EXPLORING METHODS FOR INTEGRATING DATA ON SOCIO-ECONOMIC AND ENVIRONMENTAL PROCESSES THAT INFLUENCE LAND USE CHANGE: A PILOT PROJECT

REPORT TO THE BIODIVERSITY SUPPORT PROGRAM
WORLD WILDLIFE FUND

by

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PREFACE

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The authors are responsible for the content of this report which should not be interpreted as necessarily reflecting the views of The World Wildlife Fund, USAID or MSU.

The research for this study was conducted before the recent tragic events in Rwanda.

TABLE OF CONTENTS

FIGURES

TABLES

MAPS

I. INTRODUCTION

CONSERVATION OF BIODIVERSITY IS ONE CRITICAL OBJECTIVE OF NATURAL RESOURCE management (NRM) in Africa. National Environmental Action Plans (NEAP) for a number of countries place high priority on protecting biodiversity and it is also a focus of major development institutions such as the World Bank and USAID. This project is supported under the Biodiversity Support Program of the World Wildlife Fund, which is funded by USAID.

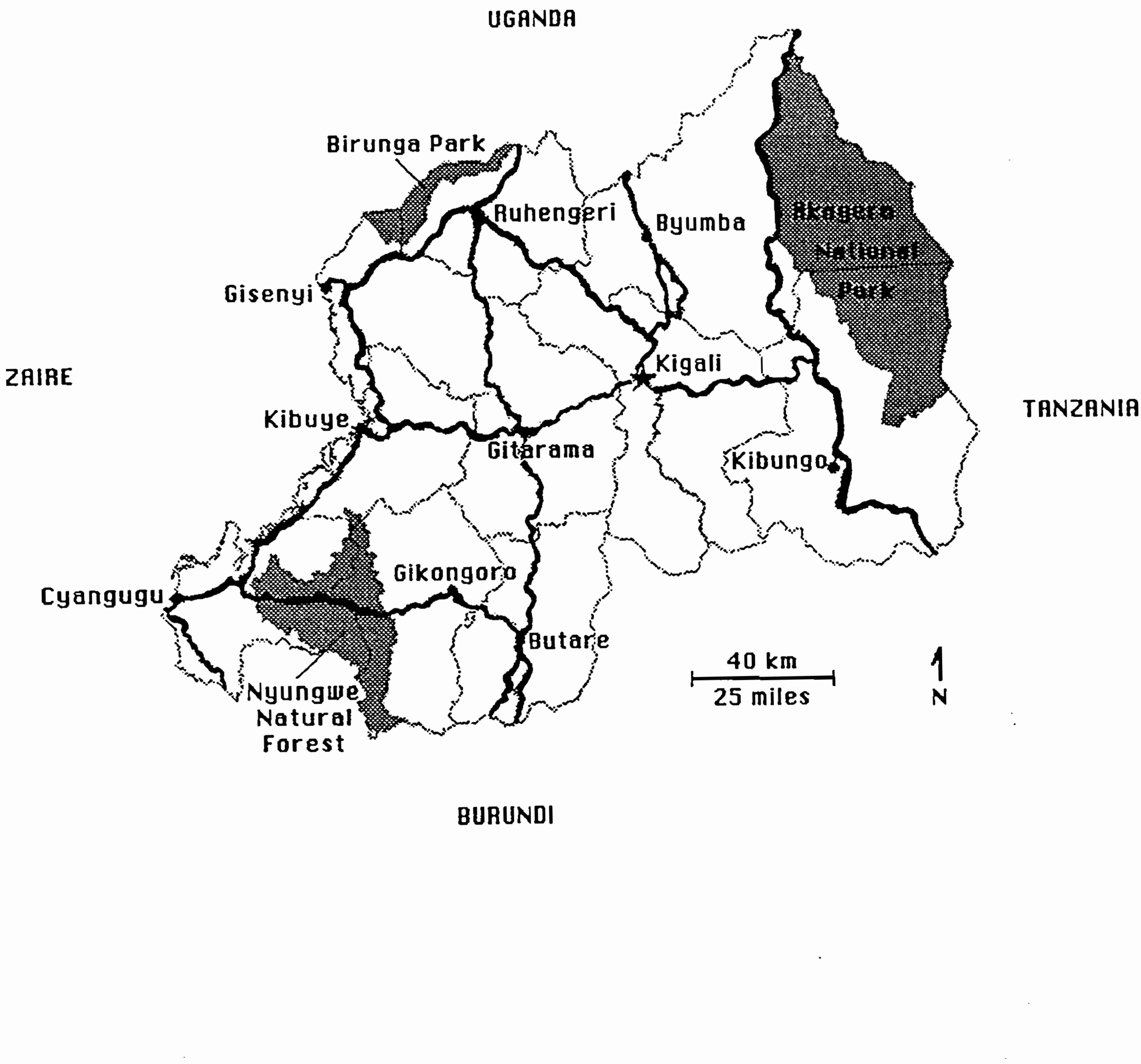
However the conservation of biodiversity is a difficult practical task when the objective of conservation is seen as an end in itself, distinct from the societal context in which it is proposed. In many African situations the preservation of environmental resources is unfortunately, perceived to be in competition with the needs of communities for resources.

Effective policy for biodiversity will only be developed in a context that examines both environmental and societal objectives and focusses upon their interaction. In African countries this implies that conservation of biodiversity be seen as an integral component of development policy. As Falloux and Talbot write (1993:216):

> Biodiversity plays a variety of essential roles in development, many of them related to sustaining the natural resource base of the country. At the same time, biodiversity conservation can be a source of very significant direct economic benefit to African nations, largely through tourism. The challenge to the NEAP process is to define the role of biodiversity in a country's development, to develop a governmental and popular constituency for biodiversity conservation, and to provide policies and specific plans for effectively incorporating it in that development.

In order to assess the role of biodiversity conservation in development it is necessary that appropriate conceptual and methodological approaches be adopted to the linkages between and societal processes. This Pilot Project is designed to provide insights to such approaches through a preliminary assessment of society-forest interactions in communities adjacent to the Nyungwe Forest Reserve in Rwanda (Map 1).

The Nyungwe Forest is unique in its diversity of flora and fauna and is one of the few remaining African montane forests. There is considerable concern over the impact of adjacent high-density populations on the biodiversity of the forest. Recent census data



Map 1 National Parks and Forests in Rwanda

(1991) indicate that some areas adjacent to the forest are undergoing rapid population growth. Given the poverty of Rwandan farming communities, the forest may be an important supplementary source of food and income for that resource-constrained population.

Under these circumstances of population growth and poverty, sustainability of the biodiversity of the Nyungwe Forest will be enhanced if the society-forest interactions are better understood and management strategies developed which acknowledge both the needs of the people and the requirements for forest sustainability.

This pilot project explores methods for assessing the patterns of population-forest interaction. It uses air photography and LANDSAT MSS imagery to assess the extent and type of change in land use in the area of the Nyungwe Forest over the past 20 years, and combines this with information from communities in the area to assess the causes of changes in tree cover.

The study seeks to inform the Biodiversity Support Program on approaches to understanding society-environment interaction as it relates to biodiversity issues. The case study focusses on areas adjacent to the Nyungwe Forest Reserve and thus contributes to the knowledge of that area as well as to discussions about NRM in Rwanda.[1]

II. SOCIETY-ENVIRONMENT INTERACTION IN AFRICA: A CONCEPTUAL FRAMEWORK

IN THE INTRODUCTION TO A RECENT BOOK ON CONSERVATION IN AFRICA, HENRI Nsanjama writes of conservation of wildlife:

> It has become clear that, to achieve our conservation objectives, to protect Africa's rich diversity of habitats and enormous wildlife endowment, we must change the system that has directed conservation for over half a century. The alienation of people and wildlife cannot continue. Local communities must participate in the management of wildlife resources; any benefits accrued from good management must be equitably shared with the communities. Moreover, because human

[1] The information on which this study is based is for the years prior to the civil war that began in April 1994. The war prevented the researchers visiting Rwanda for the purposes of this project. Two of the authors, Olson and Campbell, were last in Rwanda in January 1994. No effort is made in this report to assess the impact of recent events on biodiversity of resources in Rwanda. A number of groups have indicated an interest in studying the environmental impact of the recent events including The Mountain Gorilla Protection Project at Rutgers University, and the Refugee Policy Group.

> population in most African countries has increased more than tenfold since the precolonial days, no other approach to conservation is realistic. (Lewis and Carter, 1993:1).

Such an approach requires those concerned with NRM to interact with local societies to understand how they interpret their social system and their interaction with the environment (Kiss 1990; Western and Wright 1994). Participatory approaches to research and planning exist but are often seen as contentious by planners and scientists.

This raises the question of establishing a basis for discourse between local people, planners and scientists. Such a discourse would need to give credence to scientific and planning data and models, as well as to indigenous knowledge systems, which include such unquantifiable elements as values, beliefs, preferences and mores, and recognize the importance of considering historical processes, scale and power.

The approach to NRM called for by Nsanjama (1993 *op.cit.*) focusses on the dynamic interaction between societal and environmental systems at different scales. Implementing such an approach is a task whose complexity often frustrates problem definition, analysis and policy. NR managers would be in a better position to address this complexity were they to focus explicitly on the dynamic interaction within and between socio-economic and environmental processes. This demands an effective conceptual framework that illuminates these fundamental interactive processes.

The conceptual framework adopted by this project is Regional Political Ecology (RPE) (Blaikie and Brookfield 1987; Campbell and Olson 1991a, 1991b; *Economic Geography* 1993). Critical constructs of RPE include:

- *integration* of environmental processes (climate, vegetation, soils, water) and societal processes (economic, political, social/cultural).

- interaction between these processes through *time*, recognizing that different processes have different fundamental temporal characteristics.

- interaction at and between different *scales* from the household to the global.

- patterns of interaction determined by the structure and application of *power*.

The application of RPE is a potentially complex undertaking. A useful device to assist in application is the Kite Framework (Campbell and Olson 1991a). This framework is designed to outline the structure of these dynamic interactions through time and across scales (Figure 1). It assists NR managers in devising a strategy to describe key issues and define the fundamental causal processes underlying them.

III. THE CASE OF RWANDA [2]

THE MSU RWANDA SOCIETY-ENVIRONMENT PROJECT'S INTRODUCTION TO RWANDA begins:

> Rwanda is seen as a classic example of a country experiencing extreme population pressure; historically it has had the highest national population density in Africa and the population is confined to a very limited land base. Although small, Rwanda is environmentally diverse and provides examples of responses to population pressure from humid highland to semi-arid regions. As such, the problems in Rwanda of increasing population, declining agricultural productivity and land degradation are a precursor to similar scenarios occurring elsewhere on the continent, for example in the Kenyan Highlands and in Madagascar (Campbell *et al.* 1993, p.1)

Thus from an NRM perspective Rwanda exemplifies continent-wide processes. It is easy to accept the obvious, that rapid population growth, land degradation and declining food production are causally linked in a straight forward manner, and that reducing population pressure on resources through population reduction and/or redistribution will provide a solution.

In 1981 the problematic of Rwanda's future was expressed in these terms (Berry *et al.* 1982). There was a consensus among researchers, development workers and government officials that rapid population growth was the fundamental cause of land degradation and declining food production. The data were there. The population was growing everywhere, migration was taking place to the east, and densities were alarming relative to the quality of the land resource.

