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The Challenges of Effective Model Scoping: A FLORES Case Study from the Mafungautsi Forest Margins, Zimbabwe

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This paper explores the challenge of defining the scope of a systems model, emphasising three aspects: boundary, granularity and conceptual scope. The significance of these is illustrated by reference to a model of land-use decisions made in villages bordering on the Mafungautsi forest in Zimbabwe. The purpose of this model was to help policy players (Forestry Commission staff, non-governmental organisations, researchers and local people) to understand the impact of policy interventions on local people's livelihoods. Scoping decisions that were made in building the Mafungautsi model were deliberately liberal, to encompass the interests of all participants in the modelling process. These decisions now present a range of serious challenges: the difficulty of model calibration, the computational expense of running simulations, and the difficulty for new users to understand the model. Facilitators of modelling teams need to consider the serious implications of giving everyone what they want and including all participants' ideas in a model. In the long run, it may be better to be tough and reject many suggestions at the outset. The former approach is unlikely to lead to a tractable model, while the latter may ultimately offer greater satisfaction for all.

Keywords: scoping models, tractability, calibration, FLORES, Zimbabwe

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INTRODUCTION AND BACKGROUND

This paper relies on the Mafungautsi FLORES model (Prabhu *et al*. 2003) to illustrate how a succession of decisions about scope led to an untestable, intractable and incomprehensible model. The model attempts to simulate livelihood decision-making in relation to human usage of natural resources near the Mafungautsi Forest, Zimbabwe. An examination of the history of scoping decisions reveals several critical points when rejecting elements from the model could have enhanced the final result. The objective this deconstruction is to offer guidance for facilitating modelling processes. Facilitators should not recklessly accommodate all suggestions, but should insist on tough scoping decisions and on iterative refinement of the boundary and granularity to prevent excessive model complexity and enhance its relevance to intended users.

The Scope of a Model

Simulation models are simplified representations of shared understanding of the world. To be tractable and to generate insights they need to be limited in their scope, but they need to include in that scope sufficient of the relevant issues to be plausible. Clarifying the scope of a model is an important early part of the modelling process (Forrester 1961, Morecroft and Sterman 1994, Kim 1995, Sterman 2000). Modelling the dynamics of systems such as social forest landscapes or other systems of natural resource management requires that the system's inherent complexity is captured without resulting in a model which is too complicated to be useful. Standard systems dynamics methodology (Sterman 2000), and soft systems methodologies (Checkland 1981, Wilson and Morren 1990) provide three main ways to allow complexity to be harnessed whilst limiting complication. These are limiting the scope of the model by focussing tightly on a modelling puzzle or problem, making idealisations whilst conceptualising the model and refining or simplifying the simulation program after an initial implementation (Haggith and Prabhu 2003). This paper focuses on the first of these three ways of tackling complexity.

There are three aspects of the scope of a model. They are boundary, granularity and conceptual scope.

1. *Boundary issues* are about the outer limits of the model, such as the spatial extent of the landscape represented and the range of social and political influences treated as endogenous to the model.
2. *Granularity* concerns the size of the smallest elements in the model, its building blocks, and in how much detail they will be represented. Issues here include the smallest units of social structure (e.g. individual, household or community), the scale of the physical entities such as patches of land in a landscape and the time step and overall duration of the model.
3. The *conceptual or disciplinary scope* of the model concerns what factors are going to be dynamic within the model and which will be represented as static, or not included at all (e.g. political factors such as power relations and regulations; social factors such as family structures, friendships, health and communication; psychological factors such as knowledge, opinions and uncertainty; economic factors such as wealth and prices; or biophysical factors such as weather, pests, diseases and fire). Conceptual scoping is particularly

difficult when working with a highly multi-disciplinary team all of whom have different interests in the contents of the model.

Decisions need to be taken by the modelling team on each of these issues of scope before model conceptualisation begins. It is tempting to be 'liberal' when making these decisions and to include issues that seem relevant in the hope of being 'comprehensive' rather than exclude them from consideration. However, this leads to bigger models from which a range of serious challenges arise: the difficulty of model calibration due to excessive data demands, the demanding computer hardware requirements for running simulations, and the difficulty for new users to understand the model. Although each of these challenges may be met individually, together they can become insurmountable.

