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Why Model Landscapes at the Level of Households and Fields?

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Sustainable resource management relies upon many disciplines and deals with complex interactions at the landscape scale. Many of the issues at the landscape scale arise from decisions taken at the household level and affect land use in fields and in small patches of forest. Spatially-explicit modelling of these units is desirable because it enables rigorous testing of model predictions, and thus of underlying propositions. The greatest insights may be obtained by participatory modelling of these processes as we understand them. Despite this, few models simulate dynamics at the household and field level. FLORES, the Forest Land Oriented Resource Envisioning System, is a simulation system that attempts to bring these elements together into a coherent package to assist stakeholders to explore options and their implications. The hallmark of FLORES is explicit modelling of the interrelationship between actors and land parcels within a spatial framework. FLORES demonstrates the feasibility and possible benefits of modelling at this scale.

INTRODUCTION

During the past decade, a great deal of attention has been directed towards ecologically sustainable management (ESM). ESM of natural resources cannot be addressed within a single field – not in a farmer's field, nor in any single disciplinary field. The issues involved are of a scale and complexity that cannot be resolved through field-based experiments, or with uni-disciplinary research. Researchers, managers and advisers need efficient ways to draw upon many disciplines, to examine interactions at the landscape scale, and to communicate results effectively. There are many ways to do this, and modelling is one approach that helps to explore options and their implications (e.g. Holling 1978, Vanclay 1994, McClean *et al.* 1995, Lynam *et al.* 2002).

People usually know how they want their situation to change to secure a better future; but they do not always know how to change their situation. Initiatives intended to improve situations do not always work as envisaged, and may have

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unintended side-effects. Models of various kinds can empower stakeholders to manage resources better, by helping them to explore consequences of proposed initiatives, allowing informed selections among alternatives, secure in the knowledge that consequences have been investigated. They can enable experiments with policy and other initiatives without risks to people or to the environment. They may also provide a framework to stimulate more effective collaboration between researchers, practitioners and other stakeholders (Walters 1997, Vanclay *et al.* 2000).

Anyone involved in management is conscious of the need for up-to-date information, and of the extent to which outcomes depend on underlying systems, structures and feedback loops. The use of old information as the basis for resource management is like driving a car without forward vision, and relying on the rear-view mirrors to judge where you're going. Up-to-date information (cf. looking out of the side windows to see the roadside) helps, but forward vision (cf. predicting future outcomes) is necessary to drive safely. What can be done to provide natural resource managers with more effective forward vision? And how can feedback cycles be speeded up, so that people can respond efficiently and appropriately when they stray from their planned path?

THE NEED FOR A FOREST SIMULATOR

Policies and incentives to promote sustainable forestry and better land-use do not always achieve the desired effect. Proponents rarely foresee all the consequences, and those best able to offer alternative views may be unable to contribute to the decision-making process. This leads to inefficient – and sometimes counter-effective – initiatives. Simulation models may offer 'forward vision' for players in the policy-making process, so that they are better equipped to envisage fully the efficacy and consequences of initiatives.

Consider an analogy with the airline industry. What makes air transport so safe and pilot error so rare? Good design, careful planning, diligent maintenance and competent supervision are factors, but pilot training is crucial. Before crew members take the controls of a commercial airliner, they will have studied the theory of flight, trained in light aircraft, spent hours in a flight simulator, and flown with more experienced colleagues. They know how to read the indicators, what every button and lever does, and when and how these controls should be used. They know instinctively how to respond when something goes wrong, and what to do if the plane deviates from its planned course. They have been trained to communicate effectively with their copilot, so they can rely on a second pair of eyes, and draw on a second opinion. And they rarely need to use their training, because existing knowledge about flight has been synthesised into an autopilot that takes care of most situations.

Now contrast this with management of natural resources:

- Do managers know what to do when things go wrong?
- Can they tell when things are beginning to go wrong?

- Do they know which controls to use to improve the situation?
- Are they sure of the controls, where to find them, and how to activate them?
- Can they recognise and interpret the indicators?
- Do they communicate effectively with others and seek their opinions?
- Why don’t they have an ‘autopilot’ to give advice?

Why is it that so many amongst those who make decisions about the world’s forests have never had the opportunity to use a simulator to explore the implications of an impending decision? Would a forest landscape simulator make a difference?