At the national level, policy objectives were defined to curtail deforestation and soil erosion, and to reduce population growth. Continuing colonial policy, the independent government maintained tree planting programs, and a compulsory erosion ditch digging and terracing campaign was put in place throughout the country. Migration of people into the semi-arid eastern half of the country was encouraged alongside the *paysannat* resettlement policy, and a family planning program was designed.

[2] This discussion of Rwanda is based on Olson (1994a,b).

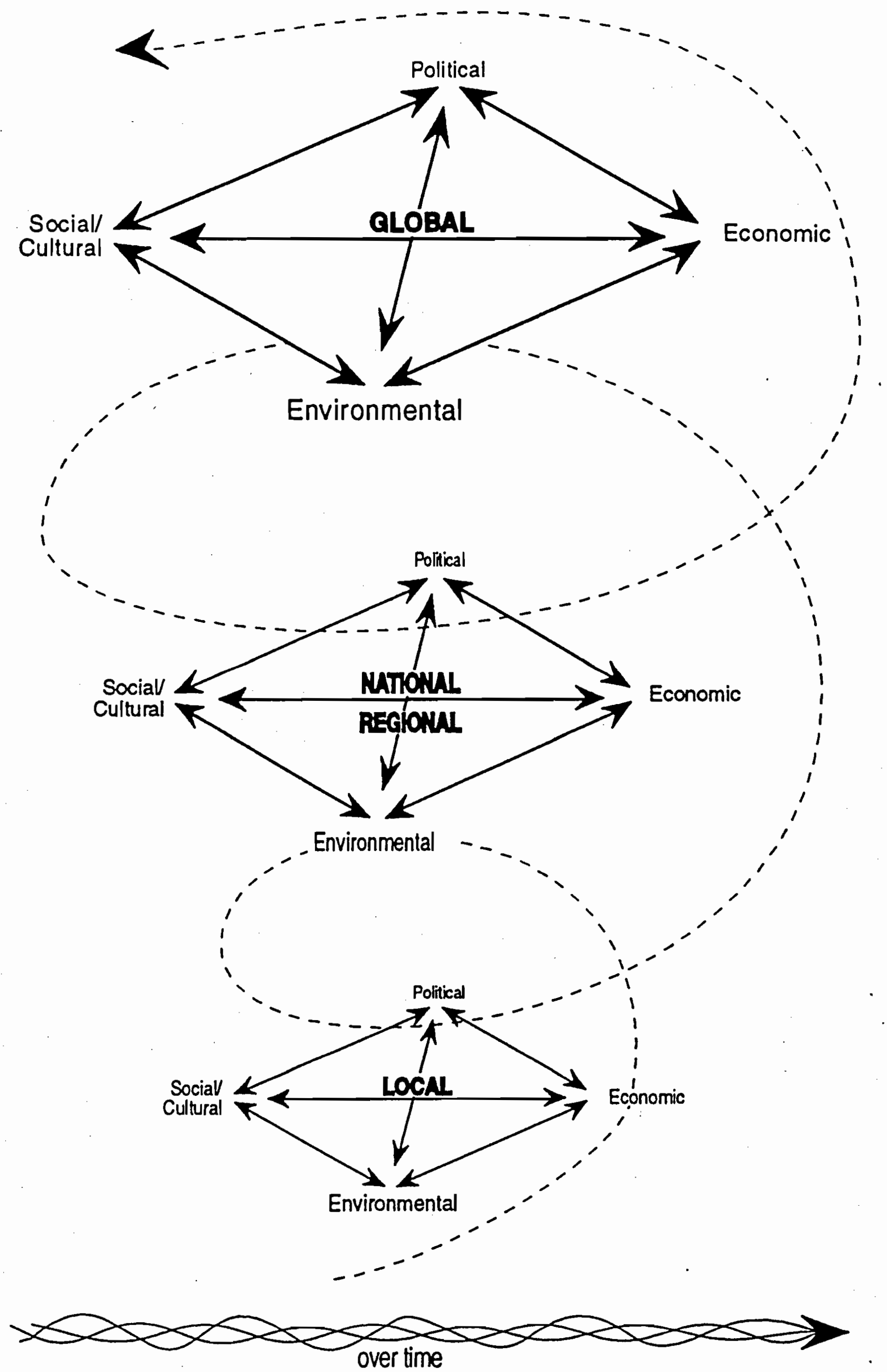


Figure 1 The Kite Framework.

While a variety of such sectoral policies related to environmental management were adopted in Rwanda during the late 1970s and 1980s, it became recognized that a coordinated approach was needed as NRM encompassed a variety of activities, each of which was the purview of a particular ministry or division. In 1992 a national environmental action plan was adopted that emphasized the importance of a coordinated approach (République Rwandaise 1992). To promote this the Service Nationale de l'Environnement was created in the Ministry of Agriculture in 1991, and in 1993 a separate Ministry of the Environment was established. One of the principal concerns of environmental management in Rwanda is the conservation of National Parks and National Forests. These have been characterized as being vulnerable to population pressures including clearing for cultivation and fuel, mining, and poaching.

The assumption that land degradation was a *recent* outcome of deforestation due to population growth and the search for additional agricultural land is incorrect, however. Deforestation has taken place in Rwanda for over 1500 years as pastoralists cleared the trees to create pasture. Photographs taken by early European settlers and explorers demonstrate that wide areas were deforested at the turn of this century, before the recent growth in population.

There is evidence that land productivity actually increased with the relatively recent change in land use from pasture to crop production (Schyns 1988). Intensification of land use under conditions of increased population pressure included mixed cropping, increased labor inputs to weeding etc, and addition of manure to the soil. Similarly, after independence, many Rwandans migrated to the east to bring under crop production lands formerly designated as pasture for the animals of the Tutsi pastoralists who ruled the country. Thus local strategies to mitigate land shortage had actually improved land productivity in a number of areas.

However, under contemporary conditions, the continued growth of the population and the dependence of the government on development strategies designed primarily to improve subsistence conditions for the rural majority, has failed to maintain a sustainable livelihood system in many parts of the country. Removal of trees from hillsides contributed to soil erosion and reduced the resources available for pasture. The government encouraged crop production in the river valleys, the alternative source of grazing for livestock. The role of livestock as a source of manure essential to maintaining soil fertility was not recognized by the central government, yet it was a critical component of local strategies. When stall feeding modelled on upland systems such as the Mandara Mountains of Cameroon were suggested to policy-makers in the early 1980s, their response was that this was not needed. Ironically, a modified version, tethering of animals, is now being widely adopted by farmers as an alternative to the free range herding disrupted by policies and actions which reduced access to grazing resources.

The Rwandan case clearly illustrates a process of interaction over time between national level analyses of society-environment concerns, and related policies and farm-level decision-making regarding production and mitigation of environmental problems. At the national level, sectoral planning dominates with outcomes which are limited to sectoral concerns, while farmers make decisions in the context of the farm as a whole.

Mitigation for farmers is related to the hardship of life, of producing sufficient food and income to sustain their families within the constraints of local conditions of land shortage, declining soil fertility etc. They have developed a range of strategies for coping with recurrent food shortages (Uwizeyimana 1991; Tardif-Douglin *et al.* 1992): they build terraces, dig ditches and alter cropping patterns to reduce soil degradation and erosion; they plant trees for fodder and tether animals to obtain manure to add to the soil; and they diversify their economies to include off-farm and non-farm occupations. These mitigation strategies are not uniformly available to all but differ with age, gender and economic status. (Olson 1994c).

These local strategies are affected by the broader national policy context. Until recently, with the definition of the National Environmental Action Plan (NEAP), there was no unified strategy regarding environmental issues. Policies related to crop prices, agricultural extension, forest protection, erosion control etc. could only be considered as *ad hoc* responses, rather than as components of an integrated national mitigation strategy. Further, these policies were implemented in a top-down manner with little consideration for their compatibility with local circumstances.

The outcome has been that these approaches are sometimes complementary - such as reforestation programs and on-farm tree planting - and sometimes in conflict - such as over the conservation of pasture for livestock. The experience suggests, however, that approaches to planning which combine local experience and the expertise of researchers and policy-makers would provide a more effective basis for dealing with global change issues, many of which in Africa are ultimately defined by questions of sustainable livelihood systems.

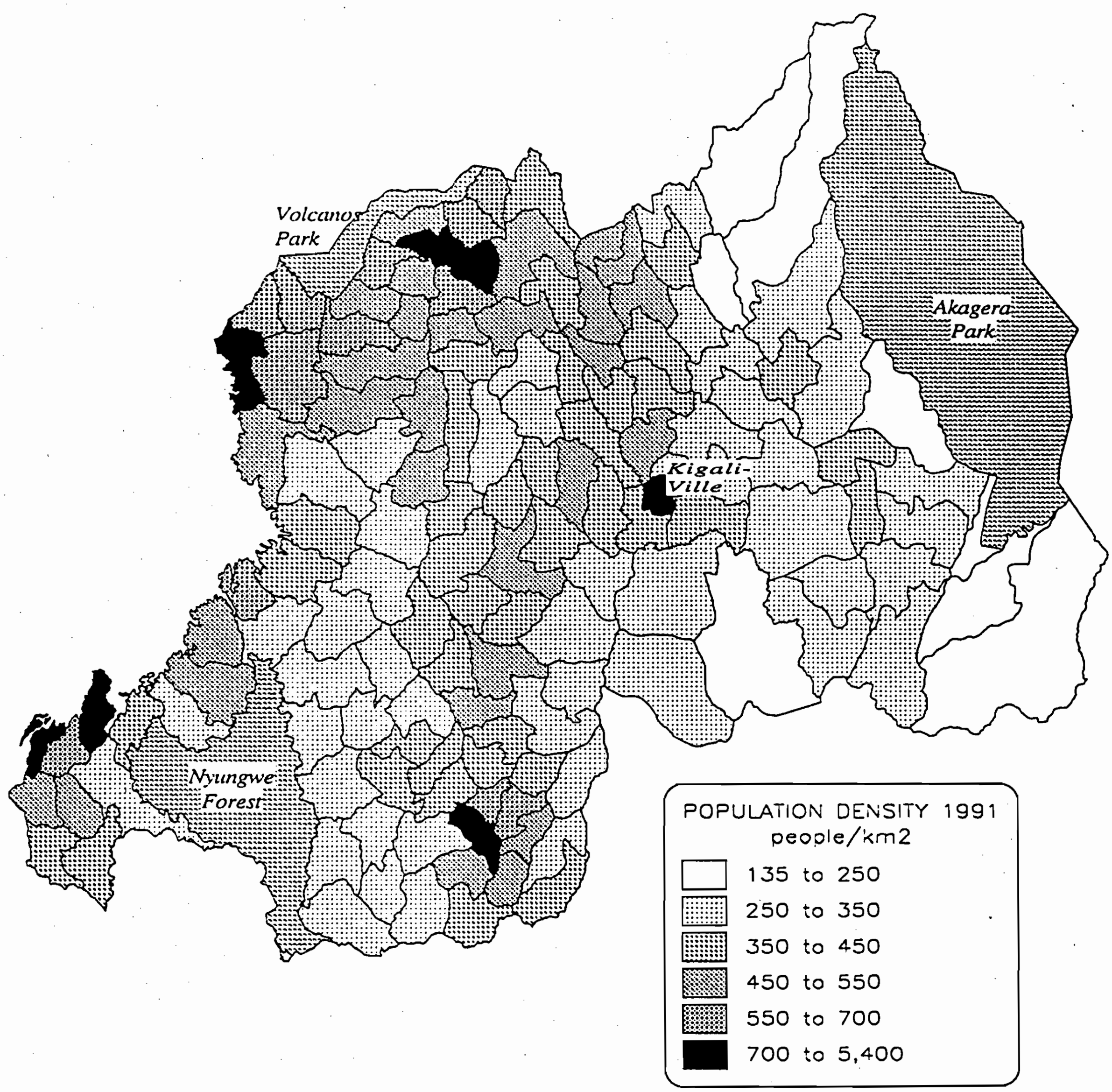
IV. THE STUDY AREA: THE NYUNGWE FOREST REGION

THE AREA ALONG THE EDGE OF THE NYUNGWE FOREST IS, LIKE MOST OF RWANDA, densely inhabited by farmers (Map 2). There are great differences between the farming systems on the eastern and the western sides of the forest, however, due to historical, cultural, economic, environmental and, especially recently, governmental factors. These differences have led the farmers to not only have distinct crop and animal mixes, which we shall examine below, but also to variations on how they responded to increasing land pressures and changing access to Nyungwe Forest resources.