FLORES History

In 1999, the Center for International Forestry Research (CIFOR) initiated an ongoing modelling process with the goal of creating a generic model of land-use change at the forest frontier, called the Forest Land Oriented Resource Envisioning System (FLORES; Vanclay 1998, 2003, Vanclay *et al*. 2000). The ensuing process has been a collaborative effort to share knowledge between people from many disciplines, from anthropology to zoology, concerned with forest resources and the people dependent upon them.

The FLORES modelling process has involved a mixture of intensive workshops and individual research work to define specifications, gather and process GIS data, implement models and even develop new modelling concepts. Sometimes, when models reached extreme levels of complexity, it seemed as if FLORES stood for 'Fiddling Loads Of Ridiculous Equations Simultaneously'. At other times, there have been serious efforts to pull the ideas together into more coherent model structures, and to 'Find Lots Of Really Enlightening Simplifications'. The result has been a number of models, including a comprehensive FLORES model calibrated for the Rantau Pandan area in Sumatra, Indonesia (Vanclay *et al*. 2003).

In April 2000, a workshop in Gwayi, Zimbabwe, initiated a new phase in FLORES modelling. It began the development of a FLORES model for the Miombo woodlands of Southern Africa. The model was intended to help policy players (Forestry Commission staff, non-governmental organisations, researchers and local people) to understand the impact of policy interventions on local people's livelihoods. The aims of the modelling work were to test the generality of some of the FLORES model structure and concepts, to develop a transferable methodology for FLORES modelling processes, and to build modelling capacity in Zimbabwe (Prabhu *et al*. 2003).

Initial versions of the model drew from previous modelling work and research on the local resource management systems and local people's livelihoods (Frost and Mandondo 1999, Monela *et al*. 2000). Over the course of a year, several workshops were held, involving dozens of participants in the development of the model, with technical support from experienced modellers, mainly through a support package called FLAC.

FLAC: *FLORES adaptation and calibration package*
The FLAC project, led by the University of Bangor in collaboration with the University of Edinburgh, aimed to develop support materials for FLORES modelling processes. It was to include a framework FLORES model able to be adapted to new contexts, plus a library of appropriate sub-models for use in the framework model (FLORES Society 2001). It also involved improvements in the user friendliness and flexibility of Simile (Muetzelfeldt and Taylor 1997, 2001), the modelling software environment which the FLORES process has mostly used, and user support and training materials for Simile and FLORES. The FLAC package was first tested in Zimbabwe in support of the Miombo FLORES modelling work.

ACM : *Adaptive collaborative management*
'Local People, Devolution and Adaptive Collaborative Management (ACM) of Forests' is a research project, led by CIFOR, seeking to understand how human well-being and forest resource quality are impacted by processes of collective action, communication and learning, and collaboration and conflict between forest stakeholders. The project is using participatory action research methods and is developing novel research and social learning tools, including simulation models.
The ACM project team in Zimbabwe took the lead role in the development of the Miombo FLORES. This team includes a mixture of social and biophysical scientists with varying levels of modelling experience. Their research sites around the Mafungautsi state forest in Gokwe district of Zimbabwe were used as a knowledge base for conceptualising the model, and as sources of data for calibrating and testing it. At the start of the FLORES modelling work, the ACM project was just beginning to collect baseline data. The ACM project also provided opportunities for other spin-off mini-modelling exercises to explore related ideas such as collaboration, spread of new ideas and social capital. Some of the ACM project's collaborators in Zimbabwe have also produced related models for other research sites or forest contexts, through the FLAC modelling support process.

As a result of the Miombo FLORES model being developed for the specific context of the Mafungautsi forest and the ACM research sites in neighbouring villages, the model has became known as the Mafungautsi FLORES model.

An over-riding aim of the FLORES modelling work is to discover insightful ways of simplifying the large quantity of relevant information, without limiting the scope of the model such that it becomes irrelevant to policy makers or implausible to researchers as a representation of the situation on the ground. This requires a delicate balancing of expressiveness (i.e. ensuring meaningful representation of the key concepts) and tractability (i.e. ensuring a model that can be implemented, and run with reasonably modest computing power). Previous versions of FLORES have not achieved this balance effectively. They have either been runnable whilst trivialising important concepts (particularly social concepts such as resource tenure and collective activity); or richly expressive but too complex to fully implement. The challenge for FLORES is to find a middle way.

MODEL OVERVIEW

An overview of the Mafungautsi FLORES model is required to gain an adequate understanding of the issues and challenges in effective scooping of complex simulation models.

