FLORES: for exploring land use options in forested landscapes

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Incentives intended to stimulate better land use practices often don't work as intended, and can have undesirable side effects that were not foreseen. How can we better equip policy makers and their advisors to envisage fully the efficacy and consequences of initiatives? One way is to provide a decision support system. The formulation and construction of such a system offers other benefits: it would make existing information more accessible, facilitate hypotheses testing, and foster collaboration between researchers working on these issues. FLORES is such a system being developed through a partnership co-ordinated by the Center for International Forestry Research.

Introduction

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 that 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. How can we better equip policy makers and their advisors to envisage fully the efficacy and consequences of initiatives?

I offer an analogy: 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 every 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. And they rarely need to use their training, because our knowledge of flight has been synthesised into an autopilot that takes care of most situations.

Now contrast this with our management of forests:

- Do we know what to do when things go wrong?
- Can we tell when things are beginning to go wrong?
- Do we know which controls we can use to change things?
- Do we know what the controls are, where to find them, and how to activate them?
- Can we recognise and interpret the indicators?
- Why don’t we have an ‘autopilot’ to give advice?

Why is it that so many amongst those who make important decisions about the world's forests have never raised a tree, tended a garden, gathered food from the forest, or used a simulator to explore the implications of an impending decision? Would a forest landscape simulator make a difference?

The Need for a Forest Simulator

The computer game SimCity provides a useful analogy of the forest simulator I envisage. The Maxis Corporation provides a simulator in the form of a game. The game offers the player an "aerial view" of a city, a menu of policies and incentives (e.g., expenditure on education, transport, sanitation, etc.), and indicators of performance (e.g., unemployment, GNP, pollution, etc.). Scenarios are available freely on the Internet, and range from real cities to fantasies.

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. Such a forest simulator should have a strong factual basis, and could be customised to suit different situations. It would:

- synthesise existing knowledge and identify gaps and other deficiencies;
- express present knowledge concisely, completely, explicitly and unambiguously as a model;
- create a framework to promote collaborative interdisciplinary research;
- provide a basis for strong empirical tests of hypotheses relating to land use policy;
- create a planning tool to allow planners and policy makers to explore future scenarios; and
- provide an educational game to improve general knowledge of tropical forest environments.

Modelling is not a panacea. At best, models are simplistic abstractions of reality. However, mathematical and computer-based modelling merely formalise our natural tendency to mental and verbal models. Using 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.

FLORES

FLORES, the Forest Land Oriented Resource Envisioning System, aims to improve our understanding of land use patterns in time and space, especially in forested landscapes, and to facilitate quantitative analyses of policy options intended to manipulate these patterns. FLORES is spatially explicit, and operates at the landscape scale, spanning both forest and agricultural lands. Agricultural lands and villages form a critical component of the landscape, and must be modelled to fully understand the processes at work in and near the forest.

The basic concepts of this work are not new; what is new is the way concepts are integrated and applied. FLORES seems most closely related to 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 basis for focusing discussion, evaluating options and formulating recommendations. 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 this pattern that we have observed? FLORES considers the converse: Given what we know about human behaviour, can we predict future outcomes for a range of scenarios? Generally we do not know 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 our present understanding of those reasons, rather than seeking the simplest rules that may reproduce a given pattern.

It is inevitable, and quite deliberate, that the initial version of FLORES will be simplistic. We are building a platform that will be the basis for on-going work over a long period. This platform must not be 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 platform should provide a basis for testing a wide range of propositions, and above all, should be easy to modify. We will begin with simple models, and will progressively enrich these as we refute inappropriate simplifications. Models excel at exposing counter-intuitive consequences of simple assumptions. Even if initial prototypes of the model are of little practical relevance, they may offer valuable insights, and their main purpose may be to focus questions rather than to provide answers. 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.

Assumptions, actors and activities

FLORES relies on four basic assumptions (Vanclay 1995), namely that:

1. Land use patterns are created by *actors*, individuals or groups of individuals who collaborate as families, clans, 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 time frame than would otherwise be the case.
3. When choosing an *activity*, actors explore all options available to them, within the constraints imposed by resources (land, time, capital, etc.), knowledge, and their comfort zone (cultural attachments, willingness to attempt novel activities, etc.).