The Nyungwe Forest Reserve is a high-altitude, tropical montane forest in Southwest Rwanda straddling the Zaire-Nile watershed divide. Together with neighboring Kibura National Park in Burundi, it forms one of the largest tropical montane forests in Africa. The forest contains a wide variety of ecosystems, from marshes to bamboo groves to dense forest. Although perhaps best known for its colobus monkeys, it also contains 12 other types of primates, at least 275 bird species, many endemic, over 100 species of orchids, and a wide variety of other plant and animal species. The biodiversity is particularly rich and important because the high-altitude ridge served as a refuge for and source of recolonization of forest plants and animals during and after the drying of much of East Africa during the Ice Ages. Also, the forest is situated in an overlap region between several large-scale biogeographical zones and therefore contains species originating from Tanzania, Ethiopia and the Zaire Basin (Offutt *et al.* 1990).

This unique wealth of biodiversity is situated in the most densely populated and one of the poorest countries in Africa, Rwanda. Within Rwanda, the Nyungwe Forest Reserve is in the Southwest, a region with an extremely long, rich history of settlement by farmers and herders, and is an area that already supported high population densities when the first Europeans arrived. Recent research in Butare indicates that deforestation in southwestern Rwanda is not a twentieth century phenomenon caused by rapid population growth, but that the land had been cleared and was being maintained in crops and especially in pasture from 2000 years ago (Schoenbrun 1993). The first farmers probably found an old-growth forest. They went through a period of slash and burn agriculture that changed the land cover to a younger, less dense forest. This eventually was converted to, and maintained as, grassland through controlled burning to support an agricultural system in which livestock were prominent (Barabwiliza 1980 Schoenbrun 1993). When the Europeans arrived in the 1890's, they found the southwestern region of Rwanda a highly anthropogenic landscape of grass-covered hills (Johanssen 1915; Maquet 1954).

The first demographic survey of Rwanda in 1948 showed that the Southwest, and the Northwest, had very high population numbers, particularly in the foothills of the



Map 2 Population Density by Commune in Rwanda, 1991.

mountains (Gourou 1953). This unusually high concentration of people was due to a variety of factors including high agronomic potential, absence of diseases (tsetse fly, sleeping sickness, malaria etc.), pleasant climate, and a highly-organized central political system (Gourou 1953).

The political system had evolved over hundreds of years. The first Europeans described a highly-structured hierarchical government with an all-powerful Tutsi king, chiefs and sub-chiefs down to level of a hill, and finally the Hutu serfs. In this hierarchical structure, one group of people, the Tutsi, had the privilege of owning cows and held most of the political and economic power. The owners of the cows had power over access to land and most land was reserved for pasture. Only a small amount of land was cropped and trees were confined to forest residuals in marshy valleys (Loupias 1903; Johanssen 1915). When the Europeans arrived, therefore, they found a grass-covered landscape that was the result of continual land management.

The German, and, subsequently the Belgian colonialists, maintained and ruled through this power structure. The political and cultural system which placed such importance on cattle and cattle ownership was reinforced. As health programs for both people and cattle were implemented and new food crops adopted, the human and animal populations increased substantially, beginning in the 1940's. The Tutsi rulers continued to reserve large areas of land for pasture even in the face of this rapid population growth and land scarcity felt by farmers. Conversion of pasture land to crops was restricted in both the higher-altitude areas and the eastern savanna lands. The farming population was confined to a limited area and population densities mounted. Intensification of the farming system therefore began in western Rwanda at an earlier date than elsewhere in Africa.

Population densities on the edge of Nyungwe Forest were not initially as high as in surrounding areas, perhaps because it is cool and mountainous with relatively poor soils. The land was maintained by controlled burning as scattered trees and grasses for use as seasonal pasture. There is little information on the size of the forest itself before World War II but the forested area probably extended beyond its current borders. This period, 1916 to 1933, is labeled the "laisser-faire" phase by Gatera (1980). The First World War and the coincident "Rumanura" famine reduced the slow deforestation that had presumably been occurring, but afterwards forest clearance began again. The poor soils forced farmers to constantly clear new lands. Oral histories indicate that the Gikongoro communes of Nshili, Kivu, Rwamiko, Mudasomwa, Musebeya and Muko had previously been forested. By 1933, they were 5 kilometers from the forest edge (Gatera 1980). The next phase, 1934-1959, was one of tree plantings and forest protection.

In 1933, the colonial government created a system of reserves, along the U.S. national park model, which established boundaries around Nyungwe Forest Reserve, Gishwati Forest, the Volcanoes Park, Akagera National Park and the Mutara Hunting Domain. At the time of their creation, the land in these reserves was not settled by farmers although there may have been Batwa pygmies, in the forests and Hima, traditional herders, in Gishwati. The designation of the Nyungwe Forest as a reserve was meant to control logging, some of which had been legal, and hunting. Logging had effectively eliminated Podocarpus usambarensis and Podocarpus milanjianus from the forest (Barabwiliza 1980). To mark the boundaries of the forest, eucalyptus, cypress or Podocarpus usambarensis were planted. A service of guards was instituted. The forest clearing stopped, but not solely due to the coercive measures adopted by the colonialists. The administration also introduced agricultural intensification techniques, drained valleys and opened them to settlement and allowed labor emigration to Uganda, Zaire, and elsewhere (Gatera 1980). Weber (1989) has estimated that the forested area shrunk by 6,000 km^2 during the time before independence.

The post-independent governments have maintained the boundary around Nyungwe Forest Reserve and have more-or-less been successful at keeping farmers from settling within its borders. The Office of Tourism and National Parks employed guards to patrol the reserve and enforce protective regulations. The guards have been not entirely successful at controlling the exploitation of forest products, particularly gold mining and poaching of large mammals. The last buffalo, for example, was killed in 1974 and in the 1970s and 1980s the elephant population declined from several hundred to under ten (Offutt *et al.* 1990).

With time, the Nyungwe Forest Reserve lost its status as being a difficult-to-reach, distant enclave. In 1962, the new, independent Hutu government lifted restrictions on previously-reserved pasture lands and farmers moved up to settle in the high-altitude areas, including alongside the Forest, and down to the savanna areas of the east. The road between Butare and Cyangugu traversing the forest was paved in the mid-1980s. Large parastatal tea plantations were founded on land adjoining the forest: Kitabi in Gikongoro, Mwaga-Gisakura in Cyangugu and Gisovu in Kibuye. The tea plantations use an enormous amount of fuelwood in their processing of the tea leaves, wood that initially came from the natural forest and only recently from planted woodlots (Barabwiliza 1980). The use of natural forest trees by the tea factories has been much greater than that used by local farmers (Barabwiliza 1980). In 1978, the threats to the forest were publicized by the Swiss Project Pilot Forestier. These threats included logging alongside roads and on the forest border, gold mining in the rivers, expanding tea plantations, and population growth (Sorg 1978).

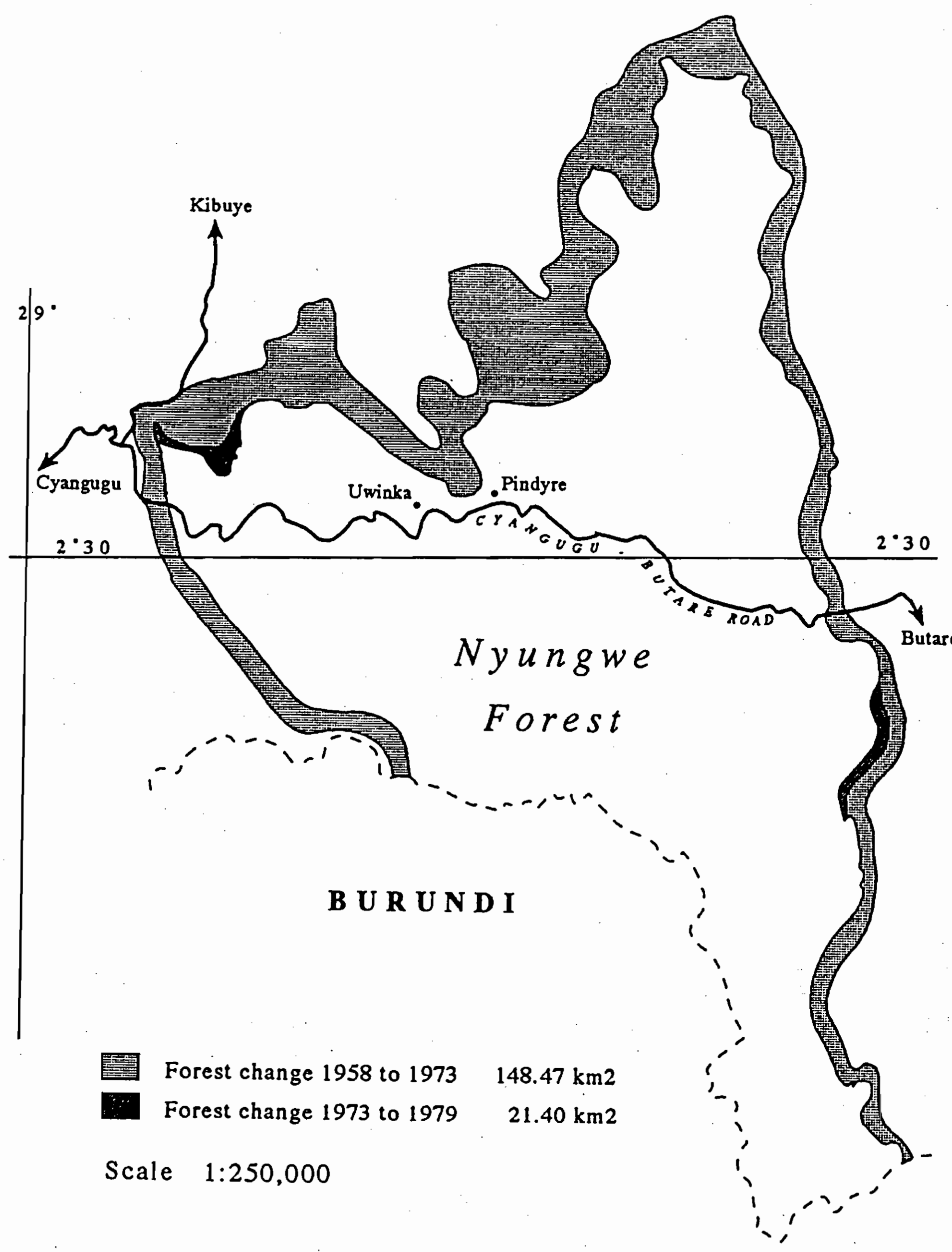
The threats certainly had an impact on the size of the forest. Studies have published various estimates of forest loss. Muderevu (quoted in Sorg 1978) estimated the forest size declined from 112,000 hectares in 1958 to 100,000 hectares in 1974. Air photo interpretation by Harroy (1981, cited in Kristensen and Turikunkiki 1992) determined that 148.47 square kilometers of the forest were cleared probably for cultivation between 1958 and 1973 (especially the northwestern edge of the forest in Cyangugu), and a smaller figure of 21.40 square kilometers were cleared between 1973 and 1979 (see Map 3). The general pattern of much forest loss along the northwest edge between 1948 and 1978 was illustrated in the maps of Cambrezy (1984). The Ministry of Agriculture estimated that in the 1960s and 1970s, 500 hectares of the forests on the Zaire/Nile Divide were being cleared annually (Gatera 1980).