The computer game SimCity (Dargahi 1994, Friedman 1995) provides a useful analogy for the kind of forest simulator that may be useful in this regard. The Maxis Corporation provides a simulator in the form of a game. The game offers the player a ‘bird's eye view’ of a city, a menu of urban planning instruments (e.g. to provide education, transport, sanitation), and a several indicators of performance (e.g. unemployment, GNP, pollution). Many scenarios are available freely on the Internet, and range from real cities to fantasies. Perhaps the most important point in this analogy is that:

> Models running on a computer are only compilers for the mental models users construct in their heads. The end product of SimCity is not the shallow model of the city running in the computer. … It's the deeper model of the real world, and the intuitive understanding of complex dynamic systems, that people learn from playing it, in the context of everything else about a city that they already know (Wright 1997).

A forest simulator would replace the cityscape with a landscape of forest and non-forest land. Its menu would include a range of options to manipulate the forest and land-use patterns, and performance indicators could include biodiversity and rural poverty. The forest simulator should not be like SimCity in every regard: SimCity is quite deliberately a black box, designed to hide the underlying model and make it inaccessible to users. In contrast, a forest simulator should be transparent, easily understood by users, and amenable to modification so that in-built assumptions can be varied. Such a forest simulator should have a strong factual basis, and could be customised to suit a variety of situations. It would help to:

- synthesise existing knowledge and identify information gaps and other deficiencies;
- express present knowledge concisely, completely, explicitly and unambiguously;
- create a framework to promote collaborative interdisciplinary research;
- provide for strong empirical tests of hypotheses relating to land-use policy;
- empower stakeholders to explore alternative scenarios; and could
- form the basis of an educational game to improve general knowledge of natural resource issues.

Modelling can assist ESM in many ways, but it is not a panacea. At best, models are simplistic abstractions of reality. However, mathematical and computer-based modelling merely formalise our natural tendency to construct mental and verbal models. The use of mathematics and computer software merely extends our mental models, while simultaneously forcing us to be explicit and unambiguous. The beauty of models expressed in this way is that they can be communicated accurately, and tested objectively. Models can be seen as a broad set of quantitative approaches and tools, some of which offer efficient ways to handle knowledge (and hypotheses) about complex systems. They enable users to derive, in a transparent manner, the behaviour of the total system, which may not easily be anticipated in other ways. Models excel at exposing counter-intuitive consequences of simple assumptions. They also offer new insights and pose new problems for research: 'More information can be read from a map than was needed to construct it' (Ziman 1978).

The process of collaboratively building models is often an effective way to reach consensus and may contribute to a better understanding about how systems work (Vennix 1996, 1999, Purnomo *et al.* 2003). Even if initial prototypes of a model are of little practical relevance, they may offer valuable insights. The purpose of models is often not so much to provide answers or to predict the future, but to help ask better questions, and to help choose among possible future scenarios. Thus models allow stakeholders to explore 'best bets' and analyse their implications. This powerful ability may be pivotal in helping to decide between land-use and policy options put forward by stakeholders.

Modelling can play a central role in ESM at three levels, by helping to:

- inform management when knowledge about the system is limited;
- test hypotheses of the functioning of systems where knowledge is adequate; and
- explore 'what if' scenarios for alternative management, situations and time scales, in cases where the system is well understood and sufficient data are available.

To fulfill these roles, it is appropriate to explore models that:

- operate at the landscape scale (cf. union of hydrological, visual, habitat and community catchments);
- draw on the range of disciplines influencing that landscape;
- have a strong scientific underpinning expressed as refutable hypotheses;
- provide predictions and allow inferences that can be tested empirically and logically;
- encourage users to investigate alternative scenarios and understand long-term implications; and
- are modular; designed to facilitate understanding, updating and exploration of alternative representations.

Simulating at the Household and Field Level

Many questions central to ESM rely on an understanding of land-use patterns in time and space, especially near the boundary between intensive (e.g. cultivation) and extensive (e.g. natural habitats such as forest) resource use. Thus a model to explore sustainability issues and policy options should operate at the landscape scale, and should span both forest and agricultural lands. Agricultural lands and villages form a critical component of the landscape, and must be modelled to understand fully the processes at work in and near the resources that are used less intensively. In this context, four basic assumptions are central to land-use modelling (Vanclay 1995a):

1. Land-use patterns are created by *actors* - individuals or groups of individuals - who collaborate as households, associations and corporations.
2. These actors make *rational* decisions based on available information, obligations and expectations, social as well as economic. Note that an actor's *perception* may be more important than reality. For example, doubt about security of land tenure may lead an owner to adopt a shorter timeframe than would otherwise be the case.
3. When choosing an *activity*, actors explore a range of options available to them, within the constraints imposed by resources (e.g. land, time, capital), knowledge, and their comfort zone (such as cultural attachments, willingness to attempt novel activities).
4. Actors tend to undertake activities that *maximize expected benefits* or *minimize anticipated risks* to themselves and their beneficiaries (household, associates, shareholders, etc.). It may be possible to model both benefit-seeking and risk-avoiding behaviour by considering risk-adjusted benefits.

