INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
Modelling deforestation and land degradation in the Guinea highlands of West Africa using remote sensing and geographic information systems

Gilruth, Peter Thomas, Ph.D.

The University of Arizona, 1991
MODELLING DEFORESTATION AND LAND DEGRADATION
IN THE GUINEA HIGHLANDS OF WEST AFRICA
USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS

by
Peter Thomas Gilruth

A Dissertation Submitted to the Faculty of the
DEPARTMENT OF WATERSHED MANAGEMENT
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY
In the Graduate College
THE UNIVERSITY OF ARIZONA

1991
THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Peter Thomas Gilruth entitled **Modelling Deforestation and Land Degradation in the Guinea Highlands of West Africa Using Remote Sensing and Geographic Information Systems**

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

Co-Dissertation Director Stuart E. Marsh

Peter F. Ffolliott

D. Phillip Guertin

Charles F. Hutchinson

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Dissertation Director Gordon S. Lehman
STATEMENT BY AUTHOR

This dissertation has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this dissertation are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Peter T. Gilbreth
ACKNOWLEDGEMENTS

The data collection phase of this research was originally funded by a grant from NASA (Grant No. NAGW - 1359), and the Arizona Remote Sensing Center (ARSC) provided continued logistical and technical support after the NASA project was completed.

I would like to thank August Hartman and USAID/Guinea for their assistance during field work in the Fouta Djallon, and Dr. Ourey Bah of the Guinean National Direction of Forest and Game for his cooperation and interest.

At the University of Arizona, each member of my committee provided useful suggestions, however Dr. Stuart Marsh, Robert Itami, and Gordon Lehman were most helpful in providing me with a sense of direction when it was no longer apparent to me. Other members of the ARSC community who provided valuable technical suggestions include Jim Walsh, Jiang Li, Rod Hay and Chris Lee.

My greatest thanks go first to my wife, Wafari, and my parents, each of whom recognized the value of education as a personal investment. Without their support, this educational voyage would never have occurred.

Finally, my gratitude and best wishes go out the hospitable people of the Diafore Region in Guinea, for whom the fruits of this research were intended.
# TABLE OF CONTENTS

List of Illustrations ........................................... 7
List of Tables ...................................................... 8
Abstract ...................................................................... 9
Introduction ................................................................ 11
  Study Objectives .................................................. 12
  Overview .............................................................. 13
Literature Review .................................................... 15
  Definitions ............................................................ 15
  Model Elements ..................................................... 17
  The Nature of Spatial Models .................................... 17
  Cellular Automata Development in Spatial Models .......... 22
  Remote Sensing Input to Spatial Models in Natural Resources Management ...................................................... 23
  Spatial Models of Land Use Change ............................ 25
  Summary of Prior Modelling Results ......................... 29
  A Combined Approach: New Directions Taken by this Research ................................................................. 29
Description of Shifting Agricultural Systems in Africa ...... 32
  Definitions ............................................................ 32
  Two Differing Viewpoints on the Justification for Shifting Cultivation .......................................................... 33
  The Process Described .............................................. 34
  Critical Population Density in Shifting Cultivation Systems ................................................................. 36
  Environmental Degradation Resulting from Shifting Cultivation ................................................................. 38
Study Area Description .............................................. 41
  Physical Description ................................................ 41
  Population ............................................................. 49
  Social Structure and Land Tenure ................................ 50
  Land Use Patterns .................................................. 51
  Environmental Degradation ....................................... 54
  Future Status ........................................................ 58
Methods ..................................................................... 60
  Data Collection ...................................................... 60
  Data Interpretation ................................................ 63
  GIS Database Creation ............................................ 67
  Model Description and Development ......................... 70
  Model Verification .................................................. 85
  Model Testing ........................................................ 85
Results................................................................. 87
Measures of Model Performance.............................. 87
Description of Simulation Results........................ 92

Discussion and Conclusions..................................... 114
Summary of Model Results..................................... 114
Management Implications...................................... 118
Future Research Needs and Suggestions for Model
Improvement..................................................... 121
Conclusions....................................................... 124

Appendix A: Batch File of RMAP Commands for Guinea Highlands
Deforestation Model........................................... 125

Appendix B: Batch File for 18 Model Iterations............ 135

List of References.................................................. 136
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Location of Diafore Study Site and Fouta Djallon Mountain Range (cross-hatched)</td>
<td>42</td>
</tr>
<tr>
<td>2. Diafore Village Location Map</td>
<td>44</td>
</tr>
<tr>
<td>3. Laterite Plateau (Bowe)</td>
<td>45</td>
</tr>
<tr>
<td>4. Home Garden in Koune Village</td>
<td>45</td>
</tr>
<tr>
<td>5. Deforested Slope Used for Shifting Agriculture</td>
<td>53</td>
</tr>
<tr>
<td>6. Home Garden on Slopes (Kouratongou Village)</td>
<td>56</td>
</tr>
<tr>
<td>7. Air Photo Showing Land Cover Classes</td>
<td>64</td>
</tr>
<tr>
<td>8. Bi-Spectral Video Image Collected Simultaneously with Figure 7</td>
<td>64</td>
</tr>
<tr>
<td>9. Air Photo Showing Eroded Areas</td>
<td>66</td>
</tr>
<tr>
<td>10. Flow Diagram for Model Logic</td>
<td>71</td>
</tr>
<tr>
<td>11. Derivation of Productivity and Labor Preference Surface</td>
<td>79</td>
</tr>
<tr>
<td>12. Procedure for Site Selection Behavior Test</td>
<td>89</td>
</tr>
<tr>
<td>13. Map of 1953 Land Cover Classes and Initial State Conditions</td>
<td>95</td>
</tr>
<tr>
<td>15. Simulated Landscape for Test 1</td>
<td>97</td>
</tr>
<tr>
<td>16. Simulated Landscape for Test 14</td>
<td>104</td>
</tr>
<tr>
<td>17. Simulated Landscape for Test 16</td>
<td>106</td>
</tr>
<tr>
<td>18. Map of 1953 Land Cover Classes for Upper Diafore Basin</td>
<td>112</td>
</tr>
<tr>
<td>19. Comparison of Test 1 and Observed Site Selection Results</td>
<td>115</td>
</tr>
<tr>
<td>20. Comparison of Test 16 and Observed Site Selection Results</td>
<td>116</td>
</tr>
<tr>
<td>Table</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>1. Remote Sensing Data Used for Diafore Study Site</td>
<td>61</td>
</tr>
<tr>
<td>2. Full Model Simulation Results</td>
<td>94</td>
</tr>
<tr>
<td>3. Individual Variable Simulation Results</td>
<td>99</td>
</tr>
<tr>
<td>4. Variable Combination and Gravity Model Tests</td>
<td>102</td>
</tr>
<tr>
<td>5. Simulation Results Without Allocation Routine</td>
<td>105</td>
</tr>
<tr>
<td>6. Random Allocation Simulation Results</td>
<td>108</td>
</tr>
<tr>
<td>7. Observed Vs. Predicted Eroded Zones for Selected</td>
<td>110</td>
</tr>
<tr>
<td>Simulations</td>
<td></td>
</tr>
<tr>
<td>8. Simulation Results for Upper Diafore Watershed</td>
<td>113</td>
</tr>
</tbody>
</table>
ABSTRACT

A dynamic spatial model of deforestation and land-use change was developed from remotely sensed data for the Fouta Djallon mountain range in the Republic of Guinea, West Africa. The objective was to simulate patterns of land clearing for shifting cultivation in terms of farmers' selection behavior for new fields based on topography and proximity to villages.

Data describing the current and historic condition of the vegetation cover, land use, and erosion for a watershed in Guinea were derived from aerial photography and ground sampling. Maps of these conditions were prepared and entered in a geographic information system (GIS) together with topographic data. From these data, maps of secondary variables (slope, village proximity, site productivity, and labor) were derived using the spatial operators contained in the GIS.

These variables were ranked for agricultural preference and combined following a pair-wise hierarchy to generate a composite agricultural site-preference surface. This ranking was done in iterations, using a two-year time increment, which corresponds to the typical duration of cultivation for any one field. Different variable combinations and underlying assumptions of model logic were tested to determine influence on simulation results.

To validate the model, the projected landscape was compared with land-use data collected in 1989. Although the model did not simulate the farmers' selection behavior for topography and village proximity successfully, test results with individual variables
suggest that site productivity as determined by the length of fallow is a critical variable in the site selection process. The addition of site quality data should improve model results.

The watershed in which this study was performed is the focus of a development initiative supported by the U.S. Agency for International Development (USAID), in which viable options are being sought for regional application. Thus, aside from documenting the dynamics of shifting cultivation, this model allows planners to evaluate alternative strategies of land-use conversion with a graphic display of zones of potential hazards. Finally, the data contained in the GIS serve as a structure for monitoring long-term change in the region.
CHAPTER 1: INTRODUCTION

The threat of tropical deforestation to the integrity of the biosphere has attracted considerable attention recently, with much of the focus on changes in global climate. While most research has focussed on the controversial felling of large forest tracts in the Amazon River Basin, comparatively little attention has been directed to the more gradual intensification of shifting cultivation in tropical West Africa.

The driving force that has been changing traditional land-use practices in West Africa is a growing population faced with a limited amount of agricultural resources such as available land, fertilizer, and equipment. Historically, management practices included a short crop production and an extended fallow period, during which natural vegetation occupied and rejuvenated the site, in each cycle. The increased demand for land results in a shortened fallow period, and more land under cultivation during each cycle of vegetation clearing and planting. Without a change in management strategy, a downward spiral of resource degradation is inevitable.

Global scale models exist to study the effects of deforestation, but the coarse spatial resolution of these models often overlooks the types and mechanisms of land degradation specific to a given region such as West Africa. Few attempts have been to assess degradation as a result of population pressure, and no effort has been made to model the spatial nature of these changes for predictive purposes or to arrive at a better understanding of
these agricultural systems. In view of the increasing population and consequent changes in land use, there is a need for tools to assess and model changes in land use and land degradation. Because of the paucity of environmental data available for Guinea and other tropical countries, these tools should be simple in concept and construction.

Recent progress in the development of geographic information systems (GIS) offers the possibility of modelling the spatially dynamic nature of shifting agriculture in tropical environments. The GIS' capacity to combine cultural and environmental features as co-registered maps within a database provides an ideal tool for studying the interaction between variables. The justification for this approach is that the relationships between population, agricultural production, forest dynamics, and the physical environment can be conceptualized, and simulated with a spatial model derived from and operating on a GIS database. Moreover, tropical deforestation itself is a dynamic spatial phenomena ideal for study with GIS technology.

Study Objectives

The primary goal of this research was to derive a dynamic spatial model which illustrated the influence of forest structure and productivity, topography, and distance to local population centers on the process of shifting cultivation in a representative watershed in the Fouta Djallon highlands of the Republic of Guinea in West Africa. The major assumption to be tested was that a
spatial model can predict the nature of sites that are used for shifting cultivation in terms of topography and proximity to population centers. The predicted number of shifting agriculture sites that fall within each category were compared with data collected from a combined aerial and ground survey carried out in April/May 1989. The relative importance of each variable in the site selection process was assessed.

The model incorporated an erosion hazard index to simulate the effect of over-utilization of the limited land resource. The number and location of cells that were found on steep slopes and have a record of repeated clearing were compared with those sites photointerpreted for signs of erosion in 1989. The resultant GIS database provides a structure for long-term monitoring of the study area, and the spatial model serves as a tool for simulating effects of land use change on the status of the natural resource base.

The watersheds in which this study was performed are the site of a development initiative supported by USAID in which viable options are being sought for regional application. Thus, aside from documenting and explaining the spatial dynamics of shifting cultivation, this model permits planners to evaluate alternative strategies for development and their long-term consequences.

Overview

Chapter 2 presents the basic definitions and concepts common to spatial models, with additional emphasis on the development of GIS models. A brief review of the use of gravity models to simulate
the effects of population centers on the surrounding environment is given. Previous efforts in modelling shifting cultivation in the tropics using GIS and remote sensing data are summarized to give an appreciation of this dissertation's contribution to the science.

A wide variety of shifting cultivation systems exist throughout the tropics. Chapter 3 presents a classification of the different types found in Africa and the sequence of activities common to each. Chapter 4 describes the environmental and cultural features of the Diafore watershed study area.

The methodology described in Chapter 5 is grouped into phases of remote sensing and field data collection, data interpretation and GIS database development, and model description and procedures for testing and validation. Results of the model tests, including sensitivity analysis and validations is presented in Chapter 6. Chapter 7 provides an interpretation of the results and a discussion of their contribution to the understanding of shifting cultivation. Recommendations for model improvement and applications are given.
CHAPTER 2: LITERATURE REVIEW

Definitions

Modelling of natural processes is both a science and art that deals with relationships between a real world process of interest and a model. A model is defined by Magill (1986) as an abstract formal representation of a system of interest that in principle can be handled by a computer. Model functions, among others, include: 1) data and information development as a means of generating system indicators, 2) data structuring, exploration, and organization to discriminate among elements and possibly to suggest taxonomies or to specify and test explanatory relationships between variables, 3) surrogate laboratories (prediction of values, paths, forecasting, etc.), 4) prescriptive tools, and 5) understanding system functioning to study cause and effect relationships (Magill, 1986).

Models can be categorized as deterministic, which have no random variables, or stochastic which contain at least one such type (Ziegler, 1976). Deterministic models are founded on the notion that the behavior of systems is controlled by natural physical laws, and that once these laws have been described, the system's behavior can be predicted exactly. Common applications are in physical geography, where laws governing the movement and storage of raw materials are used to construct models which predict the behavior of physical systems (Thomas and Huggett, 1980).

Systems in human geography are not so well suited to the deterministic style of modelling because exact laws of human
behavior do not exist. However, if observed trends in group behavior can be converted to law-like statements, models can be constructed. These models are empirical in nature in that they test relationships that have been observed, but not exactly understood. For example, the model developed in this dissertation has characteristics of normative models in human geography that are based on how a population ought to behave.

Magill (1986) notes that there are often problems with determining the accuracy of predictions from these kinds of models. Common deficiencies include: 1) models of social processes are at best partial and may be inconsistent; 2) they can be mechanical in form or function and inflexible; and 3) they can be unduly data-intensive, incapable of handling information gaps or uncertainty.

Other distinctions of model types include continuous time models in which time flows smoothly without leaps, or discrete time models in which the model clock advances periodically. Models also can be time variant or invariant depending whether the rules of interaction between variables depend on a time factor. Computer simulations may use sequential processing if one task is performed at a time or parallel processing if several tasks are performed simultaneously. A fundamental problem is that models are parallel in their construction but computers operate on instructions sequentially.

Continuous state model variables can assume real numbers, whereas in discrete state models variables only assume a discrete set of values. For example, threshold models for land suitability
may accept input of soil type, vegetation type, etc., and output a map for land capability for agriculture. If the combination of soil, vegetation, and other characteristics surpass a threshold value, the land is deemed suitable (Burrough, 1989).

Based on the above definitions, the model presented in this dissertation can be described as discrete in time and state, and time variant, with all computer operations processed in a sequential mode within a series of batch files.

**Model Elements**

Ziegler (1976) lists five major elements common to models.

1. The real system is the source of observable data. Observations on real system behavior should allow the modeler to obtain knowledge of descriptive variables required to understand the system.

2. Descriptive variables are either input or output elements, and when grouped together they constitute all that can be known about the system.

3. The experimental frame is the limited set of circumstances under which the real system can be observed. The limitations could be geographical, temporal, etc.

4. The base model gives a hypothetical and complete explanation of the real system. It is capable of accounting for all the input-output behavior of the real system. Of course, the base model can never be fully known. Instead, Ziegler describes the "lumped model", which is a simplification of the base model, and is valid in the experimental frame. Concurrent with the development of the lumped model, a statement is required of all the assumptions necessary to simplify the real world to a level usable in model.

5. The last element is the computer which is used to generate the input/output pairs of the lumped model.

**The Nature of Spatial Models**

Spatial models fall within the general category of cell space
or "tessellation" models (Ziegler, 1976) that consist of a set of geometrically located cells, each containing the same computational apparatus as all other cells and connected to other cells in a uniform way. Two types of spatial frameworks are used. One is continuous in all directions, with a cartesian coordinate system for reference. The second type, which is the type used for this research, has a spatial domain comprised of regular or irregular regions of cells. GIS models, which are a class of spatial models, usually incorporate several strata of data layers but have a fixed number of cells in a rectangular matrix.

For a model to have good results, each cell element must have its own location-specific data (Burrough, 1989). If the cell size is large in comparison to the spatial variation in the landscape, model results will be unsatisfactory. On the other hand, the user must avoid choosing small elements and filling them in with uncertain values from previously classified data. The graphic output will look better but can be illusory (Burrough, 1989). One common constraint is that huge computer memories are required for storing regional databases. In addition, independent data for each cell usually are not available so average values from choropleth maps or derived remote sensing images are used.

Spatial Model Development

Burrough (1989) describes several distinct stages in the development of spatial databases and quantitative models that relate land characteristics (soil permeability, wildlife habitat, etc.) to
land qualities (suitability for any given application). Since land qualities vary in both time and space, any system of land management should have information on: 1) spatial distribution of land qualities, and 2) temporal information on how changes may occur. Three elements are needed to satisfy these requirements:

1. an inventory to establish baseline data that can be used for comparison purposes,
2. a digital database (GIS) for storing and manipulating data, and
3. models that link land qualities to basic attributes of water, soil, and climate and that can simulate change.