Model Structure and Dynamics

The purpose of the Mafungautsi FLORES model was stated at the beginning of the project as follows: ‘to simulate the impact on local people’s livelihoods and on the forest resources, of processes of communication, collaboration and social learning in response to changes in resource access regulations and other policy interventions’. It was intended to be used by policy players and stakeholders in the Mafungautsi staff (Forestry Commission staff, non-governmental organisations, researchers and local people) to understand the impact of policy interventions on local people’s livelihoods. This is a broad objective.

Figure 1 shows the framework of the FLORES model (Prabhu *et al*. 2003). The model diagram shows the human aspects of the model on the left-hand side, and the biophysical aspects in patches of land on the right hand side. Between these is the tenure model. These three aspects of the model are briefly summarised below. The model also has a small set of exogenous variables or scenario levers, which represent climatic externalities like rainfall, and policy levers such as product prices.

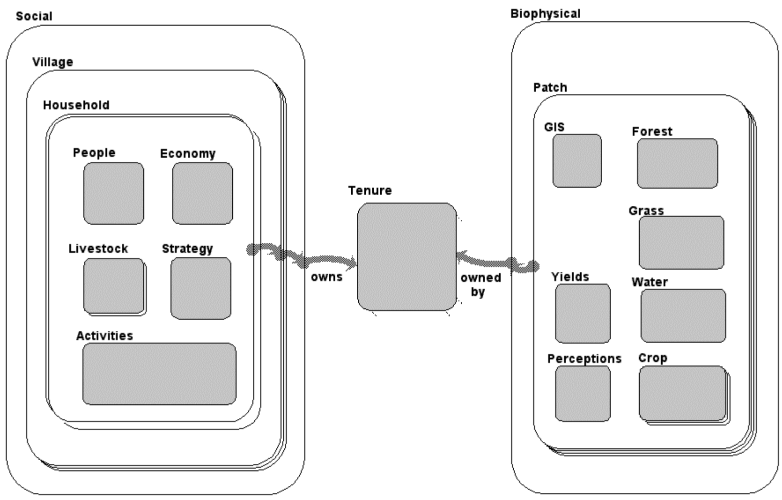

Figure 1. Overview of a model for the Mafungautsi region in Zimbabwe

Source: Prabhu *et al*. 2003

Biophysical Aspects

The biophysical model covers the fields, gardens, *vleis*[2] and forest around the villages represented as patches of land. This part of the model includes:

[2] A *vleis* is a low-lying area of marshy ground.

- Agricultural aspects, including crop models for maize, cotton and garden crops;
- A grass model involving the grazing behaviour of livestock, and harvesting of broom and thatch grass, both important non-timber forest products (NTFPs) that act as proxies for other NTFPs;
- Forestry aspects, including a forest sub-model, with harvesting of poles and firewood; and
- Other biophysical aspects including fire, rainfall and ground water.

Social Aspects
The model is intended to cover the area of one Resource Management Committee (RMC)[3]. There are several villages in the model, each led by a *Sabukhu*[4]. Within each village, there is an initial population of 40 households. New households can be formed by marriages and immigration, and households disband if everyone leaves or dies. Within each household there are the following sub-models:

- *People,* representing the demography and health of the household (i.e. the number of children, women, men and elders).
- *Livestock,* representing the household's cattle, donkeys and other small livestock, including decisions to purchase, sell and slaughter them.
- *Economy,* representing the household's economic resources, income, and investment and spending decisions.
- *Strategy,* in which each household annually assesses its needs (for subsistence), aspirations (for consumption over subsistence levels) and resources (land, labour, livestock, social capital and economic resources), and chooses a livelihood strategy. A strategy is defined as a set of prioritised options: subsistence cropping (maize), cash cropping (cotton), animal husbandry, NTFP collection and wood collection.
- *Activities,* in which households decide on a weekly basis how much labour to allocate to particular activities on each patch of their land, based on their perceptions of these patches and their strategy.

It is worth saying a little more about the strategic decision-making component as it forms the core of the model's representation of the people's sustainable livelihood strategies. Households form their strategy each year by considering various factors: their needs; their resources; the potential outcomes of the options available to them; their past performance and the advice they get from their peers. By weighting these various factors in different ways, a range of different 'personalities' can be mimicked. For example, an emphasis on the potential outcomes is 'goal-driven' decision-making. An emphasis on resources gives 'means-based' decisions. An emphasis on the advice of their peers gives 'peer-driven' behaviour.