In 1984, the government adopted an action plan for the forest and eventually initiated several projects in and around the forest. A USAID/Peace Corps project created paths and other amenities in the center of the forest to attract tourists. On the edge of the forest, Swiss, EEC, Belgian, and German development projects were established with the perhaps opposing goals of making the land along the forest edge economically productive and preserving the forest from encroachment by farmers. There is evidence that these projects were successful in reducing encroachment on the forest edge by farmers. Kristensen and Kurikunkiko (1992) found that between 1982 and 1991 most forest loss occurred within forest boundaries due to gold mining and not along forest edges. Nevertheless, population growth along the forest edge continues to be considered the greatest threat to the forest, and almost all efforts on the part of the government and the development projects have been to keep farmers from the forest.

This report concentrates on the farmers: what pressures on resources they are experiencing and how they are responding to these pressures in ways that affect the forest. Their decisions and actions are influenced by the development projects on the edge of the forest, as well as by the wider economic and political system in which they live.

The situation of farmers living in the three prefectures surrounding Nyungwe Forest, Gikongoro, Kibuye and Cyangugu, will be examined. First, a summary of their farming system will be presented. Second is a discussion of the production pressures on resources they are experiencing locally, and how the pressures are reflected in their economic situation vis à vis the rest of the country. This is followed by a study of their responses to the pressures, including changes in the crop, animal and tree mixtures on their farms, how they collect fuelwood, and migration. The examination of the actions of farmers will place the results of the air photo and Landsat image land cover change analysis into perspective. Key questions for this study include:

- has there been a change of forest cover (augmentation/ depletion)? If so where and what type of cover (forest, woodlot, trees on farms?)?
- what has replaced forest/ what has forest replaced?
- what processes lie behind the changes?
- what are the implications for the protected forest? for people?



Map 3 Change in the Vegetative Cover of Nyungwe Forest 1958-1973-1979 (source: Harroy 1981, cited in Kristensen and Turikunkiko 1992).

V. *METHODOLOGY*

THE OBJECTIVE OF THE PROJECT IS TO EXPLORE METHODS FOR INTEGRATING DATA ON socio-economic and environmental processes that influence land use change. The principal methods for assessing land use change in the pilot project area are analysis of MSS LANDSAT imagery and interpretation of aerial photography. Societal processes that have contributed to such change include those that have occurred within agricultural communities in the area, government policies and donor activity, and the interaction between these.

While different methods provide insight into each of these processes, integration of the information requires a conceptual framework that explicitly recognizes interaction between society and environment as occurring over time and between scales - the local, national and global. The conceptual framework used by this project is outlined in Section II above.

The methods employed for each part of the study are described below. The lessons learned regarding appropriate methods for integrating information and data on societal and environmental processes will be discussed in the conclusion.

A. *INTERPRETATION OF AERIAL PHOTOGRAPHY*

The traditional approach to change detection using aerial photography has for a long time relied on visual and descriptive methods of analysis. While this approach remains significant in identifying areas of change and developing a rationale for the apparent change, it lacks concise quantification and querying capabilities. Integrating aerial photography and GIS in change detection introduces the digital thematic mapping capability and data management of GIS that in combination with visual methods affords a quality final result.

Data

Two air photo sets, 1973 and 1990, were received from the Institut Géographique National in Paris, with permission of the Minister of Public Works, Government of Rwanda. Both photo sets are at the scale of 1:50,000. The 1973 photos are black and white panchromatic while the 1990 imagery is black and white infrared[3]. They represent similar seasonal surface patterns in terms of land use and vegetative cover (both were acquired during August).

[3] The black and white panchromatic film is sensitive to visible light (0.4-0.7μm) and the black and white infrared film has an extended sensitivity range between 0.4 and 0.9μm.

A four-step process was used to derive results of the analysis:

1. Photo interpretation
2. Projection of the individual interpreted results onto a stable base map
3. Manual digitization of the stable-base maps into digital coverages
4. Analysis of the results.

Photo Interpretation

In both sets of photographs the average scale was 1:50,000. This scale can only approximate the actual scale at all points covered by the photographs. There were three flight tracks in each set. Changes in tip, tilt, or flight altitude above terrain height, as well as differences in terrain relief, collectively affect the overall geometry of the photos, and thus the planimetric fidelity of the final digital product.

Classification

The identification relied on the use of a topographic map (based on 1973 aerial photographs, updated with 1:20,000 airphotos taken in 1977 and 1982, and field checked in 1986) and Jennifer Olson's familiarity with the region. The visual interpretation of aerial photography depended on the basic elements: shape, size, texture, tone, and feature proximity to delineate land cover types. The interpretation was done with stereoscopic viewing using mirror stereo-scopes.

At the scale of 1:50,000 one square centimeter represents twenty five hectares. The minimum map unit size was 5mm X 5mm, a size dictated by pen width and the ability to visually distinguish landscape features. This was considered a workable resolution, but it does create a problematic level of generalization. Five millimeters square at this scale represents about 6.25 ha -- large parcels by Rwandan standards where the average farm size is 0.7 ha!. Put another way, the minimum mapping size chosen for this project is equivalent in area to nine contiguous, average-size Rwandan farms.

With this limitation, nine broad categories of land cover were recognized in the two sets of images (Table 1). These types were based on the categories used on the topographic maps of the area supplemented with additional sub-classes (wooded pasture, agricultural frontier, project pasture, and project cultivation). These additional classes were created because they are important in the analysis of the societal processes that occur on the landscape.

Photo mapping

Photomorphic regions were compiled onto a stable-base copy of the topographic map using a Zoom Transfer Scope (ZTS). This optical instrument is designed to provide the visual matching and registration of two images (photo / photo; map / map; or map / photo). The ZTS is based on the camera lucida principle. The eye receives two superimposed images; one from the photograph and one from the corresponding base map (contour map). Both images are viewed simultaneously through a semi-

Forest:	Natural forest cover. Rough, heterogeneous texture, dark tone.
Forest savanna:	Riverine grasslands within the natural forest. Smooth texture, light tone.
Planted trees:	Trees, usually of homogenous species (often eucalyptus or pine), planted contiguously in plots. Evenly patterned (in lines), dark tone, smoother texture than natural forest.
Tea plantation:	Tea bush fields and associated factory buildings. Very light tone in BWIR photos, light grey tone in panchromatic. Very smoothly textured. Several large rectangular buildings in center of area.
Wooded pasture:	Numerous scattered clumps of trees in pasture land. Light tone and relatively smoothly textured area with frequent, irregularly placed darker masses with a rough texture. Class found along natural forest boundary.
Frontier:	Area predominately pasture but with lines of houses and fields along valleys. Smooth texture and light color on hillsides with small buildings and associated small darker blocks. Along roadsides, and between areas of intense cultivation and pasture.
Project cultivation:	Area with radical terracing and cultivated fields planted with single crop. Patterned lines of steep terraces in area within project boundaries.
Project pasture:	"Improved," planted grassland with no clumps of trees for pasturing project animals. Very smooth, homogenous texture, light tone.
Cultivation:	Settled areas by farmers with almost continuously cropped surfaces. Very heterogeneous: mixed tones often in small block patterns, rough texture. Common single trees or short lines of trees. Some terracing.

Table 1 Land Cover Classification.

transparent mirror to provide a binocular view of both images.

The ZTS allows enlargement, rotation and differential magnification ratio in X and Y directions (i.e. an optical stretch). It is also possible to adjust the amount of light on the photo and the base map surfaces independently which allows accurate registration of the two. These qualities makes the ZTS a preferred instrument for adjusting the photo image to control points on the base map, and it facilitates interpretive overlay of the landscape pattern from the contours with the features delineated from the photography.

Integrated digital/visual

The maps of photomorphic regions for each time period (Maps 4 and 5) were digitized in a vector format into a GIS using ESRI's ARC\INFO. The operation was done in a UNIX environment using a SUN Workstation. The GIS format enables convenient cartographic mapping. It is also easy to manipulate the database. Viewing, querying, and generating output also becomes easier and faster.

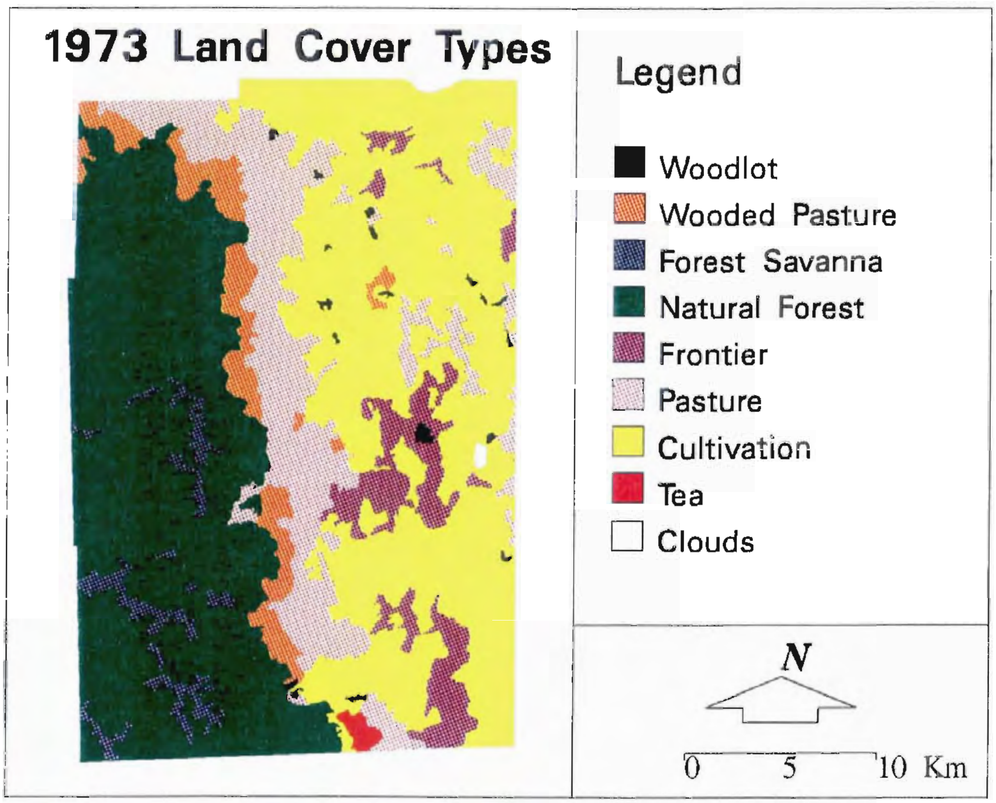
Errors

The final output is subject to a number of human and technical (mechanical) errors that may have a cumulative impact over the various stages of the mapping process. These potential errors include:

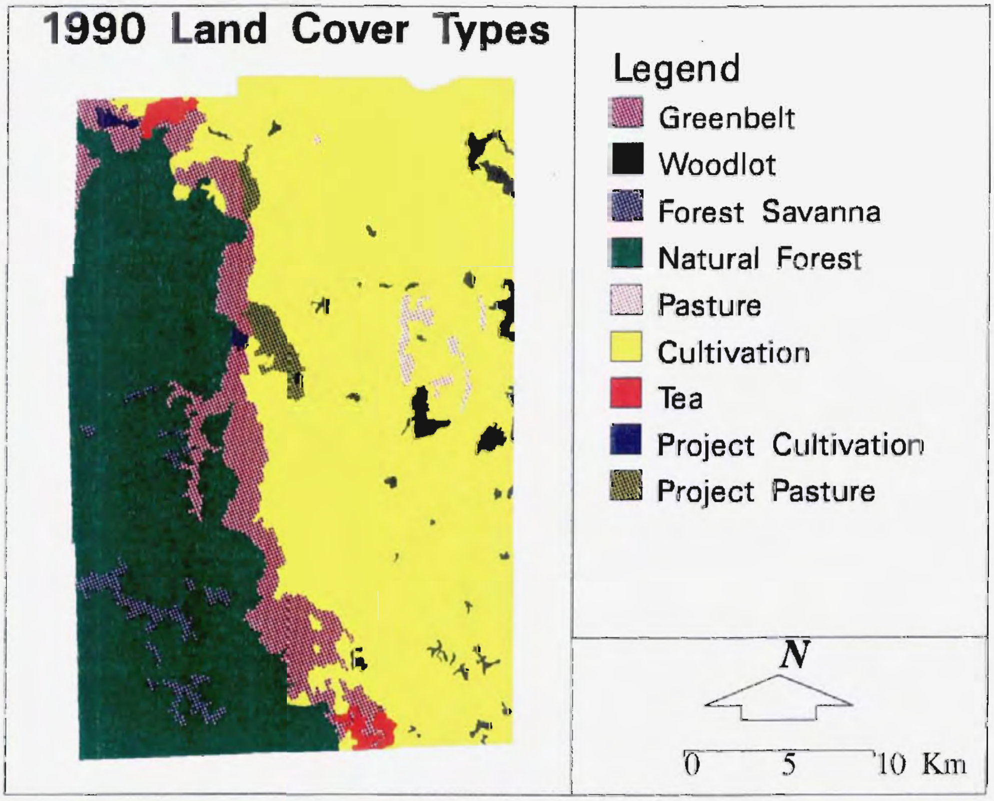
1. Errors of omission/commission in the photointerpretation process due to film resolution and/or contrast. The film resolutions of the two missions are more than adequate given the photo scales and the classification scheme (the panchromatic film type has a somewhat higher resolving power than the BWIR film does). The contrast of the panchromatic photos was rather flat (probably due to some amount of atmospheric haze). The contrast of the BWIR photos was excellent. This film type is commonly exposed through a yellow or a red filter in order to prevent atmospheric haze degradation of the film contrast. While not likely, some errors in interpretation of the panchromatic photos may have occurred due to its poorer contrast.

2. Conceptual error is associated with the definition of land cover categories. The potential for these types of errors was minimized by having people familiar with the study area do the photointerpretation. Ground truthing would have improved the categorization process but this was not possible due to the security situation in Rwanda.

3. Cartographic error can occur during both the interpretation phase and in mapping the position of the land categories. Thematic errors can be made in assigning categorical values to map features (i.e. correctly interpreted by wrongly labeled). Measurement error reflects any



Map 4 Land Cover Types, 1973.



Map 5 Land Cover Types, 1990.

imprecision in the location of significant identifying features or of attributes associated with categories. These types of errors were minimized by having the two interpreters cross-check each others work.

4. Digitizing error. Even the most proficient operator cannot digitize the same line twice in exactly the same fashion. Several types of incorrect digital line work can result (e.g. sliver polygons, dangles, overshoots, etc). To minimize digitizing errors registration consistency with the tics was ensured, a suitable level of generalization was employed (fuzzy tolerance and node snap distance).

B. INTERPRETATION OF LANDSAT MSS IMAGES

1. Introduction

Land use/cover changes are changes caused by human activity or natural causes such as fires, diseases, or pests (Lee and Hoffer 1988). These changes are of special concern especially where they are related to environmental degradation. Among the overriding goals in monitoring land use/cover changes is the immediate ecological instability. This in turn affect both natural and man-made systems (especially agriculture) based on the functional ecological role of natural vegetation cover in protecting the soil, water, and the providing wild life habitat and resources. It is therefore imperative that Rwanda, a country whose economy relies heavily on agriculture, keep updated inventories of their natural resources and agricultural land for effective management.

Natural resources continue to be exploited for human sustenance - food, shelter and clothing. However with increasing population, changing times and demands, there is increasing pressure in the form of commercial extraction and agricultural extension. Natural resource use patterns has also become a global concern because of the degenerating atmospheric quality - particularly increases the carbon dioxide concentration and the greenhouse effect due to deforestation. At the local scale, degradation has its effects on the local economies - especially through erosion, flooding, and wood-fuel shortage.

The published studies constantly present conflicting reports on the rate of land cover changes in many parts of Africa. For instance deforestation estimates in 1980 differed by 100% (Brown and Lugo 1980, quoted in Sader *et al.* 1990). FAO's 1980 yearbook on country to country deforestation ranked Rwanda 10th in the world with an annual percent change of 1.46%. The 1982 FAO/UNEP rating placed Rwanda 10th, but at the rate of 2.13%. Inaccuracy in assessment coupled with subjectivity in the use of different definitions lie at the center of the controversial reports. In particular, there is no consensus in the categorization of tropical forest types and the operational definition of what constitutes change. In 1984, Grainger defined deforestation as the temporary or permanent clearance of forest for agriculture or other purposes. He modified this definition in 1993 by replacing the word "clearance" with "deterioration in density or structure of vegetation and or species composition," befitting that of FAO/UNEP (1982). An assessment based on this definition rates Rwanda very highly on the World Scale (Allen and Barnes 1985).

2. *Methodology*

A Landsat-1 MSS scene (March 12, 1975) and a Landsat-5 MSS (July 3, 1986) were used in this study. The imagery was acquired from EOSAT, Inc. (Lanham, Maryland, USA). Subscenes covering the northern part of Nyungwe Forest were extracted from both images. These subsets are considerable larger than the test area for which aerial photography was available (5,215 sq km vs 763 sq km). The March scene (1975) represents the wet season in this part of Africa; the July image (1986) captured the dry- season appearance of the landscape. These differences were problematic regarding change detection, but were necessary due to the availability of relatively cloud-free imagery across a long time interval. Aerial photography from 1973 and 1990 and a 1986 topographic map (1:50,000) were used as ancillary data.

Spectral Resolution Problems.

Any remote sensing technique applied to image analysis must consider the spectral, spatial, temporal and radiometric resolution of the sensor in light of the various features to be interpreted. Of special significance in this study is the problem of working with insufficient data. The 1986 imagery contained corrupted and unusable band 2 data (red reflectance). As a result, this study used only three bands in both images - bands 1, 3, and 4 (even though the 1975 image had good data in all four bands). This decision was justified because the two scenes were to be analyzed for change. If two different band combinations were used, some of the changes that were detected might be partially caused by the differences in the multispectral imagery rather than true landscape changes.

The Landsat MSS instrument measures reflected radiance in four broad bands in the 0.5 - 1.1μm region of the electromagnetic spectrum. In most studies of vegetated landscapes, band 2 (visible red) and band 4 (near infrared) are considered to be the most useful, especially to enhance vegetation differences in both wet and dry seasons (Sader *et al.* 1990). Band 1 is not as useful for detecting vegetation. A mini-study was conducted in order to characterize the impact of not using the red light band. Using the 1975 imagery, which contained good data on all four spectral channels, the four-band data set was compared to the three-band set in two ways -- by principal components analysis and by unsupervised classification outcome.

The results of a principal components (PC) analysis of both data sets are listed in Tables 2 and 3. For the four-band image (Table 2), the first two components account

Components	Eigenvalues	Variances (%)	Total (%)
1	803.84	84.72	84.72
2	139.81	14.74	99.46
3	3.42	0.36	99.82
4	1.75	0.18	100.00

Eigenvectors (or loadings)

1	2	3	4
0.40	0.52	0.29	0.70
0.51	0.55	-0.10	-0.65
0.69	-0.51	-0.47	0.18
0.32	-0.41	0.83	-0.22

Table 2 Principal Component Analysis of Four-Band Landsat MSS Data (3-12-75).

Components	Eigenvalues	Variances (%)	Total (%)
1	424.51	89.36	89.36
2	48.22	10.15	99.51
3	2.31	0.49	100.00

Eigenvectors (or loadings)

1	2	3
0.31	0.94	0.14
0.85	-0.20	-0.49
0.43	-0.28	0.86

Table 3 Principal Components Analysis of Three-Band Landsat MSS Data (3-12-86); No Red Reflectance Band.

for 99.46 percent of the total four-band variance. With the three-band data set, the first two components account for 99.51 percent of the total three-band variance. This observation appears to confirm that the loss of the red-light band (channel 2) was not serious. However, it should be noted that the second component for the four-band image accounts for nearly fifteen percent of the total variance while in the three-band version of this image the second component accounts for about ten percent of the total variance. This means that less information is contained in the second component of the three-band image compared to the amount of information contained in the second component of the four-band version. The PC analysis confirms what was stated above: band 1 and 2 are not interchangeable and the red-light band 2 contains vital information (at least for vegetated landscapes).

In the second test of the differences between the three-band and the four-band versions of the 1975 MSS image, an unsupervised, clustering analysis was conducted on both data sets. In each case, 100 clusters were created; these were labelled based on homogeneity, i.e. forest, cultivated, mostly forest with some mixture, mostly cultivated with some mixture, mixed, and other (water, clouds, shadows, etc.). A cross-tabulation of the two clustering outcomes is presented in Table 4.

As shown in Table 4, some of the pixels that were clustered into the Forest class with the four-band data were classed as Mostly Forest (1.65 %) or Mixed (1.1 %) with the three-band version of the data. Very few pixels classed as Mostly Forest (0.5 %) or Mixed (< 0.1 %) in the 4-band set were classed as Forest with the 3-band version. Similarly, 2.6 percent of the pixels in the Mixed class from the 3-band data were classed as Mostly Forest with the 4-band version; 2.1 % of the pixels in the Mixed class from the 3-band image were classed as Mostly Cultivated with the 4-band data. These results confirm that the red reflectance data are necessary for a higher-quality classification of Landsat MSS data. In hindsight, the lack of a usable band 2 in the 1986 image should have disqualified it from selection, even if the time period of analysis had to be shortened.