The constraints implied by an actor's comfort zone and previous experience mean that many actors consider a rather small number of activities, often only those undertaken in the past, plus a few new activities pursued profitably by neighbours. However, there may be a few innovators who consider an extended list of activities and attempt a diverse range of enterprises. Typically, these innovators are more willing to attempt risky enterprises than are their more conservative peers. Disposition is only one determinant of willingness to accept risk, and age, assets and income also feature prominently in many explanations.

Assumption 4 (maximizing benefits and minimizing risks) deals with benefits and utility functions. These benefits may be expressed in financial terms (e.g. dollars), or in other quantitative ways. Maximizing perceived benefits may be realistic in some communities, but is only one way to represent behavioural tendencies. The role of modelling is to provide a means to calibrate and test alternatives, and to establish which alternative is most consistent with the available evidence. Note that decisions may depend on many things, including:

- anticipated yields of an activity (e.g. cropping, hunting, handicraft, share-farming, wages);
- anticipated prices, net of costs incurred in initiating (e.g. seed, fertiliser, raw materials) and realising a return (e.g. harvesting, packing, transport, marketing, commissions), discounted as necessary for any delays;
- reductions for real or imagined risks including pests, disease, fire, theft, loss of tenure, spoilage during transport and viability of an employer;

- allowances for shares that others may have in the activity, including for example, clan obligations as well as landlords who may share revenues but not costs; and
- satisfaction experienced by an actor in producing an item.

The decision made for any particular resource is not independent of decisions made for other resources, since price and risk may depend on total production across all resources, and many options may have off-site impacts such as erosion and pollution. Lagged adjustments may be needed to account for time taken to learn and implement new technologies and to meet transition costs in adopting the technology. Some of these complexities may be avoided by making the prevailing market prices exogenous to the model. This leads to the simplifying assumption that decisions on any site are independent of those for other sites, allowing the utility function to be solved without taking topology into account. However, topology may be useful in other calculations such as travel time between village and fields.

Decision-making by actors is just one component of landscape modelling, and several other sub-models are needed to predict the growth of trees and crops, changes in the soil water balance, interactions between key plant and animal species, and other ecosystem processes. Fortunately, many such models already exist (e.g. Eurostat 1997), and some are amenable to integration within a landscape-scale model.

Spatially-explicit modelling adds rigour, by allowing explicit tests of hypotheses: ‘We expect *this* household to cultivate *this* crop in *this* field’. Landscape modelling without an explicit spatial component barely advances on work by von Thunen (1826).

Addressing Needs of Model Users

To foster multidisciplinary input and collaborative modelling, a model must not become a ‘black box’, opaque to participants. It is not enough that it should be transparent; it should be enlightening, and should empower participants to make better analyses and draw more revealing insights than they could working in isolation. The graphical representation of models within the Simile modelling environment (Muetzelfeldt and Taylor 1997, 2001) is conducive to such ‘open design’, but the issue is not merely one of software, but also of design and implementation by participants. In such an endeavour it is desirable to begin with simple models, and to enrich these progressively as inappropriate simplifications are refuted. The challenge is to construct a framework that is broad enough to accommodate a wide variety of propositions, and sufficiently accessible that researchers from a range of disciplines are stimulated to collaborate and test their propositions in this integrated way.

The provision of a practical decision-support system for resource managers and land-use planners places great demands on the user interface. Success in creating an appropriate user interface should empower stakeholders to explore future consequences of current options, thus allowing risk-free experiments in policy and land-use planning. Sadly, too many models languish, under-utilised, because they do not satisfy the needs of potential users and because system developers did not explicitly engage clients, ascertain their needs and stimulate their interest. To encourage uptake, potential users must be involved in the development of the model. It is not enough to ask them what they want and how they want it. Modellers have to engender enthusiasm and involvement through mutual understanding and collaboration. This means that the model has to be explained in an accessible way, and that prototypes and mock-ups may need to be built so that ideas can be demonstrated, tested and modified.

