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CamFlores: A FLORES-type Model for the Humid Forest Margin in Cameroon

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A FLORES-type model in the Simile modelling environment is being developed for three villages in the Humid Forest Benchmark area of southern Cameroon. The modelling project seeks to investigate the effects of introduction of new crop varieties and improved farming systems on the long-term maintenance of stable mosaics of forest and agriculture, within the context of the international Alternatives to Slash and Burn programme. Biophysical data have been collated, and socio-economic and tenure data have been acquired in spatially-explicit ways. Maps of land-cover at village and benchmark scale are being prepared from detailed and semi-detailed satellite imagery, using a nested legend system that allows linking of maps at different scales. These data enable the initial construction and parameterisation of the model, and will permit the extrapolation of the results of modelling from the villages to the benchmark, and ultimately to the whole of the Congo Basin humid forests. The prototype version of the model involves 10 households and about 500 land patches, and includes the three agricultural systems dominant in the southern more forested portion of the Benchmark (mixed food-fallow systems, forest melon fields, cocoa plantations) with no rental, sale or other transfer of land. Decision-making at the household level is essentially modelled deterministically, and labour productivity is assumed to be constant between households. This model is now complete, and once it has been adjusted and suitably parameterised, it will be applied to real data from the three test villages. This will require the addition of new farming systems, the introduction of modes of permanent or temporary transfer of land, and modification of the decision model to render it more realistic.

Keywords: simulation modelling, farming systems, FLORES, Cameroon, Alternatives to Slash-and-Burn (ASB)

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INTRODUCTION

Deforestation is widely recognized as a critical problem in the humid tropics (e.g. Achard *et al.* 2002). Not only is the local environment degraded, with loss of benefits such as water, soil quality and forest products, but the global environment suffers through loss of carbon stocks and biodiversity. The global Alternatives to Slash and Burn (ASB) programme seeks to address these issues and to provide the means for sustainable livelihoods for farmers living in and around the forests of the humid tropics. The construction of system dynamics models of the interactions between farmers and their environment provides one way in which different scenarios for development can be compared.

Modelling Complex Land-use Systems

Complex land-use systems involving interactions between humans and their environment are difficult to understand and manage. Computer models provide one tool to facilitate this understanding, but should never be used as accurate predictors of behaviour. Rather, they can increase understanding of the functioning and driving forces of these systems. As Levins (1966) stated, 'computer models are essential for understanding reality, but should not be confused with reality itself'. Models are 'caricatures of reality' and can provide a metaphor to assist understanding (Carpenter *et al.* 1999). They can also allow 'learning from the future' (Oxley and Lemon 2000) through exploring the possible consequences of different scenaria.

A wide range of distinct modelling approaches are now being applied to natural resource management problems. Increasingly, these models incorporate socio-economic data and are no longer purely biophysical in approach (Carpenter *et al.* 1999, Oxley and Lemon 2000, Lynam *et al.* 2002). Three main modelling techniques have been employed. Bayesian Networks and Multi-Agent simulations have proved particularly appropriate to models constructed interactively with farmers and other actors (Lynam *et al.* 2002), while system dynamics models, often in the Stella modelling environment, have been successfully used for integration of biophysical and socio-economic aspects (Jones *et al.* 2002, Van Noordwijk 2002). The requirement to add a flexible spatial dimension to system dynamics models incorporating human and land issues led to the development of the Simile modelling evvironment (Muetzelfeldt and Taylor 1997, 2001). During the past three years, Simile has been used to construct several models to investigate interactions between humans and forest in the tropics. The first FLORES model (Forest Land Orientated Resource Envisioning System) was developed in 1999, based on data from ASB and other study areas in western Jambi Province, Sumatera, Indonesia (Vanclay *et al.* 2003a). The approach has subsequently been used elsewhere to model human activities at the forest frontier (Vanclay *et al.* 2003b). Studies of deforestation at the humid forest edge in Cameroon have been undertaken since the mid-1990s as part of the global ASB initiative, and funding was obtained in 2000 to apply FLORES-type modelling techniques in this area. The current project, financed by the European Union through ICRAF (the International Centre for Research on Agroforestry), and managed by the IITA (International Institute for Tropical Agriculture) Humid Forest Ecoregional Centre, commenced in November 2000.