Geometric Correction.
The two images were recorded at different times by different sensors. The Landsat-1 MSS which captured the 1975 image had a nominal ground resolution of 79 x 79 meters. The 1986 image was recorded by the MSS aboard Landsat-5 which has a nominal ground resolution of 83 x 83 meters.

Only an image-to-image geometric correction was performed; the 1975 image was resampled to register with the 1986. Twenty-four control points were used and the registration fit with an RMSE of 0.308 pixels (i.e. sub-pixel registration). A value of 0.308 is particularly significant considering that human-induced conversions of land cover tend to be characterized by high spatial frequencies because of the relatively local scale of human activities. Recall that in Rwanda the average farm size is 0.7 hectare -- the nominal ground resolution element of the Landsat MSS is 0.64 hectare.

THREE-BAND DATA	FOUR-BAND DATA: Forest	Cultivated	Mostly Forest	Mostly Cultivated	Mixed	Other
Forest	14,927 (1.94)	0	3,812 (0.5)	0	30 (0)	17 (0)
Cultivated	0	60,297 (7.83)	0	15,083 (1.96)	2,825 (0.37)	8,191 (1.06)
Mostly Forest	12,669 (1.65)	0	8,448 (1.1)	0	1,047 (0.14)	3,413 (0.44)
Mostly Cultivated	0	48,292 (6.27)	0	51,537 (6.69)	41,130 (5.34)	19,791 (2.57)
Mixed	8,500 (1.1)	552 (0.07)	20,111 (2.61)	16,465 (2.14)	150,808 (19.59)	3,698 (0.48)
Other	1,928 (0.25)	184 (0.02)	2,039 (0.26)	2,220 (0.29)	40 (0.01)	271,815 (35.31)

Top entry = pixels; bottom entry ( ) = percentage

Table 4 Cross-Tabulation of the Clustering Analyses of the Three-Band and Four-Band Versions of the 3-12-75 MSS Scene.

Classification.
Conventional computer assisted classifiers do not recognize spatial patterns as does the human eye. The classifiers perform class assignments (in the case of the supervised classification approach) or cluster assignments (in the case of the unsupervised classification approach) based on multispectral signatures of individual pixels. Both approaches were used in this study:

> Supervised classification - Training the software to statistically recognize the spectral signature(s) of each of the classification categories by delimiting type examples of each cover class in each scene based on the results from the air photo interpretation.
>
> Unsupervised classification - relative classification of each pixel to its statistical feature class which has minimum internal multispectral variance and maximum between-class multispectral variance.

Change maps were produced showing a complete matrix of changes. The separate classification procedures were useful in overcoming the problem of normalizing for atmospheric and sensor differences between the two dates. If the two images were taken in the same season, the areas of no change could have been those that maintain the same reflectance level while those of change differ in reflectance. However, in post-classification change detection, they were identified with the help of aerial photography. The post-classification comparison adopted required independently produced classified images.

Unsupervised Classification. The imagery was statistically clustered using the ISODATA (Iterative Self-Organizing Data Analysis) program within the ERDAS software. For the dry-season image (1986), 50 clusters were requested; 100 clusters were specified for the wet-season 1975 image. The resulting clusters were labelled with the assistance of J.M. Olson who is very familiar with the study area.

The only two land cover categories from the airphoto classification which could be identified in both MSS images were Forest and Cultivated (Table 5). None of the other cover types which had been identified by airphoto interpretation were grouped consistently in any of the clusters. As a result, the land-cover change detected by the Landsat classification cannot be directly compared to the changes delimited by the photointerpretation task. Additionally, the wet-season/dry-season contrast between the two Landsat images caused the other cluster groupings to be slightly different for each date. The clusters which represented Clouds and Shadows were not included in the land cover change analysis.

The majority of the clusters created for both data sets were unusable mixtures of numerous cover types and are labelled as Unclassified. This situation was caused or

1975	1986
Forest	Forest
Cultivated	Cultivated
Cultivated and Open Forest	Planted Trees and Cropland
Planted Trees	Crops and Savanna in Forest
Pasture	Bare Soil and Disturbed
Tea	
* Clouds	* Clouds
* Shadows	* Shadows
* Unclassified	* Unclassified

* Not included in the land-cover change analysis

Table 5 Land Cover Classification (Unsupervised) for Landsat MSS Data.

exacerbated by three factors: 1) this part of Rwanda exhibits intensely dissected topography which causes great variance in the reflectances of cover types as a function of slope angle and aspect; 2) cover type changes from place to place occur at sub-pixel spatial frequencies (i.e. < 80 m spacing) which results in most pixels being spectrally mixed; and 3) the loss of the red reflectance band as explained above.

Supervised classification. The original study plan called for the photo-interpretation maps to serve as GIS overlays to the MSS imagery in order to facilitate the selection of training sites for each of the categories used in the photo analysis. Unfortunately, this approach proved to be unworkable -- the paucity of well-defined control points meant that the land-cover maps could not be adequately registered to the MSS imagery.

Training sites were selected using a split-screen approach were the Landsat image was displayed next to the digital land cover map derived from photointerpretation. This method was serviceable, but not as comprehensive, nor accurate, as the direct overlay technique originally called for.

A maximum likelihood classification of the two MSS scenes was executed using the Maxclass module of the ERDAS Software (ERDAS Inc, Atlanta, Georgia, USA). The initial classification was evaluated and modified using the Thresh program (a Chi Square thresholding evaluation of the per-pixel, class-membership probabilities). It was obvious from these evaluations that the classifications for either scene were seriously confused for large portions of the landscape. The training statistics for many of the classes were unacceptably heterogeneous, causing serious errors of commission and omission (based on visual scrutiny, since ground truth data were unavailable).

There are at least three reasons for the poor classification results using the supervised approach. First, and most importantly, the intensely-dissected terrain in this portion of Rwanda caused wide spread, high-spatial-frequency fluctuations in solar illumination. This circumstance meant that few of the training sites would exhibit uniform reflectance. Second, the loss of the red-light reflectance record constricted the information space of the image data. Lastly, the spatial lag of the cultural landscape subdivisions produced mixed pixels across much of the scene.

For all these reasons, it was decided to abandon the supervised classification approach in favor of an unsupervised, clustering technique. It was anticipated that numerous spectral clusters would be formed for each land-cover category and that these might capture the preponderance of the within-class variance that was induced by the topographic illumination differences.

C. SOCIO-ECONOMIC ANALYSIS

A variety of methods and sources of data have been used in the compilation of information regarding the population on the edge of the Nyungwe Forest. These include household surveys, group interviews with farmers, interviews of officials, and library research of historical documents, government reports and scientific articles.

Review of Literature

The review of literature is particularly important in providing an historical context and information about a variety of domains - politics, society, religion, agriculture, economic trends, case studies etc. These provide a context within which to assess available information and to relate it to a variety of interacting processes.

Government and Project Reports

A decade ago Rwanda was a data-poor country, yet today it has one of the most comprehensive data sets in sub-Saharan Africa. This change is a consequence of a number of important initiatives to improve data availability taken by the Government of Rwanda with the support of donor agencies, such as USAID and Belgian Technical Cooperation.

The development of Rwanda's data base was founded on data collection activities begun during the Belgian colonial period. These included population censuses, aerial photography, and rainfall statistics. These activities have been maintained and in the case of censuses and rainfall monitoring, improved, and additional data gathering has been initiated, as in the agricultural surveys begun in 1983, and the soil map released in 1993. These data gathering activities are complemented by government reports from various ministries, and by the data bases and reports of the many development projects that have been initiated in the country.

Most of this information is presented in the context of discussion of national issues and trends, and the smallest geographical unit on which data is presented is usually the commune. As a result, local issues cannot be addressed with the same wealth of information as national ones. However, the national context for local issues can be clearly defined and this contributes significantly to the understanding of local issues.

Household Surveys

Some information, presented in a tabular format, was derived from statistical analyses of household survey results. The data, from the 1991 Survey of Agroforestry, are from a nationwide stratified random sample of 1240 farm households (operating 6,464 fields) by the Division of Agricultural Statistics of the Ministry of Agriculture. Interviews with heads of households and/or their spouses were conducted in June 1991. The survey included a field-level component (of variables such as changing soil fertility, number of trees and tree species, etc.) and a household-level component (e.g., changing fuelwood availability, distance to fuelwood, reason trees were planted).

The Agroforestry Survey was designed to be statistically valid at the national and at the prefectoral level. The results presented in this report of three prefectures should, therefore, not be rigidly interpreted as statistically valid but, in the absence of our ability to conduct a larger sample, they may provide a general indication of how responses vary between areas. Households in the three prefectures surrounding the Nyungwe Forest were chosen for study: Cyangugu, Kibuye and Gikongoro. These 288 households were categorized according to the distance between the households and the forest to determine the effect of the forest on their activities. The closest, direct distance between the center of each cluster of surveys households and the forest was determined with Arc\Info. Using this method, it was found that 32 of the survey households were within five kilometers of the forest, 64 were within 10 kilometers and 176 were over ten kilometers from the forest. Again, these small numbers do not provide statistical validity to the results but, as seen in the results section (Section VI), clear trends are nevertheless apparent between areas.

Informal Surveys
An essential activity in research that examines society-environment interaction is verification of the interpretations based on literature reviews, official reports and statistics, and survey data - the equivalent of ground-truthing in remote sensing analyses. The information gained from the documents, maps, and household surveys provides a basis for interpretation of the interactions between societal and environmental processes. This implies that these define the critical issues and accurately reflect the causal processes, not merely symptomatic associations between variables and/or processes. Whether this is the case requires understanding of the those critical junctures where human decisions intersect with environmental processes - *where the farmer's hoe breaks the ground.*

Participation of local people in research, policy definition, and planning is widely recognized as essential for effective development in Africa, including promotion of biodiversity conservation (Western 1982; Lewis and Carter 1993). A wide variety of participatory approaches is available (e.g. Chambers *et al.* 1989, Chambers 1992), though the utmost care is required to avoid participation being reduced to manipulation (Campbell 1987). This demands a commitment to participatory learning, and a value being placed on both expert knowledge and indigenous knowledge systems.

Procedures for this include group discussions and interviews with key informants. It should be emphasized that in some cases, particularly where costs are to be minimized, these activities can, with careful planning and implementation, replace formal surveys and yield appropriate and useful information.

Group Interviews

In many African rural societies formal group meetings are a regular feature of social, religious and political life. These meetings provide opportunities for local issues to be discussed and for information from beyond the village to be disseminated. Such meetings have socially defined rules of order, and in many cases certain segments of the society may be excluded or have only peripheral roles.

Group interviews provide a potential venue for gathering and discussing information on issues related to environmental issues. The environment is an integral part of life in a very existential sense in rural areas. Knowledge and myth are bound together to provide guidelines for appropriate interaction with the environment.

The use of group meetings for the purpose of encouraging the input of local people to the management of natural resources is becoming increasingly widespread. Pioneering efforts such as the Kenya Wildlife Management Project (Berger 1993; Western 1982; Western and Thresher 1973), and the work of David Western (1982) in the 1970s in Kenya, have influenced contemporary approaches, such as the CAMPFIRE program in Zimbabwe (Martin 1986; Murindagomo 1990; Murphree 1993; Peterson 1991).

