a change in the weather. Awareness of major events generally arises through the media − headlines, breaking news. A common response to events by managers and policy makers is reaction. However, as events represent only the symptoms of deeper problems, reaction to events often generates quick fixes and leads to firefighting behaviour. It is also ironic that most measurements (scientific or organizational performance) happen at the event level and relate to past occurrences. Ackoff (1999) estimated that about 25% of corporations and more than 50% of government agencies plan and manage in this way.

The next level of thinking is *patterns* where a larger set of events (or data points) are linked together. Patterns are much richer and more meaningful sources of information than events because they show the changes and trends in data over an extended period of time. In fact, this is how we learn about nature as we develop the ability to recognize complex patterns.

The next level of thinking is *systemic structures* which reveal how such trends and patterns relate to and affect one another. This represents a much deeper level of thinking that can show how the interaction between various factors gives rise to the outcomes that are observed. These factors could be economic, social, political or natural. The critical thing at this level of thinking is to understand *how* these factors interact.

There is yet another, deeper level of thinking that hardly ever comes to the surface. This is the *mental model* of individuals and organisations that influence *why* things work the way they do. Mental models reflect the beliefs, values and assumptions that we personally hold, and they underlie our reasons for doing things the way we do. However, despite their critical importance mental models generally remain obscure limiting our collective understanding of issues and hence impeding meaningful communications and development of common vision and action.

The four levels of thinking described above are shown in Figure 1 below. This figure uses the analogy of an iceberg, where the event level of thinking is only the tip and yet most people are satisfied with this level. This is because events are the most *visible* part and often require immediate attention and action (Maani and Cavana 2007).

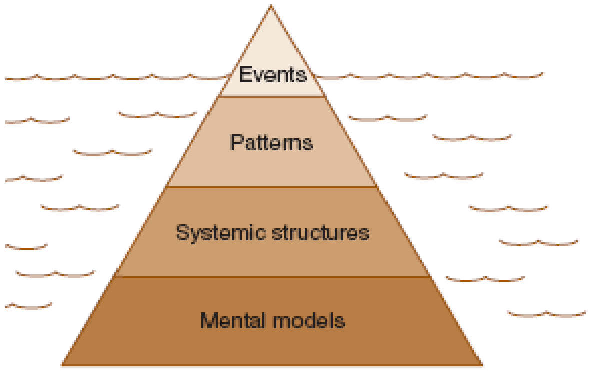

Figure 1. Four levels of thinking model
Source: Maani and Cavana 2007

A shift toward multi-disciplinary approaches is required. In order to explore the complexity of interactions within the 'hard' system (the biophysical components) and within the 'soft' system (the interactions between the biophysical components, technology and the land owners or village community) required a shift away from single disciplinary projects toward multi-disciplinary and inter-disciplinary research, and approaches that allow for the recognised complexity of and uncertainty within systems (Bosch *et al*. 2007).

More efficient approaches are needed that would allow knowledge and understanding to emerge from processes involving stakeholders. Achieving better information management and ownership and uptake of solutions, requires using a range of processes that will engage the diverse range of people (including different levels of organisation) and promote the direct involvement of all stakeholders in complex problem-solving processes towards sustainable natural resource management. Learning and action-based participatory approaches such as action learning, action research, participatory action research, and adaptive management have become valuable tools for Systems Thinking.

The tools of Systems Thinking focus on the four levels of thinking. They move the stakeholders and decision-makers from the event level to deeper levels of thinking and provide a systemic framework to deal with complex problems.

The following are examples of how various tools for operationalising Systems Thinking can help to achieve the desired outcomes.

a. Influence Diagrams

Mapping an influence diagram. The influence diagram in Figure 1 was created with graziers, researchers and extension officers using a Bayesian Belief Network (BBN) (Cain *et al*. 1999) which captured their knowledge about the factors believed to influence '*Tree Density*'. Through this process, stakeholders also identified management actions and non-manageable factors that they believed would influence the outcome.