The main objectives of the modelling programme are to investigate the effects of introducing improved plant species and new agricultural techniques on the sustainability of forest-cultivation mosaics at the humid forest margin, and to assess the impacts of changes in market structure, transportation networks and external financial factors on household livelihoods in villages. It is also hoped that the process of building models will improve understanding of the interactions between people and their environment, particularly in regard to biodiversity and carbon stocks, and will stimulate a critical evaluation of the range of biophysical and market data available to the modelers. The use of models permits consideration of time scales much longer than those possible in normal field trials, and also allows simulation of catastrophic outcomes which would be morally repugnant in the real world (Legg and Robiglio 2001).

Model design and calibration has benefited from feedback from potential users of the model, including National agricultural and international research centers in Cameroon (e.g. ICRAF, and CIFOR, the Center for International Forestry Research). Their scientists have met at regular intervals in two working groups, one on human issues in the model and the other on biophysical issues. Both working groups have commented constructively at each stage of model development, and have provided data for model calibration. Village farmers have been briefed on objectives of modelling at village workshops, and have collaborated actively in field data collection. Detailed maps of village land patches posted regularly in study villages have provoked much interest and discussion. Once the prototype model is running stably, it will be demonstrated to villagers, and their opinions sought as to its applicability.

The Humid Forest Benchmark in Southern Cameroon

The research, implementation and extension work of the International Institute for Tropical Agriculture in sub-Saharan Africa is concentrated in a series of ecozonal benchmark areas (Douthwaite *et al.* 2001). These areas have been selected to be as representative as possible of whole ecozones, encompassing within them the variability of natural vegetation, soils, climate, population and agricultural practices found in the ecozone as a whole. The benchmarks are considered as representative samples of the ecozones, and thus new plant species and improved agricultural systems tested in the benchmarks should be readily extended to the rest of the ecozone.

The Humid Forest Benchmark in southern Cameroon was originally denoted in the mid-1990s on the basis of regional surveys in Cameroon. It lies on the north-western edge of the Congo Basin humid forest zone (Figure 1), and is a representative sample of the margins of the Central African humid forest, which occupies parts of Central African Republic, Gabon, Equatorial Guinea, Congo, Cameroon and Democratic Republic of Congo (Gockowski and Baker 1996). Rainfall (over 1500mm/year), topography and population density within the benchmark are typical of the region. Several research agencies have concentrated their activities within this benchmark, contributing to a valuable data source. The relative ease of access and stability in Cameroon further adds to the utility of working in this location.

The three villages targetted in the present study lie along a gradient of population density, forest abundance and land availability. Population density increases from fewer than 10 persons per square kilometer in the south of the benchmark to an average of about 80 persons per square kilometer in the north.