For ESM, a useful output would be the bird's eye view of a rural landscape, analogous to 'SimVillage'. It would be even better if this view could be animated with a virtual reality interface, allowing stakeholders to put on a virtual reality headset and take a 'magic carpet ride' across the landscape (Vanclay 1993). They could observe the spatial pattern of various land uses and watch how they change over time, and under different scenarios. They could 'zoom in' to examine particular issues, and stand back to get a holistic overview. The technology to do this exists, and it is possible to link resource inventory, growth models, geographic information systems and virtual reality devices in this way. Recent software and hardware developments now make it feasible to approach a magic carpet implementation, and negotiation support systems should be designed in a way that does not foreclose this possibility.

Another important visual product is a dynamic map responsive to changes in input parameters (i.e. a GIS image, updated continually as a simulation proceeds), allowing users to gain a visual impression of land-use responses to changes in policies and other instruments. Under some scenarios, predicted land uses may remain relatively static, despite moderate perturbations in input variables and model parameters. Attention should be drawn to the more sensitive areas, where comparatively small perturbations in inputs and assumptions give rise to large changes in predicted land uses. Researchers and planners want to identify these areas, establish what parameters trigger shifts in dominant land-use, and understand how these shifts occur. One useful way to emphasise such changes is to compare predictions under various scenarios, and to map the difference in outcomes. Another possibility is to plot isolines showing the price change in a given commodity that is likely to result in a specified land-use change (i.e. highlighting areas where land-use patterns are relatively stable since large price changes are needed to provoke a switch in land use). Graphical outputs of this kind may be an effective way to illustrate the potential for forest degradation or deforestation as a result of lower transport costs or higher prices for cash crops. Preconceptions suggest that these sensitive areas may be near the forest edge, and may include *Imperata* grasslands. However, establishing (or refuting) this requires sensitivity analyses on input parameters to determine if a small change in an input makes a negligible, small or large change in the predicted outcomes. While sensitivity testing is critical both to understand and check the model, it will also remain an important outcome in its own right, and should contribute substantially to the understanding of rural landscapes.

THE FLORES CONCEPT

FLORES, the Forest Land Oriented Resource Envisioning System (Vanclay 1995a, 1995b, 1998, Vanclay *et al.* 2003) is an attempt to address the issues raised above. FLORES deals with land, people who interact with that land, and the land-use and related decisions they make. The landscape is made amenable to spatially-explicit modelling by tessellating it into land units that are relatively homogeneous with regard to key parameters in the model, including tenure, vegetation, accessibility and soil fertility. Within the system, sub-models deal with actors, resources such as land and capital, and activities such as clearing land, planting crops, hunting, making things and working for wages. It is assumed that actors compile a 'menu' of possible activities from which they select the most appealing item under the prevailing circumstances. The Simile modelling environment has been used in constructing FLORES, to make it accessible and easy to update, and to facilitate exploration of alternative representations and sub-models. Together, Simile and FLORES provide a range of outputs to suit various user requirements. Users most commonly plot the value of a range of variables over time, and a bird's eye view of the simulated landscape. A virtual reality interface approaching that of a 'magic carpet ride' has been demonstrated as a VRML prototype. Several variants of FLORES have been constructed (Vanclay *et al.* 2003, Legg 2003).

Implementation and Practical Implications of FLORES

Is FLORES a good platform for addressing complex land-use issues? There are several attractive features of the FLORES approach. It is:

- accessible to many researchers and stakeholders, both through its conceptual underpinnings and through its diagrammatic implementation in Simile;
- modular, facilitating the substitution of alternative sub-models;
- spatially explicit, modelling dynamics at the field level and collating these at the landscape scale; and
- process-oriented rather than empirical, building on an understanding of processes rather than on simple correlations that have been observed.

However, the FLORES approach:

- requires a knowledge of Simile, which may be intimidating for some (although less so than for many computer languages);
- is data intensive, requiring much data for calibration; and
- tends to be computationally intensive.

More generally, there are several important research questions that apply equally to FLORES and to other approaches to investigate and support ESM. These include:

- identifying the links between systems components and establishing how they work;
- finding effective ways to make best use of existing models and link them within a framework amenable to participatory input (one key issue is how to

'bring to the surface' parameters in existing models, so that they are accessible);
- developing efficient ways to manage and share the data needed to calibrate and test models;
- linking models and impact assessment by establishing efficient intermediate milestones; and
- simplifying models with minimal loss of generality and precision, for operational use by managers and other stakeholders.