The strategy is re-evaluated each year, and a memory of previous strategic decisions and performance indicators gives the households an adaptive form of

[3] Committees set up at the behest of the Zimbabwe Forestry commission to help regulate access and use of non-timber forest products in the Mafungautsi State Forest. They usually cover several villages.
[4] Village headman.

learning whereby they will not repeat a strategy which produced poor performance. Strategic decisions also include a spatial component deciding what kinds of crops to grow where.

Within each village there is a social network of relationships between households. This is conceptually an extremely important part of the model, and many representations have been explored in stand-alone models, to investigate how different social configurations affect distribution of social capital and the spread of new ideas through the community (Haggith *et al*. 2003). The social network in the FLORES model is used to influence the level of social capital of each household, and also to create a form of peer pressure to influence strategic decisions by households. It is useful to think of this as being akin to membership of a club, such as a cotton-growing or bee-keeping club, which provides recommendations to households about their livelihood strategy, and thus influences their decisions.

Tenure Arrangements

The social components of the model have access to the biophysical resources via tenure relations, which regulate resource access. The tenure arrangements include individual holdings of gardens and arable land, village common grazing and woodland, and state forest land. Resource access regulations include limiting crop cultivation to individual holdings, grazing to village lands and state forest land, NTFP collection to *vleis*, and pole-cutting to forest land. Note that pole-cutting is officially illegal thus the tenure rules reflect customary, not *de jure*, rules. It is important to recognize that this representation of the relationships between people and the resources is a significant enhancement over most land-use models which tend to represent land as either 'owned' by people on an exclusive basis, or as all shared and communally used. The advantage of the representation here is that is it flexible enough to represent the multiple and overlapping rights which are characteristic of most customary tenure arrangements for forests and certainly the case in Zimbabwe (Campbell *et al*. 1996, Campbell and Matose 2000). There are some complexities, however, which it cannot handle, such as field leasing arrangements and the privatisation of individual species such as fruit trees (Nemarundwe *et al*. 1998).

Summary of Assumptions

The resulting model scope involves the following simplifying assumptions:

- The landscape is represented as patches of land containing various biophysical resources.
- Human society is modelled as households within villages.
- Access by human agents to the resources in the land patches is defined by tenure relations, which are dynamic over time.
- Humans cause impacts on biophysical patches by *actions*, which are driven by their *perceptions* of plot conditions and their strategy. The primary feedback from the biophysical arena to the human sub-model, is in the form of *yields* of field and forest products, in response to the human activities.

- The value of forest products, crops, money and other consumable resources can be measured using a generic economic unit, the 'dosh', (daily ordinary subsistence per household) as a common currency.
- The smallest decision-making unit is the household (which comprises children, adult men, adult women, and elders).
- Decision-making within households is modelled at two levels, with strategic decisions taken annually, and labour allocation decisions taken weekly.
- Strategic decision-making is modelled by assessing a set of livelihood options in the light of household needs and resources, resulting in a priority ordering of the options (i.e. the options are not mutually exclusive).
- The strategic resources available to a household are land, livestock, labour, dosh and social capital, which are interchangeable.
- Weekly labour allocation is modelled by sharing available labour across a set of activities according to the priority ordering resulting from the strategic decision.
- Marketing of resources is modelled as a simple conversion of yields to the common currency, dosh.
- Debt and credit are not subject to limits.
- Off-farm employment is only achievable by emigration and the model does not include remittances from urban family members.

MAKING DECISIONS ABOUT MODEL SCOPE

The purpose of this section is to explore the decisions that were made about the model scope, including its political and spatial boundary, the spatial, temporal and social granularity, and its conceptual scope.

Political Boundary

At a meeting of potential model users (representatives of a non-governmental organisation which works with local people to enhance their livelihoods from natural resources, Forestry Commission staff, and forestry and social science researchers) early in the modelling process there was intense discussion of the boundary and scope of the model, and in particular a process of decision-making about what the social and institutional scope of the model should be. In Zimbabwe, as in most countries, the issue of which institutions are relevant to decision-making over forest resources is controversial. For these users this was a question of the political boundary of the model. In order to resolve which social entities (additional to households) were needed in the model, meeting participants were asked:

- What is the influence of the entities on households?
- What are they influenced by?