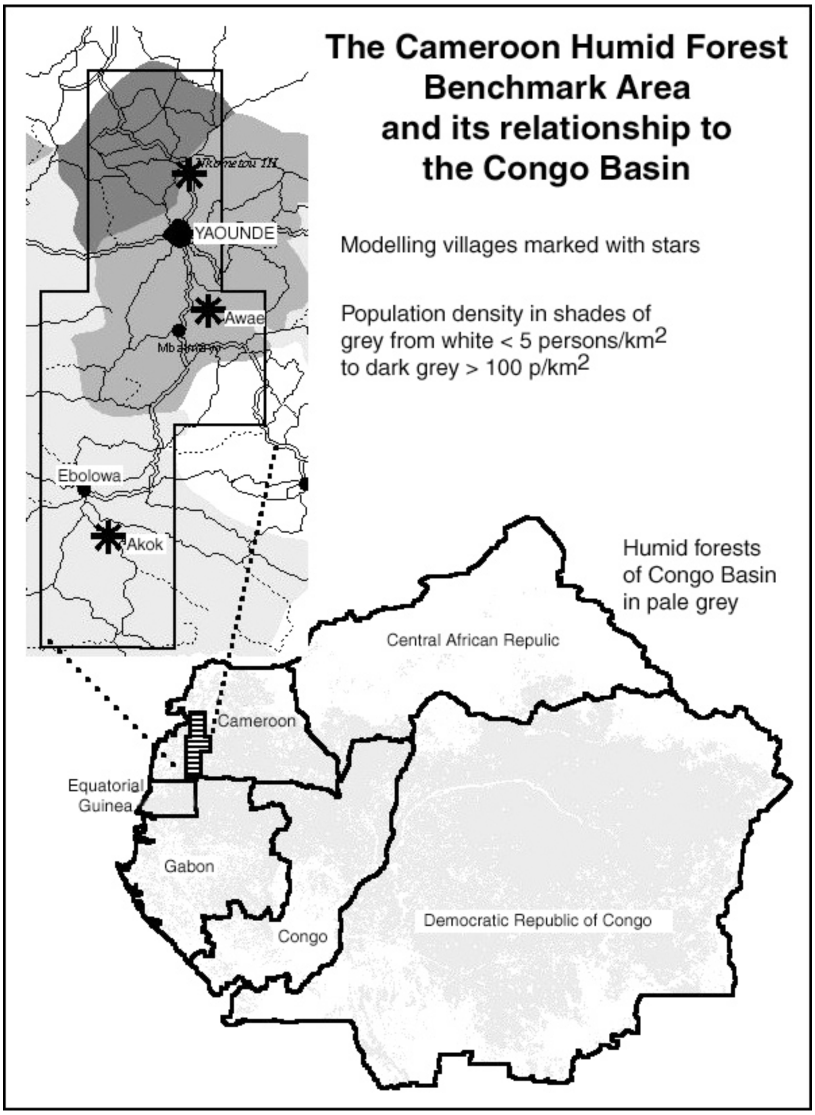

Figure 1. The Humid Forest Benchmark area of Cameroon, and its position in relation to the forests of the Congo Basin

CAMFLORES: THE MODEL

Concepts Underpinning CamFlores

The prototype CamFlores model uses a simplified landscape and an artificial village with 10 households in two lineages or clans. The village and landscape are based on observed land tenure and land-use systems in the southern part of the benchmark area, notably the village of Akok. Here the agriculture and land tenure are relatively ‘traditional’ compared to the more populated and more market-driven villages further north. Forest and long-fallow land are owned by the lineage, and all cultivated land by the household. There is no rental or other transfer of land between households.

Three distinct agricultural systems are practiced: mixed food–fallow cycles with up to eight years in fallow and only rare recruitment of new land from forest; cocoa agro-forests which are mainly stable but are occasionally developed from newly-cleared forest; and forest melon–plantain fields which form part of a long fallow cycle in secondary forest. In addition, there are large areas of forest, logged over and secondary, from which villagers obtain meat, fish, timber, medicinal plants and other non-timber forest products. Preliminary comparisons of aerial photographs from the 1970s with recent satellite imagery suggests that this land-use mosaic has been relatively stable over a period of about 25 years. Census data suggests that village the resident population is also stable, with migration to urban centres offsetting population growth. The prototype model should therefore maintain a 'steady state' over time-scales of 20-40 years, and parameterisation and internal calibration of the model will be directed at achieving this stable state before applying the model to the real, and more complex, data from the three test villages.

The key feature of the prototype model is the relationship between household and land patch, and the way in which actions in either household or patch are governed by this relationship. This is illustrated graphically in Figure 2. Information from the land patch (land-use, area, rainfall) is passed to the household. On the basis of this information, and depending on the nutritional and economic requirements of the household, and on the availability of male and female labour within the household, labour is then sent to the patch. This allows work (clearing, planting, weeding, harvesting) to be done on the patch. As a result of this expenditure of labour, and dependent on other variables such as rainfall, soil fertility, and attacks of pests and diseases, food and other produce from the patch is returned to the household. No agricultural activities can occur on the patch unless labour is allocated, and although natural vegetation including forest and it's hosted biodiversity can continue to grow in the absence of labour, no benefit from this flows to the household unless labour is invested.

