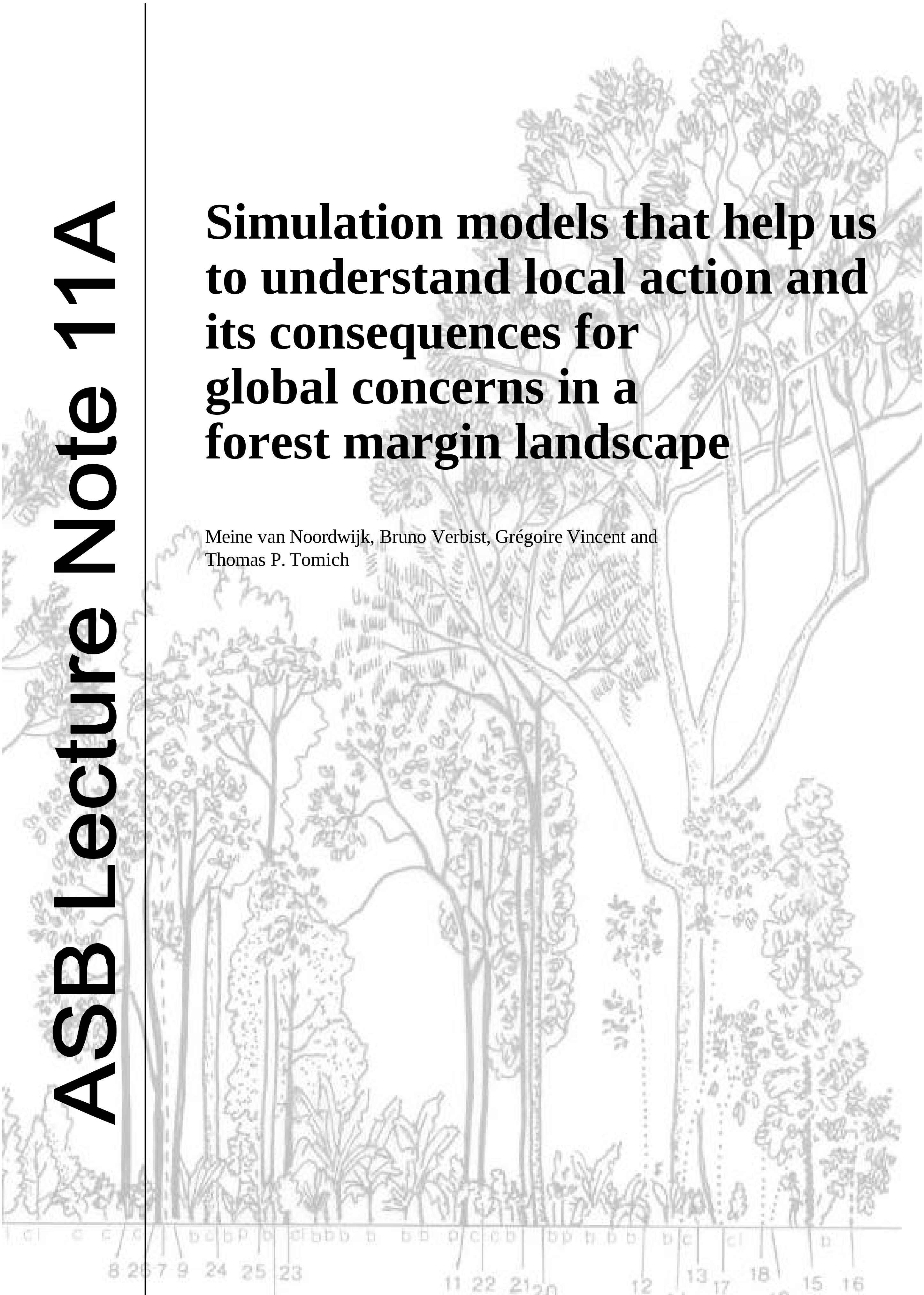
ASB Lecture Note 11A



Simulation models that help us to understand local action and its consequences for global concerns in a forest margin landscape

Meine van Noordwijk, Bruno Verbist, Grégoire Vincent and
Thomas P. Tomich

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

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Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns

Meine van Noordwijk, Sandy Williams and Bruno Verbist (Editors)

> Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can - in a global partnership for sustainable development. (Preamble to the United Nations' Agenda21 on Sustainable Development; http://www.un.org/esa/sustdev/agenda21chapter1.htm).

Background to this series of lecture notes

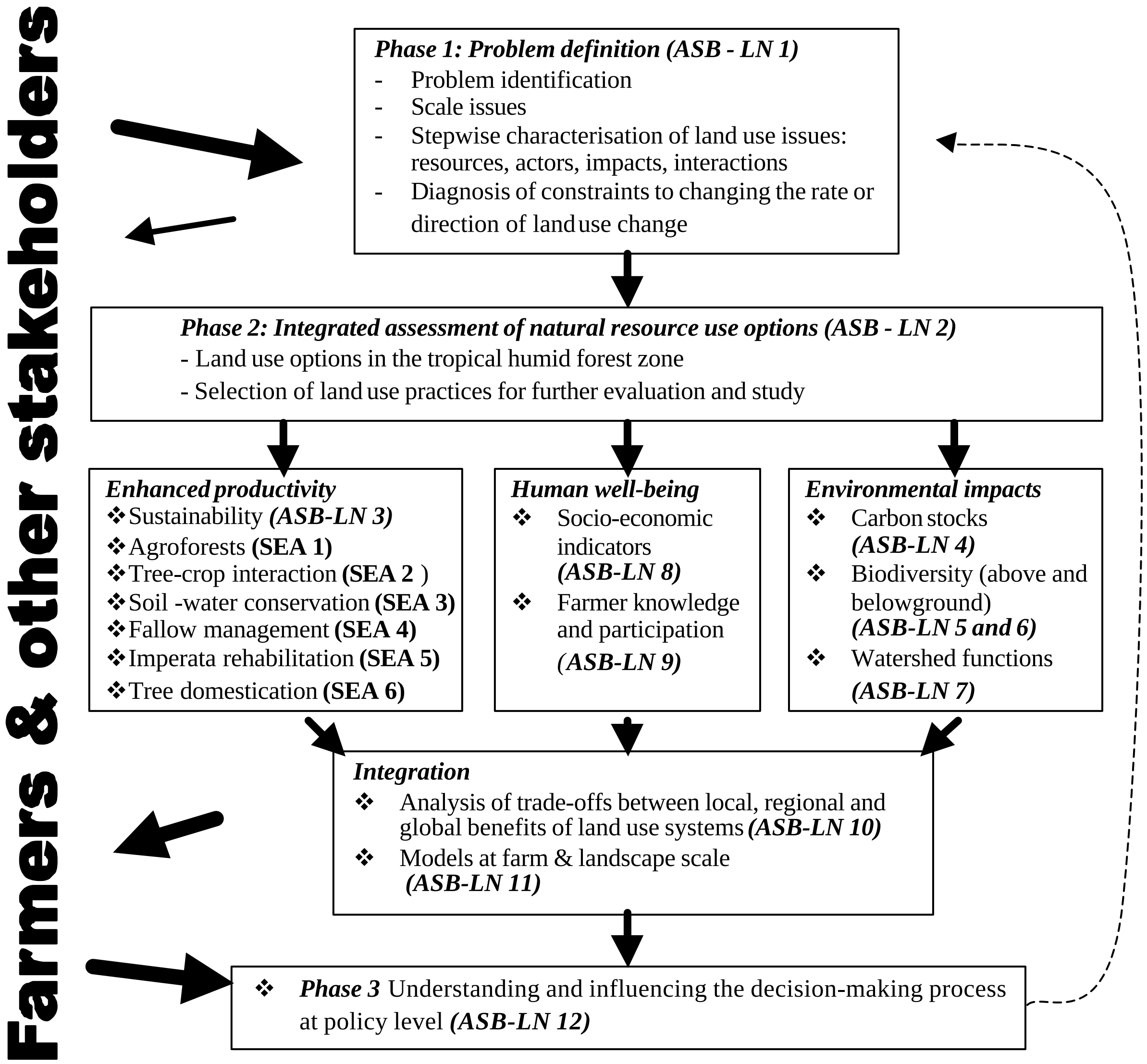
Much of the international debate on natural resource management in the humid tropics revolves around forests, deforestation or forest conversion, the consequences it has and the way the process of change can be managed. These issues involve many actors and aspects, and thus can benefit from many disciplinary perspectives. Yet, no single discipline can provide all the insights necessary to fully understand the problem as a first step towards finding solutions that can work in the real world. Professional and academic education is still largely based on disciplines – and a solid background in the intellectual capital accumulated in any of the disciplines is of great value. If one wants to make a real contribution to natural resource management issues, however, one should at least have some basic understanding of the contributions other disciplines can make as well. Increasingly, universities are recognising the need for the next generation of scientists and policymakers to be prepared for interdisciplinary approaches. Thus, this series of lecture notes on integrated natural resource management in the humid tropics was developed.

The lecture notes were developed on the basis of the experiences of the Alternatives to Slash and Burn (ASB) consortium. This consortium was set up to gain a better understanding of the current land use decisions that lead to ***rapid*** conversion of tropical forests, shifting the forest margin, and of the ***slow*** process of rehabilitation and development of sustainable land use practices on lands deforested in the past. The consortium aims to relate local activities as they currently exist to the global concerns that they raise, and to explore ways by which these global concerns can be more effectively reflected in attempts to modify local activities that stabilise forest margins.

The Rio de Janeiro Environment Conference of 1992 identified deforestation, desertification, ozone depletion, atmospheric CO_2 emissions and biodiversity as the major global environmental issues of concern. In response to these concerns, the ASB consortium was formed as a system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR), involving national and international research institutes. ASB's objectives are the development of improved land-use systems and policy recommendations capable of alleviating the pressures on forest resources that are associated with slash-and-burn agricultural techniques. Research has been mainly concentrated on the western Amazon (Brazil and Peru), the humid dipterocarp forests of Sumatra in Indonesia, the drier dipterocarp forests of northern Thailand in mainland

Southeast Asia, the formerly forested island of Mindanao (the Philippines) and the Atlantic Congolese forests of southern Cameroon.

The general structure of this series is



This latest series of ASB Lecture Notes (**ASB-LN 1 to 12**) enlarges the scope and embeddes the earlier developed ICRAF-SEA lecture notes (**SEA 1-6**) in a larger framework. These lecture notes are already accessible on the website of ICRAF in Southeast Asia: http://www.icraf.cgiar.org/sea

In this series of lecture notes we want to help young researchers and students, via the lecturers and professors that facilitate their education and training, to grasp natural resource management issues as complex as that of land use change in the margins of tropical forests. We believe that the issues, approaches, concepts and methods of the ASB program will be relevant to a wider audience. We have tried to repackage our research results in the form of these lecture notes, including non-ASB material where we thought this might be relevant. The series of lecture notes can be used as a basis for a full course, but the various parts can also ‘stand alone’ in the context of more specialised courses.

Acknowledgements

A range of investors (or ‘donors’) have made the work of the ASB consortium possible over the past years, some by supporting specific parts of the program, others by providing core support to the program as a whole. These lecture notes build on all these investments, but were specifically supported by the ASB Global Steering Group, with funds provided by the Asian Development Bank, the World Bank via the CGIAR, by ICRAF core funds, by the Netherlands' Government through the Direct Support to Training Institutions in Developing Countries Programme (DSO)-project and by the Flemish Office for Development Cooperation and Technical Assistance (VVOB). Both biophysical and policy research was supported by a Regional Technical Assistance Grant from the Asian Development Bank. Many researchers and organisations have contributed to the development of ideas, collection and synthesis of data, and otherwise making the program what it is today. A team at the International Centre for Research in Agroforestry (ICRAF), consisting of Kurniatun Hairiah, Pendo Maro Susswein, Sandy Williams, SM Sitompul, Marieke Kragten, Bruno Verbist and Meine van Noordwijk developed these lecture notes. A first test of their suitability was provided by a course on ‘Ecology for Economists’ organised by the Economy and Environment Program for Southeast Asia (EEPSEA) program – we thank David Glover, Hermi Francisco and all participants to that course for their suggestions. Key researchers within the consortium provided support and agreed to act as co-authors on the various chapters. Editorial comments on draft forms of the various lecture notes were obtained from Fahmuddin Agus, Georg Cadisch, Min Ha Fagerström, Merle Faminow, Roeland Kindt, Chun Lai, Ard Lengkeek, Jessa Lewis, Chin Ong, Per Rudebjer, Goetz Schroth, Douglas Sheil, Fergus Sinclair, Sven Wunder and others. Overall responsibility for any shortcomings in the lecture notes remains with the editorial team.

ASB-consortium members

Details of the ASB consortium members and partner organisations can be found at: http://www.asb.cgiar.org/

Lecture note 11A

SIMULATION MODELS THAT HELP US TO UNDERSTAND LOCAL ACTION AND ITS CONSEQUENCES FOR GLOBAL CONCERNS IN A FOREST MARGIN LANDSCAPE

Meine van Noordwijk, Bruno Verbist, Grégoire Vincent and Thomas P. Tomich

<u>Contents</u>

I. Objectives

- To introduce simulation modelling as a tool to understand how apparently complex results in land use change can be derived on the basis of simple assumptions,
- To give an overview of a number of approaches to modelling, with their prospects and limitations,
- To introduce sensibility, sensitivity and validation tests for critical model users

II. Lecture

1. Introduction

1.1. Everybody uses models, but some are more explicit than others

There is nothing special about 'models'. They come to you as part of any education, as physical models in all shapes and sizes from dolls, miniaturized cars and air planes and globes, as static visual representations as maps or pictures, in more abstract arithmetic or algebraic form, or as verbal or mental models in nearly all we learn. In fact 'modelling' is so common that we cannot speak, think or observe without using and modifying 'models', or 'abstractions' from 'reality' (if there is such a thing as 'reality' at all). However, there are many different types of models and languages in which they can be expressed and there are different ways how to go about developing and improving models. We will here discuss some of these in the context of land use change in the margins of tropical forests. A disclaimer, to start with:

> Don't believe the models you'll see,
> unless your observations and data agree
>
> Don't believe your data, again,
> unless your models explain
>
> However, suspicion will be surely on you
> if the agreement is 'too good to be true'

Important elements of the current wisdom in 'research design' in agricultural sciences (with equivalents in social sciences) are still based on a ***statistical model*** that the yield of a crop on a given site and in a given year is equal to some intrinsically unpredictable 'control' yield, plus terms for the specific treatment combinations used with coefficients that are unknown beforehand, plus 'error' terms. There is a rigorous system for testing hypotheses, but little attention to how to generate hypotheses and build a logical framework.