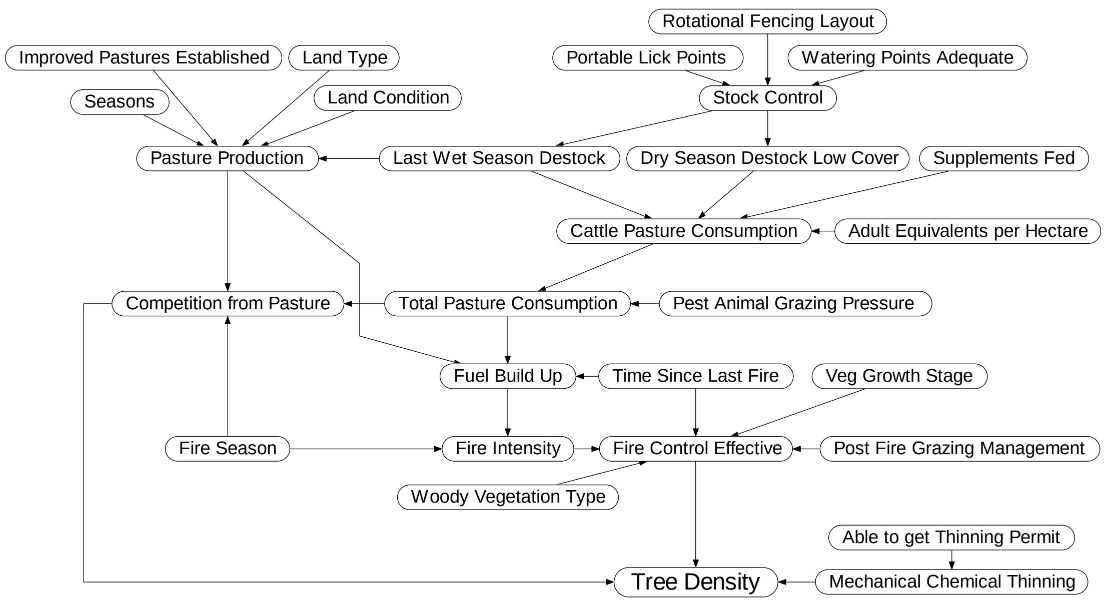

Figure 2: Multi-stakeholder influence diagram for tree density

Using the BBN as a mechanism for Systems Thinking entails effective stakeholder communication and knowledge sharing. Stakeholders could express and discuss their understanding of the cause and effect relationships between management actions, controlling factors and resource management outcomes or goals. This tool also provided stakeholders with a mechanism to identify where their knowledge fits into an overall understanding of the management system and to appreciate how other stakeholders understand the links between management actions and outcomes.

Allowing for different perspectives and divergent views. The mapping process also allows for a range of perspectives and divergent views, because stakeholders have different implicit and explicit understandings (mental models) of how ecological processes work (Ross and Abel 2000). However, in order to communicate with another person, one does not need to think (construe) in the same way, but be able to construe how the other person is construing (Bosch *et al.* 2003). This means that while divergent views occur, the appreciation of one another's views gained through 'mapping the system' helps stakeholders to converge on a common understanding of the issues involved and the management system.

Incorporating knowledge from different sources and system levels. Once an influence diagram is constructed it can provide a map on which pieces of knowledge about parts of the management system can be overlaid and integrated. Where appropriate, hard data and models can be used to quantify relationships. Where this is not available, the experiential knowledge of land managers and other stakeholders can be used to fill in the data gaps. This ensures that the full range of existing knowledge is used, where knowledge that scientists create is integrated with the implicit systems of land managers. The result is a 'working model' that can be used for scenario testing and decision support.

Adaptive management is a valuable framework for dealing with uncertainty and accommodating the diversity of treatments necessary for evaluating approaches, measuring progress and building a capacity to resolve highly complex natural and human resource management issues through continual knowledge building. This approach of stakeholder involvement and Systems Thinking leads to a model that represents the mutual understanding of stakeholders and their current knowledge base for decision-making. However, this knowledge base is rarely perfect because of continuously changing environmental, economic and social conditions in complex natural systems. New knowledge about the management system is continuously generated through observation (monitoring) and the evaluation of outcomes of implemented management strategies. Embedding the BBN model in an adaptive management cycle allows for continuous improvement of the knowledge base, and its usefulness for managing natural resources under uncertain and variable conditions. However, for this it will be necessary to institutionalize the adaptive management process, so that monitoring and evaluation will be ongoing and part of the management process.

b. Causal Loop Diagrams

A second example of a Systems Thinking modelling tool is known as Causal Loop Diagram (CLD). CLD or the *language* of Systems Thinking (Maani and Cavana 2007) reveals the *causal* relationships amongst a set of variables (or factors) influencing a system. The basic elements of CLDs are variables (factors) and arrows (links).

A variable is a condition, situation, action or decision which can influence, and can be influenced by, other variables. A variable can be quantitative (measurable) such as profit, productivity, rainfall or growth, or it can be qualitative (*soft*). Examples of soft variables are trust, motivation, morale, burnout and reputation. One of the strengths of causal loop methodology is its ability to incorporate qualitative variables in the modelling process.

An arrow (or link) indicates a causal association between two variables, or a change in the condition of the variables. For example, fertiliser increases soil productivity and land erosion reduces the same. In the CLD methodology '+' and '-' signs are used to indicate these different effects know as 'link polarity'.