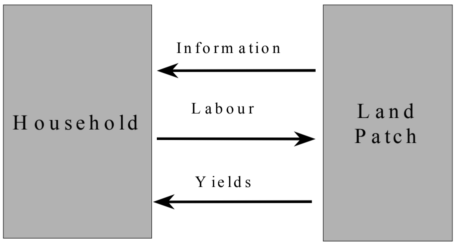

Figure 2. Basic relationships between households and land patches

Expansion of this basic model by incorporation of multiple land patches and multiple households, plus linkages through tenure relationships, results in a more complex model structure, as illustrated in Figure 3, but the basic relationships of household to patch remain, and flows of information, labour and produce are essential to the functioning of the model. This basic bi-partite structure of Simile model first developed during construction of the original FLORES model for an area in Western Jambi Province, Sumatera (Vanclay *et al*. 2003a), and appeared again in the Mafungautsi model in Zimbabwe (Prabhu *et al.* 2003). Models with this structure are known as FLORES-type models within the Simile modelling community.

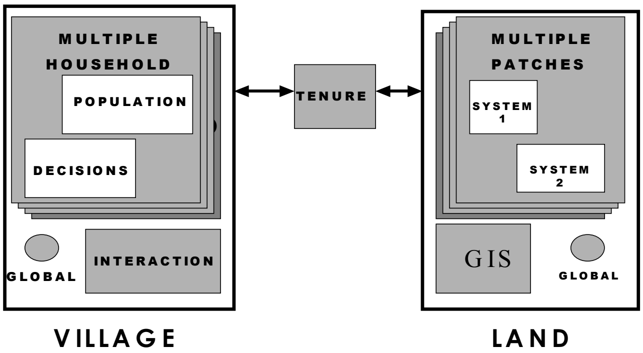

Figure 3. Structure of model linking households to land patches

Decision-making at the household level is crucial to allocation of labour, and also to sales of produce and expenditure on inputs. The decision-making process is still modeled in a simplistic way, based on a series of rules and priorities. Activities which must be carried out at a particular season or when an important crop is ready for harvest, for example the cocoa harvest, are given priority over those activities which can occur at any time and are not labour-intensive, for example fuelwood gathering and hunting. Allocation of labour depends on nutritional and economic requirements of the household, and every person-week of labour allocated produces the same effect per unit area of land in the patch in the prototype model. There are no productivity differences between individuals or households, although labour availability is modified by nutritional intake of the household, and a household with negative assets in terms of food stocks and cash ceases to exist after a short time interval.

The decision-making process is illustrated in Figure 4. A decision to allocate labour is made in two stages. Firstly, a Boolean decision whether or not to allocate labour is made on the basis of information from the land patches on work needing to be done, and the requirements of the household. The second decision on how much labour to allocate is taken on the basis of the area of the land patch, a labour norm indicating the number of person-weeks per hectare to accomplish the required task, and the availability of labour within the household. Some tasks, such as fallow clearing, may take more than one week to complete. In these cases, the maximum labour available in the household is allocated, and at the end of the week information from the land patch indicates what percentage of the task is now complete.

Many sub-models exist within the two main components of CamFlores. Within the land-patch are four sub-models for the main agriculture and forest systems. For each land patch, only one of these models is active, depending on the land-use of the patch. The land-systems sub-models include simple growth models for crops, weeds and other natural vegetation, growth and yield being a function of rainfall, soil fertility and pest and disease attack, as well as depending on labour inputs in the case of crops. There are also sub-models for soil nutrients and soil moisture, linked with the land-system models. The village sub-model includes 10 household sub-models, dealing with population, labour, stocks and decisions. The decision models are linked to land-patches through tenure relationships. Flows of information from land-patches including land use (patch state), patch area, rainfall and the condition of crops and natural vegetation proceed to households via tenure linkages, and labour flows from household to patch through the same route. Yields from patches are passed to the households owning the patches, and accumulate in the stocks sub-model, from where they feed the household or are sold to generate cash.