Young children learn that every answer can be followed by a question 'yes, but why?' and that they can thus quickly disentangle the apparently reasonable and logical world picture (model) of their parents. '***Explanations***' are not really different from '***descriptions***' ('it is like this, simply because it is like this'). Yet, we often make a distinction between 'descriptive' and 'process-based' or 'explanatory' models. This is only a difference in degree to which each new observation is respected as a new 'fact' to be entered into the encyclopaedia or database describing the world, or disentangled in terms of previously known 'relations' and 'facts'. It is the difference between being 'diligent' and being 'intelligent'. 'Explanations' are attempts to delay our 'out of memory' messages - if we can reconstruct time- and location specific observations by combining general rules with time- and location specific inputs, we'll have learned to ***interpolate*** and may gain some confidence in our ability to ***extrapolate*** and ***predict***.

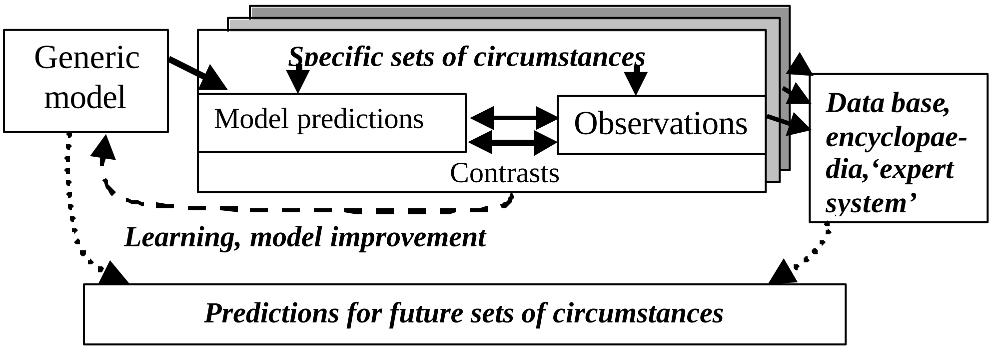


Figure 1. Models in their relation to real world observations

Models are statements about interactions (relations) between components. If these relations are sufficiently specified, models can be formulated in mathematical terms and can use the tool box of mathematics to establish logical consequences of the stated assumptions. These model results ('hypotheses') can then be confronted with the real world (or at least with our perception of the real world). If there is a discrepancy, we have a choice (Fig. 1):

- we can question the model structure, the parameter values used to initialise the model or the internal consistency of the model (are the outcomes really the logical consequences of the stated assumptions ?),

- we can question the observations made in the 'real world' ('I will not discard my beautiful model because of some ugly facts'); no observations can be made without, implicitly, using other models, and these models and the measuring instruments that are based on them may be as incomplete or wrong as the model which we wanted to test,

- we can abandon this field of research as being beyond our (current) capabilities to deal with.

There is no such thing as 'model validation', if that term may suggest that models can be declared ***'valid'*** without specifying the conditions of the tests that were performed. We may observe that the predictions of a specific model have been in accordance with the real world on a number of occasions, and that may increase our confidence in using that model again for a new situation, but we can never conclude that a model is valid in general terms. Generally, the more unlikely model predictions are at first sight, the more they'll increase our confidence in the model if real world observations are in line with them. Doing experiments 'to test the effect of such and so treatments' is thus a waste of time. If we do not formulate our models, ideas, hypotheses, predictions beforehand, we'll never feel inclined to modify these ideas on the basis of research results.

Confrontations of model predictions with the real world give a test of the '***fitness***' of the model. Often, models are formulated in such a way that they avoid the confrontation. Astrological 'predictions' and 'oracles' are good examples of statements which are (deliberately?) so vague that they make everything 'understandable' in hindsight, but hardly exclude any possible outcomes for the future. As the success of modelmakers is often evaluated on the basis of the success of their models, the 'survival of the fitter' emerged as strategy. By employing extremely flexible models, which in hindsight can be 'fitted' to any data set, they constructed models, which are almost impossible to beat. Heuristic regression models are good examples of this: they never fail (by adding enough terms to the model we can always get a perfect 'fit'), and because of that we'll never learn much from them. Unless we naively believe that the coefficients established will be valid outside the range of observations from which they were derived. Regression models then are a way to formulate quantitative hypotheses for further tests, preferably in a new set of environments.

As alternative to this 'fitter' strategy of model development, we can have a 'tinker' strategy. Tinkers provide slight, temporary patch-ups to leaking kettles and pans. Modelmakers often have to resort to 'fudge factors' to make their models correspond with real world data. By doing so, their models 'degenerate' into regression type models.

The purist approach to model development based on ‘first principles’ and a step-wise increase of complexity only as and when needed is, however, not necessarily very pragmatic. All natural tropical forests may be gone before we have a fully satisfactory model of all human decisions that lead to this outcome. In reality we need ‘horses for courses’ (in Indonesia we say ‘lain ladang, lain belalang-nya’ or every cropped field has its own type of bugs -- so do models), a variety of models that can be used for specific purposes. Discussions on the ‘quality’ of a model can be based on different tests:

- Is model ***complexity*** in line with objectives? Does it use independently measurable or generally available input, does it produce the type of output that one wants to see, is it not polluted by no ‘fudge factors’ that have no real basis in the assumed relationships between model components
- ***Sensibility*** -- ‘does it make sense?’, do we get ‘reasonable’ output for input parameters in the normal range?
- Parameter ***sensitivity*** -- how do key output parameters respond to changes of input parameters in a realistic range
- ***Validation*** test -- can independently measures inputs for test sites reproduce known outputs.

In everyday language models are often used as blueprints or prescriptions to be followed. Model farms, model schools and indeed ‘modelling’ as it relates to the human body and the way this can be dressed up, have a context of setting standards and targets that the whole world should try to achieve (but never will). They tend to reduce diversity. The way we present models here is primarily in an effort to better understand the existing diversity and thus to contribute to more flexible site-specific approaches, rather than the simple prescriptions that usually derive from world views (models) that ignore interactions.

1.2. Complex outcomes may be derived from simple rules and assumptions

“Make things as simple as possible. But no simpler.” (Albert Einstein)

One of the main lessons of constructing simulation models is that one often does not need to postulate a lot of ‘rules’ to generate patterns that can look as complex as any real-world outcome. Of course this does not mean that the real world is actually built on such simple rules -- we don’t have direct access to the rule-maker if there is any, and can only interpret the patterns that exist.

The relationship between ‘pattern’ (spatial structure) and ‘process’ (dynamic change) has long been a focus in ecology. As processes generate pattern and patterns modify processes, an apparently uniform starting position on a mud flat, beach or soil deposit from a landslide can become a complex ecosystem rich in small-scale pattern. Yet, a simple set of rules may suffice to model this type of succession.

Biological development from a single fertilised cell to a complete elephant, rain forest tree or human being shows that a consistently applied set of ‘process’ rules embodied in the DNA can amplify initial patterns (the different poles of the egg cell) to very complex structures. Does all the information thus reside in the genome, as current bio-technologists may assume? No, the expression of any gene depends on the context, the pattern that surrounds it at the time that it is ‘switched on’.

The recently produced genome maps show that in the evolution of the rules embodied in the DNA of all organisms a lot of ‘redundancy’ has slipt in to the genetic code, allowing the duplication of strings and retention of ‘instructions’ that are no longer needed and that are normally ‘switched off’ (but if the switch breaks, they can suddenly re-surface). Many of the more complex simulation models that have developed over time may have similar levels of code redundancy, and it generally pays off to ‘start from scratch’ once in a while and build up the rule set from the basis.

Modelling is the art of simplification, trying to reduce the issue to its ‘core’. However, models can not be used to prove or even indicate that factors that were left out of the model were indeed not important -- they may show that these factors are not ‘needed’ to derive explanations of real world behaviour, but not that they in fact have little influence. Generally one would first include a broader set of factors in the model and then explore which ones have relatively little impact on the overall results.

Holling (2000) warned against the oversimplicity of single cause explanations and argued that “if you cannot retain a handful of causes in your explanation, then your understanding is simplistic. If you require more than a handful of causes, then it is unnecessarily complex. If you cannot explain it to your neighbour, you do not truly understand it. That level of understanding is built upon a foundation of adequate integrative theory, rigorously developed, rooted in empirical reality, and communicated clearly with metaphor and example. The first requirement to achieving that level of understanding is to begin to integrate the essence of ecological, economic, and social science theory.”

1.3. For what questions can simulation models help?

In this lecture note a range of models will be discussed, aimed at answering different questions:

Tree-soil-crop interactions in shifting cultivation and Slash&Burn land use conversion

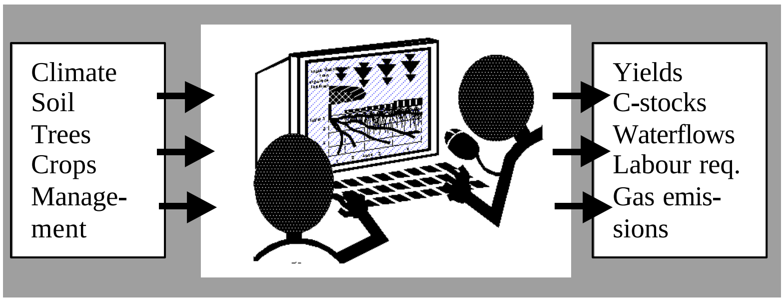


Figure 2. How do basic properties of the trees, crops and animals that occur on the same land unit compete for and complement each other in resource use on a given soil, for a given climate and in interaction with farmer management?

Such models can build on simple empirical rules for the changes in an aggregate concept such as 'soil fertility' during cropping and fallow phases of a shifting cultivation cycle (the Trenbath model, see below), or they can start from the principles of a water, carbon, nitrogen and phosphorus cycle and the way plants interact with these cycles and with each other.

Farm level models

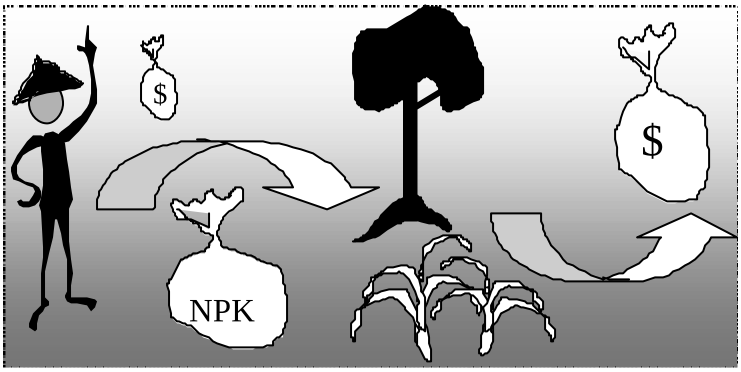


Figure 3. How can farmers best use their resources (land, capital, knowledge, labour, germ- plasm, external inputs) to manage their farm in view of their household objectives and the prices for inputs and outputs as they exist?

These models are based on 'production functions' that relate inputs to expected outputs. They.focus on the decisions farmers (either individually or as households) can make on the use of their scarce resources (land, labour, capital) to make the most of it -- on the basis of clearly defined 'objective' functions.

Land Use Change predictors

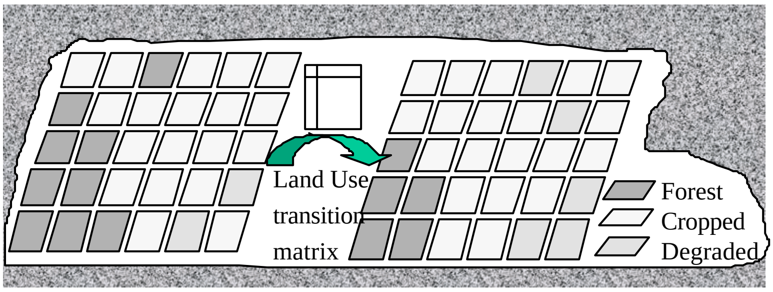


Figure 4. If we extrapolate the pat- terns of recent and cur- rent land use change to the near future, what will landscape-level land use look like; can or should interventions be made?

These models focus on the spatial pattern of land use change and derive rules or transition probabilities from past change, and extrapolate the current pattern into the future. The probability of change at 'pixel' (elementary picture element) scale is generally related to its neighbourhood, to the distance to a forest edge, road or market.

Macro-economic models

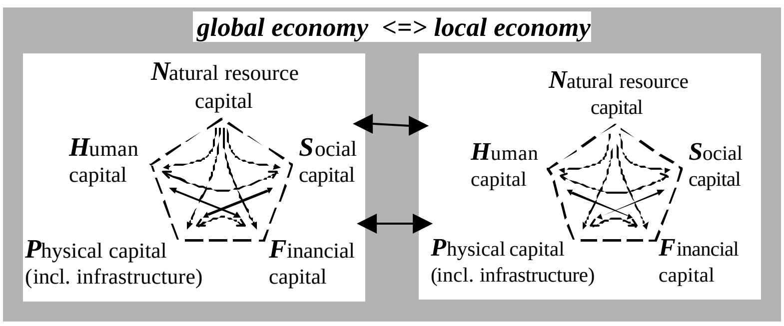


Figure 5. How do the five types of capital interact between the local and global economy? Can financial capital obtained from natural resources be converted to human and social capital for a sustainable society?