The role of the GIS is to generate a set of composite maps depicting the relative suitability of any given parcel of land for achieving a particular objective (Diamond and Wright, 1988). Boolean operators generally are used to derive the suitability maps. The stages in creating models that relate land qualities to land characteristics include (Burrough, 1989):

1. observations of a relation between land quality and attributes of the landscape,
2. an empirical description of that relationship,
3. a testing of the generality of the empirical description, and
4. an unravelling of the physical processes underlying the relation followed by a description of the processes in terms of physical or stochastic laws.

A fundamental step in model development is the identification of state variables. These are a small subset of all the descriptive variables such that only their values have to be available to the computer for it to be able to compute the future values of all descriptive variables.
Once all variables are identified and transition functions defined, the modeler develops a simulation procedure which usually has a generalized sequence of activities (Ziegler, 1976):

1. initialize state variables,
2. initialize the model clock,
3. apply the rules of interaction to the contents of the state variables as well as to derive the descriptive variables,
4. advance the clock by one time step, and
5. go back to step three until end conditions are met.

Gravity Models

Many process oriented models use rates of flow of matter or energy to construct model equations which predict how the structure of the landscape will change. For example, the rate of leaf fall could be used to predict the rate of humus formation. These rates are independent variables used to predict the value of dependent variables representing some landscape feature (Thomas and Huggett, 1980).

In gravity models, the relationship between flow and structure is reversed, such that the spatial interaction model predicts the size and direction of flow (dependent) using independent variables which measure the structural property of some aspect on the human landscape. A useful example from this dissertation is the effect of population size or density on the spatial nature of shifting cultivation. Assuming that villagers want to minimize travel time to agricultural sites, spatial allocation or gravity models can be constructed which simulate travel time preference for potential
agricultural cells. We then can compare observed with predicted behavior to assess the farmers' rationale in choosing sites.

The basic gravity model formula is derived from Newton's law of gravity, as described by Thomas and Huggett (1980):

$$T_{ij} = k \frac{W_i W_j}{d^{n_{ij}}}$$

where $T_{ij}$ is flow between sites $i$ through $j$,

$W_i, W_j$ are the weights for trip attraction and generation,

d is the distance between population centers $i$ and $j$,

$k$ is a scaling constant, and

$n$ is a friction factor.

The three basic assumptions for these models are: 1) the size of flow is proportional to the "trip-generation capacity = $W_i$" of the region where flow begins, 2) the size of flow is proportional to the "trip-attraction capacity = $W_j$" of the region where flow ends, and 3) the amount of interaction declines with the square (or other power) of the distance between regions. The value of the power is said to be the frictional effect of distance and depends on empirical evidence.

Goodness of fit then can be calculated by comparing observed with expected values. Ideally, the "$n$" value, which measures "distance decay" or "friction", can be adjusted from analysis of the goodness of fit results.
Cellular Automata Development in Spatial Models

The development of cellular automata functions is a valuable addition to GIS modelling. The best known example of the cellular automata model is Conway's Game of Life (Gardner, 1970), which used a few simple "live or dead" rules in a game format to derive complex cellular patterns as a function of the original placement of "live cells" and the number of iterations.

Couclelis (1985) defines the cellular automata model:

"...(it) consists of an infinite array of cells, a set of states per cell, a cell neighborhood, and a transition rule, which maps the present state of any given cell and its neighborhood into the next state of that cell."

The assumptions of an infinite array of cells and neighborhood uniformity are relaxed in order to apply model concepts to empirical studies of landscape change.

The state of each cell at any point in time is one of a set of possible states determined during model construction (Couclelis, 1985). For example, a grid cell representing an agricultural field could have possible state values of: 1) active cultivation site, or 2) fallow for a given number of years. The neighborhood consists of the cell itself plus the (usually) 8 surrounding neighbors. The transition rules can be deterministic, as in this dissertation, or stochastic.

Common cellular automata applications in landscape models include two-dimensional distance measuring functions (Wilkie and Finn, 1988; Olsson, 1989) and neighborhood analyses (Turner, 1987; Sklar et al., 1985). It also is possible to consider time as an element in the transition rules (e.g. Wilkie and Finn, 1988). In
the model developed in this dissertation, the transition rules are derived from hierarchical look-up-tables which combine land quality factors into a land suitability analysis.

Remote Sensing Input to Spatial Models in Natural Resources Management

The Department of Physical Geography at the University of Lund, Sweden, has made valuable suggestions for the application of remotely sensed data to spatial models of Sahelian land-use. Olsson (1989) suggests that remote sensing data are useful for assessment of the supply side of natural resources management, but coupled with GIS and spatial modelling, can be used to analyze demand and accessibility. Moreover, the spatial aspects of imagery are suited for modelling in a raster environment.

The calibration of satellite data to absolute measures of vegetation amount is a first step in determining supply side data. Early attempts by Richardson and Wiegand (1977) and Tucker (1979) provided a basis for the measurement of vegetation biomass from satellite imagery. Further research is needed on the extrapolation of annual yield from temporal data sets; this has been attempted using Advanced Very High Resolution Radiometer (AVHRR) data for the vegetation communities in the Senegalese Sahel (Tucker et al., 1985). At present, the integration of these results in spatial models is difficult because of the spatial variability of vegetation and soil (Marsh et al., in press), particularly in those lands under shifting cultivation (Gilruth et al., 1990; Olsson, 1989).
Data needs for demand include the spatial distribution of people within the study area. MSS data have been used to estimate population based on village size with high confidence (Stern, 1984). This is useful only in areas where people live in nucleated villages having a high contrast with surroundings.

In much of rural Africa, the right to cultivate land is based on tradition. The supply of land in Olsson's models is based on one simple assumption: that a piece of land belongs to the nearest village. Thiessen polygons can be constructed around each village to simulate land available per village. The result of combining maps of Thiessen polygons with population density is a model of land availability per capita. When overlaid with soil maps, a more realistic map of land supply can be derived. Another information need is demand per capita, obtainable from household surveys (Olsson, 1989).

The principle of the supply/demand model is to transform the per area measure of productivity, available from the vegetation assessment, into a per capita measure. For agricultural productivity, data on supply can be multiplied by the land availability model, to yield production in kg/capita. If agriculture or fuelwood supply is the objective, it is assumed that resources closest to the village are used first to meet demand. Thus, a spiral search outward from each village is carried out in the supply model. The resources in each grid cell are added until: 1) the demand is satisfied, 2) the search has reached a preset distance limit, or 3) there are no more resources available. The
model results will show the original supply in areas where there was no demand, areas where supply and demand are in balance, and areas of resource deficit.

The approach suggested above advocates an interesting combination of remote sensing and modelling technology within a GIS framework. The main barrier to implementation is the inability of satellite data to derive acceptable crop production estimates for small scale agriculture. Until this issue is resolved, these research efforts will remain at an experimental stage.

Spatial Models of Land-Use Change

Wilkie and Finn (1988) developed a dynamic spatial model to show patterns of shifting agriculture and forest regeneration in Zaire. They selected a study area of 10 km² within the Zairean Ituri Forest. The type of model was tessellation space, and included components for field selection and forest succession. Field selection by farmers was based on land tenure, travel time to site, and productivity using fallow time as a proxy for site fertility.

A cultivation ratio of 2 years farming to 15 to 20 years fallow was used, with new fields cleared each year. Forest successional patterns included phases of 3 years of farm-bush vegetation, 15 years of young softwood forest, 30 yrs of old seral forest, and climax. Root resprouting of the climax forest species insures return of the same species after 50 yrs. If the site is cleared before the climax stage is reached, the root stock is lost.
Wilkie and Finn (1988) used vegetation survey transects to sample the various land cover classes and visual analysis of a Landsat image to corroborate the model results. They found that, although these data were inadequate to validate their results, the model still could be used to study the potential effects of population growth on forest structure and land use. For example, testing the model with population growth set at 0% resulted in no significant degradation of forest structure over the maximum model testing period of 250 years. If, on the other hand, population growth was set at 5%, model results showed that all mature forest close to the major road would be converted to farm-bush or secondary regrowth in 250 years.

From Wilkie and Finn's results (1988), it was not possible to evaluate the spatial performance of their model. The linear transect used to validate results could not be used to reveal how well the model predicted clump size or topographic features of preferred sites. In addition, their assumption of an undisturbed initial state should be questioned because the forest had previously been used for plantation crops.

Kangas (1990) digitized a small scale vegetation map of the Amazon Basin to serve as a database for his tropical deforestation study. The objective was to simulate deforestation effects on diversity, rather than tallying simple rates of change of areal extent. Several patterns of deforestation were tested, including that along a trans-Amazon highway corridor, and radiating from different points of origin. It was found that the greatest loss of
diversity occurred with deforestation along the southern border where maximum diversity occurs. Although his methods seemed somewhat trivial, his results do point to the importance of considering the spatial nature of deforestation in context with loss of diversity.

Turner (1987) used historical aerial photography to establish a GIS database for a piedmont region in Georgia characterized by the conversion of cropland to forest, urban, or other land use. Her work tested the assumption that land use changes are not strictly Markovian, that is, cell state changes are not only a function of current state, but also are influenced by surrounding cells. She developed and compared three types of spatial simulation models of land-use change: 1) based solely on transition probabilities, 2) spatial simulation in which the four nearest cells influence transitions, and 3) in which eight cells influence transitions. Model results were compared by 1) mean number and size of patches, 2) fractal dimension of patches, and 3) amount of edge between surfaces.

Turner's overall results showed that the 4 and 8 cell neighborhood spatial simulations predicted larger and less numerous patches than the simple random simulation. The eight neighbor model predicted the largest patches, but these were 5 times larger than actual size within the forest class. Her results support the non-Markovian nature of land-use changes, suggesting that neighborhood effects do exist.

There are two criteria for the evaluation of Turner's work: 1)
the ability of the model to predict observed land use class
percentages, and 2) the ability to simulate the spatial nature of
the classes. Her model was successful in simulating percentages of
land use, which was not surprising as the rates of change were
determined empirically from census and Forest Service records.

No single model was able to characterize the spatial nature of
all the classes. For example, the 4 cell neighborhood model
simulated patch size best for the forest class, but was not
successful in capturing the spatial characteristics of the abandoned
cropland class. The difference in spatial mechanisms operating in
each land use class points to the need of considering different
scales for individual land use units and suggests new ideas for
spatial modelling methods.

Sklar et al. (1985) also developed a nine cell dynamic spatial
model to simulate changes in marsh habitat from altered
sedimentation and flow patterns in the Mississippi Delta. Although
their model was not developed at a scale to represent the complexity
of the local geography, they were able to design a set of
neighborhood transition rules that adequately simulated interaction
between model parameters. Their simulations of changes in habitat
from marshlands to open water were qualitatively acceptable, but
could not be validated with real data. The authors felt it would be
necessary to increase the number of cells (i.e. increase spatial
resolution) to use the model for planning purposes.

Problems incurred in using these kinds of models are that
transition rates are usually not constant through time. This can be
resolved with better temporal data, but with an increased time requirement for collection and processing. Another problem is that the cause of land transformation is usually economic, and not strictly a result of natural phenomena. The results from empirically derived rates masks this causality.

Other examples of dynamic spatial models of natural resources include work by Hendrix et al. (1988), Johnston (1987), Gelinas et al. (1988), DeAngelis et al. (1985), and Langran (1989).

Summary of Prior Modelling Results

From the above sample of spatial model results, it is clear that these efforts were characterized by different objectives, methods, and means of evaluating results. Hence, there is an inherent difficulty in setting standards with which the results of the present study can be compared.

Generally, these studies report descriptive statistics for the landscape patterns which are used to judge model performance. On the other hand, few researchers report the level of image similarity between predicted and actual landscapes, due partially to the inherent difficulty in predicting human behavior. Along the same line, attempts at comparing predicted and observed land-use patterns in terms of topography are few, which underlines the difficulty in evaluating site selection results in this dissertation in Chapter 6.

A Combined Approach: New Directions Taken by This Research

Olsson's recommendations have some similarity to ideas
developed in this dissertation, however the objectives are not the same. The supply and demand model was suggested as a means to predict possible areas of resource deficit for regional planning purposes. The historical patterns of change were not used as a vehicle to improve knowledge on how the shifting agricultural system operates and future changes may occur.

Wilkie and Finn's (1988) research more closely parallels the objectives of this dissertation, however, the methods are quite different. A major difference is the use of remotely sensed data to develop and validate the model, including the use of historical aerial photography to derive the initial model state. The factors analyzed for the site selection process, in addition to those Wilkie and Finn considered, included slope and village size influence. Their assumption was that the initial state consisted of primary forest with no village sites. They did recognize that the study area was used for plantation crops prior to the construction of a new highway which opened the region for development. Their model was validated using vegetation transects and visual analysis to establish the veracity of output, which the authors admit is a weak test of the model because the validation was not spatial. For this dissertation, I collected airborne and field data in 1989 to validate model output using spatial criteria.

The idea of a hierarchical combination of factors to simulate land suitability for shifting cultivation is not found in previous models of rural African land use change. Although requiring a thorough understanding of land-use practices, the method is a
flexible means of establishing the relative importance of input variables.

In addition, the incorporation of a simulation of eroded sites from over-utilizing steep slopes adds a feature not found in other studies. Although this effort needs much more ground work to improve the data quality, the addition of a feedback mechanism to show the adverse effects of resource over-utilization is valuable when judging the results of different modelling options.

An important and unique feature of this research is that the model was developed from, and applied to a region with cultural and land-use features not found elsewhere in Africa. The many links between permanent and shifting agriculture and pastoralism make land use patterns in the Fouta Djallon a challenge to model.
CHAPTER 3: DESCRIPTION OF SHIFTING AGRICULTURAL SYSTEMS IN AFRICA

Definitions

Shifting, rotational, swidden, or slash and burn cultivation are terms used interchangeably to describe an extensive land-use system common in several parts of the tropics. McGrath (1987) defines shifting cultivation as "a strategy of resource management in which fields are shifted in order to exploit the energy and nutrient capital of the natural vegetation-soil complex of the future garden sites". Types of systems range from those in which an entire village moves to a new locality once soils are exhausted, to those in which villagers living in permanent settlements use a fixed number of fields in rotation. Fallow type can be either grassland or bushland. Population densities associated with either kind of agriculture are generally low, in order for there to be enough land for a proportion of it to be left in fallow.

The main criterion used to distinguish shifting from sedentary agriculture is the length of fallow. Allan (1965) describes a land-use factor (L) used to differentiate the two agricultural types.

\[ L = \frac{(C+F)}{C} \]

where \( C \) = length of cultivation (yrs)
\( F \) = fallow (yrs)

Ruthenberg (1980) further defines a rotation intensity factor "R", which is the relationship between crop cultivation and fallow within the total length of one cycle of land utilization:

\[ R = \frac{100}{L} \]

Thus, R remains small for long periods of rotation. Larger R values...
indicate stationary farming practices. In fact, values greater than 33 generally indicate that shifting cultivation is replaced by sedentary agriculture.

Two Differing Viewpoints on the Justification for Shifting Cultivation

The traditional justification for shifting cultivation over permanent agriculture is based upon the lower labor required for a given yield. Although shifting agriculture of cereal crops may not yield as much financial return as commercial crop production, it is often the only economically feasible alternative for the farmer living at the subsistence level. Okigbo (1981) claims the bush fallow practice can be an ecologically sound and efficient use of a renewable natural resource - the soil/vegetation complex. Others (Nye and Greenland, 1960; Jurion and Henry, 1967) note that land managers have failed to evolve a superior method of staple food production in the tropics.

A differing view is offered by McGrath (1987), who states that the above arguments do not take into account the energy content of the natural vegetation cleared and burned to prepare the new field for cultivation. The fact that the soil-vegetation complex is being used to replace human labor usually is ignored. In McGrath's interpretation, biomass is a variable which the cultivator manipulates to meet his needs. Biomass serves as an input to the production process as a substitute for fertilizer and pesticide. When the energy value of removed biomass is taken into
consideration, shifting cultivation is just as energy-demanding as modern mechanized agriculture. McGrath concludes that tropical forests should not be considered as a renewable natural resource, if the resource is being used up at a faster rate than it is being produced. Although forests traditionally are considered a renewable resource, there is an element of truth in his arguments given the loss of species diversity from shifting cultivation.

The Process Described

Shifting cultivation involves a sequence of carefully timed activities: site selection, clearing to open field, burning to eliminate vegetation, planting, weeding, harvesting, and returning to fallow (Peters and Neuenschwander, 1988).

Site Selection

Factors influencing site selection include soil fertility, age of fallow, slope, aspect, distance to living quarters, topography, land tenure, and access. The maturity of the vegetation cover also plays a major role in determining the amount of labor required to open a new site. Cultivators often prefer to clear secondary regrowth rather than virgin forest, because it requires less labor (FAO Forestry Department, 1984).

Removal of Vegetation

Clearing can remove all or part of the vegetation, depending on shading requirements for the crop and competition from non-
desirable plants. Trees having medicinal or other values often are not cleared. In case a demand for forest products exists, the farmer will remove the valuable logs and poles and transport them to local markets.

The Role of Fire

Fire is the simplest means of clearing slash to increase the planting area. It destroys weeds and seeds of competing vegetation, and opens ground for hunting. Within the system, fire is thus the "great economizer of energy" (Peters and Neuenschwander, 1988), as the number of human work hours for preparing and lighting fire are insignificant compared to other phases of the cycle. Indeed, the use of fire is part of the economic justification for practicing shifting agriculture.

Burning is the quickest method to promote rapid turnover of nutrients in the shifting cultivation system. Sabhasri (1978) estimated that 3 years of natural decomposition would be required to release the same amount of nutrients in a single burn. In general, the basic cations magnesium, calcium, and potassium increase after a burn. The trend for phosphorus is more complex, as availability depends on soil acidity (Peters and Neuenschwander, 1988).