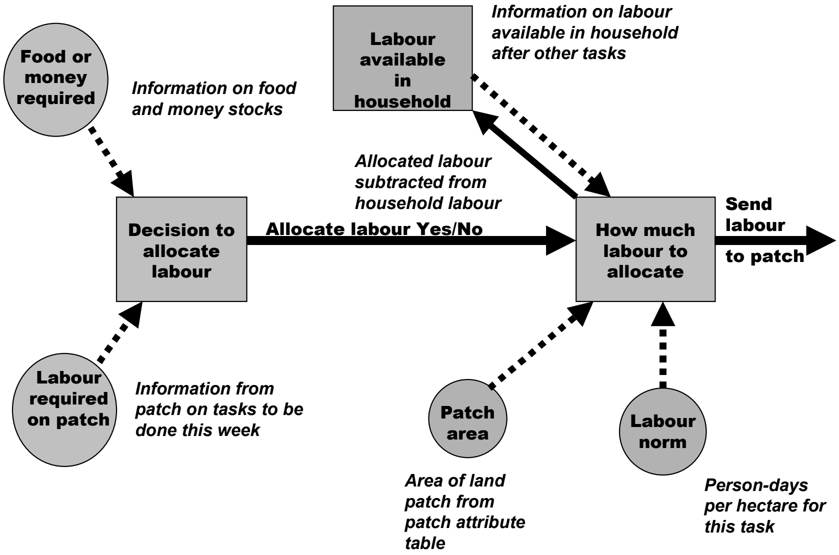

Figure 4. Model of the labour-allocation decision-making process

Data for the Model

Three forms of data have been collected for the model: maps, socio-economic data and biophysical data. Most of the map data has been generated within the project, using GPS and remote sensing (Robiglio *et al*. 2003). All roads, tracks and buildings within the study villages were mapped early in the project, and householder names were linked to physical houses. Mapping of individual land patches using GPS has become possible with the removal of GPS 'selective availability', and patches as small as 0.1 ha can now be mapped with an accuracy of plus or minus 10%. A combination of simple GPS units and hand-held computers is used for consistent field data collection. The land-use and owner of each land patch is recorded. It is rarely possible to map every land patch, and in most villages there are considerable areas of land which do not belong to individuals. This 'matrix' of land within which the cultivated patches occur is mapped using high-resolution satellite imagery. Village maps at 1:20,000 scale are prepared from Ikonos satellite images, with a spatial resolution of 4 metres. To allow village-level modelling to be extrapolated to the remainder of the benchmark area, land-cover maps of the whole benchmark are being prepared at a scale of 1:100,000 scale from Landsat 7 ETM imagery. The two sets of remote sensing derived maps share a common hierarchical nested legend, derived from the Land Cover Classification System (di Gregorio and Jansen 2000) which allows for mapping of sub-classes at detailed scale and merging of these classes in less detailed maps.

Socio-economic data at household and village level has been collected from Benchmark villages and from the ASB test villages by previous IITA surveys, and an initial task was to relate these data to the currently observed distribution of houses and householders. This task was not trivial due both to inconsistencies in the original surveys, and to the dynamics of households over the five-year period between original data collection and the present study. Fieldwork by ASB technicians, with iterative questioning of householders, resulted in satisfactory linkages being obtained for almost all data. Some new socio-economic data related to market access of benchmark villages are currently being collected.