Macro-economic models exist in several forms, ranging from empirical regression models that, for example, try to relate the rate of deforestation to national productivity or debt indicators, to accounting systems that include financial, physical, human, social as well as natural capital and the transformations between them. Key concepts are ‘elasticity’ or responsiveness of demand and supply to changes in price, interchangeability of resources and in more recent models attempts at valuation of environmental goods and services.

Integral landscape-level policy instruments

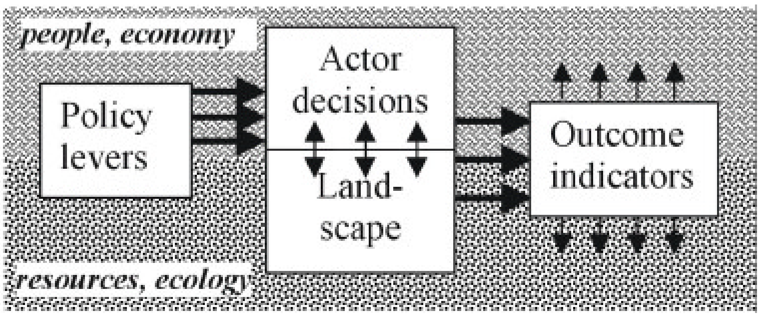


Figure 6. How will farmers and other actors respond to ‘policy levers’ and modify the way they interact with the landscape, leading to desirable outcomes?

Models of this group may contain elements of all the previous model types, but they are specifically geared to recognise the potential impacts of policy changes, on the decisions of farmers and other actors in the landscape and on the consequences this has for the various types of concerns that policy makers have to try and address.

2 Tree-soil-crop interactions in shifting cultivation and S&B land use conversion

2.1 Trenbath’s crop-fallow model

Trenbath (1989) formulated a simple model of restoration and depletion of 'soil fertility' during fallow and cropping periods, respectively. 'Soil fertility' is here taken to be a complex of effective nutrient supply and biological factors (diseases, weeds) affecting crop yield. Crop yield is assumed to be directly proportional to this (unspecified) 'soil fertility' complex. During a cropping period soil fertility declines with a fraction D per crop. Soil fertility during the cropping period:

$$F_t = F_{c0}(1 - D)^{n(t-1)} \qquad \textbf{(1)}$$

where F_t = soil fertility at time t (years), F_{c0} = soil fertility at start of cropping period, n = number of crops per year during cropping period and D = reduction factor of soil fertility per crop.

Cumulative yield for a cropping cycle is:

$$Y_{cum} = c\,F_{c0}\sum_{i=1}^{nt_c}(1 - D)^{1-i} \qquad \textbf{(2)}$$

where c = conversion efficiency of soil fertility to crop yield, t_c = length of cropping period in years.

During a fallow period soil fertility (or more correctly, the ability to support future crop yields) can be restored (re-created) with an asymptotic approach to a maximum value.

$$F = \frac{F_{\max}\,t_f}{K_f + t_f} \qquad \textbf{(3)}$$

where F = soil fertility at end of fallow period, assuming a value of zero at the start of the fallow, K_f = 'half-recovery time' or time needed to halve the difference between current and maximum soil fertility and F_{max} = maximum fertility, reached after an infinitely long fallow period.

These basic equations can be used to focus on 'sustainable' versions of fallow-crop rotations, on the basis of a recovery of fertility during the fallow to the level at the start of the previous cropping cycle. Van Noordwijk (1999) derived that the maximum yields per unit land that can be obtained sustainably require that the fallow phase is interrupted for a new cropping cycle when the relative fertility is:

$$\frac{F}{F_{max}} = B - \sqrt{B^2 - B}\ , with\ B = 1 + \frac{K_f}{t_c} \qquad \textbf{(4)}$$

For normal parameter value this leads to a relative fertility of 50 – 60 % of the maximum. When one operates the system at higher fertility the fallow periods have to be disproportionately longer, but the yields obtained per unit labour may be higher. The simple model does indicate that intensification (shortening of fallow periods) can lead to increases in yield until this range of 0.5-0.6 is reached (Fig 7 C and D); beyond that a further reduction in fallow length leads to less yields per unit land as well as per unit labour. The highest yields may be obtained for a 4 crop sequence, but the yield increase beyond 3 crops may not be worth the labour invested; 5 crops per cycle leads to lower physical yields than 4 crops. A comparison of Fig. 7C and D can show that a reduction in the soil fertility recovery factor K_f can lead to higher yields per unit land (due to shorter fallow periods), but not to a change in the optimal relative soil fertility at the start of a cycle or number of crops per cycle. Thus the physical yields per crop and the returns to labour are probably not modified much by such a change, if farmers are maximizing sustainable yields per unit area in both systems. Thus, this simple representation of the core of a 'shifting cultivation' or 'crop-fallow' system does offer valuable insights beyond the trivial.

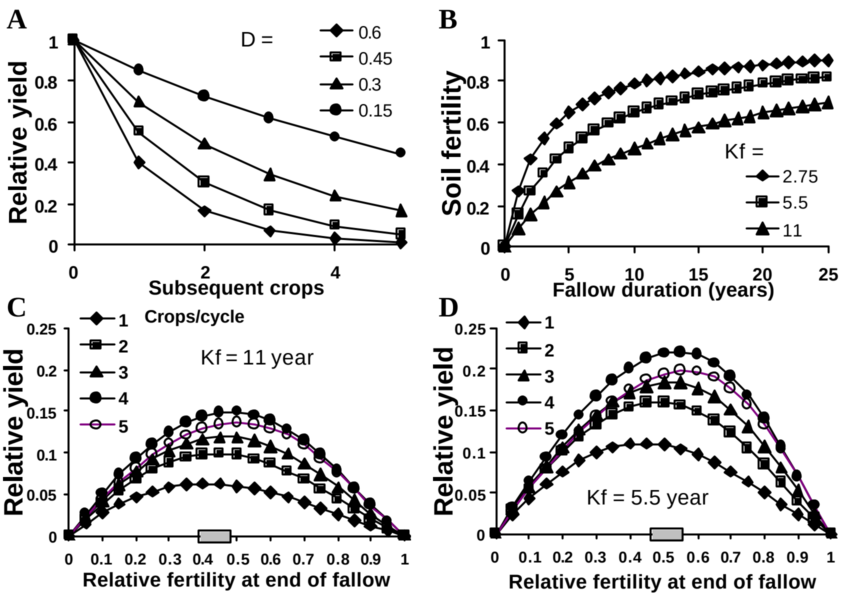


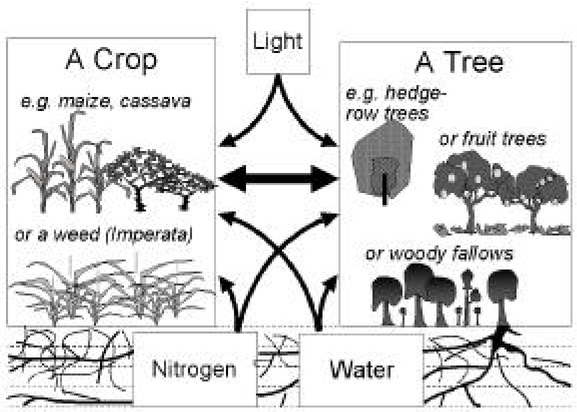
Figure 7. Assumptions in the Trenbath model on yield decline with subsequent crops (A) and recovery of soil fertility during a fallow period (B), and results for the maximum sustainable yield per unit area as a function of the relative soil fertility at the start of a new cropping cycle, for a natural (C) and 'improved' fallow (D), characterises by a 'soil fertility half-recovery time', K_f, of 11 and 5.5 years, respectively (based on Van Noordwijk, 1999).

As is true for any model, the relevance of these conclusions depends on one's trust in the validity of the assumptions. The weakest assumption may be the lack of long term degradation of the soil. The trade-off between yields per unit labour and yields per unit land, however does not depend on the exact correspondence of reality and the assumed functions for changes in soil fertility. As a number of properties, such as Carbon stocks and the successional stage of the fallow vegetation can be derived from the parameters in this Trenbath model, it can be used as the core of a more holistic assessment (see FALLOW model, below).

2.2 The Century model

As explained in Lecture note 4, the Century model can be used to predict the long term changes in various soil organic matter pools as well as the biomass accumulation in forests or crops that can respond to nutrient supply from mineralization, as well as generating the inputs for subsequent years. Compared to Trenbath's fallow model, the description of 'soil fertility' is much more explicit and potentially testable, but the price for this is a larger number of input parameters that are required, some of which are not easily measurable (especially the initial values of the various soil organic matter pools). The specific sequence of events during a slash-and-burn land clearing event can be simulated.

Figure 8. The Century model has been compared to independently measured parameters for a number of sites in the tropics and generally its results for Carbon are fine, results for N have uncertainties on short term changes and gaseous losses, whole results for P are questionable. Yet, as a first approach to new situations the Century model can help us specify expected results.



2.3 WaNuLCAS

The WaNuLCAS model of water, nutrient and light capture in agroforestry systems (Van Noordwijk and Lusiana, 1999) was developed to deal with a wide range of intercropping or agroforestry systems, where multiple crops and trees compete for water and nutrients, while partly complementing each other in root development, aboveground demand for nutrients and water, and in providing organic inputs to the soil. The description of soil organic matter pools is similar to that in the Century model, but the model requires many additional parameters to characterise trees and crops in their above- and belowground architecture. It runs on a daily time step and is thus appropriate for simulations of a few growing seasons to periods of say 25 years.

The model does include a detailed process description of slash-and-burn land clearing and their effects on haze and greenhouse gas production (although this section needs further parameterisation). As example we show here some output for a scenario where forest is converted into an oil palm plantation, with intercropping of maize and groundnuts in the first two years (Fig. 10).

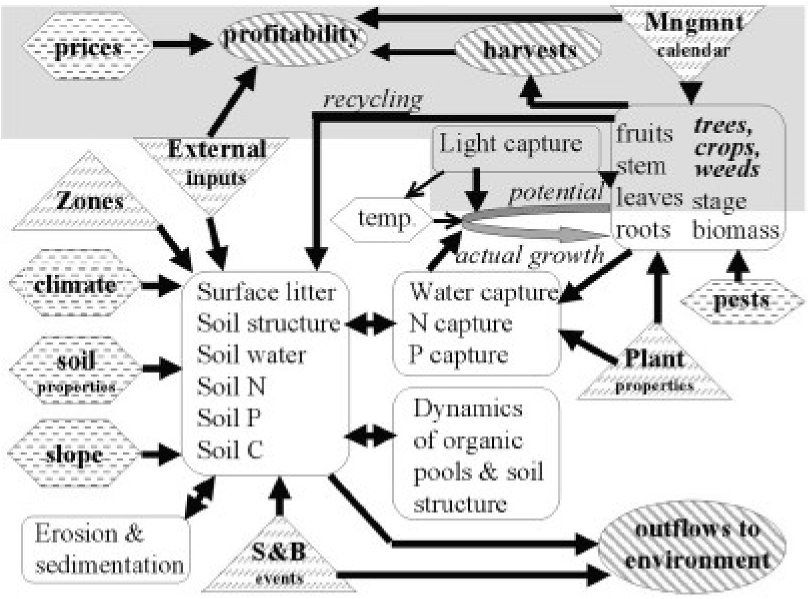


Figure 9. Components of the WaNuLCAS model

The scenario starts with a forest that is logged and a few weeks later slashed; forest vegetation will still regrow after this slashing. When the slashed vegetation has dried to a specified water content, fire is set, the unburnt wood is collected for a pile-up secondary burn. The fire causes external haze and a loss of nitrogen, but also modifies the P sorption of the topsoil, and thus increases P availability for subsequent plants. In our scenario, the farmer will plant maize and start oil palm into this maize crop. After harvest of the maize, a groundnut crop is grown, and the next year this cropping pattern is repeated. The oil palm starts to produce the first fruits in year 3 after planting. Fig 10A traces a number of parameters that can tell the story for this particular simulation. Fig 10B shows some details on the palm: the development of its canopy biomass until full canopy closure, the continued dry weight increment of the stem, the strongly fluctuating pattern of the internal growth reserves that respond to daily balance of photosynthesis and use of reserves for growth and respiration, and the accumulation of generative tissue, that takes more than a year to yield the first harvested bunches. In Fig 10C we can see that the palm had rather serious water stress throughout much of the early growth, and this is reflected in mainly male flowers, and only a few out of the potential bunches actually produce fruit.

We must emphasise that this run is largely based on 'default' parameters and apart from the scheduling (initial forest biomass, date for harvesting timber and slashing and planting times for the various crops), the model takes care of the dynamics based on built-in rules. Relative to the Trenbath and Century model, the WaNuLCAS model can give a more detailed account of the performance of a wide range of mixed cropping systems, but the model does not lend itself for easy ‘optimisation’ procedures, as there are a large number of parameters with many non-linear interactions between them.