The following example shows an application of CLD modelling in a Biosphere Reserve in Vietnam, (Cat Ba Island − Figure 3). This island is currently experiencing strong growth in tourism (and revenue), while environmental degradation continues and high levels of poverty in several of the communes persist.

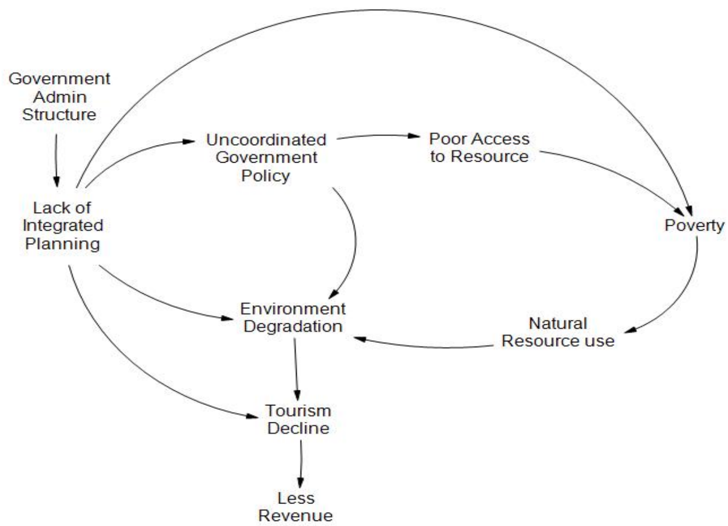

Figure 3. CLD for the Cat Ba Island current situation

Identification of root causes of problems. The CLD in Figure 3 explains the sources of complexity that has given rise to Cat Ba's predicament. From the CLD it is apparent that the relationships between the key variables are far from simple or linear. The CLD further demonstrates the influence of qualitative variables such as 'government policy' and its chain effects on other key outcomes.

An inspection of this CLD reveals that the current undesirable outcomes (poverty, environmental degradation and unsustainable tourism growth) can be traced back to the lack of integrated planning leading to fragmented government policies. An unintended consequence of this is that the international aid agencies operate in isolation, each trying to 'fix' a different problem separately.

Identifying leverage points. Having identified the root causes of complex problems, the appropriate intervention strategy can be devised. In the case of Cat Ba, the leverage lies in integrated planning and coordinated government policies. The effects of these strategies are shown in the following CLD (Figure 4). As can be seen, these strategies create two positive reinforcing 'loops' (shown by 'R'). These loops represent the reciprocal and beneficial effects of integrated planning and international co-operation (through aid agencies) and the chain impact of these on sustainability and livelihood of the communes (the link from tourism revenues to livelihood of the communes).

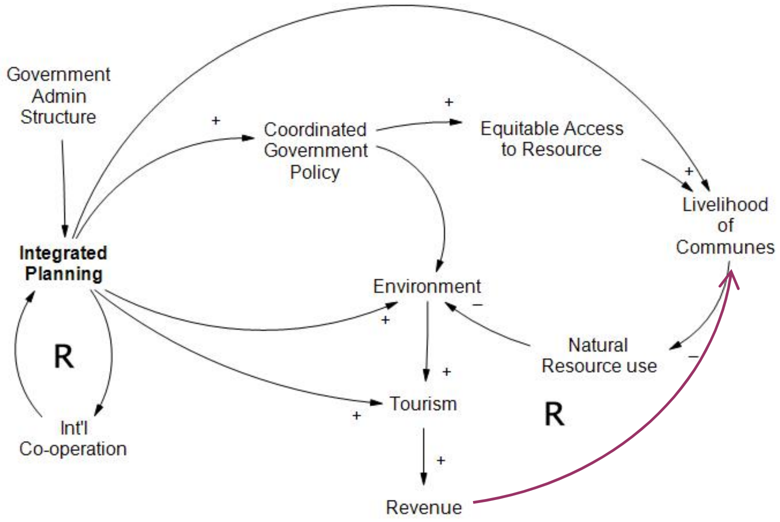

Figure 4. CLD for the sustainability model of Cat Ba Island

Interdependency between factors affecting the system. In summary, the CLD process reveals systemic structures underlying a complex system (i.e. the four levels thinking model) (Maani and Cavana, 2007). It shows that the factors affecting a system are not isolated and independent but are dynamically linked and cause growth or decline in each other as well as in other key areas of the system. One of the strategic insights of the CLD process is that trying to improve the parts in isolation is counterproductive and can hurt the overall system and its performance.

c. Stock and Flow Modelling

Stock and flow diagrams are generally constructed from a causal loop diagram, but where the system under consideration consists of clearly defined stocks and flows in and out of the stocks, it is easier to go directly to a stock and flow diagram.