Fire temperature also affects nutrient availability. A 200°C fire can be beneficial, but above 400°C effects are negative as organic matter is destroyed, cation exchange capacity is reduced and nutrients lost (Peters and Neuenschwander, 1988).

The large stock of nutrients present in the ash after burning
is susceptible to removal from wind or water erosion during torrential storms at the beginning of the wet season. The most critical period occurs before crops establish leaf cover (Heermans and Williams, 1988; Roose, 1977).

Planting and Maintenance

Planting and weeding of cereal crops in the traditional bush/fallow systems in West Africa are performed manually, or with animal traction. Duration of cultivation normally lasts for two or three years, which coincides with a decrease in soil fertility or an increase in competition from undesirable plants. Traditional methods tend to disrupt the soil cover less than modern, mechanized techniques.

Site Abandonment and Fallow

Fallow periods in Africa vary greatly by region, prevalent crop type, population density, and site productivity. Traditional fallow periods in the highlands of Guinea range from 15 to 25 years in bush/fallow types, and 5 to 8 years in grass fallow types (MacGahuey, 1985; Heermans and Williams, 1988). Chidumayo (1987) reports similar periods for the bush/fallow systems of Northern Zambia. In both cases, current fallow periods are being decreased by a factor of 50% or more.

Critical Population Density in Shifting Cultivation Systems

Ruthenberg (1980) claims shifting cultivation can support a
maximum of 56 persons/km$^2$, assuming an even use of land, a ratio of 3 crop years to 15 years fallow, and 0.3 ha. of crops/person.

Chidumayo (1987) describes the "chitemene" system of Northern Zambia and methods for estimating a critical population density. "Chitemene" fields consist of a large "outfield" plot which is cleared of vegetation. The smaller and medium tree branches are stacked and burned in a smaller subsection of the outfield called an "infield" within which ashes are concentrated. High nutrient demanding crops such as finger millet can then be cultivated in the infield area.

A critical population level that "chitemene" lands can support has been derived using a simple formula based on the minimum area required to support one person for one year and knowledge of certain environmental factors (Chidumayo, 1987).

$$CPD = \frac{100}{Cp} \times Ca \times L$$

where $CPD$ = Critical Population Density (# persons/km$^2$),
$Cp$ = % of territory arable
$Ca$ = minimum area to support one person/yr

and $L = \frac{R}{U} + 1$
where $L$ = # plots for a proper fallow ratio
$R$ = # years fallow
$U$ = # years of successive use

From a study site in Zambia, with $U = 1$ under normal use, and $R = 25$, Chidumayo (1987) calculated a CPD of 41.5. The actual population density in 1980 was 71.4 persons/km$^2$, or 171% of CPD.

High population density can lead to rural exodus, increased cropping period or decreased fallow, or a change from shifting to
permanent agriculture. A regional example of population migration is from the sub-humid and Sahel regions of Africa to the humid forest zones.

Environmental Degradation Resulting from Shifting Cultivation

Several studies have shown how the soil-vegetation complex can be degraded through an intensification of shifting cultivation.

Watershed Condition and Erosion

Sanchez (1976) and Annersten (1988) state that the effect of canopy removal in a tropical forest is equivalent to a drastic increase in precipitation in terms of erosion. Ash remaining after a clearing fire will clog pores and decrease infiltration with a consequent increase in runoff and erosion. If the litter layer is removed during burning, raindrop impact effects can be severe.

Serious cases of soil erosion on a local scale are usually due more to the extreme intensity of rainfall during critical periods rather than to soil erodibility. Vegetation cover is the major determining factor. When vegetation cover is lacking, other factors such as slope, cultural practices, and anti-erosion measures become important.

Roose (1977) found that sheet erosion plays a major role in the degradation of tropical soils in the African peneplains, similar to those found in much of West Africa. Based on over twenty years of observation, he concluded that because tropical soils concentrate nutrient wealth in topsoil, sheet erosion is more of a hazard than
for soils in cooler climates.

Different systems of shifting agriculture have different responses to erosion. Maintaining some plant cover during clearing minimizes soil erosion. Systems producing only one cereal crop tend to require a complete clearing and burning, leading to greater soil exposure and disturbance than multicrop systems which generally do not leave the soil exposed.

Degradation of Vegetation Cover

The composition and rate of secondary succession depends on whether the clearing is made in a primary forest or a secondary forest. Other factors include slope, use of fire, type of cultivation, etc.

The timing of fire application after clearing plays an important role. In vegetation associations characterized by coppice regeneration, a delayed fire can kill resprouts and retard the re-establishment of cover. Other studies (Peters and Neuenschwander, 1988) have shown that fire eliminates a considerable percentage of seed stored in the soil; this is actually one of the reasons why fire is used. Thus, the intensity of the burn and proximity to a seed source become factors in succession.

Reduction of gene pool: Diversity characterizes most tropical forests. Certain tree species can be found in low density, but have a high occurrence within sample plots (Mueller-Dombois, 1981). Such a spatial relationship hampers the reestablishment of certain forest species. If the seedlings of these rare trees are destroyed and no
primary forest exists next to the fallow site, the species could disappear from the environment. Peters and Neuenschwander (1988) note that fire has influenced the conversion of forest to savanna by reducing the genetic stock. However, frequent non-cultivation fires tend to be more severe than infrequent shifting cultivation fires.

**Loss of wildlife habitat:** Concurrent with the loss of diversity and degradation of the structure of the vegetation cover is the disappearance of many faunal species found only in tropical environments. Local officials in the Guinea Highlands (Under Prefect, Bantinel District, (Pita Prefectship), pers. comm.) complained of the virtual elimination of traditional game species through hunting and habitat destruction. It is probable that certain species will become extinct without ever being studied by the scientific community.

**Loss of soil fertility:** Ruthenberg (1980) noted that the yield of the soil drops with the number of cultivation years and recovers in the fallow period. With a high R factor, the fallow is no longer sufficient to restore soil productivity and the yields per hectare fall. This shortening of the fallow is accompanied by an increase in the total area cultivated if production levels are to be maintained. The result is a downward spiral of resource degradation.
CHAPTER 4: STUDY AREA DESCRIPTION

Physical Description

The Fouta Djallon, the central mountain range of the Guinea highlands (Figure 1), gives rise to most of the major rivers that deliver water to the Sahelian Zone of West Africa. Because changes in land use and deforestation in the Fouta Djallon will have profound effects on the flow regimes of rivers that support agriculture, transportation, and energy needs throughout the Sahel, the management of lands within these headwaters is of regional importance. Downstream countries potentially affected by land degradation in the Fouta Djallon include Guinea-Bissau, The Gambia, Senegal, Mali, Mauritania, Niger, and Nigeria (Varady, 1983).

Guinea possesses a tropical climate in which variation is due to the migration of a discontinuous front known as the Inter-Tropical Convergence Zone. The rainy season occurs between May and October, while the remainder of the year is typically dry. Annual rainfall in the Fouta Djallon averages between 1600 and 2000 mm., although Isbecque (1985) reports an approximate decline of 300 mm. over a 15 year period, beginning in 1970.

Site Characteristics

The following geographic description of the study site is drawn from a variety of references as well as the author's field work during three visits to the area in 1989 and 1990.

The study area consists of the Diafore watershed located
FIGURE 1: LOCATION OF DIAFORE STUDY SITE AND FOUTA DJALLON MOUNTAIN RANGE (CROSS-HATCHED)
within the Tougue District, which is on the gently sloping eastern face of the Fouta Djallon (Figure 2). It is located between 12° 25' and 12° 45' North, and 11° 20' and 11° 45' West. The Diafore watershed has an area of 60 km².

The Diafore basin does not exhibit exceptional relief common to other areas in the Fouta Djallon, with local topography ranging from 600 to 875 meters above sea level. The region is composed mostly of sandstones, which developed into rich, but easily eroded soils (Heermans and Williams, 1988).

The main control on both human population and vegetation distribution is the presence of deeply dissected laterite plateaus (Figure 3), which are either barren or veneered by a thin soil layer supporting a sparse woodland. These surfaces play a major role in the agro-ecological system and in the evolution of the landscape: they determine water flow, percolation, ground water dynamics, soil fauna, and have an effect on the local climate (Pascual, 1986). Local people generally do not settle on bare laterite because there is no possibility of growing crops.

The Diafore landscape also is characterized by a dense stream network associated with multi-tiered gallery forests in the bottomlands. A dry woodland is found on slopes¹, with the density and height of the vegetation canopy a function of the most recent agricultural clearing.

¹. The term "slope" is a direct translation of versant which French geographers use to describe this landscape unit.
FIGURE 2: DIAFORE VILLAGE LOCATION MAP
FIGURE 3: LATERITE PLATEAU (BOWE)

FIGURE 4: HOME GARDEN IN KOUNE VILLAGE
The Diafore basin receives about 1500 mm. annual precipitation, which is 200-300 mm/yr less rainfall than other parts of the Fouta Djallon to the south and west. Local farmers complain of a downward trend in precipitation (Heermans and Williams, 1988).

Vegetation Associations

Gupta (1987) claims that the Fouta Djallon was once covered with a dense forest of Parinari excelsa that has been degraded due to anthropogenic causes in recent years. Jean (1990a) reported that only 800,000 ha of forest remain in Middle Guinea (13.4% of its surface area), which is the administrative district encompassing most of the Fouta Djallon mountain range. Of this total, only 50,000 ha are dense primary forest. These resources are barely enough at present to meet the local populations' needs in lumber and fuelwood.

Dominant local woody species still found in the Diafore basin are Parkia biglobosa, Holorrhena africana, Parinari excelsa, Erythrophleus guineensis, Butyrospermum parkii, and Prosopis africana (Kelleher et al., 1990). The Diafore Basin is noticeably drier than other parts of the Fouta Djallon to the south and west, and has more Sahelian species such as baobab (Adansonia digitata).

Water Resources

The Diafore River has intermittent flow, breaking up into a series of stagnant ponds in the dry season. These ponds are used
for human and animal drinking water, irrigation, and washing. The author's interviews with villagers revealed that one source had begun to go dry beginning in the 1980s. This change in water availability coincided with the clearing of vegetation around the headwaters to plant local rice. Villagers since have banned clearing above this spring. Wells are found within permanent home gardens, with 94 total for the entire watershed (Kelleher et al., 1990).

Pedo-Morphological Units

Gupta (1987) describes the zone around Tougue as being dominated by dolerite (diabase), which is one of the principal basic igneous rock types (Williams et al., 1954). Although no soil map has been produced at a scale larger than 1:250,000, local inhabitants recognize pedo-morphological units by their production potential. A description of these units is given using the local tribal (Fulani) name (adapted from Gupta, 1987):

**Hansangere**: This unit generally is found on hills or slopes. Its soils are derived from transported materials from mountain slopes, cliffs, or rock slides. Soils are heterogenous, with elements ranging in size from large sandstone boulders to fine clays. This unit is common on the valley walls of the Diafore basin.

**Ndantari**: This unit is characterized by its accumulated soils at the base of slopes. Ndantari soils are finer, more compact and more homogenous than hansangere soils, and are generally silica-clay
dominated. They usually have lower infiltration rates and are workable but prone to acidification. Ndantari soils are rare in the Diafore basin.

Dounkire: These are hydromorphic soils in alluvial flood plains, which receive annual deposits of clay, silt, and fine sand. They remain moist throughout the year. Dounkire soils offer the best possibility for increases in agricultural production, but land ownership problems must be settled before improvements are made. A discussion of how traditional land ownership rights are conflicting with bottom land development is given in the following section.

Hollande: These units are found in the plain. The soils can be shallow and are saturated sometimes during the rainy season, but do not remain moist throughout the year as do dounkire soils.

Suunture: These are not true pedo-morphological units, rather the term is used to describe the permanent garden surrounding the living quarters. Fresh inputs of organic matter are added to the soils throughout the year to maintain soil fertility.

Bowe (singular bowal): These are bare laterite crusts (ironstone hardpan is another term invariably used) with little or no "A" horizon development in the soil profile. The skeletal soils support scanty woody growth, however a grass cover does appear during the rainy season. Although not suitable for cultivation, bowe provide pasture during and immediately after the rains.

The predominance of bowe in the Diafore basin is characteristic of the Tougue region and is the reason for its selection as a pilot watershed management study supported by USAID.
Population

The area was settled by tribes of Fulani immigrants from the Sahel about 350 years ago. Early researchers (Tricart, 1956; Richard-Molard, 1949) stated that the Fulani were attracted by the extensive bove for pasture for their herds. Today, they remain dependent on their livestock, however, sedentary farming now constitutes a major livelihood in the region.

The Fouta Djallon is the most densely populated region of Guinea outside the capital of Conakry. The overall population density is 66 persons per square kilometer. There is, however, great variation in population density both between urban and rural areas and among rural areas differentiated by their dominant pedo-morphological characteristics. Rural populations are densest in the central plateau areas most suited to traditional farming.

The total 1990 population in the Diafore Basin was estimated at 1805 with a density of 30 inhabitants per square mile (Kelleher et al., 1990). Given an earlier estimate of 1511 inhabitants in 1985 (Boulet and Talineau, 1986), a growth rate of 3.5% per annum is suggested.

Rural Exodus

The emigration of young men from the Fouta Djallon dates back to colonial times, when men left their villages in search of employment to earn cash to pay French taxes. Now, it is common for young men to go abroad or to urban areas in search of adventure and cash paying employment. Many return for visits during the dry
season when roads are passable, but leave again before the heavy work begins in the next rainy season (Gaudreau et al., 1990).

This customary exodus of young men was exacerbated by the flight of refugees from the Fouta Djallon during the First Republic (1958 - 1984). Although many are now returning, they tend to return to urban centers rather than to their original villages.

The exodus limits the agricultural labor force and results in the "feminization" of the rural areas. A survey of four villages in Labe found 40 - 61% of adult males absent in March, the period for clearing fields, preparing land, and repairing fences. Most go to the cities. There also is considerable seasonal migration to the peanut raising areas of Senegal (Gaudreau et al., 1990).

Many men do return after years abroad, but by then they are approaching retirement. Thus, agriculture is disproportionately in the hands of women and old men. Some of those who return from abroad bring financial resources and innovative ideas for development, but the actual strength of youthful "manpower" remains lacking.

Social Structure and Land Tenure

Traditional land ownership in the Fouta Djallon was developed under a quasi-feudal social structure dating from the Fulani displacement of local tribes. Four status levels ranging from chieftain to serf evolved which determined land allocation and privileges (Gaudreau et al., 1990). The chieftain class would grant use of lands, particularly bottom lands which were perceived as
being non-desirable, to members of the serf class. In return, the recipients might offer symbolic gestures such as kola nuts, or a percentage of harvest or livestock, to their masters (Jean, 1990a). Upon the master's death, land would be sub-divided among his sons.

In 1958, the new socialist government under Sekou Toure claimed legal title to all land, but people generally continued to use land according to old claims. Landless serfs did gain the possibility of acquiring rights to land they had traditionally farmed. Conflicts were settled by a council of village elders or some similar local authority.

With the implantation of regional and local government decision makers, the problem of land tenure resolution became more complex. Recently, traditional land owners have attempted to reclaim their traditional bottomlands as their value has increased (Jean, 1990a). Other conflicts have arisen between the determination of the extent of traditional village domains and government delineated territorial boundaries. The resolution of these issues will be the cornerstone of successful rural land management.

**Land Use Patterns**

Traditional agriculture in the region is complex and utilizes each landscape element. The permanent agricultural unit is the home garden, a small field of about 0.5 hectares surrounding the living quarters (Figure 4, page 45). Although not always true in other areas of the Fouta Djallon, home gardens in the Diafore basin are
interspersed with gallery forests in the fertile bottomlands. Maize, taro, sweet potatoes, okra, beans, hot peppers, tomatoes, and spinach are planted yearly. Fruit trees such as oranges, bananas, and avocados are also cultivated. Brush fences surround each garden to prevent entry of domestic or wild animals. The wood for these fences is gathered yearly from surrounding forests which contributes to deforestation.

Home gardens are the nucleus of the family unit defined by a household head, wife, and four children. Polygamy is common, although traditionally the man must provide each wife with her own living quarters and garden. Each unit has an average of 3 cows and 4 sheep or goats. Cultivation within the home garden is strictly a woman's duty, whereas the man is responsible for the maintenance of the surrounding fence.

Shifting cultivation is practiced in "exterior fields" (exterior to the home garden) on wooded slopes which comprise the secondary agricultural unit (Figure 5). Individual families or entire villages may cultivate a piece of land for two or three years or until yields begin to decline significantly. Generally, slopes are planted with mountain rice in the first year and with a cereal crop, *fonio* (*Digitaria exilis*) in the second year. Until recently, normal fallow periods were typically between ten and fifteen years (Heermans and Williams, 1988; MacGahuey, 1985).

Livestock production forms the other major base of the Fouta Djallon agricultural system. During and after the rainy season, cattle graze the laterite plateaus (*bowe*) where forage is locally
FIGURE 5: DEFORESTED SLOPE USED FOR SHIFTING AGRICULTURE
abundant. In the dry season, when range forage is depleted, the cattle are returned to the vicinity of the home garden where their manure revitalizes the soil.

Environmental Degradation

Different opinions exist as to the current rate of soil loss, deforestation, and laterization in the Fouta Djallon. Jean (1990b) states that land degradation is in its advanced stages as the region has been subjected to intensive land use for longer periods of time. The major causes have been: 1) high population density, 2) resource over-utilization, 3) vegetation clearing on steep slopes, 4) brush fires, and 5) over and selective grazing. Richard-Molard (1949) described the region as being overpopulated, and even in 1821 as being deforested and consequently converted to laterite. Thus, it has been asserted for some time that erosion problems in the Fouta Djallon are serious and constitute a regional hazard.