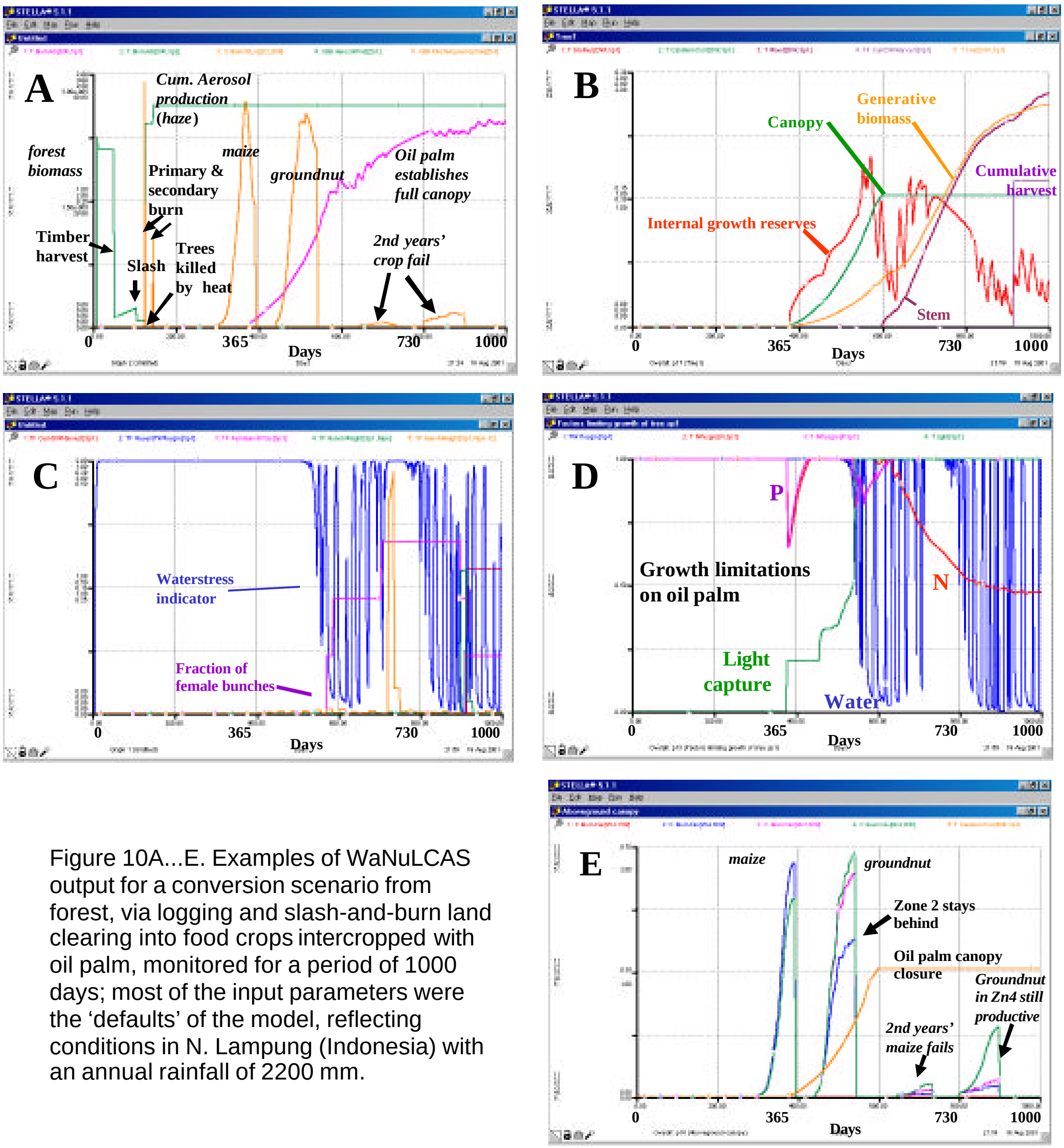


Figure 10A...E. Examples of WaNuLCAS output for a conversion scenario from forest, via logging and slash-and-burn land clearing into food crops intercropped with oil palm, monitored for a period of 1000 days; most of the input parameters were the 'defaults' of the model, reflecting conditions in N. Lampung (Indonesia) with an annual rainfall of 2200 mm.

2.4 Spatially explicit individual tree-based forest simulator (SEXI-FS)

Spatially Explicit Individual-based forest simulator (SEXI-FS)

The SExI forest simulator focuses on tree-tree interactions in a mixed multi-species agroforest. The high level of structural complexity of such traditional agroforestry systems defies classical forestry approaches when it comes to optimising management practices. To cope with this complexity, farmers have adopted a tree-by-tree management approach, which is closer to gardening than to any usual tropical forestry or estate crop management model. Individual tree care and regular tending takes the form of seedlings transplanting, selective cleaning and felling, adjusted harvesting intensity.

Farmers' approach appears to be in line with two basic tenets of biology: first, individuals are all different with behaviour and physiology that result from a unique combination of genetic and environmental influence, and second, interactions are inherently local. Based on the same premises a computer model was developed to explore different management scenarios. The model uses an object-oriented approach where each tree is represented by an instance of a generic class of tree. The simulated object trees, mimicking real trees, interact through modifying their neighbours' environment. These modifications are mediated through two major resources: space and light. A 3D representation of a one-hectare plot of forest serves as the grounds for the simulation of this competition.

The major objective of such a model is to get a coherent dynamic representation of a complex system, where complexity refers here to the assemblage of locally interacting individuals with different properties more specifically to the degree of interconnection between individual trees. The model provides insight on what are the critical processes and parameters of the dynamic of the system. It should also allow exploring prospective management scenarios, help assessing the relevance of present management techniques etc.

Model sensitivity tests confirm the importance of the parameters related to tree geometry. This directly stems from the fact that competition is simulated by means of spatial interactions, so that anything that alters either the shape, the size, or the relative position of the trees have direct impact on the outcome of the competition and therefore on the growth dynamic. These elementary influences are straightforward but their effect at different times and scales are difficult to predict without simulating because of the numerous feedback loops at work and the non-linear dynamics of the system. To illustrate this, let’s examine very simple cases. By simulating growth in a mono-specific stand of regularly spaced trees planted at increasing densities, we observe the following response. Planting at medium density translates into growth in height of the trees in the centre of the plot being *superior* to that of border trees, which is a response to the increasingly limited access to light of the trees in the centre of the plot. When planting density is increased further though, growth in height of the trees in the centre of the plot becomes *less* than their neighbors: the level of competition is so high that these trees get overtopped and suppressed by border trees in more favorable position with respect to access to light. Another simple test shows that ability to respond to low light availability by enhanced growth in height (a response, which occurs at the expense of growth in diameter) appears to be advantageous under specific conditions and disadvantageous under others. If all species in the mixture share the same ability and the same sensitivity to light level then this potential competitive advantage turns out to be disadvantageous both for individual tree growth and for overall plot productivity. But when trees with different sensitivity to light level or different ability to alter their allocation of growth between height and diameter occur in a mixture then this capacity proves to be an effective competitive advantage for individual species. By accelerating the establishment of a multi-strata structure it also increases the overall productivity of the plot through better allocation of spatial resources. Similarly, rather counter intuitively, an increased growth rate for a given crown size appears to be an advantage for a species under certain circumstances but not all: under very crowded conditions large crowns (showing low efficiency in terms of light and space utilisation) can show competitive advantage by suffering less from crown encroachment and shading out competitor more efficiently. These are but a few examples of the insight such generic models can bring.

More direct application of the model include comparing alternative scenarios in terms of financial return for instance involving rotational versus permanent agroforests, etc.

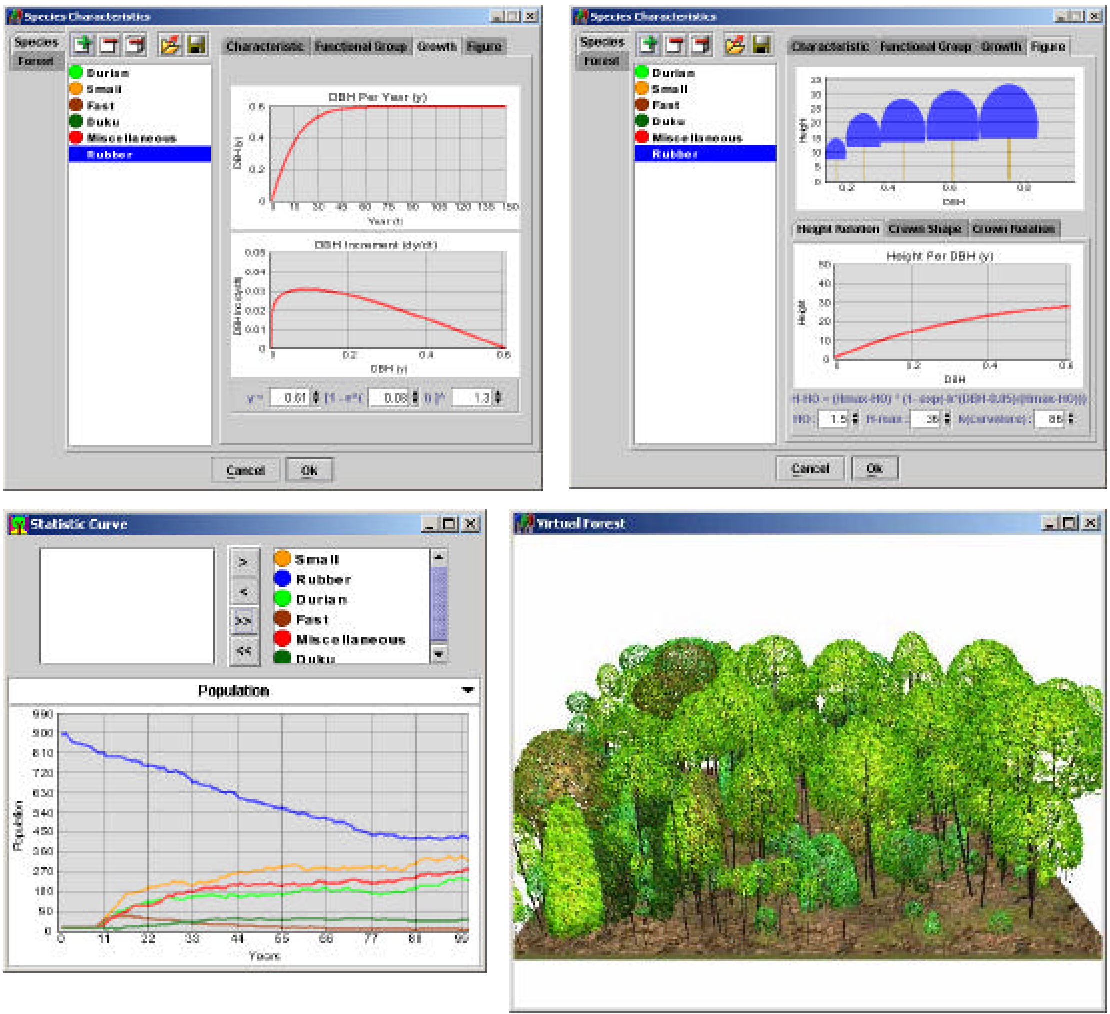


Figure 11. A fully interactive interface allows the user to manipulate simulation parameters and explore the impact of such manipulations both at individual tree level and population level. (http://www.icraf.cgiar.org/sea/AgroModels/SExI/SExI.htm)

3 Farm economic models

3.1 Linear programming: FaleBEM as example

The Trenbath model discussed before ended up with a single production function that describes the potential sustainable food crop production from a unit land; as this is a single function and it is continuous (though non-linear) an 'optimum' solution can be derived by simple algebra. But, in reality farms have usually more than one option for production, while land, labour and capital are limited. Optimisation for such situations has to consider multiple, linked equations. Where the basic equations can be approximated as linear functions and constraints are clearly specified the toolbox of 'linear programming' can provide solutions.

The FaleBEM program (Charpentier et al., 2000) was made to simulate the typical farmer's responses to a wide range of policy, technology and project interventions in the forest margins of Brazil. The model incorporates all biophysical and economical factors that are considered to be important in farmers' decisions about land use and deforestation.

The model assumes that farmers maximise the discounted value of their household consumption over a 15-year time horizon. There are also minimum consumption constraints that must be met each year for food, clothes and farm implements. The model allocates farm income each year to consumption and on-farm investments. When income is invested it increases future production potential, and hence future consumption, but at the expense of current consumption. Production choices are subject to an array of resources and technology constraints, including seasonal labour and cash flow constraints. In addition to on-farm production the household can engage in extractive activities in the forest (e.g. harvesting Brazil nuts) and sell household labour off farm or hire non-family workers for the farm. All output prices are fixed in the model, as the region simulated is too small to influence global price levels (for the Brazil nuts they assumption may be questioned…). The model tracks soil nutrient balances and current soil fertility, with impacts on future productivity levels.

Examples of the use of Falebem for exploring the likely farmer response to policy changes and the consequences for C stocks are presented in lecture note 12.

4 Land Use Change predictors

4.1 Extrapolations from current trends based on transition probabilities

If land use maps (either derived from remote sensing imagery or ground-based methods) are available for more than one point in time, they can be used to derive the probabilities of a change in land use, conditional on current land use. In the simplest case one would only use current land use as ‘explanatory’ variable for change, but other parameters such as soil quality or distance to roads (or rivers if these are used for transport) can be used as well. The resulting matrix (which has a constraint in that all probabilities in a column have to add to 1) can then be repeatedly applied to an initial map. If the probabilities only depend on the current land use (and not on location specific history), the model represents a simple ***Markov*** process. If location specific ‘history’ seems to play a role, one should try to capture this in a current state variable, rather than having to relate to conditions many steps back.

Table 1. Matrix of transition probabilities for land use systems A…F at time t to land use systems A…F at time t+1

Before / After	A	B	C	D	E	F
A	$\mathbf{P_{AA}}$	P_{BA}	P_{CA}	P_{DA}	P_{EA}	P_{FA}
B	p_{AB}	$\mathbf{P_{BB}}$	P_{CB}	P_{DB}	P_{EB}	P_{FB}
C	p_{AC}	P_{BC}	$\mathbf{P_{CC}}$	P_{DC}	P_{EC}	P_{FC}
D	p_{AD}	P_{BD}	P_{CD}	$\mathbf{P_{DD}}$	P_{ED}	P_{FD}
E	p_{AE}	P_{BE}	P_{CE}	P_{DE}	$\mathbf{P_{EE}}$	P_{FE}
F	p_{AF}	P_{BF}	P_{CF}	P_{DF}	P_{EF}	$\mathbf{P_{FF}}$
sum	1	1	1	1	1	1

Chomitz and Gray (1996) applied this method to an analysis of roads, land-use and deforestation in Belize and could account for the major patterns of land use change on the basis of simple distances of pixels to the road, with corrections for land quality.