If they influence and are influenced by household level or biophysical factors, then they should be included within feedback loops in the model. If they influence but are not influenced by household level or biophysical factors then they can be treated as external factors using exogenous variables. The results are summarised in Table 1.

It was recognised that there may be interactions between some of these institutions, for example, due to macro-economic factors. The question was raised whether an economic model needs to be included in order to capture the macro-economic dynamics, or whether the macro-economic factors can be treated as exogenous. However, as these factors are not likely to be influenced by the village level, this led us to treat them as exogenous variables. However, if a model will have several macro-economic policy levers, it is important to be careful to think about whether there may be interactions between them. In other words, beware of non-independent exogenous variables.

Spatial Representation of the Landscape – Boundary and Granularity
The political decision that the model should cover an RMC has spatial ramifications. In particular, RMCs include several villages, so the decision was made that the model should cover three villages, in order to model the overlaps in their resource use, plus their associated lands, plus an area of forest extending to at least a 10 km radius or a little greater to allow for some forest land to be beyond the usual reach of village impact. There is a clear logic to this decision about spatial boundary and scope of the model.

Table 1. Entities, influences, and recommendations for inclusion in the model

Entity	Influenced by	Influences	Include?
Resource Management Committees	Household social capital	Tenure relations	Yes
Traditional spiritual leaders (chiefs)	Kinship links	Land allocation	Yes
Forestry Commission; Forest Protection Unit	—	Rule enforcement	Exogenous
Cotton companies Grain Marketing Board	—	Prices; Market access	Exogenous
Gov't agencies (Campfire); Rural District Committees	—	—	Omit
Extension agencies; Churches	—	—	Omit

At a separate meeting, another intensive discussion took place about the granularity of the model. This meeting involved different model stakeholders including agronomists and other biophysical experts whose knowledge of biophysical processes would be used as the basis of much of the 'right hand side' of the model. These experts were adamant that the model required sufficient granularity to represent individual field patches and the cultivation activities of households on those patches, in order to be able to properly simulate the impacts of household livelihood decisions on the landscape. Again there is a clear logic to this decision (and note that this was a major step down from earlier positions in which it had been posited that individual fruit trees might need to be included in the model).

However, adopting these two decisions together would require a landscape representation of at least 20 km by 20 km, or 40,000 ha, with a patch granularity of no more than 0.25 ha, which would require 160,000 patches. Clearly a compromise was needed.

The highest granularity was needed to represent the diversity of agricultural land-use, but it seemed possible to treat forest as a more homogenous land-use. This allowed for one reduction in complication from the biophysical side of the model. On the social side, it was suggested that a single village (Batanai) might serve as a proxy for the several villages in the RMC.

In the end, two patch sizes were adopted: around 1 ha on average for fields, and a few patches of forest of several hundred hectares each. This allows for a complete digitisation of the landscape around Batanai village, on just over 900 patches. However, even this proved intractable initially and the preliminary working version involved a sample of only 240 patches. This compromise, however, meant that the model was no longer a model of the whole RMC's area of concern, and the result is a great loss in the social and political plausibility of the model from the point of view of the first group of model users.

Temporal Granularity

The temporal granularity question was as vexed as the spatial one. From the perspective of the users, particularly those who are social scientists, the issues of interest concern political changes in regulations and enforcement of those regulations, economic changes and the opportunities they present, and the strategic responses by households to these changes. These are all events and decisions that happen relatively infrequently. Therefore an annual or seasonal time step was deemed appropriate for representing them. From the perspective of the agronomists and biophysical experts, the issues of importance concern processes which happen much more rapidly and human activities, such as weeding, wood-cutting, herding, etc which happen frequently. In particular the agronomists viewed subseasonal model time steps as essential and a weekly time step as preferable. An expert on forest fire insisted that to model the sweep of fire across the landscape required modelling changes with a temporal granularity of a few hours.

The result is that different parts of the model use different time steps, with strategic social decisions made annually and operational decisions about activities made weekly. Some versions of the model have experimented with a fire sub-model which runs on an hourly time step. Although this theoretically possible with the constructs available in Simile, it makes the model virtually intractable, and difficult to comprehend.

Social Granularity

In the model, the smallest unit of society is the household. This decision has been challenged by some anthropologists who point out that it means the model cannot represent factors which involve differentiation of gender and family structures, and misrepresents aspects of resource tenure which should be relationships between individuals and resources, not between households. It is anticipated that other FLORES research will further examine the implications of representing individuals rather than households. In Indonesia, some FLORES modelling work is exploring an even bigger social unit, by modelling household clusters rather than households as the smallest unit of decision-making (Purnomo *et al*. 2003).