Other relevant socio-economic data relate to food consumption and market prices. Much data have been collected (e.g. Leplaideur 1985, Gabaix 1966, Dury 1999, Dury *et al.* 2000), but careful study indicated many internal inconsistencies. Most of these have now been resolved by discussion within the modelling working groups, and the results have been incorporated in the model. Data on labour allocations for specific farming tasks in the villages have also been compiled from a range of sources, and an agricultural labour calendar compiled for use in the model.

Biophysical data (crop and other plants growth and yields, crop chemistry, soil chemistry and rainfall) have been collected mainly from within the IITA. Some data on planting densities and yields from mixed food crop fields in the ASB trial villages have been collected within the ASB project itself, while other data on plant and soil chemistry have been provided by other IITA researchers.

PRELIMINARY FINDINGS FROM BUILDING CAMFLORES

The performance of the prototype model can be demonstrated with three examples, showing changes in land-use, labour allocations, and cash reserves in households.

CamFlores Simulation of Land-Use Dynamics

Figure 5 shows changes in land-use, as indicated by the ‘patch-state’ of about 600 land patches, during a five-year model run. The 40 possible patch-states are outlined in Table 1. In Figure 5, upward lines are a result of model design and represent age of a field and succession of the forest. Downward lines are an emergent property, and reflect how the model simulates clearing of some land patches at six-monthly (e.g. fallow) and two-yearly intervals (e.g. forest cleared for melons). The basic dynamics of the land systems are effectively modeled in this prototype, although for a relatively simple set of tenure and land-use options.

Simulation of Labour Availability

Figure 6 shows simulated female and male labour availability in 10 households following weekly labour allocation over a period of one year. Male labour is is greatest demand for fallow clearing during the first and third quarters of the year, and for the cocoa harvest during the fourth quarter. Female labour requirements are greatest following fallow clearing, when planting, weeding and harvesting are undertaken in mixed food fields. Simulated labour allocations appear plausible, although occasional short periods of negative labour availability are of course physically impossible. Considerable manipulation of labour norms was necessary to arrive at this qualitatively acceptable result. Some of the original published labour figures used in the model were found to be unrealistically high, and did not permit basic tasks of land clearing and planting to be undertaken by any of the households. Detailed discussion with farmers and other researchers indicated that the labour norms arrived at by a process of trial and error were in fact closer to people's personal experience than the original published norms.

Table 1. Patch-state codes used in the prototype of CamFlores

State	Class	Comments
1	Cocoa	No change during simulation
3	Forest Melon/Plantain	Cleared from old secondary forest. Revert to young secondary forest (state 25) after 2 years.
4-7	1st-4th season mixed food	Age to next patch state after 6 months.
8-24	Fallow	Age every 6 months. Some older fallows selected for clearing every half year, thus changing to patch-state 4.
25-40	Long fallow and forest	Age every year. Some converted to patch-state 3 (melon) every 2 years.

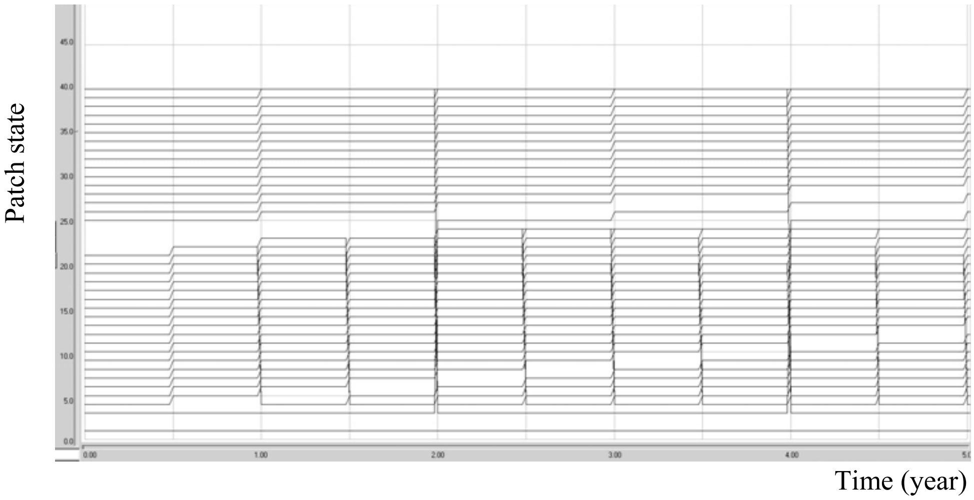

Figure 5. Simulated changes in state of individual land-patches over time

Notes: State 1 is cocoa; 4–7 are successive seasons of mixed-food fields; 8–24 are fallows of increasing age; and 25–40 are secondary forest of increasing age.