4. Actors tend to undertake activities that maximise expected benefits or minimise anticipated risks to themselves and their beneficiaries (families, clans, 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 done in the past, plus a few new activities pursued profitably by neighbours. However, there are usually a few innovators who consider an extended list of activities and may attempt a diverse range of enterprises. Typically, innovators are more willing to attempt risky enterprises than are their more conservative fellows. Disposition is only one determinant of willingness to accept risk, and age, assets and income also feature prominently in many explanations.

Assumption 4 deals with benefits and utility functions. These benefits may be expressed in dollars, or in other quantitative ways. Benefit maximising may be realistic for some communities, but is only one way to represent behavioural tendencies. The role for FLORES is to provide a way 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, etc.);
- anticipated prices, net of costs incurred in initiating (e.g. seed, fertiliser, raw materials, etc.) and realising a return (e.g. harvesting, packing, transport, marketing, commissions, etc.), discounted as necessary for any delays;
- reductions for real or imagined risks including pests, disease, fire, theft, loss of tenure, spoiling during transport, viability of an employer, etc.;
- 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 also be needed to account for time taken to learn and implement new technologies and to meet transition costs in adopting the technology. However, in the initial prototype of the model, we may avoid these complexities by making the prevailing market prices exogenous to the model, and assuming that they remain constant. We can then assume that decisions on any site are independent of other sites, and the utility function can be solved without taking topology into account.

Decision-making by actors is just one component of FLORES, and several other sub-models are needed to predict the growth of trees and crops, changes in the soil and water balance, interactions between key plant and animal species, and other ecosystem processes. Fortunately, many such models already exist (e.g., Vanclay

1994, Anon 1997), and some are amenable to calibration and integration within the FLORES framework.

Implementation

FLORES deals with land, people who interact with that land, and the land-use and related decisions that they make. The landscape is made amenable to 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. Utility functions deal with actors, resources such as land and capital, and activities such as clearing land, planting crops, hunting, making things, working for wages, and so on. We assume that actors compile a ‘menu’ of possible activities from which they select the item that appeals most under the prevailing circumstances. For many individuals in a forested landscape, such a menu could be relatively small, comprising those activities that have been entertained in the past, or which have proved successful for neighbours. The innovators may have a very extensive menu, and a stochastic selection may be appropriate, at least for their novel enterprises.

Box 1 outlines how FLORES could be implemented in an algorithmic language such as Fortran, Pascal or C. However, this algorithm may make decision-making by actors too structured, because unless it is programmed carefully, decisions will be taken in turn, with each actor having sufficient time to reach a decision. Most algorithmic languages imply a serial representation, whereas in reality, decisions are taken in parallel. FLORES should allow all actors to make decisions simultaneously, sometimes independently, sometimes in concert, with some options foreclosing for those who are too slow to decide.

Another disadvantage of implementing the model directly as computer code, irrespective of the approach, is that it reduces involvement by potential participants who are not conversant with the computer language used. AME, the Agroforestry Modelling Environment (Muetzelfeldt and Taylor 1997), has a graphical interface that makes the model accessible to researchers who are not fluent in computer programming, while allowing access to the underlying code. AME offers a powerful and flexible platform that does not exclude less computer-literate participants in the project.

Box 1. Possible algorithm for the FLORES model.

There are other advantages in using AME, some of which include the ability to

- represent relationships as simple sketches, mathematical equations, or as sets of rules, to
- substitute alternative models easily via the Windows click-and-drag facility, and to

- create customised user interfaces with software "helpers" that can be developed independently and "plugged in" later.

Outputs and Clients

Too many models languish, under-utilised, because they do not satisfy the needs of potential users and because system developers did not explicitly contact clients, ascertain their needs, and stimulate their interest. To encourage uptake, potential users must be involved in the development of the model. Obviously, users may not be interested in all aspects of model design and construction, but they should have the opportunity to participate in specification and design of the user interface. It is not enough to ask them what they want and how they want it. Team members 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 simple prototypes and mock-ups need to be built so that ideas can be demonstrated, tested and modified.