Conceptual Scope of the Model

Underlying all the problems of boundary and granularity lie the fundamental question of the conceptual or disciplinary scope of the model. Agronomists and political scientists have radically different views of what is going on in a forest landscape, what the processes are, and what timescales they are operating at. It has been an ongoing complication of FLORES that whereas the key users in one particular site have particular conceptual interests, in this case communication, collaboration and adaptation to changes in the environment, other stakeholders in the modelling work bring to it a much broader range of relevant concerns and knowledge. The community of practice of FLORES modelling is multi-disciplinary and has never fully come to grips with how to achieve sufficient conceptual focus to develop tractable models, whilst also encouraging full participation in model design decisions by a broad church of relevant experts.

IMPACTS OF SCOPING DECISIONS

During the early phases of model development, it is satisfying for the modelling team to welcome the ideas and knowledge of a broad range of participants. The resulting model specification seems like an interesting intellectual challenge. Several months down the line, however, the full extent of the challenge of a broad model scope becomes much clearer. There have been difficulties in implementation that have been overcome, but at what price? This section indicates some of the major areas in which a broad model scope produces later problems.

Calibration and Testing

After implementation is complete, model testing can begin. This involves various different kinds of tests (see e.g. Sterman 2000).

1. *Calibration and testing of content*. This requires rigorously questioning each model parameter and equation, and matching it to the knowledge and data of the Mafungautsi sites. There are various problems here, but the main issue is that of data availability across the broad range of variables in the model. If this were the only problem, then of course it could be overcome in a satisfying manner by using the model as the basis of a definition of a body of research to establish all the required data values and heuristics. But then the question arises of who will do this research and with what resources? The opportunity to do such as structured body of research may not be available in which case the lack of data cripples the calibration phase. It is therefore necessary to look at the capacity to acquire the relevant data before scoping the model.
2. *Testing model behaviour*. This involves systematic tests of model behaviour, during multiple model runs, varying parameter values to extremes to check for bizarre and unreasonable results, and assessing if the overall model behaviour is plausible. However, when the model runs to several hundred variables to carry out model behaviour tests in a systematic manner requires more person-

months of time than most projects have available. In addition, any attempt to compare model behaviour with real world indicators requires suitable data, and this takes us back to the issue of data availability.

3. *Testing for user relevance*. This involves asking if the model stakeholders can actually use the model to answer their questions. It is amazing how the original purpose and interests of users can be ignored in the attempt to achieve a working implementation of a model. For example, scaling down the spatial representation from a circle of radius 10 km to one of 3 km, for example, reduced the landscape under consideration to an area much smaller than the original area of interest of intended users. Although the model area is indicative of the area of interest, it can no longer directly answer any questions that are directly about the larger land area, and the model behaviour may not be at all indicative of what is happening beyond 3 km from the village centre. If these more distant parts of the forest are the main interest of a user, scaling down may have caused the total loss of interest of that user in the model.

Tractability

An obvious impact of a broad model scope is that it may lead to a simulation program which is bigger, more complex and thus requires more computer power to run. In the FLORES project there has always been a tendency to take the view that the forest margins are inherently complex, that models are thus inevitably going to be big, and that if this is a problem then a more powerful computer should be used. Although it is tempting for researchers, who have ready access to frequent technology upgrades, to say 'buy a bigger computer', this ignores the reality that intended users and beneficiaries do not have access to powerful computers, nor to budgets that will allow them to upgrade as frequently as they might wish. In any case, wider access to such models means relying on portable computers and aiming to increase the people power, rather than the computer power of modelling teams.

Comprehensibility

The other main cost of complicated models resulting from a broad model scope is that they are difficult to understand. The model diagram is a tangled circuit diagram which is off-putting on first sight and difficult to follow even when studied for some time. All models have the risk of making sense only to those who designed them, but this is even more risky when the model is complicated. If the aim in modelling the forest margin is to develop a tool which can be used to generate insights that empower people to manage the resources more sustainably, then care is needed to aim for a final model that is comprehensible and insightful. Clarity and elegance are vital to ensure that the model can be used for good communication. The speed with which a user can grasp some core ideas is critically important, and model design needs to facilitate this.