Simulated Household Cash Income

Figure 7 shows household cash reserves modeled over a period of two years. While the details of cash income will be critically dependent on commodity, and especially cocoa, prices, the general trend of reserves appears reasonable. The main income for each household occurs following the cocoa harvest late in each year (time 0.8 to 0.95 years). Supplementary income is also derived from sale of produce from mixed food fields in the middle of each year, and at the end of the year, although the latter is masked by the income from cocoa. The divergence between cash reserves of individual households increases as the simulation proceeds. Initial sensitivity analysis indicates that this divergence depends on commodity prices. Sensitivity tests also drew attention to the need to vary initial cash reserves of the households consistent with the size of their land holdings.

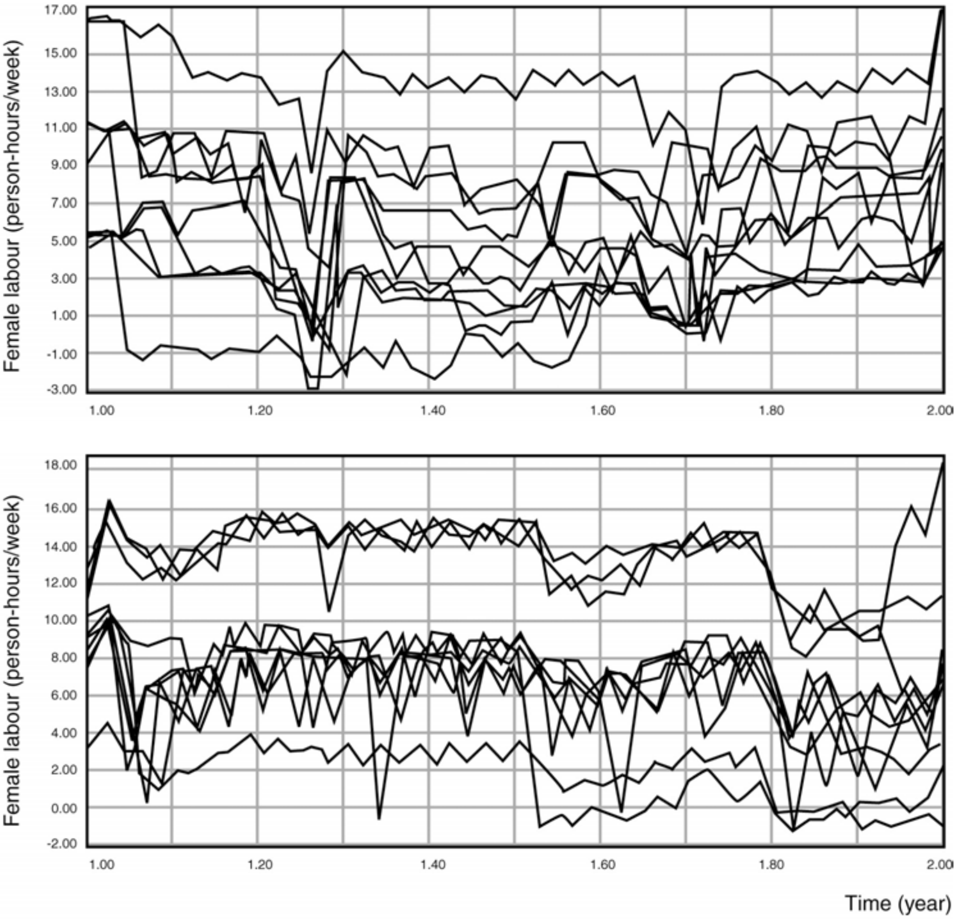

Figure 6. Simulated male (bottom) and female (top) labour availability by household by week for one year