Finally, scientific principles (Occam's razor) require parsimony, a challenge when linking diverse models from different disciplines. There is a need to find efficient ways to conduct reliable sensitivity tests to establish the relative influence of variables under consideration in models.

Alternative Approaches for Modelling Resource Conflict

No single modelling approach can be 'all things to everyone'. Modelling is not like a jigsaw puzzle, where there is one way to do it and it is obvious when the solution is correct. On the contrary, modelling is like making a mosaic, in which there are many ways to complete the picture, several of which may be equally effective and attractive, and all of which may reveal the 'big picture'.

Many decision-support systems for natural resources are static, and offer guidance for better resource management at one point in time, e.g. LUPIS (Ive *et al.* 1985), SIRO-MED (Cocks and Ive 1996) and Bayesian Belief Networks (Jensen 1996, Lynam *et al.* 2002). While such static approaches do offer useful insights, many of the questions central to ESM involve land-use dynamics which cannot be addressed fully within static approaches.

The basic concepts outlined for FLORES are not new; what is new is the way concepts are integrated and applied. In some ways, FLORES is comparable with work by Bousquet *et al.* (1993, 1994), who constructed a multi-agent simulation (MAS) model of an inland fishery in the Central Niger Delta as a basis for focusing discussion, evaluating options and formulating recommendations. MAS has been used in many other natural resource contexts (Bousquet *et al.* 2001a, 2001b).

There is an interesting contrast between FLORES and MAS. Both are concerned with *agents* that can modify and respond to their environment, but the emphasis differs. Generally, MAS attempts to find the simplest set of rules that can reproduce a particular pattern from a defined scenario. In essence, the usual question for MAS is: 'What are the rules that might explain the pattern that has been observed?' FLORES considers the converse: 'Given what is known about human behaviour in a particular context, can we predict future outcomes for a range of scenarios?' Generally it is not known what future outcomes should look like, except in a few specific cases that may be used to test the model. FLORES also recognises that people may have complex reasons for their behaviour, and attempts to represent present understanding of those reasons, rather than seeking the simplest rules that may reproduce a given pattern. It is anticipated that the FLORES approach (including explicit tests of hypotheses) will help to reduce the danger of confabulation, i.e. a plausible but irrelevant explanation (Crick 1995).

RESEARCH NEEDS

Superficially, FLORES appears tractable, but it involves many challenges. Is it really possible to quantify the social profile of all actors in a community in sufficient detail to provide meaningful predictions from simple heuristics? There is no clear answer, and only empirical tests can elucidate if numerical approximations of complex social structures provide an adequate basis for action. The issue for ESM is not whether the model is 'right', but whether it inspires sufficient confidence and provides suitable insights to motivate actions that lead to better land use. Participatory modelling is an effective way to build confidence and encourage new insights to this end (Purnomo *et al*. 2003).

Several issues for methodological research are evident: whether to model individuals, households or other classes of actors; how to quantify risk and willingness of actors to accept risk; what is an appropriate balance between day-to-day decisions and strategic decisions, and between private and collective decisions. All are central to the FLORES approach, and in each case, the issue is whether the preliminary approach is a necessary and sufficient representation of reality. There are some advantages in modelling individual actors: this approach is conceptually elegant and facilitates empirical testing, but imposes a substantial computational load. Simulation based on groups of individuals (e.g. households, or actors classified by age and gender) speeds up simulations, and may ease data input requirements, but how this may affect the reliability of predictions is not clear. The issue may be best resolved through empirical trials and sensitivity tests.

The functional relationships required to formulate and implement FLORES may be relatively simple, but the data requirements are demanding. The proposal requires data relating to anticipated yields and values of crops possible under various situations, detailed tenure and demographic data, and a thorough understanding of the socio-economic culture of the community. This is a major undertaking (Robiglio *et al.* 2003), and may be a serious limitation, even when the model is restricted to a limited geographic area. However, it may be possible to sample only selected actors to reduce the burden of data acquisition.

There are many other important issues that may need to be addressed, for instance communication between actors, health, migration and remittances. For example, it can be inferred from the rapid introduction of rubber to Sumatra a century ago, that word-of-mouth communication can have a major influence on the uptake of new technologies, and thus on land-use patterns (Penot 1997). Modelling these information flows may be critical to the reliability of predictions.