Recently, however, it has been argued that current erosion rates are only part of the geological processes responsible for shaping current topography in the Fouta Djallon (Boulet and Talineau, 1986). Hesch (1985), suggests current erosion problems in the Fouta Djallon are significant only on a local level, and do not extend to the entire watershed or the larger West African region. Unfortunately, because no long-term studies have been undertaken, most hypotheses are based on a limited set of observations. Most observers do agree that the greatest danger of soil erosion is immediately prior to planting when unprotected soils are most
erodible and the heaviest rains occur (Pascual, 1986). Brush fires, set by local farmers to clear fields for shifting cultivation, can also escape and destroy organic material contained in the surface soil horizon.

Due to the physical limits on the amount of arable land, the growth of permanent agricultural (i.e. that enclosed in home gardens) land has not kept pace with the expanding population within the region (Richard-Molard, 1949; Boulet and Talineau, 1986). Thus, to increase total production, villagers must intensify cultivation on valley slopes in two ways. One way is to shorten the rotation in shifting agriculture. This leads to a loss of soil fertility and consequent decline in yield. The other way is to establish new permanent home gardens on the lower portion of valley slopes just above the crowded bottomlands (Figure 6). However, these soils generally are shallower, rockier and require more fertilizer inputs than traditional bottomland home gardens.

Several researchers feel that the major problem in the Fouta is not erosion at all, but a loss in soil fertility due to an increase in human population and the consequent shortening of the fallow period in the shifting agricultural rotation (Pascual, 1986). In certain areas, fallow periods have been shortened from 9-15 years to 5-7 years (Heermans and Williams, 1988). As a consequence, crop yields have declined as traditional methods of insuring soil fertility have lapsed. A decrease in fallow periods also leads to a depletion of floral and faunal diversity, as many species require the complex structure of a mature forest for adequate habitat.
FIGURE 6: HOME GARDEN ON SLOPES (KOURATONGOU VILLAGE)
Erosion and Landscape Change

Bowe genesis: The process of bowe formation varies throughout West Africa, however, it can be described in general terms (Gupta, 1987). A zone of concretization is found in the subsoil, at a level corresponding to the site of mineral deposition during seasonal, vertical movement of solutes in the soil column. They are formed in the illuvial horizon, where iron compounds accumulate and harden during seasonal wet and dry periods. When, for whatever reason, the topsoil disappears, this zone of accumulation hardens and becomes ironstone. Gupta claims that the remaining topsoil is less able to support vegetation which in turn increases erosion hazard. This cyclical process gives rise to the bowal. Because bowe support little vegetation, local runoff can be substantial and increase flooding and erosion (Kelleher et al., 1990).

Erosional Processes

Vertical erosion: This process is responsible for the loss of soil fertility on over-used agricultural sites. The soil structure changes as valuable minerals are leached to subsoil horizons and beyond the root extraction zone. The phenomena is most common on highly permeable, sandy clay soils, where clay particles are washed downward to deeper horizons, leaving a sandier, and more porous topsoil.

Sheet erosion: This form of erosion is most commonly cited as one of the principal causes of soil loss in the Fouta Djallon. Thin layers of topsoil are dislodged and washed away by unimpeded
rainfall. In the Fouta, soils are at greatest risk in exterior fields which have been recently cleared and planted. Major rainfall events (as many as three or four) before the vegetation cover can be re-established are the major cause of sheet erosion.

**Gully erosion:** Found on steep slopes cleared for farming, this type of erosion is more spectacular, but fortunately not as common in the Fouta Djallon as other parts of Africa (Gilruth, pers. obs.).

**Future Status**

The general consensus is that the Fouta Djallon is not threatened by an extensive deforestation like that in the Amazon Basin, rather, observers point to a more subtle land degradation that jeopardizes the productivity and quality of life of the Fouta's inhabitants. In particular, the vertical erosion of critical soil elements represents the greatest threat to local agricultural production in the home gardens.

The issue of erosion and its consequences for downstream populations still has regional importance. Although the fear of flooding and dam siltation in neighboring countries has been the driving force behind much of the research and conservation efforts in the Fouta Djallon, no consensus has yet been achieved as to the level of risk involved.

Recently, the Fouta Djallon has been suffering from an exodus of its labor force (males aged 15 to 45), which places a major constraint on intensification of land use. Some observers (Jean,
pers. comm.) believe that degradation in the Fouta Djallon will stabilize because a part of the population is migrating to urban areas. The future status of this region is the subject of on-going debate.
CHAPTER 5: METHODS

Data Collection

Topographic Maps

The Fouta Djallon is not well mapped. The few thematic maps that do exist for the region are at scales smaller than 1:1,000,000 and were not useful. The base map for the study was a 1:250,000 U.S. Army Mapping Service (AMS) topographic map, which showed major errors in hydrography, but no other source was available. No maps were found in Guinea that offered improved scale or accuracy.

Remote Sensing Data (Table 1)

Landsat Multispectral Scanner Data (MSS) were obtained for 1973 and 1985. These data were used for location purposes in the initial registration of the aerial photo maps, because they offered better ground control than the topographic maps themselves. They were not used to develop or test the model because of the impossibility of distinguishing the same land use classes visible on the air photos due to the spatial and spectral limitations of the Landsat system.

Black and white aerial mapping photography was acquired by the French Institut Geographique National in 1953. Although old and frayed through use, these photos allowed identification of agricultural classes. A total of 17 photos were interpreted for land use and erosion status at a scale of 1:50,000.

Both black and white and color infrared 1:30,000 aerial
<table>
<thead>
<tr>
<th>DATE</th>
<th>SENSOR</th>
<th>FORMAT</th>
<th>SCALE AT INTERPRETATION (SPATIAL RESOLUTION)</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARCH, 1953</td>
<td>AERIAL CAMERA</td>
<td>9&quot;X 9&quot; B &amp; W PRINTS</td>
<td>1:50,000</td>
<td>NATIONAL DIRECTION OF FORESTRY AND HUNTING, CONAKRY, GUINEA</td>
</tr>
<tr>
<td>MARCH 7, 1973</td>
<td>LANDSAT MSS</td>
<td>COMPUTER COMPATIBLE TAPE</td>
<td>1:40,000</td>
<td>EOSAT/EROS DATA CENTER</td>
</tr>
<tr>
<td>APRIL 15, 1985</td>
<td>LANDSAT MSS</td>
<td>COMPUTER COMPATIBLE TAPE</td>
<td>1:40,000 to 1:125,000 (79m)</td>
<td>EOSAT/EROS DATA CENTER</td>
</tr>
<tr>
<td>APRIL, 1989</td>
<td>AERIAL CAMERA</td>
<td>11&quot; X 11&quot; B &amp; W AND COLOR IR PRINTS</td>
<td>1:30,000</td>
<td>HZ AERIAL SURVEY AND MAPPING COMPANY, CONAKRY, GUINEA</td>
</tr>
<tr>
<td>MAY 31, 1989</td>
<td>AERIAL CAMERA</td>
<td>35MM COLOR SLIDES</td>
<td>1:20,000</td>
<td>ARIZONA REMOTE SENSING CENTER, TUCSON AZ</td>
</tr>
<tr>
<td>MAY 31, 1989</td>
<td>VIDEO CAMERA</td>
<td>780 X 488 PIXEL VHS IMAGE</td>
<td>1:6,000 (4m)</td>
<td>ARIZONA REMOTE SENSING CENTER, TUCSON AZ</td>
</tr>
</tbody>
</table>
mapping photography were acquired by HZ Aerial Survey and Mapping, Inc., under contract with the Government of Guinea (GOG) in April, 1989. The purpose of this mission was to create large scale topographic maps for an integrated development project in the Diafore basin. These data were interpreted for land use.

On May 31, 1989, the author, with logistic support from the GOG, rented a twin engine Piper Aztec airplane equipped with a belly port for collecting data for the deforestation monitoring study. A makeshift platform was mounted in the belly port to hold a Canon AE-1 35 mm. camera loaded with Kodachrome 100 and Ektachrome HC 100+ 35 mm. color slide film. At an altitude of 2000 meters above ground level, with a 28 mm. lens, a contact scale of 1:70,000 was obtained.

On the same platform, a bi-spectral video camera (Hutchinson et al., 1990) was mounted next to the 35 mm. camera. Although the noise level within the system did not allow the use of the system for location purposes during the flight, the video data were useful in the laboratory for photointerpretation and land cover classification.

Field Data Collection

Two days after the aerial survey was completed, the author and a GOG Ministry of Forestry official team spent a week at the Diafore site to gather ground data. Before departure, potential sites were selected and located on the photomap based on analysis of the 1953 and 1989 HZ air photos. Unfortunately, it was not possible to use our own remote sensing data at that time due to logistical problems.
Twenty-five sites were visited, based on their representation of land cover/use units interpreted on the photos or depending whether the site showed change in forest or agricultural extent from 1953 to 1989. In addition, a brief description of the tone/texture seen on the 1985 Landsat MSS image was included. At each site, general observations included slope, general soil characteristics, an estimate of percent canopy cover at shoulder height or above, land use, and any other salient characteristics. Color slides were taken in each cardinal direction and annotated with descriptions of the landscape. Summaries of observations were made daily.

A rural development office in the regional capital Labe (Projet Integre d'Amenagement du Fouta Djallon) housed a small library of reports, books, and a few thematic maps of the Fouta Djallon. These sources provided general historical information about land use change, population patterns, erosion hazards and types, and a brief socio-economic description. Finally, an overview of the geomorphology was noted for background information.

Data Interpretation

Definition of Land-use Classes

Land use classes mapped were: (1) permanent agriculture; (2) shifting agriculture; (3) bare laterite plateau; (4) gallery or riparian forest; and, (5) a variously vegetated slope class dominated by a mixed tree savanna or brush. Examples of these units are seen in Figures 7 and 8. From the 1989 photography and video imagery, it also was possible to identify two subclasses of
FIGURE 7: AIR PHOTO SHOWING LAND COVER CLASSES: 
A: HOME GARDENS  B: LATERITE PLATEAU  C: SHIFTING 
AGRICULTURE  D: VEGETATED SLOPE  E: GALLERY FOREST

FIGURE 8: BI-SPECTRAL VIDEO IMAGE COLLECTED SIMULTANEOUSLY WITH FIGURE 7.
vegetated slopes and shifting cultivation showing signs of active erosion (Figure 9). These classes were derived from analysis of photography, discussions with GOG Ministry of Forestry staff, and site visits.

Permanent agricultural units (home gardens), defined in the project area description, were easy to identify. Key signs included irregular honeycomb-shaped features interlaced with prominent fences constructed of live or dead brush. Groupings of several home garden units form villages, which in the Diafore region are found in bottomlands on alluvial soils. Because all photography was acquired in the dry season, only crop residue remained in the fields.

Rectilinear cuttings into the forested slopes were interpreted as shifting cultivation. This class is characterized by large, isolated trees left standing after slash is cleared for planting. Fallow fields of one or two years were discernible sometimes, but were not included in this class; only active fields were mapped.

Exposed laterite plateaus (bowe) typically were devoid of woody vegetation and easily interpreted as medium gray tones (on black and white photography) or dull reddish hues (on color photography) with a smooth texture. Forest cover was differentiated by density and size of tree crown. Due to the small scale of the 1953 photographs, only large stands of gallery forests were identified, however, a thin ribbon of large trees not shown on the 1953 photomap did border the Diafore river. This class is characterized by dark tones and a rough texture. On the larger-scale 1989 photography, the band of forest along rivers was
FIGURE 9: AIR PHOTO SHOWING ERODED AREAS
delineated in addition to the larger stands. Therefore, the 1989 estimate for gallery forest area was greater than that of 1953.

The vegetated slope class is a dry forest characterized by medium gray tones and a rough texture on the black and white mapping photography. Fallow fields were included in this class.

Eroded subclasses were identified by the accumulation of light-colored sediments at the foot of slopes or on the slope itself. Thus, the eroded secondary agriculture became a third agricultural class.

**GIS Database Creation**

**Air Photo Map Digitizing**

Seventeen aerial photos from 1953 were interpreted manually for land-use with a mirror stereoscope and delineated on plastic overlays. The land-use overlays were assembled in a single map and digitized into the Earth Resources Laboratory Application Software (ELAS) at the NASA Stennis Space Center in Mississippi. The photomap could not be registered to the best available topographic map (1:250,000 AMS) because of scale differences and the poor quality of the topographic base map.

Instead, the 1985 Landsat MSS image was registered to the U.S. Army map and served as a reference base. The purpose of this step was to provide the satellite image with the Universal Transverse Mercator (UTM) coordinate system. Next, the 1953 photomap was registered to the satellite image. The ELAS map then was converted to ERDAS (ERDAS, 1990) at the University of Arizona and vectorized
The 1989 map used for change detection was produced through the combined interpretation of the aerial 35mm and video imagery, with interpolated interpretations from the HZ photos on areas not covered during the ARSC aerial survey. The HZ photos were interpreted first and used as a template upon which the ARSC data interpretations were transferred with a reflecting projector. The resultant land use map (Gilruth et al., 1990) was registered to the 1985 Landsat reference image and digitized into the pcARC/INFO database. As a final step, all vector coverages were rasterized to a 50m$^2$ cell size, which corresponds to the smallest mapping element equivalent to an isolated permanent home garden.

Derivation of Digital Elevation Model (DEM)

Elevation data for the Diafore basin were supplied by HZ Aerial Survey Company. The file consisted of 17,637 random UTM Easting, Northing, and altitude data points covering the entire watershed. Hard break lines and soft break lines (local maxima or minima corresponding to hill crests or stream channels) were included.

SURFER software (Golden Software Inc., 1990) was used to interpolate a topographic surface. Grid cells were set at 50m$^2$, yielding a matrix of 237 rows by 199 columns. Duplicate data points were dropped from the set. A Kriging option was selected (Jones et al., 1986) using a quadrant search for the nearest 10 points for interpolation.
For slope map generation and display purposes, the SURFER file was converted to a raster format that could be displayed using IDRISI (Eastman, 1990) software. A BASIC program was written by Jiang Li of the University of Arizona Remote Sensing Center to perform this task. The IDRISI modules were used to generate slope maps and drapes of land use maps on the DEM. The final slope map was reclassified to low (0 - 5%), moderate (5 - 15%), and high (15 - 90%) slope.

Co-registration of Data Layers

The hard break lines, which were draped over the DEM to improve visual interpretation, were used to define 25 control points also visible on the air photo maps. After converting the IDRISI files to ERDAS compatible files, a first order polynomial was chosen to transform the file coordinates from the land use map to those of the break lines draped on the DEM. The root mean square error (RMS) was 1.65, but all 25 control points were maintained for the rectification process because the deletion of any single control point was not accompanied by a substantial drop in the RMS error. Resampling was performed with a nearest neighbor algorithm. The rectified land use maps were clipped to cover the geographic extent of the DEM data, yielding co-registered maps of 220 rows and 192 columns of 50m² cells. The DEM data and rectified land use maps were reconverted to IDRISI format.
Model Description and Development

The simulation model consists of a batch file of commands using a Beta version of RMAP operators developed by Robert M. Itami\textsuperscript{2}, formerly of the University of Arizona. This software package is an improvement of C. Dana Tomlin's Map Analysis Package (Tomlin, 1986) in that it processes real number data and allows command line processing. An annotated version of batch files representing two full model iterations is provided in Appendix A.

The model development includes: 1) the derivation of the initial state, 2) a subroutine for simulating growth in permanent home garden sites, 3) a subroutine for developing a preference surface for shifting cultivation site selection, 4) an algorithm for selecting a given number of sites from the preference surface to be allocated to the next iteration's simulated landscape surface, and 5) a mechanism for updating the landscape with the changed land-use elements. Figure 10 presents a flow diagram of the model structure.

Initial State Input and Description

The initial state (Figure 10, Item 1) for which model time is set at zero, is simply the rasterized land use map derived from the earliest data set available, e.g. the 1953 aerial photography. Because of scale and data quality problems with the air photos, it

\textsuperscript{2}Copies of the RMAP modules can be obtained from R.M. Itami, School of Environment, University of Melbourne, Parkville, Victoria, 3052, Australia.
FIGURE 10: FLOW DIAGRAM FOR MODEL LOGIC
was not possible to interpret the narrow gallery forests that bordered the river channels, although these forests did exist. To compensate for this shortcoming in data quality, the gallery forest class polygons were extracted from the 1989 digital map and superimposed on the 1953 map in such a manner that the boundaries of the 1953 agricultural classes remained intact. This can be justified given that the 1989 polygons should represent the minimal extent of the forest class in 1953. Other classes include bowe, vegetated slope, permanent villages and shifting agriculture sites.

The initial state map was used to derive key GIS variables in the model, including:

1. Village locations from 1953 were extracted from the data set and placed into a separate map from which a proximity surface was generated.

2. Vegetated slope and shifting agricultural sites were extracted from the initial state to derive the clocks for the productivity and ease of clearing variables, and ultimately, the variables themselves. Both site productivity and labor are functions of the amount of time a field is left in fallow.