4.2 Von Thünen: Adding 'distance to markets' to economic analysis

The way profitability of land use systems was assessed in Lecture note 8 started from a survey of prices for inputs and outputs of the various land use systems, in the locations where these land use systems actually occur in the landscape.

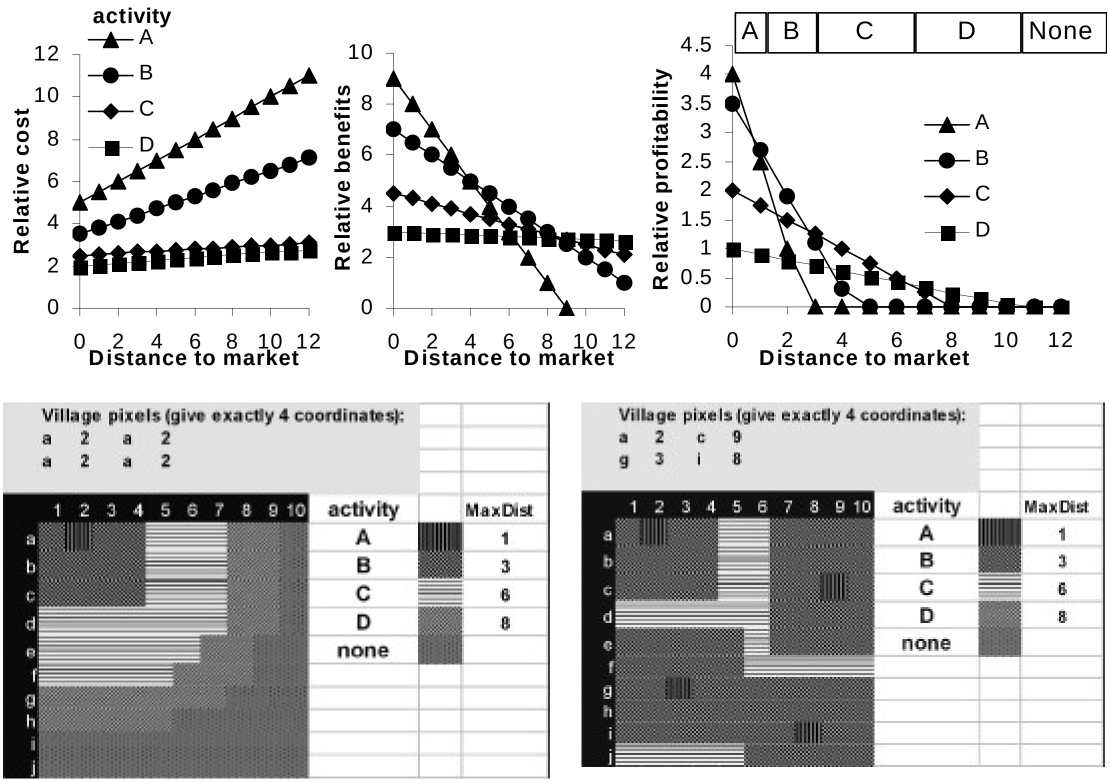


Figure 12. Basic assumptions of economic geography, where both costs and benefits of any land use activity depend on the distance to the market (at village level or beyond), and hence the relative profitability of a range of extensive-to-intensive land use systems depends on distances, as does the 'best bet' land use practice. The basic pattern of concentric land use organization around villages was first analyzed by Van Thünen in the mid 19th century. The file Thunen.xls, distributed with these lecture notes, allows exploration of the effects of village location and different distance functions for the activities

Box 1 Dynamics of Land Use Change in Jambi Province, Sumatra

K Chomitz, D Deborah, D Hadi, F Stolle, TP Tomich and UR Wasrin

Background of the study

Forest conversion in Indonesia, using slash-and-burn as a land clearing technique, can involve a range of actors and objectives. Local smallholders, migrants, loggers, large-scale tree-crop estates (including industrial timber plantations), and government-sponsored resettlement schemes (called transmigration) all play a role in forest conversion. Although smallholders often receive much of the blame for forest conversion, there has been little empirical work on this in Indonesia. Here we examine one aspect of this complex issue: the two-stage deforestation process in which smallholders 'encroach' on logged-over forest. The focus of this study is the peneplains and piedmont (below 3000 masl) of Jambi Province in central Sumatra, a relatively homogenous lowland region (once) covered by rich Dipterocarp forests and well-suited to rubber, oil palm, and timber planting by smallholders or large estates. Three events may have had a big effect on deforestation in Jambi in the 1980s:

Box 1 (Continued)

- The Trans-Sumatra Highway was completed, an all-weather road spanning the island and linked to population centres in Java by ferry
- Large areas were logged by commercial firms
- Government-sponsored transmigration projects expanded

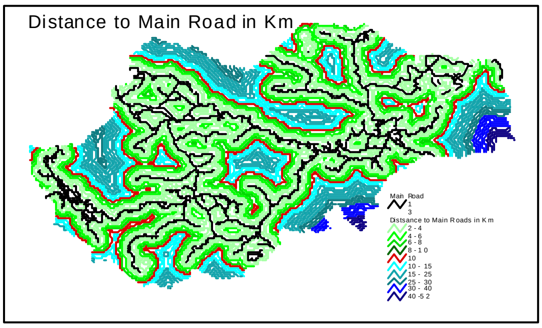
Hypotheses about forces driving deforestation by smallholders
Smallholder conversion of logged forest to other uses is most likely:
- near main roads and rivers, which provide access to markets (especially for exports)
- near social amenities (neighbours, schools, clinics)
- where favourable biophysical factors increase profitability of conversion

Data on land cover change
Three sets of digitised land cover maps for Jambi Province are used, one for the 1930s, one for the early 1980's, and one for 1992. The 1992 map was prepared for this project by BIOTROP. The map for the early 1980s was compiled by BIOTROP from maps created by RePPProT, with additional detail on logged forest from a map by Y. Laumonier. The map of forest cover from the 1930s is from van Steenis. For Jambi as a whole, more than a third of the natural forest standing in the 1930s was converted prior to 1982; a rate of 260 km^2/yr. Conversion accelerated to over 1000 km^2/yr in the 1980s, with almost half the forest standing in 1980 converted by 1992.

Explanatory data
Land cover data are combined with spatially-referenced data on explanatory variables in a Geographic Information System (GIS), which includes:
a) distance to rivers
b) distance to main roads built in the 1930s, before 1980, and between 1980-90
c) distance to main towns and settlements in 1930s, before 1980, and between 1980-90
d) distance to processing facilities (data to be added)
e) distance to transmigration sites before 1980 and between 1980-90
f) distance to large-scale tree crop estates before 1980 and between 1980-90
g) distance to industrial timber estates planned in the 1980s
h) distance inside (or outside) logging concessions before 1980 and between 1980-90
i) whether the site was logged commercially
j) biophysical characteristics, including soil physical and chemical data
k) agronomic suitability and limiting biophysical factors for 68 spp, incl. rubber and timber
Access to markets for exports is affected by a, b, c, d; a, b, c, and e affect access to social amenities. Secondary road construction associated with e, f, g, h, and i links main roads and forests. Biophysical determinants of attractiveness of conversion are captured in j and k.

Models of land use change
Geographically explicit studies of tropical deforestation have employed a simple but powerful model: forests are converted to agriculture when it is profitable to do so. These studies (e.g. Chomitz and Gray 1996) use a von Thünen approach, deriving the potential agricultural rent at each point on the landscape; points with positive rent are predicted to be converted. Attractiveness of exploiting plot i at time t is related to the benefit/cost ratio of conversion. Potential benefits can be expressed as the product of soil productivity and farmgate price. Farmgate price can be expressed as P_t*exp(d_1Dit), where D_{it} is distance to the road, d_1<0, and P_t is the on-road price of rubber, closely related to the world price. (Distance to the processing plant or port is an alternative measure, but since off-road transport costs dominate, distance to the road is an easy-to-calculate proxy). The principal costs of production are the labour costs of initial clearing and subsequent harvesting. Because farmers value access to medical, educational, and social facilities, the supply price of labour increases with distance to the road. Labour supply price is lower, however, when there is a nearby transmigration site. Both labour productivity and farmgate prices may increase if the plot i is in a working forest concession. (This is only true if the concessionaires do not prevent encroachment by farmers.) Construction of logging roads reduces transport costs; logging activities remove trees and facilitate slashing and burning.

Box 1 (Continued)



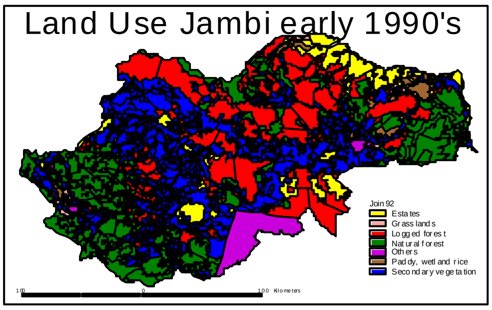


Figure 13. Equidistant areas to roads and land use in Jambi

Results from a preliminary econometric model

A sample of 9477 data points was drawn from forest logged in the 1980s using a one km grid and a multivariate econometric model (a probit) was used to control for biophysical differences and to estimate effects of distances to main roads and rivers on probability of conversion to rubber agroforests and other uses. This simple prototype model correctly predicted 85% of conversion from logged forest to smallholder uses and 78% of the logged forest that was not converted. Site characteristics (soil and topography) were highly significant, indicating smallholders are selective in their choice of sites. This model indicated that conversion of logged forest is much more likely within 10 km of main (asphalted) roads.

Developing a better econometric model

The prototype model would work well in a long-term comparative static framework—say comparing land cover in Jambi in the 1970s with the 1930s. It fails, however, to capture short term dynamic adjustments. When new roads and large projects enter remote areas – as in Jambi in the 1980s -- the economic frontier expands instantly, but deforestation proceeds at a slower pace. The rate of deforestation is constrained by available labour and capital, by the limited season during which slash-and-burn is possible, and by the rate of diffusion of information about the quality of new areas. For situations such as this, a 'hazard model" may be employed in which the hazard (instantaneous probability of deforestation, conditional on no prior deforestation) is related to the attractiveness of the point for conversion. Hazard models employ an exponential specification long used in epidemiology and other fields for survival analysis.

Reference

Chomitz KM and Gray DA. 1996. Roads, land use, and deforestation: a spatial model applied to Belize. *World Bank Economic Review* 10 (3): 487-512.

4.4 ANDALAS: a model that ANalyses Driving factors Affecting LAnd-use/cover changes in Sumatra (as described in: http://www.icsea.org/models/andalas.htm)

ANDALAS is the old name of Sumatra when the island was part of the Buddhist Kingdom of Sriwijaya, the leading maritime power of Southeast Asia from the 6th to 12th centuries.

ANDALAS is also a user-friendly modelling tool constructed under the STELLA modelling environment by D. Murdiyarso *et al.* (see web site for further details). It is developed to study the process of land-use/cover change by considering the major driving forces. The model's outputs may be used to support the decision-making processes regarding land resource allocation within the context of sustainable development.

At the present stage, ANDALAS focuses on socio-economic factors driving land-use/cover change in a rather specific site, where the roles of the stakeholders are quantitatively identified. The process of change was directly affected by large-scale operators and smallholders decisions. They have contrasting scales and modes of operations, therefore it is worth studying. Although the current status is site-specific, users can easily modify the parameters according to the best knowledge and information they have. It is expected that the future development of ANDALAS will cover biophysical factors (dash lines, circle, and box in the diagram) and institutional processes as well.

The goal of achieving sustainable development in the context of global change is posing a severe challenge to our understanding of how terrestrial ecosystems respond to rapid environmental change. The challenge is particularly acute for developing countries, which are coming under increasing pressure to modify their development strategies to reduce the adverse impacts of climate change, due to the increase of greenhouse gas emissions. ANDALAS is designed to accommodate this global agenda by converting land-use change process and magnitude in terms of aboveground carbon-stocks. Decision may be made based on the potential roles of the system in emitting or sequestering carbon.

ANDALAS was tested at Bungo Tebo Site, a-145,693.57-ha area of the Alternative-to-Slash-and-Burn (ASB) Project benchmark site in Jambi, Sumatra. The site represents the peneplain zone, populated by three different groups of communities: local people, transmigrants, and spontaneous migrants. The presence of large-scale operators (logging industries, oil palm and rubber plantations companies) and their roles in changing land-use are considered very significant. Four vegetation maps at different points in time of Rantaupandan and Bungotebo (scale 1:250,000) were used to identify the pattern and the magnitude of the changes among several vegetation/land cover types found in these sites. The maps were derived from Landsat-TM images acquired in 1988, 1992, 1994 and 1996, which were visually interpreted. As cell-based analysis is considered best suited to study the dynamics of changes through time, therefore, the data available were converted to raster format to obtain a raster representation. The spatial data processing and analysis were done in Idrisi and Arcview/Spatial Analyst. To obtain the dynamics of land cover change, time series analysis is done in three pairwise analyses, namely: 1988-1992, 1992-1994 and 1994-1996. Overlaying the gridded data involves cross-classification operation, to show the spatial visualization of the changes and cross tabulation to see the magnitude of the changes. The outcome of these processes is calculated a percentage of changes, area of changes and annual probability of changes. Annual probability is derived from each period of analysis (four-year and two-year), and is assumed uniform within each period. The process-based model of land cover change dynamics was then developed by considering only the annual probability of change of every land cover type during the 1988 - 1996 period at both sites.