A simple *ithink* (High Performance Systems 1997) stock and flow diagram of tree survival and how these processes contribute to the formation of hollow trees that serve as habitat for arboreal mammals in an Australian forest is provided in Figure 5. The building up of the model as: stocks (rectangles); flows (circles attached to double lines in or out of stocks); converters (remaining circles) which can consist of relationships, constants, parameters or graphs; and showing the links between the variables (single-line arrows) provides a systems map that can directly be used as a basis for developing a dynamic model of the system.

In this example, the system consists of a cohort of trees (stock) that loses some trees from one year to another through mortality. The mortality flow and number of trees in the cohort in one year determines the flow of trees to the next year. Mortality is affected by factors including fire, tree age, extreme weather conditions and natural mortality (converters). Natural mortality is described as a function of tree size (diameter at breast height, dbh), which in turn is affected by various growth parameters and the initial age of the trees. The relationship between tree size (dbh) and formation of hollow trees, together with the initial number of trees in one particular year is also used to determine the formation of hollow trees in the next year – the final outcome that determines the habitat quality for the survival of arboreal mammals in the system.

Developing this model through stakeholder participation allows for all involved to share their mental models (beliefs, values and assumptions) with each other. Connecting the stocks, flows and converters provides an opportunity to develop a systemic structure of which factors interact with each other, leading to a better and shared understanding by all of how the system works. This systems framework helps to identify the information, data, knowledge and sub-models (developed elsewhere through research) that are required to quantify or qualify the interactions. These are obtained from various sources and in different forms such as relationships, graphs, parameters, constants that are derived from both scientific and experiential knowledge.

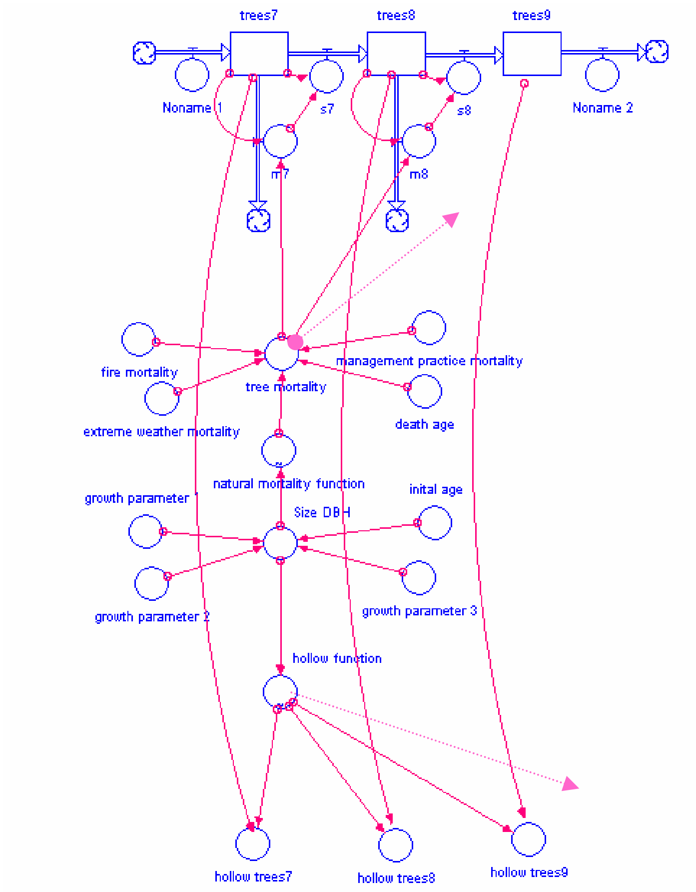

Figure 5. Section of a stock and flow model of a planted tree cohort's survival over time and the effects of processes in the system on hollow tree formation

Taking the above into account, the constructing of a stock and flow model through participatory processes could be especially valuable to facilitate:

- a better understanding of the bigger system that surrounds the specific problem (in this case the habitat quality of arboreal mammals);
- the integration of prior research (existing equations), available data and experiential knowledge;
- the integration of sub-models developed by different researchers, maximizing the usefulness and applicability of research (often not intended for the specific problem under consideration);
- meaningful communications and development of a common vision and action amongst stakeholders through co-developing a tool that can be used (and is well understood) for scenario analysis, thereby helping to agree on actions or strategies to achieve a management goal.