3. A counter variable was created to tabulate revisit frequency to monitor the number of times a site is cleared.

Sample Data Selection for Model Development and Testing

A sample data subset was chosen based on representation of spatial phenomena occurring throughout the watershed. A 120 by 120 cell matrix was selected around the Koune village and degraded to a 60 by 60 matrix using a pixel thinning operation in IDRISI which retained one in four cells. The purpose of degrading the data was
to decrease processing time and test the robustness of the model at different scales:

Village Growth Subroutine (Figure 10, Item 2)

A cursory analysis of the land use maps from 1953 and 1989 showed that the number of permanent home gardens had increased (Gilruth et al., 1990). This expansion occurred mostly in river bottoms and to a lesser extent on slopes next to pre-existing sites. There was a tendency to build new homes close to other units for two reasons. First, it was assumed that most of the fertile sites already had been occupied in 1953 (Richard-Molard, 1949). Logically, adjacent sites had the highest fertility of the remaining potential sites. Second, for social reasons, new families looking to establish a home prefer to remain close to their relatives living in neighboring compounds. The fact that villages mapped in 1953 had not moved by 1989 supported this conclusion.

Thus, the village growth subroutine constrained growth only to those cells found next to the previous year's village compounds and along river bottoms. For simplification, only those cells within a 250 meter distance were considered for the next iteration.

The sequential land use maps also showed that no growth occurred on bowe surfaces for reasons previously stated. This factor also was built into the model subroutine (Appendix A).

The critical operation in simulating village growth was performed by the RSPREAD operator in RMAP which measures the
shortest distance from source cell(s) on the raster map to a set of target cells (Itami, 1991). The RSPREAD operator uses the concept of the cellular automata described in Chapter Two.

A friction factor was generated with slope values derived from the DEM. The friction factor, in effect, sets the speed at which the distance measuring process (a cellular automata) moves across the surface. Steeper slopes increase the friction factor and slow the process.

The output surface from the RSPREAD operation represented those cells closest to streambeds and having moderate slope with the lowest values. Distant cells on steep slopes had the highest values. Cells with the lowest values were chosen first and added to the current year's map to represent growth.

The number of cells added at the end of each iteration was calculated from the growth rates in home garden area observed on the sequential aerial photography. This resulted in a 2.8% biennial growth rate.

Preference Surface Subroutine

This subroutine, which was the heart of the model (Figure 10, Items 3-12), assessed the potential of each raster cell to become an active shifting agricultural site. The method used the "hierarchical combination" approach to generate land suitability maps discussed by Hopkins (1977) and Diamond and Wright (1988). First, all factors that determine land suitability were grouped in
subsets according to their interdependence. Each subset then was rated for its composite suitability. Finally, different orders of subset combinations were valued in a hierarchical sequence until a rating was attained that included all relevant factors. The advantages of this combination method are: 1) no assumption of linearity between factors is made, 2) the user can apply his or her experience in the rating process, 3) it offers a more structured approach than a straight linear combination, and 4) the user is not required to evaluate all possible combinations of factors. The main disadvantage is that it requires extensive user knowledge of the study area and the occurrence and relative importance of each factor.

The hierarchical combination was implemented in this model by a series of two-way look-up-tables that assigned a suitability rating to each cell. Input to the look-up-table was the ranks from a pair of factors. The look-up-table function was performed by a customized cross-tabulation command within RMAP (Appendix A).

Variable Extraction

The first set of variables derived from the initial state was a pair of clocks (represented by maps) that recorded model time and were used to derive the variables for productivity and labor.

Clock for productivity variable (Figure 10, Item 3): The productivity "clock" was simply a GIS variable that acted as a timer to track site potential. During model development, all vegetated
slope cells were assumed to have been in fallow for 15 years, cited as the traditional fallow period (Heermans and Williams, 1988). Active shifting agriculture cells had clocks set to zero, and vegetated slope sites were assumed not to have been cultivated during the last 15 years, as no knowledge about the previous cultivation pattern was available. The impacts of this assumption on model results were eventually tested during model development. The time increment for each iteration of the clock was two years, which corresponded to the average cultivation period in the exterior fields.

Derivation of productivity variable (Figure 10, Item 4): Site productivity for shifting agriculture is directly influenced by forest age, composition and structure. After 10 years in fallow, the forest/woodland has attained secondary forest status (Diallo, I.K. pers. comm., Wilkie and Finn, 1988) and can be considered for cultivation, although longer fallow would further improve site productivity. Over 30 years of uninterrupted growth are required to reach mature forest status.

A major assumption in this model was that agricultural potential was directly proportional to the fallow period in the shifting cultivation sites. As the vegetation cover is reestablished, organic matter is replenished and soil structure improved. Thus, the number of years after a site is abandoned was used as an index for soil fertility.

To simplify analysis, all cells within the vegetated slope
class were considered potential sites having the same production potential and the same recovery rate after abandonment. The justification for this assumption is that cultivation of fonio is mostly practiced on the vegetated slopes (in the Diafore basin), much of which probably is hansangere land. With no soils data available, it was not possible to divide this class into productive or non-productive sub-classes. Thus, the number of potential sites was likely overestimated.

The productivity variable was derived directly from the productivity clock using a reclassification rule similar to a one-way look-up table. Sites in fallow for less than 4 years were given the worst relative ranking. The best rank was given to sites with over 20 years in fallow. The variable parameterization derived from the productivity clock was:

- Less than 4 yrs................................. 5
- 5 to 8 yrs................................. 4
- 9 to 13........................................... 3
- 14 to 20........................................ 2
- 21+........................................ 1

Clock for ease of clearing (labor) variable (Figure 10, Item 5): The derivation of this variable was similar in concept to the productivity clock previously described. Again, in the initial model development, all vegetated slope cells were assumed to have been in fallow for 15 years, and the clocks for actively cultivated cells were set to zero, with a two year time increment.

Derivation of ease of clearing variable (Figure 10, Item 6): The amount of labor required to prepare a new site depends on the
amount of above-ground biomass. Primary forests are hardest to clear because large boles and branches require additional effort to remove or burn. On the other hand, the woody products often have economic value that partially compensate the extra labor required to clear a mature stand of trees.

Competition from undesirable plants makes the first few years of cultivation labor intensive (Wilkie and Finn, 1988). Farmers are obliged to expend continued effort to clear recent fallow from invading grasses and weeds. This problem is accentuated during the second year, and some observers claim this to be a reason why cultivation of exterior fields is ceased after two years (Diallo, I.T., 1991, pers comm.). Thus, the variable parameterization derived from the ease of clearing clock was:

Less than 4 yrs, highest difficulty .................... 3
5 to 7 yrs or greater than 20 yrs, average difficulty .. 2
8 to 19 yrs, lowest difficulty .......................... 1

The ranks for the productivity and labor variables were input to a look-up-table to derive the combined rating for the two factors (Figure 10, Item 7; Appendix A). Figure 11 is a schematic representation of the process used to develop the productivity and labor preference surfaces.

Derivation of slope map (Figure 10, Item 8): IDRISI GIS modules were used to convert the elevation data into a slope map which was entered into the database. The slope map was recoded to derive an index for erosion hazard with ranks of low (0-5%), medium (5-15%) and high (greater than 15%).
FIGURE 11. DERIVATION OF PRODUCTIVITY AND LABOR PREFERENCE SURFACE
Bad data lines in the original DEM or slope maps were removed with an ERDAS line averaging module, using values borrowed from neighboring lines.

**Site proximity routine**: The purpose of this routine was to simulate the influence of village size (a proxy for population) on selection of shifting cultivation sites. Logically, large villages should have a greater influence on surrounding lands than smaller villages. The main assumptions here included: 1) sites closer to population centers have a greater probability of selection than more distant sites, if all other conditions are equal, and 2) cultivators return to their family compound at night, and do not set up temporary camps.

I.T. Diallo (1991 pers. comm.) stated that farmers may walk up to 5 km to reach a field, however, this willingness seems to vary with the farmer's social status and current needs. For instance, during a recent trip to the Fouta Djallon by the author (Gilruth, 1991), a local leader stated that 2 km was the maximum distance his family members travelled to outlying fields. However, given his high social standing, this probably should not be considered an average value.

Input to this routine was derived from cells representing village sites extracted from the initial state map (Figure 10, Item 9). The RSPREAD operator in RMAP was used to generate the proximity surface (Figure 10, Item 10).

A simple Euclidean distance measure was used to develop the
model initially. It represented the assumption that village size had no effect on site selection; only simple distance was the criterion.

A standard gravity model was tested to ascertain the influence of village size. This was implemented by 1) creating two separate distance surfaces from the large and small villages found in the study site, 2) multiplying the surface generated by the smaller village by a factor of two as its weight relative to the surface generated by the larger village, and 3) overlaying the two surfaces and reporting the smallest value of the two as output for each cell in a third layer.

Output from the proximity and slope preference surfaces was cross-tabulated to generate a composite rating (Figure 10, Item 11). This result was cross-tabulated with the combined labor and productivity rating to obtain a second order of combination (Figure 10, Item 12).

Final preference surface derivation (Figure 10, Item 13): Once all factors were input to the suitability map, the resultant map was analyzed for contiguity of favorable sites. A surface with values representing the size of clumps was generated and ranked for preference. This surface was cross-tabulated with the site preference surface (Appendix A) to obtain the final preference surface that includes all factors.
Site Allocation Routine (Figure 10, Item 14)

This final routine selected a predetermined number of cells from the above preference surface to be reassigned to the shifting agriculture class after each iteration. The number of cells was determined by rates derived from photointerpretation of historical data. These cells were removed from the vegetated slope class and recoded into the shifting cultivation class. The reassignment of land use classes generated a new, simulated land-use map that was input to the next iteration.

Because the number of cells in each preference group was unknown at the beginning of each iteration, an algorithm was written to choose the precise number of individual cells from within each preference class. This algorithm gave first preference to those cells found nearest to village sites. In essence, this was a refinement of the selection process described in the site preference routine.

The final criterion for selection used a unique number surface which acted as a final "tie breaker" so that each cell had its own individual rank.

In summary, the selection process had three criteria, listed below in order of relative importance:

1) cells were grouped according to preference for the four primary variables (distance, site potential, labor, and topography),

2) each of the above groups was considered for proximity to village sites as a secondary decision criterion, and
3) a unique number was assigned to each cell as the final decision criterion.

As part of the model testing procedure, described in the next chapter, the proximity algorithm and the unique number assignment function were varied to study their effect on model output. These tests are described in Chapter 6.

Mechanism for Updating Next Year's Simulated Landscape:

The cells selected for deforestation were added to the current year's surface using the RMAP COVER operator. This operator superimposed only those cells having non-zero values (e.g., shifting cultivation cells) on the map for the current model cycle (Figure 10, Item 15).

Before the next iteration was begun, those cells in the shifting cultivation class for the previous cycle were recoded back into the vegetated slope class as their fallow period began.

The number of cells to replace the previous year's shifting cultivation sites was calculated in a similar fashion to the village growth subroutine described previously. This analysis was hampered by the inability to adequately interpret the extent of shifting agriculture in 1953 due to the scale and poor quality of the photos (Gilruth et al., 1990). The authors identified 243 hectares of shifting cultivation and 292 hectares of permanent agriculture for the global data set in 1953. In the data subset centered around the village of Koune, 55 hectares of permanent agriculture (cells) and
no shifting cultivation cells were found. Since it was felt that the global count of shifting cultivation cells in 1953 was underestimated, a value inferred from the data was used for the number of cells for the initial model iteration. The justification for this assumption is that shifting cultivation around Koune village did occur in 1953, and the best method of assigning a value for this class should be derived from the data. Since the model was constrained to allocate the same number of shifting cultivation cells as were identified in 1989, this assumption has a limited effect on model results. By applying a ratio of \((243/292) \times 55 = x\), a starting value of 46 shifting cultivation cells was added to the initial iteration for 1953. Using this number of cells as a base, a simple biennial growth rate of 7.3% was calculated to yield the same number of cells for the model output as those found in 1989 (e.g., 165 cells). The number of cells to be added yearly into both the shifting agriculture and the permanent agriculture classes were calculated by hand and input through the DOS batch file mode using the replaceable parameter feature (Appendix B).

Test for Ability to Predict Erosion Zones (Figure 10, Item 16)

A simple test was devised to predict how well the model could predict those zones susceptible to erosion. A counter for the number of times each cell was cleared was updated at the end of each iteration. Cells tapped frequently for clearing were matched with those cells in the medium and high erosion hazard zones. The output
was compared with those cells interpreted for signs of erosion in 1989 to calculate the percentage of predicted cells that actually did show signs of erosion.

**Model Verification**

Model verification is the process of determining whether a simulation model performs as intended (Law and Kelton, 1982), and is usually associated with debugging the computer model and checking model logic.

The subroutines represented by the village growth, preference surface development, and site allocation were each written and tested separately. Once debugged, all routines were run together and a final debugging performed. A "tracing" technique was used from which interim maps were output during trial runs and checked to see if the program was running as expected.

Next, the program was reviewed by Robert M. Itami, the author of the RMAP software used to develop the model. His suggestions were incorporated in the model structure as part of the verification procedure.

**Model Testing**

Three sets of tests were developed in the form of questions to compare model output with the 1989 land use map:

1. How well did the model predict the characteristics of slope of and distance to sites selected for shifting cultivation in 1989?
2. How well was the model able to predict the observed location of the shifting cultivation sites?

3. How well was the model able to predict the observed shape of sites chosen for cultivation? Were the sites chosen clumped or randomly dispersed?

These questions are analyzed in Chapter 6.
CHAPTER 6: RESULTS

Measures of Model Performance

The following simulations were designed to assess the model's ability to predict the nature of sites used for shifting cultivation. The objective was to quantify how well the model emulates the selection process, which varies through time as a function of changing resource availability and demand. A sequence of steps was followed in testing and reporting each trial run of the model:

1) Define the objective of each test,

2) Beginning with the full model, first delete non-pertinent subroutines or variables. Verify that the reduced model version runs without logical errors,

3) Check the model output, specifically the maps of each iteration's simulated landscape, preference surface, clocks and counter of deforestation frequency, and

4) Store final map and batch files used to generate the landscape and compute statistics for comparison with the 1989 map.

The simulations were performed with the full model including all variables, and with separate variables to assess their relative importance in the site selection process. Finally, different variable combinations and site allocation assumptions were tested in combination with a standard gravity model.
Test for Site Selection Behavior

The first test assessed the model's ability to predict site characteristics in terms of slope and distance from permanent villages. Changes in site characteristics can be a sign that less desirable fields are being selected from the pool of available sites because the best sites have already been used and their resources depleted. A shift in the histogram of distance or slope classes in use over time can be used as an indicator of potential land degradation. Figure 12 is a schematic representation of the process used to develop the site selection behavior test.

First, a simple "distance from village" map was created with the RMAP distance measuring operator. Twenty distance classes were used, with the 20th class representing all cells at a distance greater than 20 cells, or 2 km. The 20 cell distance limit was chosen because 1) the villages were located centrally, and 2) most of those cells located further than 20 cells distance were outside the watershed (see Figure 2). Next, a binary map was derived from the 1989 photomap data set, with the actual shifting cultivation cells receiving a value of 1 and all others 0. By multiplying (or crosstabulating) both maps together, a new map was created that shows co-occurrence between shifting agriculture and distance. The process was repeated for each simulation, using the final iteration (e.g., 1989) output map for comparison with the 1989 photomap.

For this comparison, a null hypothesis was defined that no difference existed between the distribution of cells in the
chi-squared test:

$H_0$: No difference between simulated and observed site selection behavior for slope and distance.

dist-slope
class | # counts observed | # counts simulated
--- | --- | ---
1 | 3 | 5
2 | 3 | 4
3 | 6 | 5

$n = 24$, reject $H_0$ if $X^2 > 41.6$ at 99% confidence level

FIGURE 12: PROCEDURE FOR SITE SELECTION BEHAVIOR TEST
simulated 1989 shifting cultivation class and the observed class in
terms of distance from villages. Since the number of shifting
agriculture cells were constrained to be the same on both the
observed and predicted surfaces, a simple Chi Square test for
goodness of fit (Clark and Hosking, 1986) was used to analyze
results.

A similar process was followed to test for slope selection
using the same three classes derived during model development.

After several simulations, it was obvious that certain
variables or combinations thereof performed better on the distance
test and others on the slope test, making it difficult to decide
which simulation gave the best overall fit. Consequently, a test
surface was created which combined both distance and slope. The
distance and slope maps were crosstabulated in IDRISI to derive a
matrix with cells having values representing each unique combination
of slope and distance classes. A total of 30 "distance-slope"
classes were generated using this method. The derived map served as
a template upon which binary maps of simulated and actual shifting
cultivation maps were overlaid and compared using the Chi Square
statistic. To meet the requirements of the Chi Square test,
expected class values should have a minimum of 4 elements (Clark and
Hosking, 1986) for a valid comparison between distributions. Thus,
the original 30 "distance-slope" classes were recombined to yield 24
classes.

From a table showing the distribution of the Chi Square
statistic (Wonnacott and Wonnacott, 1977), the critical points at different confidence levels can be read. At the 99% confidence level, and with 23 degrees of freedom, the critical point is 41.6. In other words, the null hypothesis was rejected if the test statistic was greater than that found at the critical point.

Test for Image Similarity

Although it was not a stated goal to develop a model that successfully predicts the exact geographic location of the shifting cultivation fields, it was useful to include such a test because it complemented the test for site preference. For example, the model could do well on the site preference test, but poorly on the image similarity test. This situation could arise when one of two cells having the same distance and slope classes was chosen for deforestation in 1989, yet the model picked the other one.

A simple error matrix was computed for the direct comparison between each simulated landscape and 1989 photomap using the crosstabulation operator in IDRISI. An overall Kappa image similarity statistic (Congalton et al., 1983) was reported with the results. The Kappa value is a measure of the difference between the observed agreement between two maps (from the diagonal entries in the error matrix) and the agreement that might be contributed solely by chance matching of two maps (Campbell, 1987). The range of Kappa values is from 1.0 for a perfect classification to -1.0 for no correct classifications.
There seemed to be little overall difference between Kappa values for each test, because the remaining land use classes and background greatly influence the overall Kappa statistic. For this reason, the individual Kappa statistic for the shifting cultivation class was also included.