Based on the assumption that people who have a direct role in land-use/cover change processes are mainly from productive labour force age groups, the human population model in this study was developed to simulate age composition dynamics of a human population that is stratified further based on sex and status (local people, spontaneous migrants, and transmigrants).

The land-use/cover change simulation was run from 1988 to 1996, and was compared to the observed data resulted from RS/GIS works.

No.	Land-use/cover Type	Observed Data in 1996 (ha)	Simulated Data in 1996 (ha)	Difference to Observed Data (%)
1	Lowland Primary Forest	0	0	0
2	Logged-over Forest	28,231.50	33,320.08	+18.03
3	Secondary Vegetation	32,561.00	29,958.12	-7.99
4	Smallholder Jungle Rubber	44,225.25	50,020.63	+13.10
5	Mosaic of Settlement, Paddy Field and Homegarden	18,316.25	6,887.42	-62.40
6	Cropland	5,983.75	9,311.46	+55.61
7	Rubber Plantation	9,025.50	8,677.17	-3.86
8	Oil Palm Plantation	7,829.25	7,518.49	-3.97

Comparison between observed and simulated data of every land-use/cover type area (in ha) at Bungo Tebo Site, Jambi, Sumatra, in the last year of simulation period of 1988-1996. Positive values (+) in the last column represent overestimate simulation results and negative values (-) represent underestimate results.

Box 2

Timothy Brown, Mubariq Ahmad and William Hyde of the NRM/EPIQ program in Indonesia recently developed an elegant modification of the von Thünen model (see lecture note 11) by including the cost of securing tenure into the equations. Their assumption is that for sustainable forestry a form of security of tenure is required to support the necessary investments and provide a long-term time frame for management decisions. Where forest harvesting is economically attractive without such security of tenure, a form of 'pulse' forestry can be expected, just harvesting the best part of the forest resources. Where the costs of forest extraction no longer pay off, a form of 'wilderness' can be expected.

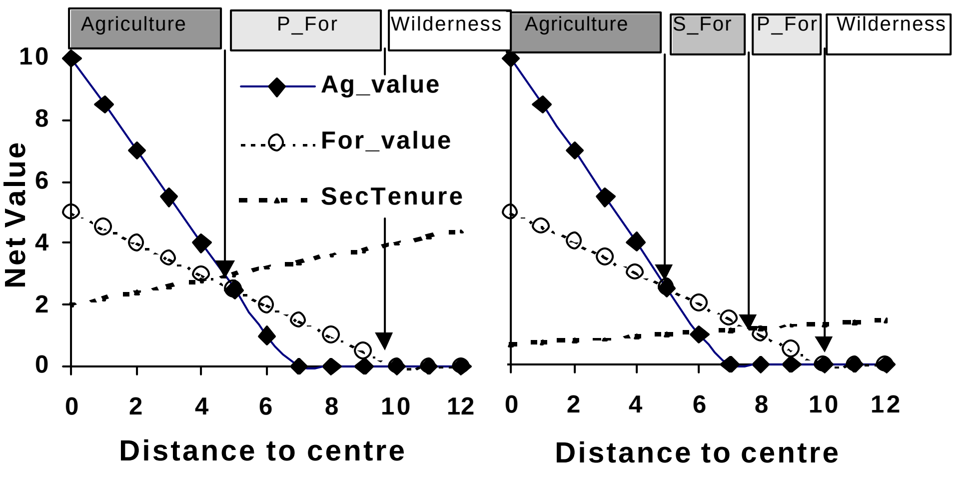


Figure 14. Modification of the von Thünen model (compare Fig. 12) by explicitly incorporating costs of securing tenure as a function of distance to the centre. For the configuration on the left side, all forestry is expected to be of a 'pulse' type (P_For); by slashing the costs of securing tenure by 2/3, the situation on the right is obtained that allows for a substantial 'sustainable forestry' (S_For) domain

Many policy changes that are suggested to help protect tropical forests are shifting the direct net value of forestry (e.g. taxation, log export ban). In this simple scheme, such changes decrease the likelihood of sustainably managed forests. Reducing the (transaction) costs involved in securing tenure does not lead to shifts between 'wilderness' and forestry, or that between forestry and agriculture, but it will lead to a shift from 'pulse' forestry to 'sustainable' forestry under the assumptions made.

As shown in the table, the current version of ANDALAS could give simulation results with difference values ranging from -62.40% to +55.61% to the observed data in the last year of simulation period of 1988-1996. Further improvements will be needed to have any confidence in using this model for extrapolation purposes. Simply extrapolating recent trends may not be sufficient basis to predict the near future….

5 Macro-economic models

5.1 Computable General Equilibrium (CGE) models

Where models of a farm or household can still be formulated as multiple constraints to a single overall 'objective function' (see 'linear programming' in section 3.1), the economy at levels above a single household has to recognise a more complex set of feedbacks between decisions of various actors. At the level of a national (or regional) economy, such relations can be described in the form of a 'computable general equilibrium' model. These models assume that any change in prices, taxes or other economic factor can lead to adjustments by all parts of the system. The basic assumption of CGE models is that the system will always move back towards an 'equilibrium' situation, and by imposing such equilibrium the set of equations can be solved (not requiring 'linearity' as in 3.1), hence the term 'computable'. A basic description of the economy as seen by a CGE model is given in Fig. 15.

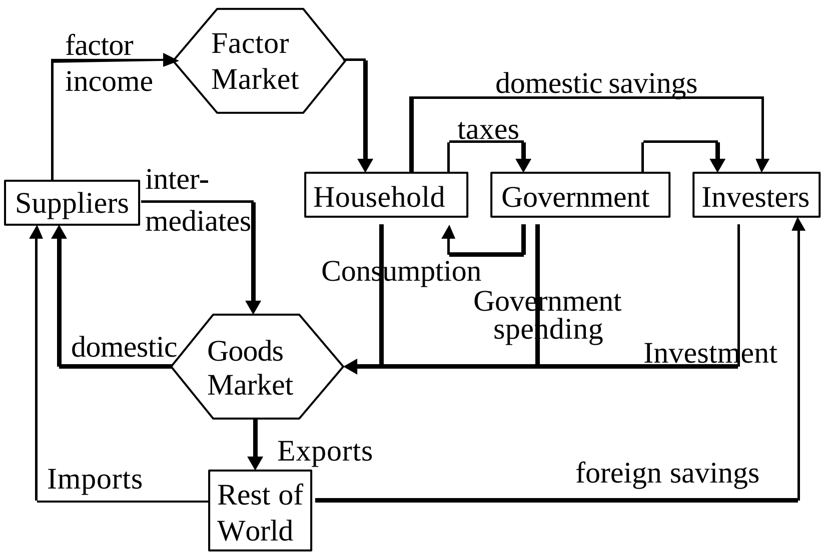


Figure 15. Components and main relations between them in a national or regional 'computable general equilibrium' model.

Box 3 Technology, migration and the last frontier: a general equilibrium analysis of environmental feedback effects on land use patterns in the Brazilian Amazon

Andrea Cattaneo -- IFPRI

In the past, much deforestation in the Brazilian Amazon was the result of policy distortions that promoted migration and the establishment of large farm enterprises. While those policy distortions no longer exist, they are being replaced by other policies and/or economic trends that may have greater impacts on deforestation, land use and welfare in the Amazon. Among the macroeconomic and regional events whose impact on deforestation, growth and poverty alleviation need to be analysed are:

- A major devaluation of the Brazilian real
- Improvements in the regional integration in the Amazon
- Modification of tenure regimes and the mode of acquisition of property rights
- Technological change in agriculture inside and outside the Amazon region.

Studying or predicting the likely impact of such phenomena require an economy-wide view. The international food policy research institute (IFPRI) developed a Computable General Equilibrium model in which the Amazon, Northeast and Center-west regions and the rest-of-Brazil as aggregate are identified as separate production entities, producing for a national market. Economic agents enter the model via production decisions, trade, migration and investment.

Following preliminary results were obtained for following scenario's:
1. The effect of devaluation of the exchange rate
Generally speaking a major devaluation dramatically increases the value of internationally traded goods relative to non-traded goods and the returns to land, labour and capital involved in their production. On the other hand, demand declines sharply for products that depend heavily on imported inputs and are consumed domestically. Results suggest that as nationally the gross domestic product (GDP) decreases, poverty increases in the urban side of the economy, while low income rural households will gain; income distribution improves in rural areas and worsens in urban areas. Future growth may be undermined. Deforestation rates depend on government crisis plans: if the government balances the reduction in private consumption government demand and investment, deforestation rates can decline in the short run and show a small increase in the long run. If the government does not actively intervene and capital flight out of the country is not halted, deforestation rates in the short term will increase, and increase substantially in the longer run. The Amazone is likely to fill the domestic demand gap created as other regions move towards tradables for export.

2. A reduction in transportation costs will essentially increase the rate of deforestation (compare box 2). The return to arable land would increase and this increases the incentive to deforest. However, welfare effects at the national level would be very limited, as positive regional impacts in the Amazon is offset by negative impacts on other agricultural areas of Brazil.

3. Effects of changing tenure regimes. At the Amazon policy level of analysis, regulating tenure regimes is the best option to reduce deforestation assuming that current deforestation is largely occurring at the hands of untenured deforesters who acquire tenure in the process. Unfortunately new tenure regimes are very difficult to implement and enforce in a region the size of the Amazon.

4. The effect of agricultural technological change depend on the sector involved. *Livestock technology* improvement appears to have the greatest returns for all agricultural producers in the Amazon and should improve food security in the region; however, deforestation will increase dramatically as in the long run, as the incentives to convert forest increase
Perennial crop technology improvement could reduce deforestation rates considerably, especially if labour productivity is increased. Small farmers are likely to benefit most, but food security will have to change form local production to market-based supply from elsewhere.
Annual crop technology a improvement appears to have little potential, and its impacts on income as well as deforestation will probably be small.

Overall, the CGE model suggests that processes occurring outside the Amazon region can have a strong impact on deforestation in the Amazon.

5.2 Relations between capital types

Although the CGE models can represent important aspects of the national economy, they do not (yet) incorporate a full accounting of the five types of capital (natural, human, financial, social and physical (infrastructure). Questions at this level are, for example:

How do the five types of capital interact between the local and global economy? Can financial capital obtained from natural resources be converted to human and social capital for a sustainable society?

There have been various attempts to improve the way ‘natural capital’ is represented in overall economic models. Apart from future productive values entailed in natural capital, there are methods to express the non-market values involved in people’s appreciation of the persistence natural capital, e.g. on the basis of a ‘willingness to pay’ survey. Similarly, aspects of human and social capital can be reflected in direct or future productivity, as well as in values that can be ‘measured’ in financial terms. Yet, all such efforts to bring the five types of capitals back to a single currency make clear that much of the value is, like beauty, ‘*in the eye of the beholder*’ and different groups in society and internationally can have strongly different appreciation of the values involved. There is no ‘objective’ way of measuring all five capital types, but the results of partial quantifications can be important tools in the negotiations between stakeholders.

6 Integral landscape-level policy instruments

6.1 Dynamic consequences of household-decisions on land use in the forest margin

All the types of models discussed so far can offer important perspectives on land use issues in the margins of tropical forests -- yet, none of them can claim to tell the whole story. There have been a number of attempts recently to develop models that try to combine elements of all the above in Dynamic consequences of household-decisions on land use in the forest margin.

One of them is the **Forest Land Oriented Resource Envisioning System or** FLORES, which is intended to be a model to help explore the consequences at the landscape scale of policies and other initiatives intended to influence land use in tropical developing.

We can have a look at the ‘specifications’ for such a model:

Such a model should be spatially explicit in its description of land use change, so it may have to have a grid-based part, completely covering a well-defined area. The model should be driven by decisions of individuals/households to move and/or change the land cover of a part of the landscape in a given time step, based on model-user defined criteria, weighing the consequences of the landscape as it exists at that moment, influenced by general conditions (policies, incentives, taxes, regulations) which may change over time and have different impact on different parts of the population (political economy). For this part the model should contain explicit rules on how individuals make decisions and keep track of a number of parameters influencing this decision for a population, based on stratification (but with 'social mobility') or complete accounting for all individuals.

The model should have 'external' relations, reflecting the possibilities of people moving into or out of the area considered based on some weighing of livelihood options external to the area (which may fluctuate over time), as well as options for feedback of the conditions in the area studied on the 'general rules' which apply at any point during the simulation.

The model should also allow evaluation of performance of a number of indicators of environmental service functions from an outsider's perspective, aggregating over the current situation in the study area as a whole. A starting point for the model maybe a matrix of land use characteristics as developed by the Alternatives to Slash and Burn (ASB) program:

	A. Global concerns		B. Regional concerns		C. Long term local concerns		D. Short term local concerns		E. Institutional requirements	
Land use	Biodiversity conservation	Net GHG emissions	Water flow: qual. and quant.	Smoke production	Sustainable use of soil resources	Build up of pest, weed and disease	Profitability: NPV at given disc. rate	Employment (#/ha),& returns to labour	Required access to markets and info	Required overall institu-tions
Natural forest										
Log-ging										
Agro-forest										
.....										

Both the rows and columns of this matrix will have to be carefully considered for the (Flores) model in general and for each specific simulation application. The list of land uses should cover all possible outcomes for parts of the area modelled. The ASB project made a 'generic' list of land use types which can serve as starting point for Flores and which can be specified for each situation. The amount of detail chosen here is directly reflected in how crude the overall model predictions are bound to be. A first step will be to disaggregate 'land use' systems into a sequence on 'land covers' during the typical life time of a system. As remote sensing data would apply to land cover rather than land use, this translation is important and non-trivial.