Group meetings have the advantage that they can be organized to focus on specific issues and in the course of discussion the group acts as its own arbitrator of the validity of information and of its interpretation. Experience has shown that the lively discussions that arise at a properly prepared meeting can provide extraordinary insights to issues, insights that go far beyond what might be achieved from intensive survey work alone (Campbell 1984).

Group meetings can also be very difficult experiences and can provide misleading information. Political circumstances, and failure to respect local custom as to format, attendance and participation can prevent a productive meeting (Campbell 1987). Further, care has to be taken to assess the biases inherent in these situations such as those arising from age, gender, or socio-economic prejudice in the participant group.

Much of the information presented in this report on the interaction of people with natural resources was obtained from discussions with villagers in the study area (Olson 1994c). The meetings were structured around the findings of household surveys that involved questionnaire interviews at the household level. The discussions at the group meetings went far beyond the specific questions and provided " a broad historical and especially political context to supplement the narrower answers given by individuals concerning their own fields and farms." (Olson 1994c: 69).

Key Informants

While the group meetings can provide details on the broad context for local circumstances and practices, there are frequently particular individuals who for whatever reason, have acquired significant knowledge about specific issues. These individuals come from a variety of segments of society , including farmers, bureaucrats, elders, priests, and local "historians." What sets them apart as key informants is that they are recognized by others in their community as being particularly knowledgeable about the area, or facets of it.

VI. RESULTS

A. LAND COVER CHANGES 1973-1990

The results discussed in this section concentrate on the land cover changes detected using air photography for 1973 and air photography for 1990, supplemented in areas of unmatched coverage with the 1973 photography by information from a 1:50,000 scale topographical map with land cover indicated for 1986.

Changes in land cover over the period 1973-1990 are summarized in Table 6 and Maps 6 and 7. Significant changes are the expansion of the cultivated area (14.8% increase in land area), the emergence of land uses associated with national policies, and the disappearance of the wooded pasture, and the agricultural frontier.

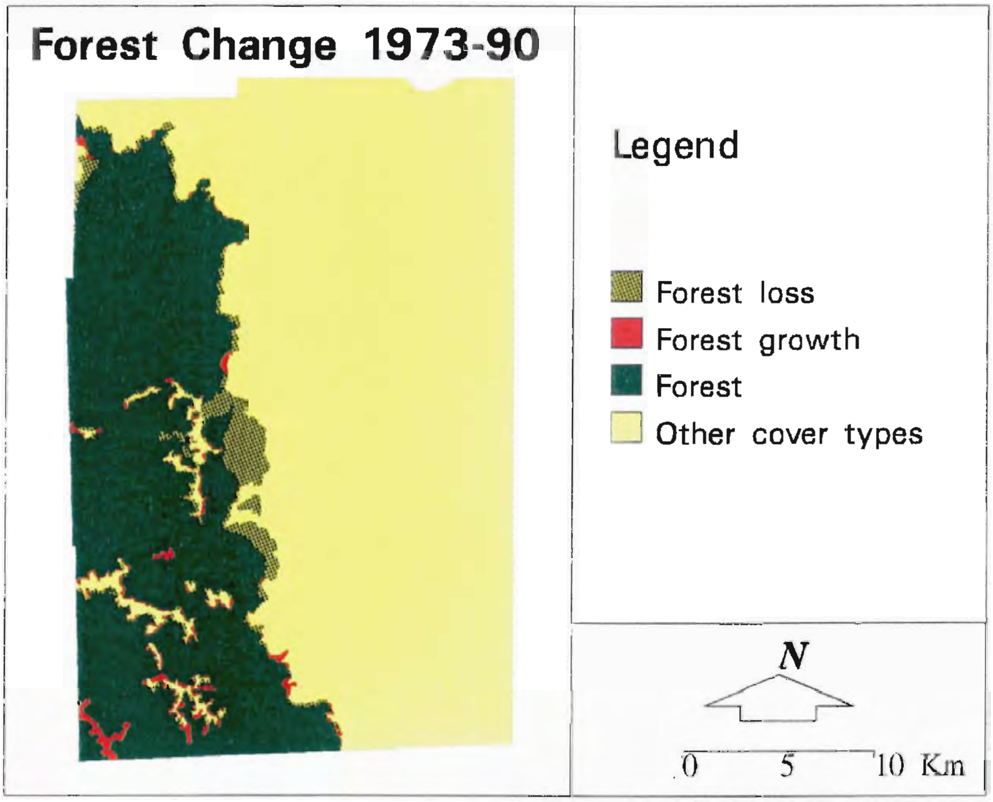
The policy-related land uses are: the green belt, designed to act as a buffer between the natural forest and smallholder cultivation; tea plantations, and demonstration projects for improved cultivation, and pasture. The green belt was planted on land previously occupied by wooded pasture, natural forest, and pasture. It was the most important cause of decline in the area of natural forest, replacing almost 16 km^2 of natural forest in the area studied. A small area of the natural forest was also cut for tea plantations and for project cultivation. An additional forest area of just over 2 km^2 was replaced by forest savanna, perhaps indicating cutting of areas within the forest by activities such as gold mining. These losses, which represent a 1.6% decrease in natural forest area, were to some extent offset by gains from forest savanna, woodlots, and wooded pasture.

The temporal trend for arboreal vegetation in general (taken as Green Belt + Woodlot + Wooded Pasture + Natural Forest) was quite stable, declining only 0.6% from 1973 to 1990. Large-area arboreal stands (taken as Natural Forest + Green Belt), on the other hand, increased 6.2% in area over the same period.

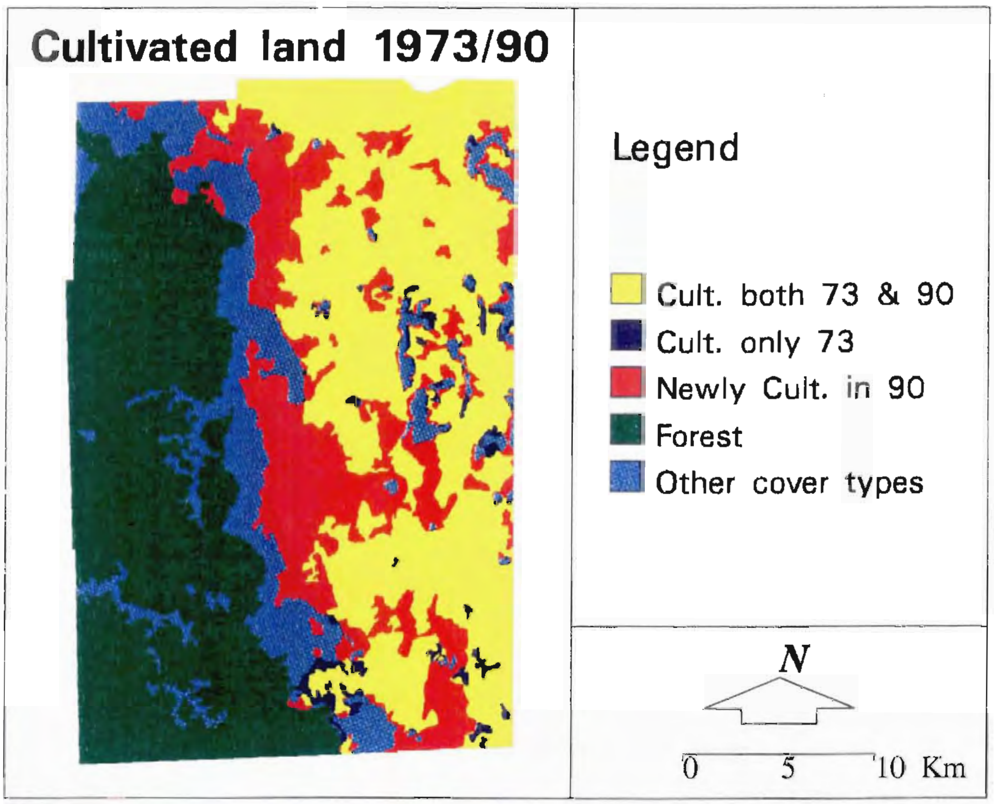
Cultivation did expand, from 260 km^2 in 1973 to over 370 km^2 in 1990, mainly at the expense of pasture and the agricultural frontier. This indicates the success of the green belt in acting as a buffer between agricultural activities and the natural forest. *No incursion of cultivation into the natural forest is shown in the area analyzed with air photography.* This finding may not be surprising given that the analysis was conducted on the eastern edge of the Nyungwe Forest, in communes that have been undergoing out-migration. We cannot be as confident about cutting for

Land cover changes between 1973 and 1990 (hectares)												
1990->	Greenbelt	Woodlot	Wooded pasture	Forest savanna	Natural Forest	Frontier	Pasture	Cutivation	Tea	Project cult.	Project pasture	Clouds
Greenbelt	0	0	0	0	0	0	0	0	0	0	0	
Woodlot	58	179	0	0	16	0	0	5	151	0	0	0
Wooded pasture	2096	8	0	0	103	0	0	961	0	130	3224	0
Forest savanna	300	0	0	751	459	0	0	0	0	0	0	0
Natural Forest	1597	0	0	240	23892	0	0	0	76	11	0	0
Frontier	0	301	0	0	0	0	51	3993	0	0	0	0
Pasture	1528	594	0	0	10	0	385	7394	446	22	851	0
Cultivation	318	608	0	0	15	0	175	24891	10	0	4	0
Tea	74	0	0	0	0	0	0	31	160	0	0	0
Project cultivation	0	0	0	0	0	0	0	0	0	0	0	0
Project pasture	0	0	0	0	0	0	0	0	0	0	0	0
Clouds	0	25	0	0	0	0	0	49	0	0	0	0
Total	5971	1715	0	991	24495	0	611	37324	843	163	4079	0

Table 6 Land Cover Changes, 1973 and 1990 (Hectares).



Map 6 Forest Cover Change, 1973-1990.



Map 7 Change in Area of Cultivated Land, 1973-1990.

cultivation on the western side of the forest as population increase and in-migration have been occurring in the communes of the area.

The total agricultural landscape, comprised of Wooded Pasture, Frontier, Pasture, Cultivation, Tea, Project Cultivation, and Project Pasture, sustained a 7.1% decrease in area from 1973 to 1990. The largest change was 107 km^2 of Pasture land that was converted primarily to Cultivation and some to Green Belt land. Wooded Pastures (65 km^2) disappeared to become mostly either Project Pastures or Green Belt land.

B. LAND COVER CHANGES 1975-1986

The results discussed in this section focus on the land cover changes detected using Landsat MSS imagery from 1975 and 1986. As mentioned above, the majority of both images were clustered into functionally meaningless spectral groupings which included several unrelated cover types. Due to differences in the sensors, platforms, seasons, and land cover changes, the portions of the landscape covered by these heterogeneous clusters were different in each of the two MSS scenes. When the classification outcomes were overlain (cross-tabulated), the Unclassified, Shadow, and Cloud clusters constituted 57 percent of the study area -- the majority being the Unclassified category.