Test for Similarity of Clump Size

The third test of model performance was based on the desire to describe and compare the distribution of cells within clumps selected for shifting cultivation. The reason for including this analysis was that the above two tests did give an indication of how well the simulation was performing on a global level, but ignored the size of the individual clumps of cells selected for deforestation. As farmers do not usually choose randomly dispersed, isolated sites, it was useful to test how well the model predicts clump size. In essence, this was a test for contiguity of chosen sites.

Binary maps of shifting cultivation cells were produced for each simulation and analyzed for the number of cells per clump. The total and mean number of cells per clump and the standard deviation were used to describe and compare model output and the 1989 raster map.

Description of Simulation Results

The following description is based on a chronology of testing
activities. The findings made during the process are given along with model results. It was the increased insight obtained after each simulation that directed the model testing procedure.

Initial Simulation of Full Model Version

The first simulation used the full version of the model which included all variables and the site allocation routine. A 15 year fallow period was assumed for all cells within the vegetated slope class. The parameter settings and results for Test 1 are given in Table 2, and the 1953, 1989, and Test 1 land cover maps are found in Figures 13, 14, and 15, respectively. The site preference test resulted in a poor fit as did the image and clump similarity tests. In an initial effort to improve model performance, a random number generator was used to simulate values for the number of fallow years in the vegetated slope class for the 1953 initial state. The assumption for this manipulation was that shifting cultivation did occur before 1953, although no record of past patterns was available.

A random number map generator in IDRISI was used to derive a surface having a mean of 10 years and a standard deviation of 3 years. Negative values on the map were reassigned to one. All other model parameters were held constant. The results for Test 2 are given in Table 2. These results represented no improvement in site selection behavior over Test 1, and only a slight improvement for the image and clump similarity results.
<table>
<thead>
<tr>
<th>Variable tested</th>
<th>Starting fallow period</th>
<th>Site allocation function</th>
<th>Gravity model</th>
<th>Chi Square Statistic *</th>
<th>Kappa Image Similarity Test overall</th>
<th>Clump similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 Land-use Map</td>
<td>All</td>
<td>All</td>
<td>Euclidean Spread</td>
<td>187</td>
<td>0.7008</td>
<td>(0.0028)</td>
</tr>
<tr>
<td>1989</td>
<td>15 years (all veg slope)</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>187</td>
<td>0.7008</td>
<td>(0.0028)</td>
</tr>
<tr>
<td>Test 1</td>
<td>All</td>
<td>Random Mean = 10 yrs S.D. = 3 yrs</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>219</td>
<td>0.7050</td>
</tr>
<tr>
<td>Test 2</td>
<td>All</td>
<td>Random Mean = 10 yrs S.D. = 3 yrs</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>235</td>
<td>0.7027</td>
</tr>
<tr>
<td>Test 3</td>
<td>All</td>
<td>Uniform Random</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>235</td>
<td>0.7027</td>
</tr>
</tbody>
</table>

* Reject $H_0$ if $X^2 > 41.6$
FIGURE 13: MAP OF 1953 LAND COVER CLASSES AND INITIAL STATE CONDITIONS

1 cell = 1 hectare

KOUNE53

0  outside wshed 1057 points 14.7%
1  bare laterite 1402 points 19.5%
2  vegetated slope 974 points 13.5%
9  village/perm ag  55 points  0.8%
15  gallery forest  12 points  1.6%
FIGURE 14: MAP OF 1989 LAND COVER CLASSES

- 0: outside wshed, 1057 points (9.8%)
- 1: bare laterite, 1280 points (11.9%)
- 2: vegetated slope, 551 points (5.1%)
- 4: eroded zones, 349 points (3.2%)
- 7: shiftag, 165 points (1.5%)
- 9: village/perm ag, 91 points (0.8%)
- 15: gallery forest, 107 points (1.0%)

1 cell = 1 hectare
FIGURE 15: SIMULATED LANDSCAPE FOR TEST 1

TLAND2

0  outside ushed  1057  points  29.4%
1  ----- bare laterite  1402  points  38.9%
2  ======== vegetated slope  795  points  22.1%
7  xxxxxxxx shiftag  165  points  4.6%
9  zzzzzzzzzz village/perm aq  91  points  2.5%
15  555555555 gallery forest  90  points  2.5%

1 cell = 1 hectare
A third test based on the fallow period was tried with a surface derived from a spreadsheet random number generator. Random numbers were generated within the 1 to 25 year range, giving a uniform distribution. This surface was converted first into IDRISI and finally to RMAP for the Test 3 simulation run. The results (Table 2) indicated a poorer fit than either Test 1 or 2 for all test categories.

From the above tests, it was clear that the model in its present form was not a good predictor of the spatial aspects of shifting cultivation. In an effort to calibrate the model, it was stripped down to single variables to test their significance and possibly to determine orders of combination.

Simulations With the Productivity Variable

The first variable to be tested individually was the site productivity factor. This variable was isolated first because, based on conversations with GOG Forestry Department officials and local inhabitants of the Diafore basin, it is an influential variable in the site selection process. The slope, distance, and labor variables were removed from the full model with all other model parameters held constant as in Tests 1, 2, and 3.

The results for Tests 4, 5, and 6 are given in Table 3. These results indicated that the simulations with the productivity variable alone gave a higher Chi Square statistic in two out of three cases, based on the site selection behavior test, than the
<table>
<thead>
<tr>
<th>Test</th>
<th>Variable tested</th>
<th>Function</th>
<th>Allocation</th>
<th>Gravity model</th>
<th>Statistic</th>
<th>Overall Similarity</th>
<th>Clump Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Kappa Image</td>
<td>(shifting cultivation)</td>
<td>n = 18 Mean = 9.16 S.D. = 11.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 4</td>
<td>Productivity</td>
<td>15 years (all veg slope)</td>
<td>Euclidean Spread</td>
<td>329</td>
<td>0.7093</td>
<td>(0.0790)</td>
<td></td>
</tr>
<tr>
<td>Test 5</td>
<td>Productivity</td>
<td>Random Mean = 10 S.D. = 3 yrs</td>
<td>Euclidean Spread</td>
<td>177</td>
<td>0.7112</td>
<td>(0.0854)</td>
<td></td>
</tr>
<tr>
<td>Test 6</td>
<td>Productivity</td>
<td>Uniform Random</td>
<td>Euclidean Spread</td>
<td>256</td>
<td>0.7097</td>
<td>(0.0599)</td>
<td></td>
</tr>
<tr>
<td>Test 7</td>
<td>Labor</td>
<td>15 years (all veg slope)</td>
<td>Euclidean Spread</td>
<td>570</td>
<td>0.7085</td>
<td>(-0.0099)</td>
<td></td>
</tr>
<tr>
<td>Test 8</td>
<td>Labor</td>
<td>Random Mean = 10 S.D. = 3 yrs</td>
<td>Euclidean Spread</td>
<td>255</td>
<td>0.7147</td>
<td>(0.0472)</td>
<td></td>
</tr>
<tr>
<td>Test 9</td>
<td>Slope</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>594</td>
<td>0.7265</td>
<td>(0.1552)</td>
</tr>
<tr>
<td>Test 10</td>
<td>Distance</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>317</td>
<td>0.7137</td>
<td>(0.0091)</td>
</tr>
</tbody>
</table>
full model simulations. The results for the image similarity tests were generally better than those for the full model version, however, only Test 5 showed clump characteristics similar to the 1989 landscape.

Simulations with the Labor Variable

The purpose of these simulations was to assess the relative significance of the labor variable in the site selection process. As with the test for the productivity variable, all other variables were removed before the simulation run.

The results for Tests 7 and 8 are found in Table 3. Not surprisingly, the labor variable did not give as good a result on the site selection behavior or image similarity tests as the productivity variable simulations. By looking at the labor clocks after each iteration, it can be seen that the value distribution becomes bi-modal after ten iterations. The middle of the distribution is selected each year because it has the best rankings of suitability for labor. When cells reach a fallow age greater than 20 years, they are given a lower preference rating than any of the "middle-aged" cells.

The clump similarity test results indicated better clump characteristics than for the productivity variable simulations.

Slope Variable Simulation

Results from the slope variable simulation (Test 9, Table 3)
showed that the site selection behavior fit was poorer than for other test results. These results were understandable, as only slope category one (less than 5%) was chosen during the simulation. Because of the contiguous nature of slope categories, the clump similarity test showed a relatively good fit.

Distance Variable Simulation

Results from the distance test (Test 10) also are found in Table 3. This test was similar to the slope variable test in that the model was run for only one iteration.

Because only those cells found closest to villages were chosen at each iteration, the simulation results were no better than any of the above tests. For example, the clump similarity test showed that only one clump was chosen that consisted of all sites.

Simulations for Combined Productivity and Labor Variables

Results for combined productivity and labor variables simulations showed a better site selection behavior fit than for the individual variables (Tests 11 and 12, Table 4). On the other hand, the results for the image and clump similarity tests showed a lower classification accuracy and less similar clump characteristics.

Simulations with the Gravity Model

The results for the gravity model replacement of the simple Euclidean spread (Tests 13 and 14) are given in Table 4.
### TABLE 4: VARIABLE COMBINATIONS AND GRAVITY MODEL RESULTS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fallow period</th>
<th>Allocation routine</th>
<th>Gravity model</th>
<th>Chi Square Statistic</th>
<th>Kappa image similarity test overall (shiftag)</th>
<th>Clump size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 Land-use Map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 11 Productivity and Labor</td>
<td>Random Mean = 10 S.D. = 3 yrs</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>169</td>
<td>0.7050</td>
<td>(0.0409)</td>
</tr>
<tr>
<td>Test 12 Productivity and Labor</td>
<td>15 years (all veg slope)</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>124</td>
<td>0.7042</td>
<td>(0.0282)</td>
</tr>
<tr>
<td>Test 13 All</td>
<td>Random Mean = 10 S.D. = 3 yrs</td>
<td>ON</td>
<td>Weighting factor = 2</td>
<td>312</td>
<td>0.7178</td>
<td>(0.0917)</td>
</tr>
<tr>
<td>Test 14 All</td>
<td>15 years (all veg slope)</td>
<td>ON</td>
<td>Weighting factor = 2</td>
<td>166</td>
<td>0.7147</td>
<td>(0.1362)</td>
</tr>
<tr>
<td>Random selection</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>86</td>
<td>0.7256</td>
</tr>
</tbody>
</table>

n=18
Mean = 9.16
S.D. = 11.36

n=25
Mean = 6.6
S.D. = 11.2

n=6
Mean = 23.6
S.D. = 13.6

n=7
Mean = 23.6
S.D. = 18.5

n=8
Mean = 20.6
S.D. = 12.9

n=81
Mean = 2
S.D. = 2.0
Surprisingly, this simulation gave no better or worse fit than the simple Euclidean spread. The site selection behavior test result was about the same as for the Euclidean distance simulation for the full model tests. Figure 16 is a map of the simulated land cover map for Test 14.

Simulations without the Allocation Routine

From the above simulations, the following observations were:

1. The site allocation algorithm incorporated a distance and a contiguity factor inherent in the unique number map. Since these elements existed within the site preference routine, the model should be tested without the allocation routine as an attempt to improve model performance.

2. The observed shifting cultivation cells (1989) showed an even distribution within the distance classes. The model, on the other hand, seemed to clump them in groups within the distance classes. This suggested building a random factor into the selection algorithm.

Thus, the objective of the next series of analyses was to run the same tests as before, but without the distance function within the site allocation routine.

The test on the productivity variable using a random surface for initial clock settings, and with the distance function removed from the allocation routine gave the best result for site preference to date (Tests 15, 16, and 17, Table 5). Figure 17 is a map of the simulated land cover for Test 16.

The second series of tests consisted of simulations with the labor variable without the distance function in the site allocation
1 cell = 1 hectare

FIGURE 16: SIMULATED LANDSCAPE FOR TEST 14
<table>
<thead>
<tr>
<th>Variable Tested</th>
<th>Starting Fallow Period</th>
<th>Site Allocation Function</th>
<th>Gravity Model</th>
<th>Chi Square Statistic</th>
<th>Kappa Image Similarity Test Overall (Shifting)</th>
<th>Clump Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 Land-use Map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 15 Productivity</td>
<td>15 years (all veg slope)</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>117</td>
<td>0.7126 (0.2060)</td>
<td>n = 18 Mean = 9.16 S.D. = 11.36</td>
</tr>
<tr>
<td>Test 16 Productivity</td>
<td>Random</td>
<td>Mean = 10 S.D. = 3 yrs</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>92</td>
<td>0.7329 (0.2314)</td>
</tr>
<tr>
<td>Test 17 Productivity</td>
<td>Uniform Random</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>164</td>
<td>0.7283 (0.1997)</td>
<td>n = 41 Mean = 4.12 S.D. = 11.3</td>
</tr>
<tr>
<td>Test 18 Labor</td>
<td>15 years (all veg slope)</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>181</td>
<td>0.7143 (0.0599)</td>
<td>n = 16 Mean = 10.3 S.D. = 10.0</td>
</tr>
<tr>
<td>Test 19 Labor</td>
<td>Random</td>
<td>Mean = 10 S.D. = 3 yrs</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>270</td>
<td>0.7093 (0.0282)</td>
</tr>
</tbody>
</table>
FIGURE 17: SIMULATED LANDSCAPE FOR TEST 16
routine. The results for Tests 18 and 19 are given in Table 5.

A similar trend found in the previously described simulations of individual productivity and labor variables (Tests 4, 5, and 6 versus Tests 7 and 8) was seen. The productivity variable simulations again gave better results than those using the labor variable alone.

Simulations Using a Random Factor in the Allocation Routine

Due to the unsatisfactory nature of results to date, a simple comparison was devised between totally random selected sites and model output. A random number map having unique values between 1 and 3600 was overlaid on the map of vegetated slope cells. The first 165 cells were chosen, converted to a separate map and compared with the 1989 map for site selection, map similarity, and clump size and distribution. The comparison yielded a better site selection behavior result (Table 6) than any of the simulations, although by contrast, the clump similarity was the poorest. Because a high importance was placed on the site selection feature in the study objectives, further simulations were tried using a random selection function within the site allocation routine.

Once the final preference surface was derived and the distance selection process complete, a random and unique number map was overlaid on the resultant surface and selected for the first 165 cells. The effect was to remove the northward bias imparted by the use of the unique number map in earlier tests. The results of Tests
### TABLE 6: RANDOM ALLOCATION SIMULATION RESULTS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fallow period</th>
<th>Allocation routine</th>
<th>Gravity model</th>
<th>Chi Square Statistic</th>
<th>Kappa image similarity test overall</th>
<th>Clump Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989 Land-use Map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Test 20</td>
<td>All</td>
<td>15 years</td>
<td>Random selection</td>
<td>Euclidean Spread</td>
<td>134</td>
<td>0.7091</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>(all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td>(0.0536)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Random selection</td>
<td></td>
<td></td>
<td></td>
<td>n = 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Euclidean Spread</td>
<td></td>
<td></td>
<td></td>
<td>Mean = 20.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S.D. = 13.0</td>
</tr>
<tr>
<td>Test 21</td>
<td>All</td>
<td>Random Mean = 10</td>
<td>Random selection</td>
<td>Euclidean Spread</td>
<td>141</td>
<td>0.7161</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>S. D. = 3 yrs</td>
<td></td>
<td></td>
<td></td>
<td>(0.1044)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Random selection</td>
<td></td>
<td></td>
<td></td>
<td>n = 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Euclidean Spread</td>
<td></td>
<td></td>
<td></td>
<td>Mean = 27.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S.D. = 26.0</td>
</tr>
<tr>
<td>Random selection</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>86</td>
<td>0.7256</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.1044)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n = 82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean = 2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S.D. = 2.0</td>
</tr>
</tbody>
</table>
20 and 21 are given in Table 6.

The improvement in the site selection behavior results over the initial simulations using the full model suggests that this aspect of the model performance can be improved, but only at the cost of a poorer clump similarity result and ultimately less believability in overall model results. This inability to have three favorable tests simultaneously (site preference, image similarity, and clump size similarity) occurred throughout the testing phase.

Erosion Hazard Simulation

A map which displayed the frequency of deforestation was output after each iteration. The final counter map was compared (crosstabulated) with those cells having slope categories greater than 15% to derive the erosion hazard map. This product was compared with those sites photointerpreted as having signs of erosion in 1989.

The results for selected simulations are found in Table 7. The consistently poor predictions result from the fact that the sites photointerpreted for erosion signs were never field checked and probably overestimated.

Simulations With Data From Upper Diafore Watershed

To validate some of the findings derived from simulations on the Koune village data subset, the model was run on a second data
### TABLE 7: OBSERVED VS. PREDICTED ERODED ZONES
FOR SELECTED SIMULATIONS

<table>
<thead>
<tr>
<th>Test</th>
<th>Simulated</th>
<th>Photointerpreted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>101</td>
<td>349</td>
</tr>
<tr>
<td>Test 2</td>
<td>91</td>
<td>349</td>
</tr>
<tr>
<td>Test12</td>
<td>88</td>
<td>349</td>
</tr>
<tr>
<td>Test 13</td>
<td>88</td>
<td>349</td>
</tr>
<tr>
<td>Test 14</td>
<td>75</td>
<td>349</td>
</tr>
<tr>
<td>Test 16</td>
<td>11</td>
<td>349</td>
</tr>
</tbody>
</table>
subset located on the upper reaches of the western branch of the Diafore River (Figure 18). A 60 by 60 cell matrix was selected and maintained at the original spatial resolution for the simulations.