The columns differ in nature and in role they play in the model execution. Global and regional externalities (A and B) will be important ways of expressing the overall outcome of a simulation, but will have no direct feedback on events during a simulation, unless they are linked to E. For some criteria an area based attribute may be provided which can be added for the simulated area as a whole, for others a frequency dependent valuation will apply (biodiversity) and/or location dependent valuation (watershed functions). For several attributes the area will not be a priori homogeneous and a number of matrices will have to be developed for different 'ecological zones' within the study area as a whole. Columns C is concerned with longer-term local impacts and it may be necessary to keep track of the history of every patch in the simulation, or at least of some summary statistic reflecting this history in its impact on current land use and (remaining) options for conversion. The weeds, pests and diseases columns is strongly density and context dependent. The columns D reflecting private concerns will have to be stratified by population group (e.g. because different effective discount rates apply) and scale considerations come in strongly for certain land use types where economies of scale exist (usually linked to processing of products). Columns E can include absolute constraints to certain land use types for certain groups of people, or lead to reduced profitability (or other attractiveness parameter) for specific groups (thus allowing a political economy as well as set of 'cultural preferences' to be reflected).

If such a matrix (or a set of them reflecting ecological zones and population strata in the simulation) is indeed to be used as basis for the dynamic part of the model, a number of separate tasks is suggested in model development:

- developing submodels/ routines, which can generate the values for the various cells in the matrix/ices; for several of the columns this is a heroic task in itself, for others existing simulation models or spreadsheet procedures can be used on the basis of well-defined input parameters; as short cut we may have to rely on 'expert judgement' to fill in values,

- developing explicit rules for how individual decisions on movement (within the model domain or out of/into the study area) and land use change are made on the basis of the options currently available,

- developing methods for keeping track of the current state of affairs in all cells of the simulation linked to all 'stakeholders',

- developing rules for how the institutional/ macro economic parameters change over time, with or without impacts from 'emergencies' developing in the simulation run itself (e.g. smoke crisis leading to ban on/increased cost for land clearing by slash and burn)

Generic policy levers to which the model should be sensitive include:

* urban wage rate
* (multipliers on) price vector for all marketable products (e.g. taxes, subsidies)
* (multipliers on) price vector for all external production inputs (e.g. taxes, subsidies)
* modifying the strength of local institutions
* extension of new technologies to the area (increasing array of options from which farmers choose, reducing uncertainty about these options)

Area-specific changes within or in the neighbourhood of the simulated domain to which the model should respond include:

* modifying the resource access rules (e.g. allocating part of the area to 'forest reserve')
* constructing or improving road ***within*** simulated area (parallel to or perpendicular to previous access)
* modifying opportunities for daily labour (e.g. new oil palm plantation nearby)
* (multipliers on) price vector for all marketable products (e.g. road access to market)
* (multipliers on) price vector for all external production inputs (e.g. road access to market)

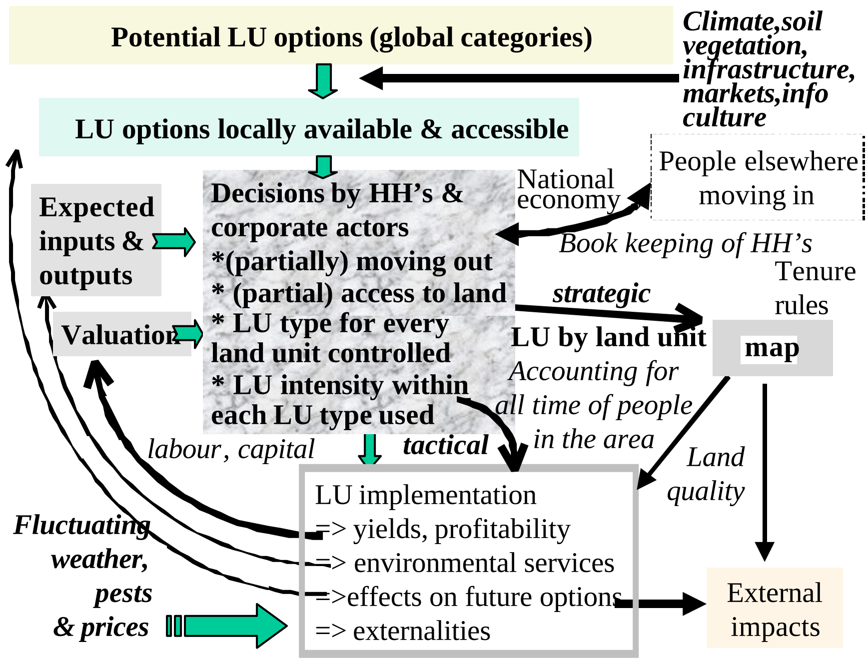


Figure 16. Schematic design of an integral model that links household level choices from the array of options actually available to the private and landscape level consequences (HH = households; LU = land use).

Exercise

A Define a 'focal' area for the discussions and identify in small groups:

- Actors/stakeholders in land use/cover change of the focal area,
- Landscape functions that matter to local or external stakeholders,
- Institutions that (potentially) influence what actors do in the landscape.

Group the outcomes into locally relevant categories.

On the basis of these results, discuss a minimum definition of model components and the types of relations between them.

B. Respond to questions 1...3 in sub groups, 4 in plenary

1. Describe three possible/plausible outcomes, by reference to the focal area:
   - a 'degradation' case as can be observed somewhere in the neighbourhood,
   - an outcome with strong economic development, and
   - an outcome based on persistence of sustainable versions of current resource use.
2. Suppose either one of these possible outcomes would have happened in 20 years, what (scenario of) driving forces does the group think to have caused this outcome, through a combination of choices made by actors and institution-actor interactions, with or without major 'external' interventions.
3. For the same set of outcomes, try to answer the 'so what' question for the three outcomes and a list of landscape functions (to be developed separately).
4. Discuss the results in plenary, and derive a consolidated list of 'driving forces', invoked by the various groups to generate the various types of 'outcome'. The consolidated list (with some sense of dominant and secondary drivers) will define the minimum complexity of the dynamic model.

6.2 FALLOW

Although it certainly does not meet all the specifications described above, a first attempt to implement these ideas is provided in the accompanying lecture note 11B in the form of the FALLOW model. This model links a spatial representation of a landscape mosaic to a set of dynamic processes, reflecting the decisions of households who can choose between collecting forest products, slash-and-burn based production of food crops, or make a transition into ‘agroforests’ or tree-crop based systems. The outcome of these decisions is reflected in indicators of global (C stock, biodiversity), regional (watershed functions) and local (food security) performance, and the model can thus be used to explore the trade-offs and search for ‘win-win’ situations.

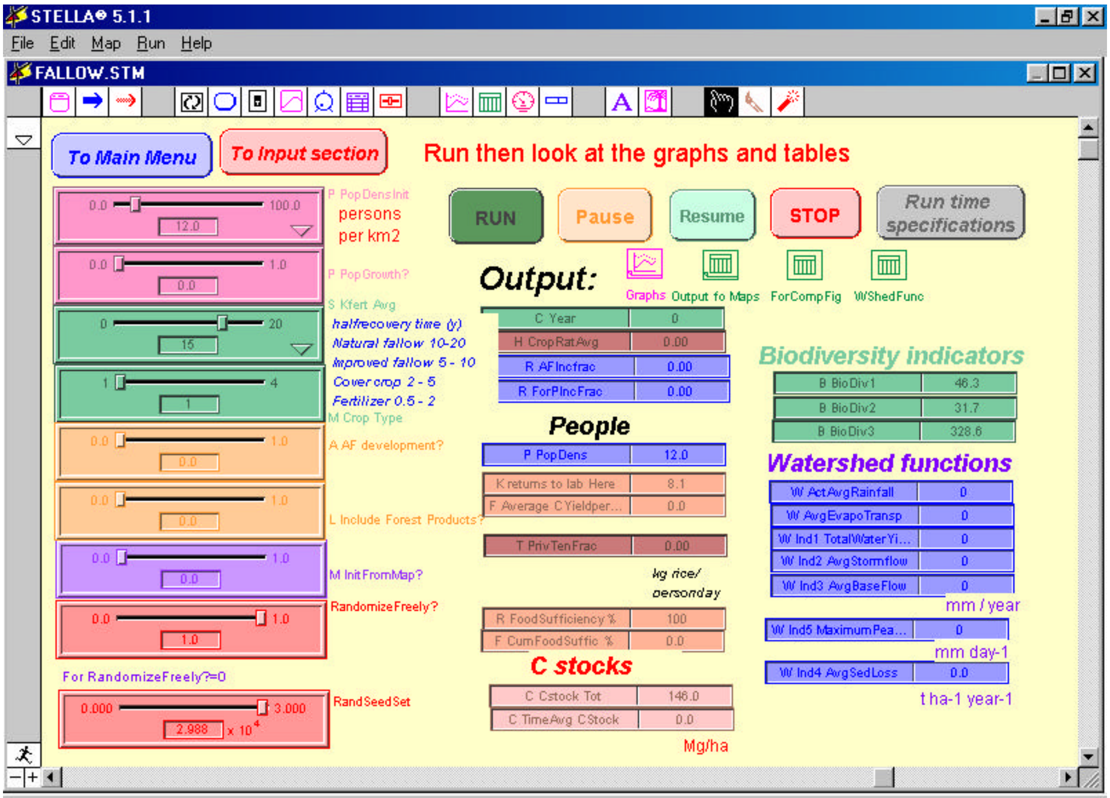


Figure 17. The fallow model will predict a large range of performance indicators, as discussed in the previous lecture notes, and explore the consequences of household decisions on clearing forest lands for (temporary) agriculture, modified by variable weather and prices, and by changes in the natural capital as a consequence of past activities. See lecture note 11B for a ‘hands on’ experience with this model.

6.3 Negotiation support systems

In real terms, humanity’s impact on the world’s natural resources is a consequence of a large number of individual decisions. The individuals who make such decisions have access to different sources of knowledge, and information of varying quality. Moreover, they use different technical resources to organise the exploitation of such natural resources, and work with different objectives, constraints, priorities and strategies in mind. The best we can hope for, therefore, is that a process of negotiation will evolve among stakeholders and lead to the modification of individual decisions. Such a compromise would, from the broader social perspective, improve human-impact on natural resources (Figure 18).

The term ‘decision support model’ suggests that a single entity will take decisions, (seeking a solution that optimises the way multiple objectives can be achieved), that will then imposed on the various actors and stakeholders. We prefer the term ‘negotiation support models’ for constructs that help in obtaining a common perspective on the 'if this, than that' relations for a range of possible future landscapes. To function adequately, the 'negotiation support model' itself will have to be subject of negotiation and shared development efforts between stakeholders (Fig. 18). In this view, the main role of research and development organisations is to help in developing the **tool** of a predictive system, as well as in the **process** of stakeholder consultations and negotiation. However, as a facet of this process, organisations have to acknowledge that there exists an intrinsic problem; access to resources, as well as to information, wealth, political power and social status, is unequal.

The social process used to achieve this objective requires a series of confidence-building experiences, and a political climate of openness (- that only recently developed in Indonesia). The processes of project-modeling and social interaction need to be iterative and parallel (rather than serial), thus contributing towards a process of adaptive-learning. Such an approach will make a positive contribution to the processes of problem definition, evaluation of options, negotiation, and implementation and monitoring of agreed solutions, all of which comprise various stages of project management.

For the 'tool' part, integrated system models can be used to support the development of various landuse scenarios depending on some management options by stakeholders in two ways. First, they serve as a **common framework of analysis** and clarify what type of information is required from the various stakeholders and participants in the research program. Second, a point that is perhaps more important in the implementation of a project, they function as a **discussion tool**. Thus different "what if" scenarios, outlined by the various stakeholders, can be clarified in the first instance in a qualitative way. Possible future changes can be examined and discussed. Such discussion may, moreover, reconcile the conflicting interests of those involved in the project, and thus ensure improved co-operation and group cohesion in the future. Disciplinary research can offer the "building blocks" necessary to make quantitative simulations (see fig. 19). Scenarios need to be developed for less common or uncontrollable external parameters, such as migration, world market prices or precipitation. The main objective of such model building is to put stakeholders on a more equal footing and thus to help them in negotiating an agreement over future resource use and access rights.

A toolbox of support models is expected to clarify some the problems associated with research, while an integrated model is intended to stimulate discussion by simulating potential scenario's.

Research to map the "mental models" of all participants in negotiations (see Fig. 18) can be used to clarify the service each stakeholder can reasonably expect from the watershed. The mental model of a model-builder (see the example given in Fig. 19) needs to be completed using, and verified against, the mental models utilised by the various other stakeholders (van Noorwijk *et al*. 2000).

Taking the various issues and the objectives of the different stakeholders as his starting point, a modeller reasons back, identifying potential management options, land use, watershed and nature functions (which often compete) and various (external) scenarios. At this point, it is important to identify how these various issues and management options are related. One of the best ways to get an insight into this is to develop a causal relationship or system diagram (see box).