The interrelation between land-use patterns and the health of the workforce cannot be ignored in agrarian communities. Health affects land-use patterns through labour availability, and land use may in turn affect people's health (e.g. incidence of malaria). Similarly, migration to cities, and remittances from those in paid employment, may have a substantial influence on land-use patterns at the agricultural frontier.

A FLORES model is easy to conceive for a small village, in which each actor can be simulated. However, to be useful, the model must be scaled-up to deal with broader landscapes. In doing so, it may become impractical to examine decision-making by all actors, and it may be necessary to extrapolate from a sample of actors. The choice of sample may be critical to the outcome, and suitable sampling strategies must be investigated before the approach can be scaled-up. A crucial part of this investigation will be to identify the minimum essential set of prime determinants. It is likely that this will be an iterative process involving several cycles of idealisation and abstraction.

FLORES seeks to provide a framework for testing and refining ideas. This means that the basic framework must be carefully tested, and that baseline data should be acquired for detailed empirical testing. Two components of these tests warrant special attention and preparation: sensitivity tests and benchmark tests (Vanclay and Skovsgaard 1997). Ideally, a thorough program of sensitivity testing should examine each input, every parameter and all assumptions to ascertain how much influence they have on predicted outputs. This is useful information that can be used to direct further development of a model, with a lower priority assigned to parameters and assumptions that have little influence on predicted outputs.

Thorough benchmark testing requires planning and preparation. Comprehensive data are required about a series of sites for at least two points in time, preferably over a reasonably long timeframe. Ideally, the situation at some sites should remain more-or-less unchanged, while substantial changes should be evident at other sites. There are always difficult issues to be addressed if these sites involve only passive monitoring, and empirical tests are strengthened if experimental data are available. In agricultural situations, it is customary to use paired and replicated experiments to compare treatments against control plots. Such data are more difficult to obtain at the landscape scale and when people are involved, so greater ingenuity is required. Survey data pose special problems, since many factors may vary simultaneously (cf. a designed experiment) and it can be difficult to make reliable inferences. In theory, it is possible to conduct experiments to gather rigorous data to test models, but there are ethical questions that would need to be considered carefully. For example, it is feasible to go to a village and buy locally produced goods at prices higher than the prevailing market rate, and watch how the community responds. Fortunately, this experiment is not necessary, because in many countries, such ‘experiments’ happen frequently. For instance, new bridges and roads can markedly change transport costs. Thus the data required for model testing may be obtained by strategically choosing and monitoring selected communities over an extended period.

Satisfactory ways to value the intangibles involved with land-use decisions pose a major challenge. One particular aspect that needs to be addressed is how to value prestige. Prestige may take many forms, and may explain land purchases at prices inconsistent with production (e.g. prestige of owning a larger estate), herd sizes (e.g. prestige of large flocks leads to overstocking, even though smaller flocks may offer equivalent returns and lower risks), and possession or production of particular items.

A further challenge for later versions will be to model selected species interactions in both plants and animals, especially for apparently pivotal or keystone species. It is not sufficient to model the food web, because energy flows are only one of the aspects (Polis and Strong 1996). It is also important to consider relationships such as mycorrhizal and other symbiotic relationships, pollination and transport of seeds, microclimate and other modifications of the environment that may facilitate the establishment of plant and animal species. It is probably impossible to model all of these relationships in a tropical forest, but it is important to recognise and include suspected pivotal relationships in the model.

Perhaps the best test of a model is how well modellers and their clients can answer the questions ‘What do you know now that you did not know before?’ and ‘How can you find out if it is true?’. FLORES has many limitations, but provides a fertile test-bed for ideas, and offers scope for furthering knowledge of policies, incentives and land-use patterns in rural landscapes. It may help to bring together scientists from diverse disciplines to work towards a common goal, and may help add rigor to natural resource management and research.

CONCLUSION

There are compelling reasons to model landscape issues at the level of households and fields. Spatially-explicit modelling of these units is desirable because it enables rigorous testing of model predictions, and thus of underlying propositions. The sets of simple rules underlying multi-agent simulation may offer useful insights, but increase the danger of confabulation (plausible but irrelevant explanations). It may be that the greatest gains may be realised by participatory modelling of the processes as we understand them. This is what is being attempted in the FLORES series of models. The FLORES experience has demonstrated that it is possible to model landscapes at the level of households and fields. Current research seeks to test the utility of this approach.

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