As well as end-users, developers need to think about other members of the modelling team and their ability to contribute to the modelling process. Ideally a model is developed in an iterative manner, not expecting to develop a perfect model in one go, but expecting that successive re-modelling efforts will generate a range of different insights and allow different issues to be addressed. This means that different members of the modelling team need to be able to contribute to different parts of the model, or take over the implementation role for issues that interest them.

However, once a model becomes complicated, only the people directly involved in implementation fully understand it, and the other team members become exhausted with it. Thus it becomes extremely difficult for the rest of the team to contribute effectively. This was illustrated in the case of the Mafungautsi model, when, inevitably given the current political and economic climate in Zimbabwe, a modeller left the ACM team to work overseas, and his job was filled by a new staff member who found the model extremely difficult to understand. If a new team member finds a model monolithic and impenetrable, the model is no longer able to function as a useful tool.

CONCLUSIONS

A detailed examination of the impact of various kinds of scoping decisions made in developing a simulation model has led to four key recommendations for addressing the scope of a model.

First, it is vital to take time to address the necessary boundaries of the model and to try to limit these as much as possible. The boundary questions should include both physical or spatial boundaries and institutional, political and social boundaries. It is only necessary to include in the model factors that both influence and are influenced by the core issue of the model.

Secondly, having determined the outer limits of the model, it is then necessary to decide on the granularity, or smallest units of the model and to try to encourage as coarse a grain as possible to avoid drowning in unnecessary detail. Granularity involves three main factors – time (the smallest time step needed in the model to capture the dynamics), space (the smallest area that can be treated as a homogenous patch) and society (the smallest unit of decision-making or acting).

Thirdly, the conceptual scope of the model needs to be set within limits. The more heterogenous the group involved in model development, the more likely they are to have different views of what is important within the system. It is important to be clear that whilst modelling is a powerful forum for the exchange of ideas and sharing of knowledge, it is not necessary for everything that all participants know to be captured in the model. Brainstorming processes are useful ways for allowing participants to share what they know and believe to be important to the model, however, the raw results of brainstorming should not form the basis of a model diagram! It is important to follow up with exercises in ranking or clumping, to allow a shared perception of the most important conceptual issues to develop.

Fourthly and finally, a critical issue for facilitators is to identify quite specifically the intended users of the model, especially if they differ from the modelling team. It is preferable that the users and modellers should be the same people, and that modelling enterprises should not seek to build models that are scoped to reflect the possible interests of a broad church of people who are not closely involved in model development. Such people can easily make demands to broaden the scope of a model, which the modelling team may then have great difficulty in achieving effectively. Facilitators need to be careful to limit this kind of modelling ‘greed’. Our most successful modelling results have been achieved when the modelling team has built their own model for their own learning purposes, with no requirements imposed on them by non team members. Graphical modelling environments such as

Simile make it possible for people with no previous modelling experience to join in the model development work and if they are actively engaged in drawing the model diagram then they quickly understand the need to avoid over-complication.

Following on from the FLORES modelling work, the ACM project team have developed new methodologies and tools to link modelling with other processes of adaptive management such as visioning and monitoring, and to carry out modelling processes in a more participatory way with local stakeholders. For example, researchers have facilitated a group of around 40 broom grass users from Batanai village, mainly women, to develop their own model of the broom grass ecosystem to explore the sustainability of different harvesting methods and the impact on their incomes. The result of this process was that the broom grass users had insights and ideas for new ways of making brooms which enhance their income whilst ensuring sustainability of the resource. This has demonstrated that a model does not need to be comprehensive to be useful and that involving the resource stakeholders directly in the process of modelling, leads to insights which they can turn directly into concrete actions.

Although it may seem helpful to let all members of a modelling team participate in the modelling process by bringing their disciplinary interests to bear on the model, such a liberal approach has substantial later costs. Thus modelling team facilitators face a dilemma. They can either appear generous, like Santa Claus[5], and allow all the team to include all the concepts that they feel are most important, or they can appear mean, like Scrooge, by refusing many suggestions about what the model should include. The model built by Santa Claus's team is likely to be a monster that is difficult to calibrate, run and understand, whereas Scrooge's team may end up with a model that works and generates useful insights.

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[5] Santa Claus is a popular figure in Christian cultures who brings presents to children at Christmas time. Scrooge is a mean, miserly person depicted in the novel, *A Christmas Carol*, by Charles Dickens.

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