ACHIEVING THE DESIRED OUTCOMES

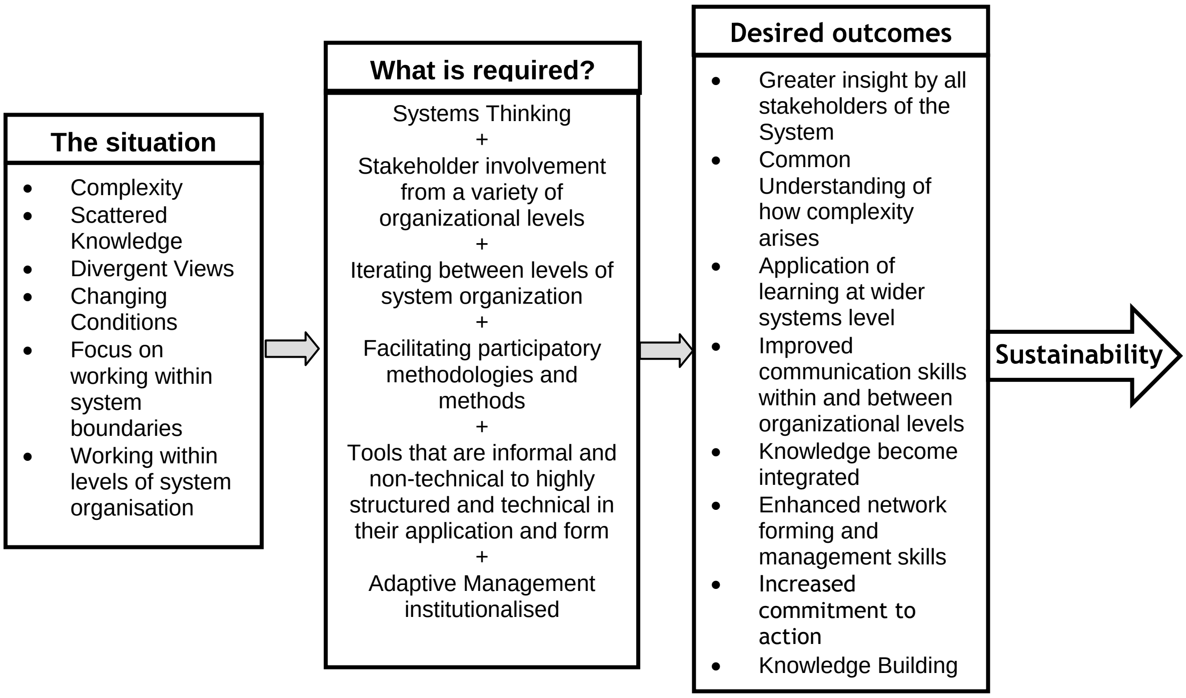

Figure 4. Framework for application of Systems Thinking concepts that would help achieving outcomes that will contribute to sustainable land management

Source: Bosch *et al* 2007

Systems Thinking tools provide a conceptual framework and a methodical process which can be used to achieve outcomes that could contribute to the development of sustainable systems. Figure 4 summarises the main factors contributing to the complexity of natural systems and the requirements for dealing with these complex situations. The cases discussed above demonstrate how these requirements can be met through the applications of systems thinking tools, leading to various desired outcomes. These tools can be used individually or in combination, and they are equally applicable to social, economic and organizational situations.

In addition to the outcomes identified in Figure 4, the various processes involved in Systems Thinking and the desired outcomes also have important implications for the development of sustainable systems. Maani (2006) summarises these as follows:

- Stakeholders' participation — leads to buy-in and commitment to collective action.
- Surfacing of hidden assumptions — leads to greater insights into how systems work.
- Surfacing of unseen and unintended consequences — leads to avoidance of strategic failures.
- Identifying key leverage points for intervention — leads to clear priorities for actions.
- Challenging individual and organizational mental models — leads to team and organizational learning.
- Diffusing contentious and 'hot' issues — leads to avoidance of turf protection and politicking.
- Breaking down cross-functional barriers and conflicts — leads to greater collaboration and ownership of the 'whole' (common good).
- Improving group dynamics and team learning — leads to organizational learning and systemic decision making.

These culminate into an ultimate desired outcome where Systems Thinking would not be seen as a specialist discipline, practiced only by systems professionals, but rather as a language that we can learn to use in research and management. Statistical analysis has become an integral part of all disciplines of science, and is often used as standard practice within research projects. Systems

Thinking, in contrast, is not (Bosch *et al.* 2007). A paradigm shift – 'a new way of thinking about the world and relationships' (Maani 2006) is required. Systems Thinking not only offers a language for understanding complexity and dynamic change, but also provides sophisticated modelling technology and associated collaborative learning environments.

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