The results for these simulations are found in Table 8. The most noticeable trend, also seen in the previous simulations, was the relative success of the productivity and labor variables in the site preference tests. The better fit achieved with the productivity variable tends to support earlier conclusions concerning the influence of site productivity in the selection process.

The inability to achieve a good site selection result and clump similarity was also evident. For example, Test 4 on the Upper Diafore data set had the best site selection fit, yet the clump sizes and numbers were not similar to those found in the observed data set.
FIGURE 18: MAP OF 1953 LAND COVER CLASSES FOR UPPER DIAFORE BASIN

1 cell = 1 hectare

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Points</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside watershed</td>
<td>1133</td>
<td>31.5%</td>
</tr>
<tr>
<td>Bare laterite</td>
<td>1322</td>
<td>36.7%</td>
</tr>
<tr>
<td>Vegetated slope</td>
<td>907</td>
<td>25.2%</td>
</tr>
<tr>
<td>Village/perm ag</td>
<td>90</td>
<td>2.5%</td>
</tr>
<tr>
<td>Gallery forest</td>
<td>148</td>
<td>4.1%</td>
</tr>
</tbody>
</table>
### TABLE 8: SIMULATION RESULTS FOR UPPER DIAFORE WATERSHED

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fallow period</th>
<th>Allocation routine</th>
<th>Gravity model</th>
<th>Chi Square Statistic</th>
<th>Kappa image similarity test overall</th>
<th>Clump Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(shiftag)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n = 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean = 11.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S.D. = 14.7</td>
<td></td>
</tr>
<tr>
<td>Photomap</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n = 9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean = 11.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S.D. = 10.6</td>
<td></td>
</tr>
<tr>
<td>Test 1</td>
<td>All</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>126</td>
<td>0.6144</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>Mean = 10</td>
<td>S.D. = 3 yrs</td>
<td>81</td>
<td>0.6082</td>
<td></td>
</tr>
<tr>
<td>Test 2</td>
<td>All</td>
<td>ON</td>
<td>Euclidean Spread</td>
<td>81</td>
<td>0.6082</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>Mean = 10</td>
<td>S.D. = 3 yrs</td>
<td>97</td>
<td>0.6136</td>
<td></td>
</tr>
<tr>
<td>Test 3</td>
<td>Productivity</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>97</td>
<td>0.6136</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>Mean = 10</td>
<td>S.D. = 3 yrs</td>
<td>26</td>
<td>0.6002</td>
<td></td>
</tr>
<tr>
<td>Test 4</td>
<td>Productivity</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>26</td>
<td>0.6002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>Mean = 10</td>
<td>S.D. = 3 yrs</td>
<td>255</td>
<td>0.6109</td>
<td></td>
</tr>
<tr>
<td>Test 5</td>
<td>Labor</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>255</td>
<td>0.6109</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Random</td>
<td>Mean = 10</td>
<td>S.D. = 3 yrs</td>
<td>269</td>
<td>0.6140</td>
<td></td>
</tr>
<tr>
<td>Test 6</td>
<td>Labor</td>
<td>OFF</td>
<td>Euclidean Spread</td>
<td>269</td>
<td>0.6140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 years (all veg slope)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=9
Mean = 11.5
S.D. = 14.7

n=6
Mean = 17.3
S.D. = 10.6

n=9
Mean = 11.6
S.D. = 7.6

n=7
Mean = 14.8
S.D. = 10.8

n=3
Mean = 34.7
S.D. = 26.0

n=10
Mean = 10.4
S.D. = 12.0

n=7
Mean = 14.8
S.D. = 19.7

(0.0792)
CHAPTER 7: DISCUSSION AND CONCLUSIONS

Summary of Model Results

General Trends in Model Simulations

Focus on site selection behavior: A cursory analysis of the histograms of deforested areas in 1989 shows that sites were selected evenly across the range of available slope/distance combinations (Figure 19). Because of the series of decision rules which form the basis of its logic, the model selects cells from adjacent bins forming groups within the histogram. This trend can be seen from the compared histograms of the 1989 shifting cultivation class and Tests 1 and 16 (Figures 19 and 20).

Results do show a improvement in the site selection behavior test results as a random factor is introduced into the site allocation sub-routine (compare, for example, Tests 1, 2, and 3 in Table 2, and 20 and 21 in Table 6). This should not be interpreted as a suggestion that villagers choose their agriculture fields at random. To the contrary, there is a set of criteria that enter into the selection process. The simulations do suggest that a random and unique map added to the site allocation performs better than a simple, ordered sequence map with a northerly bias. A possible explanation is that the selection algorithm is no longer limited to one geographic zone within the pool of acceptable sites.

The different choices made to represent prior cultivation history constituted a useful investigation. Although the 15 year assumption gave a better site selection behavior result for the full model versions
FIGURE 19: COMPARISON OF TEST 1 AND OBSERVED SITE SELECTION RESULTS
FIGURE 20: COMPARISON OF TEST 16 AND OBSERVED SITE SELECTION RESULTS
in both the Euclidean spread and the gravity model versions, the simulations with the single variables showed that the random history of previous cultivation gave lower Chi Square statistics for the site selection behavior results than the 15 year assumption. These results point to the inherent volatility of spatial models of landscape change (Itami, 1991, pers. comm.) and reminds the user that the single model simulation result in itself has little value. The combination of several results should be analyzed together to discern the general trends. Another possibility is that the ratio of permanent to shifting cultivation cells derived from the global data set does not apply to sample data selected for model development.

Focus on image similarity tests: As stated in the study objectives, a prediction of the precise geographic location of sites was not the goal of this research. The test was only used as a means to gain additional information about the performance on the site preference performance. Even Test 16, which had the highest Kappa statistic (0.2314) for the shifting cultivation class, still shows a poor classification accuracy.

Focus on clump size test: This test imparts a measure of believability to results. For example, for the Test 16 simulations above, the clump similarity result is rather poor. The high standard deviation indicates the presence of a very large clump, which is not the case in the observed 1989 landscape. The best results for clump similarity were found in simulations using the labor variable.

Focus on individual variables: Results from these simulations suggest the relative importance of the site productivity variable in the
preference surface derivation. This finding is supported by conversations with local Diafore basin inhabitants and GOG officials.

The simulations with the labor variable gave higher Chi Squared statistics than with the productivity variable, which may have been due to the exclusion of many cells from the selection pool after several iterations. This result contrasted with the generally good results for clump size similarity.

Neither of the simulations which isolated distance or slope gave good results, because only a restricted number of cells are ever considered after each iteration.

Management Implications

Short Term Benefits to Local Population

The Government of Guinea, with support from USAID/Guinea and other donor agencies, is undertaking several pilot studies to promote agricultural productivity in the Fouta Djallon while maintaining or improving the condition of the natural resource base. The protection of the natural vegetation cover, improvement of local infrastructure, and the identification of appropriate technologies for dissemination throughout the rural environment are the main goals of these endeavors.

From observations made during a recent watershed management study in Guinea (Gilruth, 1991), the author was able to view a variety of development projects that, although having different objectives at project inception, used methods that often converged in what actually was implemented on site. For example, shifting cultivation often is considered a poor use of resources by many within the development
community. Not surprisingly, these views are often implanted in the thinking of local officials. Thus, one of the goals of agricultural development projects has been the sedentarization of agriculture, encouraging farmers to slowly, over a period of many years, convert their more productive shifting agricultural fields to permanent fields farmed every year. Of course, this change in management is encouraged with the use of fertilizers, improved seed, credits or other subsidies. The problem with this approach is that it assumes people will cease their traditional activities, or the demand on the remaining forest resources will remain constant or decrease. If, on the other hand, population growth or immigration does occur, and the remaining resources are still used in the traditional manner at an increasing rate, there is a risk of accelerated resource degradation. Another factor is that cultural preferences for certain local crops will remain after the change in land use, and people will continue to cultivate their traditional crops. This is the case in the Fouta Djallon, where the Fulani people prefer fonio and local rice to imported grain.

With the knowledge that a proposed management plan will take a sizable portion of land out of shifting cultivation production, this model can serve as a means of playing out different scenarios. If the model is improved with the addition of better soils and sociological data, the simulations will gain more believability and identify areas susceptible to degradation. The user should recognize that the development of this model represents an initial step and a long-term tool for the planning process.
Long Term Benefits to the Entire Region

Once successful methods of achieving the above goals are identified within the pilot study areas, the same techniques will be introduced into regions with similar geographical characteristics. With the model structure already in place, it will be easy to input data from the new region to simulate other scenarios. It is important to emphasize here that this model was derived for use in the Fouta Djallon and the land use practices which are specific to that region.

Suggested Simulation Scenarios for Users

**Changing population growth rates:** A biennial growth rate in village size of 2.7% was derived from the photointerpreted data and used to calculate expansion rates for permanent agriculture. Different rates are found in the literature, including a country-wide rate of 2.2% and a rate of 3.5% for the Diafore region (Kelleher et al., 1990). Inputting these rates leads to different frequencies of deforestation, total number of cells in shifting cultivation, and erosion hazard indices.

**Changes in the initial state:** Better information about site productivity for shifting cultivation would improve the initial state used in this model. Different assumptions about optimum rotation periods for the various soil types might be tested once the information is available.

As suggested above, it would be useful to run simulations removing cells from the potential pool of shifting agriculture sites. This scenario has potential for immediate use in the Fouta Djallon.

**Different scales:** The model was developed on an area using a 100
meter cell size and tested on a second area using a 50 meter cell size. The justification for this choice of spatial resolution is the minimum field size of about 0.5 hectare. It would also be interesting to test the model with different size data sets, although computer processing time and storage capacity become an issue.

Changes in demand: The relationship between supply (e.g. number of cells within the shifting cultivation class) and demand (e.g. number of cells within the permanent agriculture class) was inferred from the data. It also would be valuable to run simulations using ratios between the two agriculture classes reported in the literature or determined through household surveys. These new numbers could be input to the model using the DOS replaceable line parameter options.

Future Research Needs and Suggestions for Model Improvement

To improve model performance, the user should consider further refinements. Additional data needs include maps of soil or site index, better knowledge of erosion processes and extent, improved temporal resolution of mapping efforts, and a sociological component to investigate cultural aspects of land use.

Soil Map of Arable and Non-arable Sites Within Vegetated Slope Class

It is the author's impression that as much as one third of the land interpreted as vegetated slope is probably not arable. For example, the 1989 rasterized photomap shows cells that are within the pool of potential agricultural sites but that can not be productive and are never considered for clearing. The model selects some of these
cells, which inevitably contributes to error when determining the site preference goodness of fit or image similarity. This error is one of the major shortcomings in the data collection and is one of the first suggestions for model improvement.

Removal of these cells from the pool of potential sites would also change model output with an increase in the number of revisits per cell, and possibly better results from the erosion hazard test.

Justification of the Fallow Period/Site Productivity Assumption

The assumption that the number of fallow years in a shifting cultivation field can be equated with site productivity is probably the most critical factor upon which the model is based. This assumption should be investigated by including a study of soil fertility as a function of age. This analysis should be simple in design to reduce field work costs. For example, the data collection could focus on organic matter content, and nitrogen and phosphorus levels, or other key indicators of local soil fertility.

Improvement of Temporal Nature of Data Collection

An important recommendation would be to collect data in a more timely fashion. The 36 year period between data sets did not allow the establishment of a growth rate with a high degree of confidence. If a shorter time period (i.e., 2 or 3 years) between data sets were available, the villager's preference for agricultural sites should be easier to establish. The rules which govern model logic would be based less on general statements found in the literature and more on real
data. An ideal situation would include data sets collected every two or three years over a period of several years.

The expense of updating maps can be reduced to a minimum of field work. A local official trained in photointerpretation can make hand drawn maps which rely heavily on the experience of local leaders. These maps then would be transferred to the base map (updated) to analyze trends in the selection of the current year's shifting cultivation sites.

Local Survey Information Needs

A better description of the sociological aspects of shifting cultivation would complement the combined ground and aerial survey. Household surveys should be conducted to determine the amount of grain sown which can be equated with the number of hectares cultivated. Each household usually clears 3 to 4 times the surface area of the permanent home garden each year for cultivation of fonio or mountain rice. This relationship should be verified locally.

Another question to be considered is the distances walked on a daily basis to reach new fields. This question was asked of several villagers throughout the Fouta Djallon, but a more systematic survey should be performed locally. It is possible that an upper limit of 4 or 5 km. exists because of the presence of neighboring villages. If this is the case, distance might not play a major role in site selection behavior.

Finally, the role of the slope factor should be investigated. Relief in the Tougue District is not as high as in other parts of the
Fouta Djallon, which suggests that its role in site selection behavior might be minimal.

**Conclusions**

This research achieved its major goal of developing a spatial model of deforestation for the Guinea Highlands. It meets the objective of deriving a conceptually simple model with minimal data, that can be run with inexpensive computer hardware and software. These facts increase its usefulness for many African countries where data are insufficient and financial resources limited. The model represents one step in the process of developing practical tools to help planners understand the outcome of proposed development projects entailing changes in land use.

The model was not able to predict with a high degree of confidence the local farmers' selection pattern in terms of distance from living quarters and topography. This inability results mainly from 1) the lack of data on site index for agriculture, and 2) the insufficient temporal resolution of the data sets in the model. In addition, simulations that provided the best fit for the site selection behavior test also gave the worst results for similarity of clump size.

Results from a series of simulations did suggest that site productivity, determined by the number of years a field is left in fallow, has an influence on the selection of sites for shifting cultivation. For the data set used to develop this model, the distance and slope variables were not important factors in the site selection process.
APPENDIX A: BATCH FILE OF RMAP COMMANDS FOR GUINEA HIGHLANDS DEFORESTATION MODEL

REM
REM THE FOLLOWING MODEL CONSISTS OF A SERIES OF BATCH FILE COMMANDS
REM WRITTEN WITH RMAP MODULES DEVELOPED BY R.M. ITAMI. THE MODEL
REM SIMULATES DEFORESTATION RESULTING FROM SHIFTING AGRICULTURE.
REM THERE ARE THREE MAJOR ROUTINES: ONE FOR SIMULATION OF GROWTH IN
REM PERMANENT AGRICULTURE, ONE FOR DERIVATION OF SITE PREFERENCE
REM SURFACE, AND ONE FOR SITE ALLOCATION ONCE THE PREFERENCE SURFACE
REM IS DEFINED.
REM
REM THE FIRST PART OF THE MODEL DEALS WITH GROWTH IN THE PERMANENT
REM VILLAGE SITES. BECAUSE VILLAGE GROWTH IS PERMANENT AND SHIFTING
REM AGRICULTURE IS TEMPORARY, WE NEED TO PERFORM THE VILLAGE GROWTH
REM SUBROUTINE FIRST.
REM
REM FIRST SET THE DEFORESTATION COUNTER TO ZERO
rcopy zero f counter
REM ISOLATE VILLAGES FROM WHICH GROWTH OCCURS. THE BATCH FILE USES
REM A DOS REDIRECT COMMAND TO ASSIGN VALUES FOR RECODE AND CROSS
REM COMMANDS. THESE VALUES ARE FOUND IN *.ASN FILES WHICH ARE GIVEN
REM HERE IN THE REMARKS, BUT MUST BE MAINTAINED IN SEPARATE FILES
recode landuse f village1 / < village.asn
REM a 0 t 1 u 8.1 /
REM a 1 t 9 /
REM a 0 t 10 u 20
REM DETERMINE GROWTH SURFACES BY SPREADING THRU SLOPE WHICH ACTS
REM AS A FRICTION SURFACE SLOWING GROWTH ON STEEP SLOPES
rspread village1 t 5 across th slope f vilgrol
REM DERIVE SEPARATE MAP OF LATERITE SURFACES UPON WHICH NO VILLAGE
REM GROWTH MAY OCCUR
recode landuse f nobowel a 0 t 1 a 1 t 2 u 8 a 0 t 9 a 1 t 15 u 20
REM ASSIGN A UNIQUE NUMBER TO EACH CELL, ACCOUNT FOR DISTANCE,
REM AND REMOVE LATERITE SURFACES FROM POOL OF POTENTIAL CELLS
rmath gronobol = ((vilgrol * 4000) + sequence) * nobowel
REM SORT OUTPUT SO THAT ALL CELL NUMBERS ARE ORDERED, WITH NO GAPS
rsort gronobol f lgrowvll
REM ADJUST THE SORTED MAP
rmath 2growvll = (1growvll - 1)

REM EXTRACT THE REQUIRED NUMBER OF NEW VILLAGE CELLS FOR THE NEXT
REM ITERATION USING VALUES FROM DOS COMMAND LINE. A COPY OF THE
REM CUMULATIVE BATCH FILE WHICH CONTAINS COMMANDS FOR EACH ITERATION
REM IS FOUND IN APPENDIX 2.

recode 2growvll f vilcovl a 9 t 1 u %1 a 0 t %1 u 10000

REM UPDATE OLD LANDUSE MAP WITH NEW VILLAGE GROWTH
rcover landuse w vilcovl f landl

REM DERIVE THE CLOCKS FROM THE UPDATED LANDUSE MAPS, BEGINNING WITH
REM THE CLOCK FOR PRODUCTIVITY

recode landl f clkprdl / < clkprd.asn
REM a 0 t 1 /
REM a 15 t 2 /
REM a 0 t 3 u 20
rtoint clkprdl f clkprdl

REM APPLY THE PRODUCTIVITY LOOK-UP-TABLE TO DERIVE RANKS FOR
REM PREFERENCE BASED ON THE CLOCK VALUES

recode clkprdl f prdprfl / < prdprf.asn
REM a 5 t 1 u 4.1 /
REM a 4 t 5 u 8.1 /
REM a 3 t 9 u 13.1 /
REM a 2 t 14 u 20.1 /
REM a 1 t 21 u 140
rtoint prdprfl f prdprfl