CONCLUDING COMMENTS

The prototype model is now complete, and testing is well advanced. The model appears to respond in an intuitively correct way to changes in rainfall, commodity price and other external variables, and the importance of labour is dramatically demonstrated. Plans for further development of the Cameroon FLORES-type models are now formulated, and the implications of the Cameroon experience for construction of other similar models can be assessed.

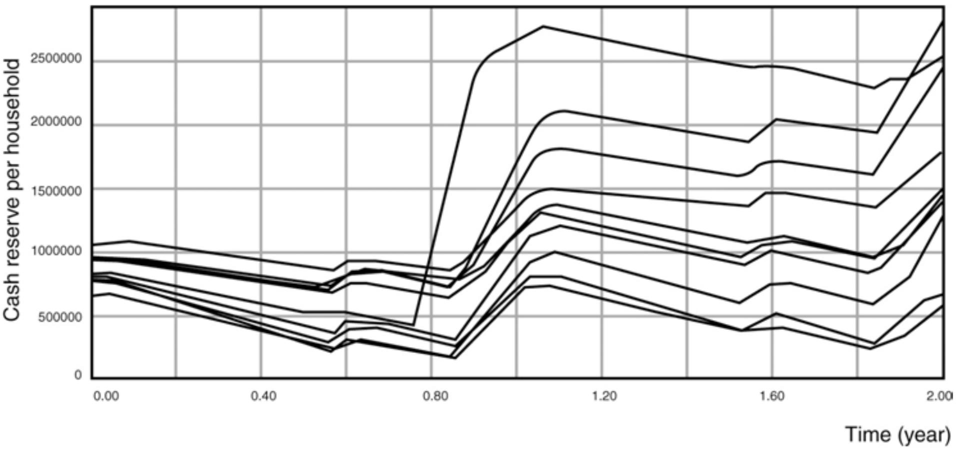

Figure 7. Simulated cash reserves by household during a two-year period

Future Plans for CamFlores

Collection of basic geographic data from the three study villages is still continuing. Mapping of fields by GPS will probably continue for the life of the project, so as to provide information on the dynamics of land-use in the villages, and in particular the reasons for selection of particular fallow patches amongst many others for clearing. Biophysical data on crop growths and yields, and on effects of pests and diseases, is probably as complete as necessary for preliminary modelling, but new data will be continually assessed and used to modify model parameters as necessary. Collection of data for extrapolation of village model results to the benchmark and the ecozone continues. Additional socio-economic data from other villages in the benchmark are currently being collected, and land-cover maps for the entire benchmark are being prepared by remote sensing. An assessment of land-cover change in selected areas of the benchmark over the past 25 years will be undertaken using historic aerial photography, and this information will be used to check model calibration.

Once the prototype model runs stably over medium time-scales (20-40 years) the model will be adapted to deal with real data from the three study villages. This will necessitate the incorporation of new agricultural systems, for example monoculture maize, tomatoes and oil palm, and also the application of fertilizers and irrigation. The decision models will have to become more complex to model more realistically differences between households, to permit cooperation between households in terms of transfer of labour and cash, and to allow for adoption and spread of innovation.

Implications for Building Other Models

The CamFlores model is the most complex FLORES-type model so far attempted. This is largely a result of the extreme complexity of rainforest agricultural systems, where a wide range of plant species are cultivated together, both to provide a varied diet and to provide protection against pest or disease attack on one or more species. If this modelling project is successful, then this should provide great encouragement to modelers elsewhere who will normally be dealing with more simple systems. If the household decision model evolves along the planned route, allowing for more individuality and adoption of innovation, this would have important application other FLORES-type models since the decision-making is probably the least realistic aspect of all current FLORES models.

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