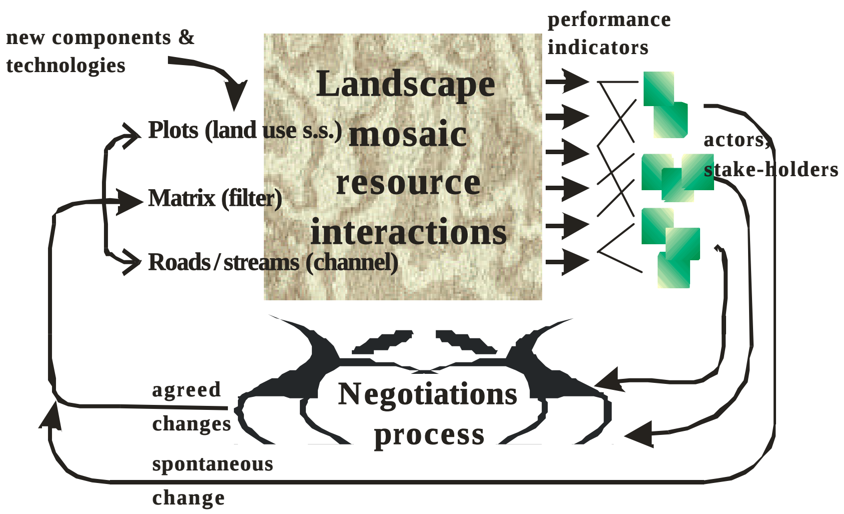


Figure 18. Conceptual framework of a negotiation support system for better natural resource management or NSS for NRM. It relates the predicted impacts of landscape level changes in land use, channels and/or filters to the range of performance indicators that is considered to be relevant by the actors and other stakeholders of this landscape. On the other hand there is the facilitation of a process of negotiation that may lead to changes in the way actors manage various parts of the landscape

Box 4. Case study: Sumberjaya, Lampung, Sumatra, Indonesia

An area where this negotiation support system approach is being tried out is Sumberjaya, an area of about 50.000 ha, which has experienced a lot of conflict. The Sumberjaya watershed, is located at the forest border adjoining the Bukit Barisan National Park in Lampung (Sumatra) Indonesia. In this area, the Forest department wishes to conserve protected forest next to the National Park, and has, in the past, evicted farmers. However, farmers need to earn a living and so return to the areas from which they have been evicted, often with the silent approval of a local government that needs the income they provide and wants to see economic development.
Until now the result of the difficulties discussed above was often sub-optimal - (A euphemism for violent eviction!).
This example illustrates that there exists no simple solution to these problems.
The underlying causes of conflict within this area are non-specific, and are related to a general lack of insight into the extent to which a landscape - and its various elements - functions as the provider of certain services to various users and stakeholders. The key hypothesis underlying present research projects is that some farmer-developed agroforestry mosaics are as effective in watershed protection as the original forest cover, and hence that conflicts between state forest managers and local population can be resolved to mutual benefit of both. Thus, the need for a "toolkit", which can be used both to clarify the issues associated with this subject and adapted and applied more widely.
However, for our "toolkit" to reach such a stage of development particular questions needed to be asked, certain of which had not previously been posed because a lot of preconceptions and myths are linked to this subject. Hence diagnostic research and iterative **stakeholder analysis** was (and is) carried out in the Sumberjaya watershed.

The following general issues were the result of the first diagnostic research results:

- **Erosion** in the uplands is seen the major culprit for an increased sediment load in the river; this could reduce the efficiency of a recently built hydroelectric-dam.
- **Past land use change** (from forest to coffee) is seen as the main cause of erosion in this case
- **Economic macro-conditions** (unemployment in other areas and favourable coffee prices) encouraged farmers to convert upland forest to coffee plantations
- **Unclear delineation of forest boundaries,** both on maps and in the field, created a lot of confusion and created disputes as to which areas should be considered private land and which State Forest land
- **Institutional problems** were raised by the fact that there is insufficient and often contradictory inter-sector and hierarchical co-ordination in the administration of land resources.

Box 4. (Continued)

In an integrated systems modelling approach the watershed of Sumberjaya can be considered to be a large-scale system, consisting of a network of interacting social, economic and biophysical processes. System analysis is an appropriate methodology to use when dealing with the complex nature of watershed systems. Moreover, such a methodology simultaneously fulfils the role of a design procedure for use in decision support systems. Such decisions support systems have intrinsic value because, at some point in time, decisions (including the option to do nothing) will have to be taken by some of the stakeholders.

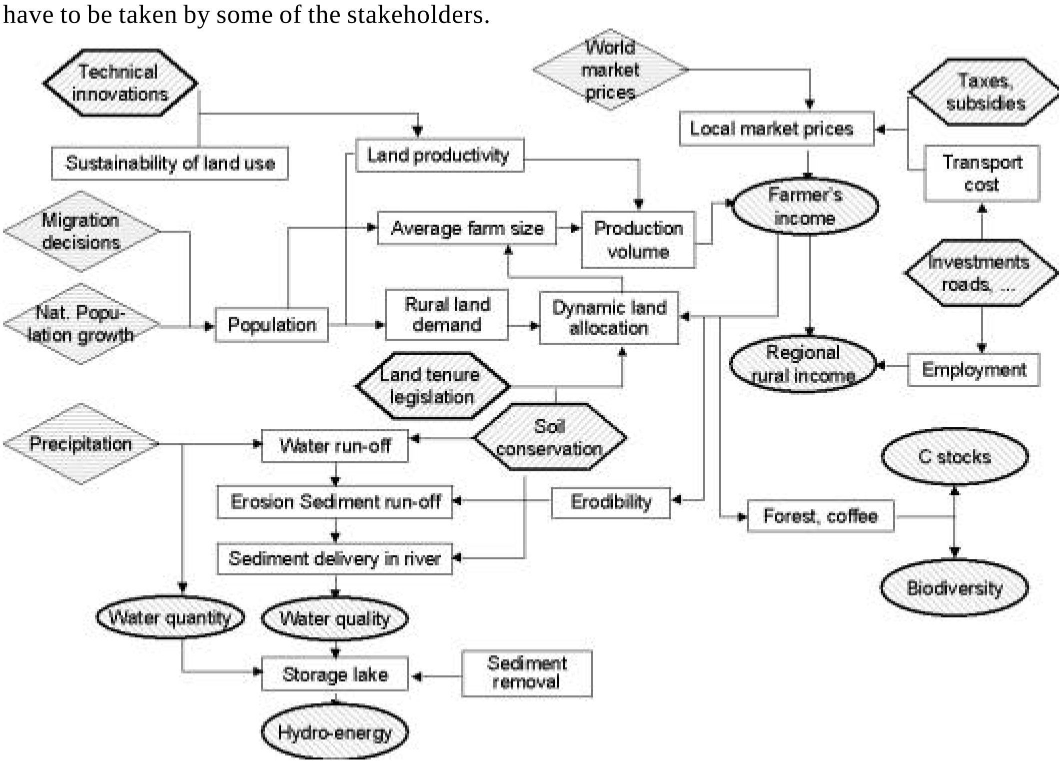


Fig. 19. System diagram with various 'building blocks'. (Shaded diamond shaped boxes indicate external variables, shaded hexagons are possible management options for some of the stakeholders, shaded ovals represent the impacts important to stakeholders.)

To identify how these issues and possible management options are related a causal relationship diagram was developed. This qualitative diagram is illustrative, and needs to be verified by a consideration of more stakeholders. Further analysis should include quantitative modelling and a strength-weakness analysis of the various processes.

The Sumber Jaya case study is still in the early stages, and will form a base study for INRM research and development efforts. Ultimately, this research subscribes to the naïve, positivist view that the quality of decisions made and of negotiations undertaken can be improved by providing the various stakeholders with better (though not necessarily more) information, allowing the generation and evaluation of more alternatives. However it may not, in reality, be possible to implement such an optimistic proposal, and we should bear in mind that too often a course of action is selected as a solution to a problem when, in fact, it bears no relation to the officially stated objectives of the project or to the problem it is intended to solve. For the information we contribute to be of actual value in the negotiation process, the various stakeholders require equal access to information. Moreover, it is essential that a process is implemented to lend clarity to debates concerning these essential issues.

7. A way forward?

Modelling is as much an effort to analyse issues and get insight at their core, as it is an effort to 'fiddle lots of ridiculous equations simultaneously' (a reinterpretation of the FLORES acronym, thanks to Mandy Haggith).

Holling (2000) formulated: "Sustainable development and management of global and regional resources is not an ecological problem, nor an economic one, nor a social one. It is a combination of all three. And yet actions to integrate all three typically have short-changed one or more. Sustainable designs driven by conservation interests often ignore the needs for an *adaptive* form of economic development that emphasizes human economic enterprise and institutional flexibility. Those driven by economic and industrial interests often act as if the *uncertainty of nature* can be replaced with human engineering and management controls, or ignored all together. Those driven by social interests can act as if community development and empowerment of individuals encounter no limits to the imagination and initiative of local groups. Each view captures its prescriptions in code words: regulation and control; get the prices right; empowerment; stakeholder ownership. These are not wrong, just too partial. Investments fail because they are partial. As a consequence, the policies of governments, private foundations, international agencies, and NGOs flop from emphasizing one kind of myopic solution to another. Over the last three decades, such policies have switched from large investment schemes, to narrow conservation ones to (at present) equally narrow community development ones.

Each group builds its efforts on theory, although many would deny anything but the most pragmatic and non-theoretical foundations. The conservationists depend on theories of ecology and evolution, the developers on variants of free-market models, the community activists on theories of community and social organisation. All these theories are correct, in the sense of being partially tested and credible representations of one part of reality. The problem is that they are partial. They are too simple. We lack an integrated theory that can serve as a foundation for sustainable futures, a theory that recognises the synergies and constraints among nature, economic activities, and people, a theory that informs and emerges from thoughtful practice."

III. Reading materials

Scientific journal articles

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Van Noordwijk M, Tomich T and Verbist B. 2000. "Negotiation support model for integrated natural resource management in forest margins and in landscapes with trees: can they solve local as well as global problems?" Conservation Ecology: 18 pp.

Manuals

Van Noordwijk M and Lusiana B. 2000. WaNuLCAS 2.0 Background on a Model of Water, Nutrient and Light Capture in Agroforestry Systems. International Centre for Research in Agroforestry (ICRAF), Bogor.

Websites

The ANDALAS model at http://www.icsea.or.id/models/andalas.htm

The FLORES model at http://www.cifor.cgiar.org/flores/

The WaNuLCAS model at http://www.icraf.cgiar.org/sea/AgroModels/WaNulCAS/

The FALLOW model at http://www.icraf.cgiar.org/sea/AgroModels/FALLOW/

The SExI model at http://www.icraf.cgiar.org/sea/AgroModels/SExI/

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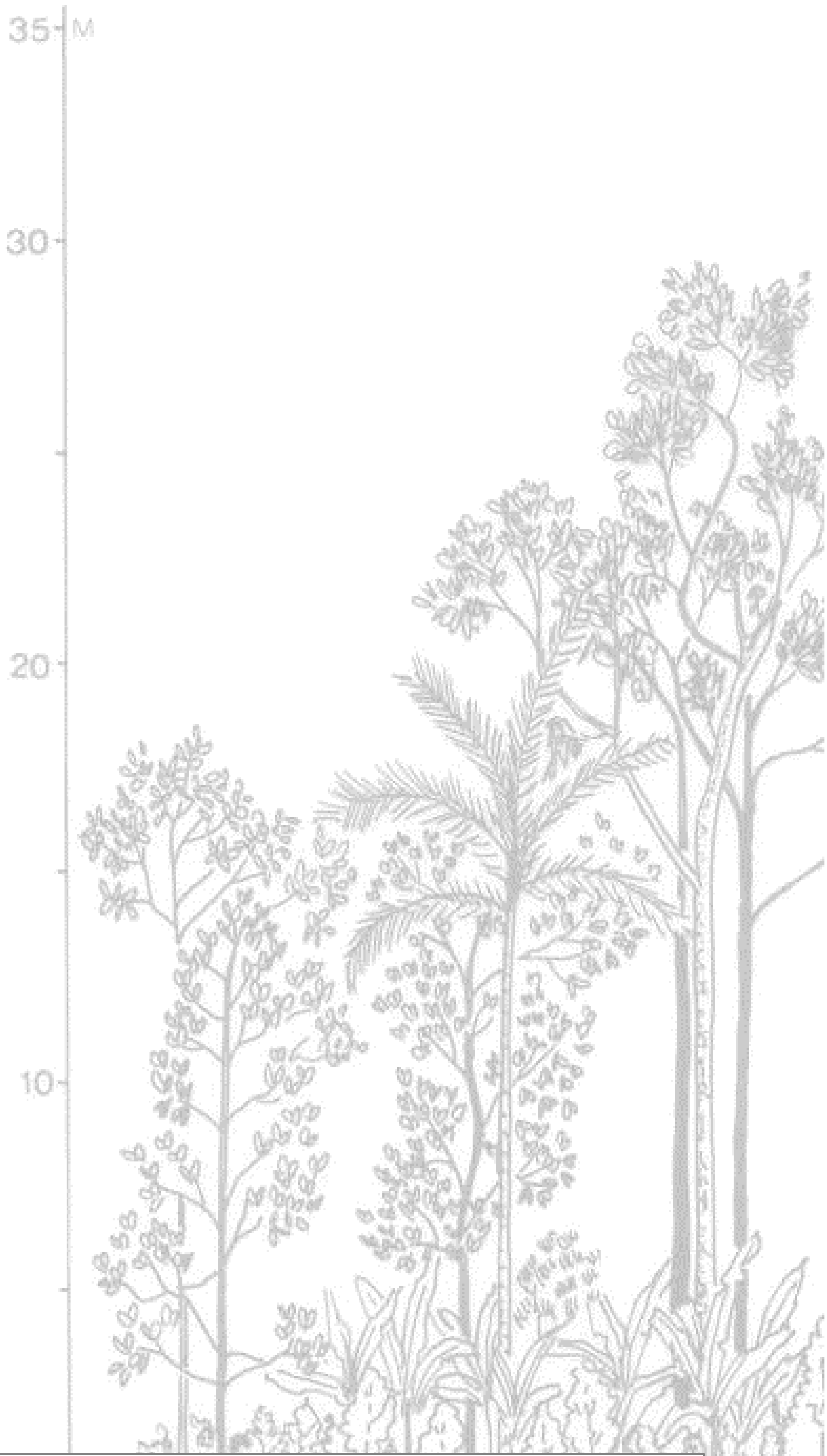

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