REM REPEAT PROCEDURE FOR THE LABOR, OR EASE OF CLEARING VARIABLE

recode landl f clkeezl / < clkeez.asn
REM a 0 t 1 /
REM a 15 t 2 /
REM a 0 t 3 u 20
rtoint clkeezl f clkeezl

recode clkeezl f eezprfl / < eezprf.asn
rtoint eezprfl f eezprfl

REM USE A TWO-WAY LOOK UP TABLE TO COMBINE RANKS FROM EACH OF THE TWO
REM PREFERENCE SURFACES DERIVED FROM THE CLOCKS.

cross eezprfl w prdprfl f temprefl / < tempref.asn

REM a 1 t 1 1 /
REM a 2 t 1 2 /
REM a 3 t 1 3 /
REM a 4 t 1 4 /
REM a 5 t 1 5 /
REM a 2 t 2 1 /
REM a 3 t 2 2 /
REM a 4 t 2 3 /
REM a 5 t 2 4 /
REM a 5 t 2 5 /
REM a 3 t 3 1 /
REM a 4 t 3 2 /
REM a 5 t 3 3 /
REM a 5 t 3 5

rtoint temprefl f temprefl

REM DERIVE THE DISTANCE VARIABLE. USE A NEW SPREAD SURFACE FROM THE
REM UPDATED LANDUSE MAP. FIRST ISOLATE THE VILLAGES.

recode landl f tpopl / < tpop.asn

REM a 0 t 0 u 8.1 /
REM a 1 t 9 /
REM a 0 t 10 u 20

rtoint tpopl f tpopl

REM THEN IMPLEMENT THE SPREAD

rspread tpopl t 50 f popl

REM SLICE THE SPREAD MAP INTO 5 CLASSES TO SIMPLIFY CALCULATIONS.
REM THE SPREAD SURFACE IS A PREFERENCE SURFACE RANKED FROM 1 (HIGH)
REM TO 5 (LOW).

rslice popl i 5 fr 0 t 50 f spopl

REM COMBINE THE DISTANCE PREFERENCE WITH THE SLOPE PREFERENCE INTO A
REM SURFACE USING A TWO-WAY LUT

rcross slope w slopop1 f slopop1 / < slopop.asn

REM a 0 t 1 0 /
REM a 0 t 2 0 /
REM a 0 t 3 0 /
REM a 1 t 1 1 /
REM a 1 t 1 2 /
REM a 2 t 1 3 /
REM a 3 t 1 4 /
REM a 4 t 1 5 /
REM a 4 t 1 6 /
REM a 1 t 2 1 /
REM a 2 t 2 2 /
REM a 3 t 2 3 /
REM a 4 t 2 4 /
REM a 5 t 2 5 /
REM a 5 t 2 6 /
REM a 4 t 3 1 /
REM a 4 t 3 2 /
REM a 5 t 3 3 /
REM a 5 t 3 4 /
REM a 6 t 3 5 /
REM a 6 t 3 6

REM COMBINE THE DISTANCE/SLOPE PREFERENCE SURFACE WITH THE
REM LABOR/PRODUCTIVITY SURFACE

rcross temppref1 w slopop1 f prefer1 / < prefer.asn

REM a 1 t 1 1 /
REM a 1 t 1 2 /
REM a 2 t 1 3 /
REM a 2 t 1 4 /
REM a 3 t 1 5 /
REM a 3 t 1 6 /
REM a 2 t 2 1 /
REM a 2 t 2 2 /
REM a 3 t 2 3 /
REM a 3 t 2 4 /
REM a 4 t 2 5 /
REM a 4 t 2 6 /
REM a 3 t 3 1 /
REM a 3 t 3 2 /
REM a 4 t 3 3 /
REM a 4 t 3 4 /
REM a 5 t 3 5 /
REM a 5 t 3 6 /
REM a 4 t 4 1 /
REM a 4 t 4 2 /
REM a 5 t 4 3 /
REM a 5 t 4 4 /
REM a 6 t 4 5 /
REM a 6 t 4 6 /
REM a 5 t 5 1 /
REM a 5 t 5 2 /
REM a 6 t 5 3 /
REM a 6 t 5 4 /
REM a 7 t 5 5 /
REM a 7 t 5 6

rtoint prefer1 f prefer1

REM BEGIN THE SITE CONTIGUITY FACTOR. CLUMP THE OUTPUT FROM THE
REM ABOVE CROSSES TO DETERMINE CLUMP CATEGORIES

rclump prefer1 f clmpsit1

REM SIZE THE CLUMPS

rsize clmpsit1 for tsizel

REM RECLASSIFY THE CLUMPSIZE MAP TO IDENTIFY THE ISOLATED CELLS
REM AS NON-CONTIGUOUS SITES

recode tsizel for sizel / < size.asn

REM a 1 t 1 u 3.1 /
REM a 2 t 4 u 11.1 /
REM a 3 t 12 u 4000

rtoint sizel f sizel

REM QUALIFY THE PREFERENCE SURFACE BY DOWNGRADE THOSE CELLS IN
REM THE HIGHEST PREFERENCE CLASSES THAT ARE ISOLATED.

rcross sizel w prefer1 f prfclmpl / < prfclmp.asn

REM a 1 t 3 1 /
REM a 2 t 3 2 /
REM a 3 t 3 3 /
REM a 4 t 3 4 /
REM a 5 t 3 5 /
REM a 6 t 3 6 /
REM a 7 t 3 7 /
REM a 2 t 2 1 /
REM a 3 t 2 2 /
REM a 4 t 2 3 /
REM a 5 t 2 4 /
REM a 6 t 2 5 /
REM a 7 t 2 6 /
rtoint prfclmpl f prfclmpl
rsort prfclmpl f sortprf1
rmath prfmin1 = (sortprf1 - 1)
rtoint prfmin1 f prfmin1

REM END THE SITE PREFERENCE ROUTINE
REM
REM BEGIN THE SITE ALLOCATION ROUTINE
REM THE LOGIC FOR THE FOLLOWING IS THAT EACH PREFERENCE CATEGORY
REM MUST BE TREATED SEPARATELY. ONCE EACH PREFERENCE CLASS IS TREATED
REM FOR DISTANCE AND ASSIGNED A UNIQUE NUMBER, THE INDIVIDUAL LEVELS
REM ARE RECOMBINED. FIRST ISOLATE EACH PREFERENCE CLASS INTO ITS
REM OWN MAP.

rccode prfmin1 f lonel a 1 t 1 a 0 t 2 u 10.1
rccode prfmin1 f ltwol a 0 t 1 a 1 t 2 a 0 t 3 u 10.1
rccode prfmin1 f lthree1 a 0 t 1 u 2.1 a 1 t 3 a 0 t 4 u 10.1
rccode prfmin1 f lfour1 a 0 t 1 u 3.1 a 1 t 4 a 0 t 5 u 10.1
rccode prfmin1 f lfivel a 0 t 1 u 4.1 a 1 t 5 a 0 t 6 u 10.1
rccode prfmin1 f lsix1 a 0 t 1 u 5.1 a 1 t 6 a 0 t 7 u 10.1
rccode prfmin1 f lseven1 a 0 t 1 u 6.1 a 1 t 7 a 0 t 8 u 10.1
rccode prfmin1 f leight1 a 0 t 1 u 7.1 a 1 t 8 a 0 t 9 u 10.1
rccode prfmin1 f linel a 0 t 1 u 8.1 a 1 t 9 a 0 t 10.1
rccode prfmin1 f ltenl a 0 t 1 u 9.1 a 1 t 10

REM ASSIGN A UNIQUE NUMBER TO EACH CELL IN EACH LEVEL

rmath 2one1 = lonel * sequence
rmath 2twol = ltwol * sequence
rmath 2three1 = lthree1 * sequence
rmath 2four1 = lfour1 * sequence
rmath 2five1 = lfivel * sequence
rmath 2sixl = lsixl * sequence
rmath 2seven1 = lseven1 * sequence
rmath 2eight1 = leight1 * sequence
rmath 2nine1 = linel * sequence
rmath 2ten1 = ltenl * sequence
REM SORT THE RESULT TO CONTROL FOR ZERO

rsort 2onel f 4onel
rsort 2twol f 4twol
rsort 2three1 f 4three1
rsort 2fourl f 4fourl
rsort 2fivel f 4fivel
rsort 2sixl f 4sixl
rsort 2sevenl f 4seven1
rsort 2eightl f 4eightl
rsort 2ninel f 4ninel
rsort 2tenl f 4tenl

REM SPREAD THE VILLAGE MAP TO DERIVE THE DISTANCE SURFACE

recode land1 f village2 a 0 t 1 u 8.1 a 1 t 9 a 0 t 10 u 20
rspread village2 to 28 for prox1

REM CONVERT REAL NUMBER SPREAD MAP TO INTEGER

rmath prox1 = CINT ( prox1 )

REM MULTIPLY DISTANCE MAP BY 1000 TO OPEN RANGE FOR THE PREFERENCES
REM SURFACES CELLS TO BE PLACED AND TO LEAVE ENOUGH ROOM TO ACCOUNT
REM FOR PRECISION ERRORS

rmath dist1 = (prox1 * 1000)

erase village1.*
erase prox1.*
erase 2onel.*
erase 2twol.*
erase 2three1.*
erase 2fourl.*
erase 2fivel.*
erase 2sixl.*
erase 2sevenl.*
erase 2eightl.*
erase 2ninel.*
erase 2tenl.*

REM INCORPORATE DISTANCE FACTOR WITH THE UNIQUE NUMBER MAPS AND
REM CONTROL FOR NON-SITES BY MULTIPLYING TIMES A BINARY MASK

rmath 5onel = ((4onel - 1) + dist1) * lonel
rmath 5twol = ((4twol - 1) + dist1) * ltwol
rmath 5three1 = ((4three1 - 1) + dist1) * lthree1
rmath 5fourl = ((4fourl - 1) + dist1) * lfourl
rmath 5fivel = ((4fivel - 1) + dist1) * lfivel
rmath 5sixl = ((4sixl - 1) + dist1) * lsixl
rmath 5sevenl = ((4sevenl - 1) + dist1) * lsevenl
\[
\text{rmath } 5\text{eight}1 = ((4\text{eight}1 - 1) + \text{dist}1) \times \text{eight}1
\]
\[
\text{rmath } 5\text{ninel} = ((4\text{ninel} - 1) + \text{dist}1) \times \text{ninel}
\]
\[
\text{rmath } 5\text{ten}1 = ((4\text{ten}1 - 1) + \text{dist}1) \times \text{ten}1
\]

REM SORT THE SEPARATE MAPS

rsort 5onel f 8onel
rsort 5twol f 8twol
rsort 5threel f 8threel
rsort 5fourl f 8fourl
rsort 5fivel f 8fivel
rsort 5sixl f 8sixl
rsort 5sevenl f 8sevenl
rsort 5eightl f 8eightl
rsort 5ninel f 8ninel
rsort 5tenl f 8tenl

erase 4onel.*
erase 4twol.*
erase 4threel.*
erase 4fourl.*
erase 4fivel.*
erase 4sixl.*
erase 4sevenl.*
erase 4eightl.*
erase 4ninel.*
erase 4tenl.*
erase 5onel.*
erase 5twol.*
erase 5threel.*
erase 5fourl.*
erase 5fivel.*
erase 5sixl.*
erase 5sevenl.*
erase 5eightl.*
erase 5ninel.*
erase 5tenl.*

REM CONTROL FOR ZERO VALUES WITH BINARY MASK

\[
\text{rmath } 9\text{onel} = (8\text{onel} \times \text{onel})
\]
\[
\text{rmath } 9\text{twol} = ((8\text{twol} + 3000) \times \text{twol})
\]
\[
\text{rmath } 9\text{threel} = ((8\text{threel} + 6000) \times \text{threel})
\]
\[
\text{rmath } 9\text{fourl} = ((8\text{fourl} + 9000) \times \text{fourl})
\]
\[
\text{rmath } 9\text{fivel} = ((8\text{fivel} + 12000) \times \text{fivel})
\]
\[
\text{rmath } 9\text{sixl} = ((8\text{sixl} + 15000) \times \text{sixl})
\]
\[
\text{rmath } 9\text{sevenl} = ((8\text{sevenl} + 18000) \times \text{sevenl})
\]
\[
\text{rmath } 9\text{eightl} = ((8\text{eightl} + 21000) \times \text{eightl})
\]
\[
\text{rmath } 9\text{ninel} = ((8\text{ninel} + 24000) \times \text{ninel})
\]
\[
\text{rmath } 9\text{tenl} = ((8\text{tenl} + 27000) \times \text{tenl})
\]
erase 8onel.*
erase 8twol.*
erase 8threel.*
erase 8fourl.*
erase 8fivel.*
erase 8sixl.*
erase 8sevenl.*
erase 8eightl.*
erase 8ninel.*
erase 8tenl.*
erase lonel.*
erase ltwol.*
erase 1three1.*
erase 1fourl.*
erase 1fivel.*
erase 1sixl.*
erase 1sevenl.*
erase 1eightl.*
erase 1ninel.*
erase 1tenl.*

REM RECOMBINE THE SEPARATE MAPS INTO ONE MAP

rmath tnewcov1 = 9onel + 9twol + 9threel + 9fourl + 9fivel + 9sixl
rmath 1newcov1 = tnewcov1 + 9sevenl + 9eightl + 9ninel + 9tenl

REM SORT THE OUTPUT

rsort 1newcov1 f 2newcov1

REM CONTROL FOR ZERO

rmath 3newcov1 = (2newcov1 - 1)

REM EXTRACT SHIFTING CULTIVATION CELLS FROM THE SORTED MAP

recode 3newcov1 f cover1 a 7 t 1 u %2 a 0 t %2 u 10000

REM OVERLAY THE NEW SHIFTING AGRICULTURE CELLS ON THE UPDATED
REM LANDUSE MAP TO CREATE A NEW, SIMULATED LANDUSE MAP

rcover land1 w cover1 f tland2

REM PREPARE THE DEFORESTATION COUNTER BY RECODING THE SHIFTING
REM CULTIVATION CELL MAP TO ONE

recode cover1 f cover1 a 1 t 7
REM UPDATE THE COUNTER

rmath counter = (counter + cover1)

REM OUTPUT MAPS FOR EACH ITERATION

describe tland2 for tland2.%3
rcopy tland2 for out%3
erase 9one1.*
erase 9two1.*
erase 9three1.*
erase 9four1.*
erase 9five1.*
erase 9six1.*
erase 9seven1.*
erase 9eight1.*
erase 9nine1.*
erase 9ten1.*

REM END OF MODEL BATCH FILES
REM
REM MODEL SPECIFICATIONS
REM
REM THE SOFTWARE USED FOR MODEL DEVELOPMENT CAN BE RUN ON MOST
REM MICROCOMPUTERS BASED ON THE INTEL 8086, (OR LATER) FAMILY OF
REM MICROPROCESSOR CHIPS USING MS-DOS 2.11 OR LATER, BUT THE
REM RECOMMENDED HARDWARE IS 1 MEGABYTE OR MORE OF INTERNAL MEMORY, A
REM 20 MEGABYTE OR LARGER HARD DRIVE, EGA OR VGA GRAPHICS ADAPTOR, AND
REM FOR HARD COPY OUTPUT, A DOT-MATRIX OR INK-JET PRINTER IS REQUIRED.
REM FOR LARGE APPLICATIONS, INCREASED PROCESSOR SPEED AND SIZE IS
REM NECESSARY.
REM
REM DATA REQUIREMENTS
REM
REM 1. DIGITAL LAND USE MAP FOR INITIAL STATE INPUT: THE MAP USED
REM WAS A 60 X 60 CELL RASTER MAP WITH CLASS VALUES OF:
REM 0 = BACKGROUND
REM 1 = LATERITE
REM 2 = VEGETATED SLOPE
REM 7 = SHIFTING CULTIVATION
REM 9 = HOME GARDEN (TAPADE IN FRENCH)
REM 15 = GALLERY FOREST
REM
REM LARGER MAPS REQUIRE ADDITIONAL PROCESSING TIME OR MORE
REM PROCESSING POWER.
REM
REM 2. DIGITAL ELEVATION MODEL (RASTER) FOR SAME NUMBER OF CELLS AND
REM CO-REGISTERED WITH THE LAND USE MAP.
APPENDIX B: BATCH FILE FOR 18 MODEL ITERATIONS

REM THIS IS THE CUMULATIVE BATCH FILE FOR ALL MODEL ITERATIONS.
REM THE FIRST TWO NUMBERS IDENTIFY THE NUMBER OF PERMANENT AGRI-
REM CULTURE CELLS AND SHIFTING CULTIVATION CELLS, RESPECTIVELY,
REM FOR EACH ITERATION. THE LAST NUMBER IDENTIFIES THE ITERATION.

echo off

call itami0 0.1 75.1 1

call itami2 0.1 76.1 2

call itami2 0.1 77.1 3

call itami2 0.1 78.1 4

call itami2 1.1 79.1 5

call itami2 1.1 80.1 6

call itami2 1.1 82.1 7

call itami2 1.1 84.1 8

call itami2 1.1 86.1 9

call itami2 1.1 88.1 10

call itami2 1.1 90.1 11

call itami2 1.1 92.1 12

call itami2 1.1 94.1 13

call itami2 1.1 96.1 14

call itami2 1.1 98.1 15

call itami2 1.1 100.1 16

call itami2 1.1 102.1 17

call itami2 1.1 104.1 18
LIST OF REFERENCES


Itami, R.M., 1991. (pers. comm.) Assistant Professor, University of Arizona, Tucson, AZ.