FLORES will provide a range of outputs to suit different user requirements. One output will be the forested landscape of a SimForest implementation. I have previously argued that the single greatest contribution that information science could make for conservation and wise use of forests would be to construct a virtual reality interface for a forest management system (Vanclay 1993). This could allow a minister and his advisors to don a virtual reality headset and take a ‘magic carpet’ ride over a forest estate. They could observe the spatial pattern of their forest and watch how it changes over time, and under different scenarios. They could ‘zoom in’ to examine particular issues, and stand back to get an overall perspective. The technology to do this exists, and it is possible to link forest inventory systems, growth models, geographic information systems and virtual reality systems in this way. However, it has not been done at this time, and awaits further software and hardware development to make it more affordable. In developing FLORES, we need to be mindful that the eventual user interface may well be a virtual reality system, and we should deliberately design an open and flexible system that does not foreclose this possibility. However, the SimCity-style interface is adequate for many applications, and would be particularly useful for educational applications and general information dissemination.

Another important visual product will be 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. We want to identify the more sensitive areas, where comparatively small perturbations in inputs and assumptions give rise to large changes in predicted land uses. In particular, we want to know where these areas are, what parameters trigger shifts in dominant land use, and how these shifts occur. One useful way to emphasise such changes is to compare predictions under different 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. Graphical outputs of this kind may be a good 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, to establish or refute this, we need sensitivity analyses on all input parameters to establish if a small change in an input makes a negligible, small or large change in the predicted outcomes. While this 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 our understanding of forested landscapes.

Challenges and scope for collaboration

There are several specific problems that need to be addressed before this model can be realised as anything more than a simple prototype. Many of these challenges can be addressed as separate tasks, and are amenable to research by others, including students. Some of the more obvious issues are listed below.

In the proposed model formulation, the underlying functional relationships may be relatively simple, but the data requirements are rather demanding. Most utility functions appear innocent enough, but they require a lot of data: anticipated yields and prices of all possible crops under a range of situations, detailed tenure and demographic data, and a good understanding of the socio-economic culture of the community. This is a major undertaking, and may be one limitation of the model. We envisage that initial prototypes will be restricted to a limited geographic area, allowing a complete census of all inhabitants for thorough model testing. However, subsequent operational implementations may sample only selected actors to reduce the burden of data acquisition. Crop yields may be inferred from models, but prices and elasticities must be gleaned from field survey work. This task may be particularly onerous for non-timber forest products such as medicinal plants.

Superficially, the model 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 a simple utility function? There is no clear answer, and only an empirical test can elucidate if numerical approximations of complex social structures provide an adequate basis for planning. Two further issues for methodological research are evident at this stage: whether to model individual actors or classes of actors, and how to quantify risk and willingness of actors to accept risk. Both are central to the FLORES approach, and in both cases, the issue is whether the preliminary approach is a necessary and sufficient representation of reality. There are some advantages in modelling individual actors: it is conceptually elegant and facilitates empirical testing, but it imposes a substantial computational load. Simulation based on a few classes of actors (e.g., classified by age and gender) would speed up simulations, and may ease data input requirements, but it is not clear if this would lead to the same result as individual-based modelling. The issue may be best resolved through empirical trials and sensitivity tests.

It is presently assumed that an actor’s willingness to accept risk can be quantified, in part through the historic variation in benefits accruing from a particular activity, and from the actor’s age, tangible assets and income. However, this assumption warrants closer scrutiny since attitudes to risk have a major influence on land use decisions. Our ability to quantify risks and attitudes to risk will have a major influence on the accuracy of FLORES predictions.

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 bigger 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 certain items.

A further challenge for later versions will be to model selected species interactions in both plant and animal species, 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. 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 the pivotal relationships in our model.

A FLORES-type model is easy to conceive for a small village, where we can simulate every individual actor. However, when we scale up our efforts to model larger landscapes, 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 to the provincial or national level. A crucial part of this investigation will be to identify the minimum essential set of prime determinants.

FLORES seeks to provide a framework for testing and refining ideas. This means that the basic framework of FLORES 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 see 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 is another big job that requires planning and preparation. It requires comprehensive data about a series of sites for at least two points in time, preferably over a reasonable interval. 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 and it can be difficult to make reliable inferences. In theory, it is possible to conduct experiments to gather rigorous data to test FLORES, 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 developing countries, governments conduct such ‘experiments’ all the time. 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.

Prognosis

Perhaps the best test of a model is how well can the modeller 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 it provides a fertile test-bed for ideas, and offers ample scope for furthering our knowledge of policies, incentives and land use patterns in forested landscapes. We need the product, and we need the process. We need to bring together scientists from diverse disciplines to work towards a common goal. We also need to add more rigour to forest policy research. FLORES can help realise it.

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