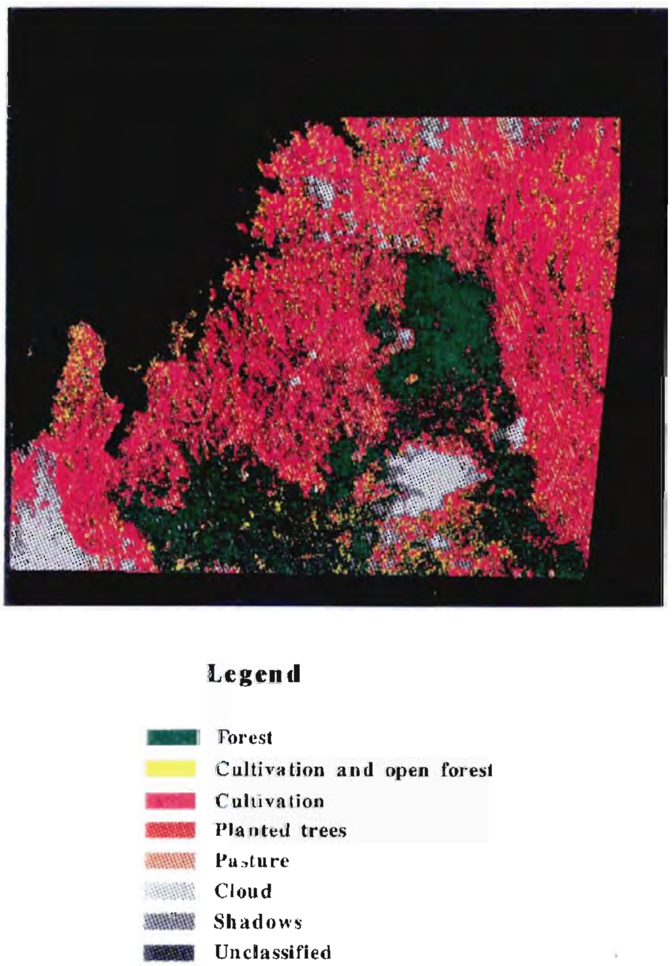
The land cover changes detected by the unsupervised classification approach are summarized in Table 7, and Maps 8 and 9. The Natural Forest category decreased in area by 2.4 percent (53 km^2). On a percentage basis this is comparable to the loss of 1.6 percent measured by the airphoto technique. The cluster analysis of the MSS data described a decrease of 3.6 percent in the area of Cultivation from 1975 to 1986. This contrasts sharply with the increase of 14.8 percent which was measured by photointerpretation. There may be two explanations for this discrepancy. First, the MSS data cover a much larger area than the airphoto analysis study and the land cover changes along the northeastern border of the Nyungwe Forest (the airphoto study area) may not be extant throughout the region. Secondly, the cover type heterogeneity within the Cultivation category means that nearly every pixel falling in such an area will be spectrally mixed. As a result, any categorization of such a landscape based on multispectral reflectance patterns will succumb to numerous classification errors.

An examination of the total amount of land supporting significant arboreal vegetation (i.e. Forest + Planted Trees in 1975 and Forest + Planted Trees and crops in 1986) as detected by MSS reveals an increase of 6.2 percent -- exactly the same amount of change as measured by the airphoto analysis. On the other hand, the total land area supporting some type of agriculture (i.e. Cultivation and open forest + Cultivation + Pasture in 1975 and Planted Trees and crops + Cultivation + Crops and savanna in

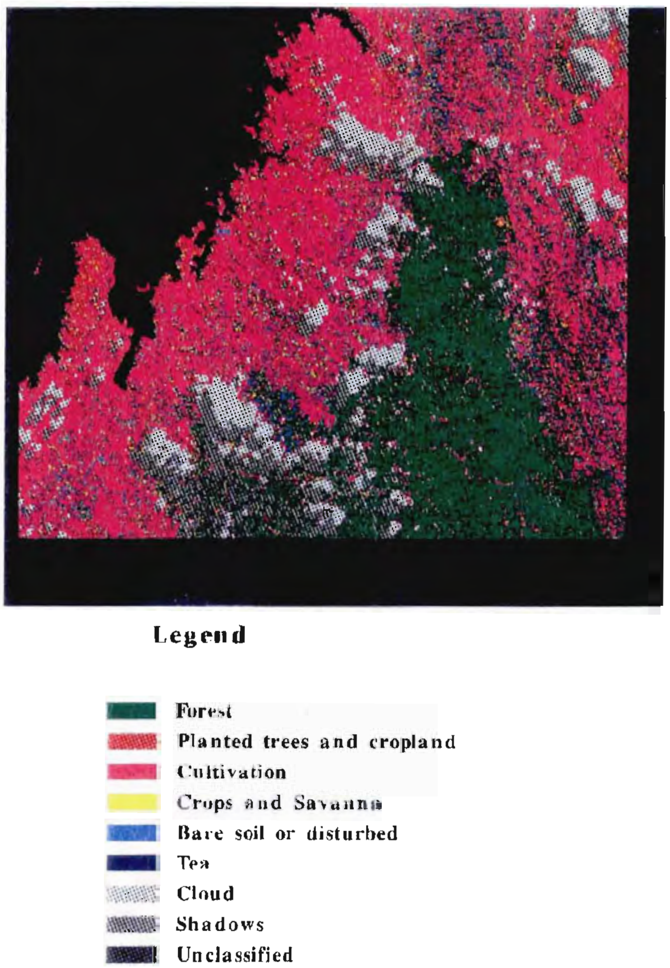
July 3, 1986 Data	Forest	Cultivation and Open Forest	Cultivation	Planted Trees	Pasture	Total (1986)
Forest	32,210	4,328	12,795	1,256	1,607	52,196
Planted Trees and Crops	13,965	2,408	6,805	172	314	23,664
Cultivation	6,168	10,300	84,785	2,141	12,447	115,841
Crops and Savanna	2,277	2,019	7,419	291	1,125	13,131
Bare Soil or Disturbed	2,803	2,134	11,611	467	1,241	18,256
Tea	86	41	532	40	464	1,163
Total (1975)	57,509	21,230	123,947	4,367	17,198	224,251

Data expressed in hectares. Based on pixel counts where 1 pixel (80 m x 80 m) = 0.64 hectares.

Table 7 Land Cover Change 1975-1986 as Determined by Unsupervised Classification of Landsat MSS Data.



Map 8 Unsupervised Land Cover Classification, March 1975.



Map 9 Unsupervised Land Cover Classification, July 1986.

1986) appears to have decreased by 4.3 percent -- an underestimate of the changes to this land cover association as detected by the photointerpretation.

Once again we must caution that the land cover categories used in the MSS analysis are not directly comparable with those used in the airphoto study. Hence, the interpretation of the results from the MSS analysis is somewhat ambiguous. In addition, the accuracy of the MSS classifications remain suspect since adequate ground-truth information was unavailable. The fact that 57 percent of the MSS subscene was unclassified by the ISODATA clustering routine should serve as a strong cautionary note.

C. EXPLANATION OF LAND COVER CHANGE 1973-1990

The analyses of the MSS images and the air photography indicate that both local actions within agricultural communities, and government policies and donor-funded projects have contributed to land cover changes. This section of the Report discusses the societal processes underlying these land use changes, processes that reflect local conditions, national policy, and the interaction between them.

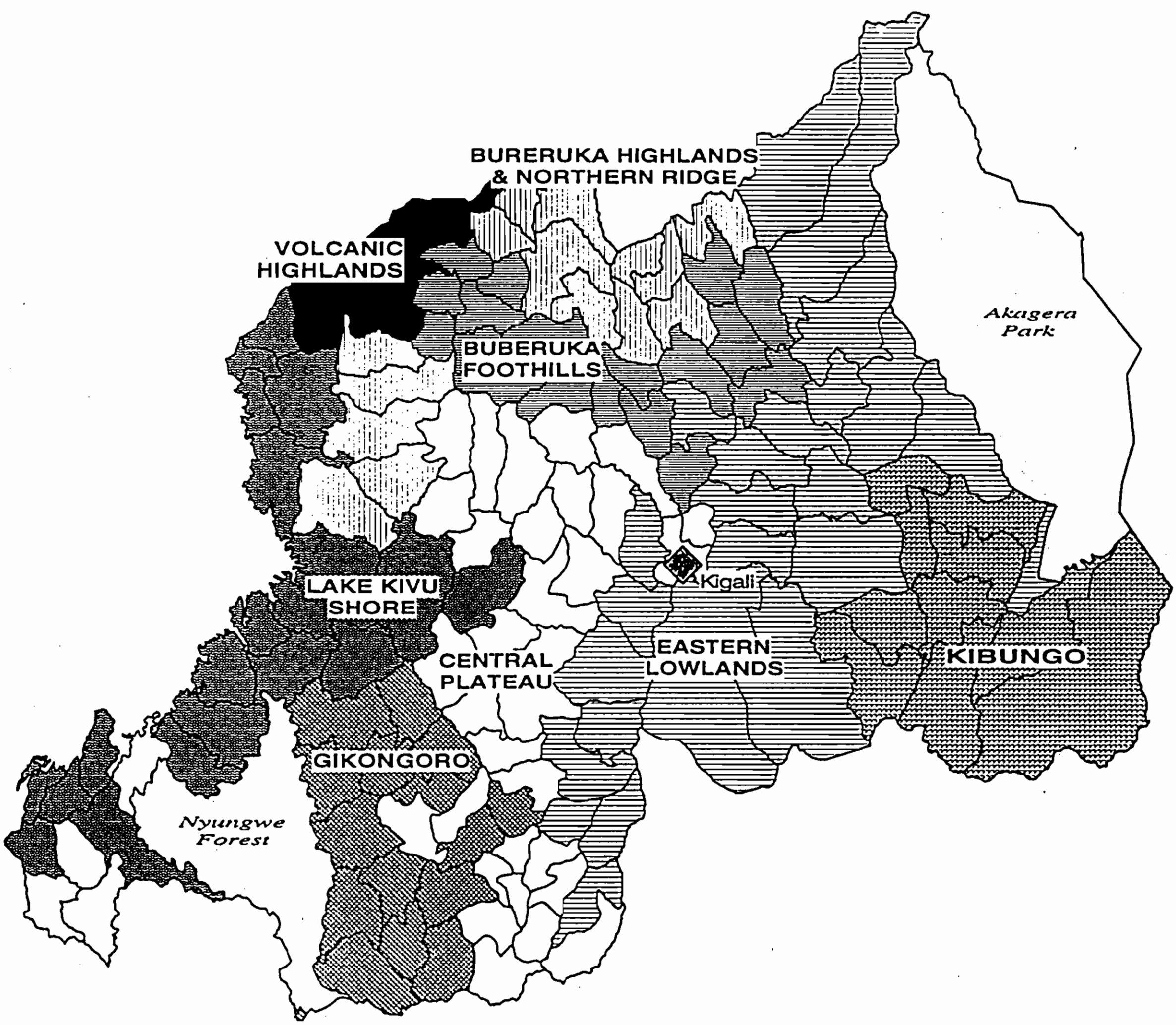
1. The Farming Systems

A statistical analysis of the geographical distribution of major crops and animals was conducted to identify homogenous regions whose farming systems are based on the same staple crops and animals (Map 10).[4] The large livestock of cattle, sheep, goats and pigs, were all included in the classification along with the crops of bananas, beans, sorghum, sweet potatoes, white potatoes and cassava. The concentration of some livestock and crops illustrates the uniqueness of each farming system region and contributes to its individual "personality."

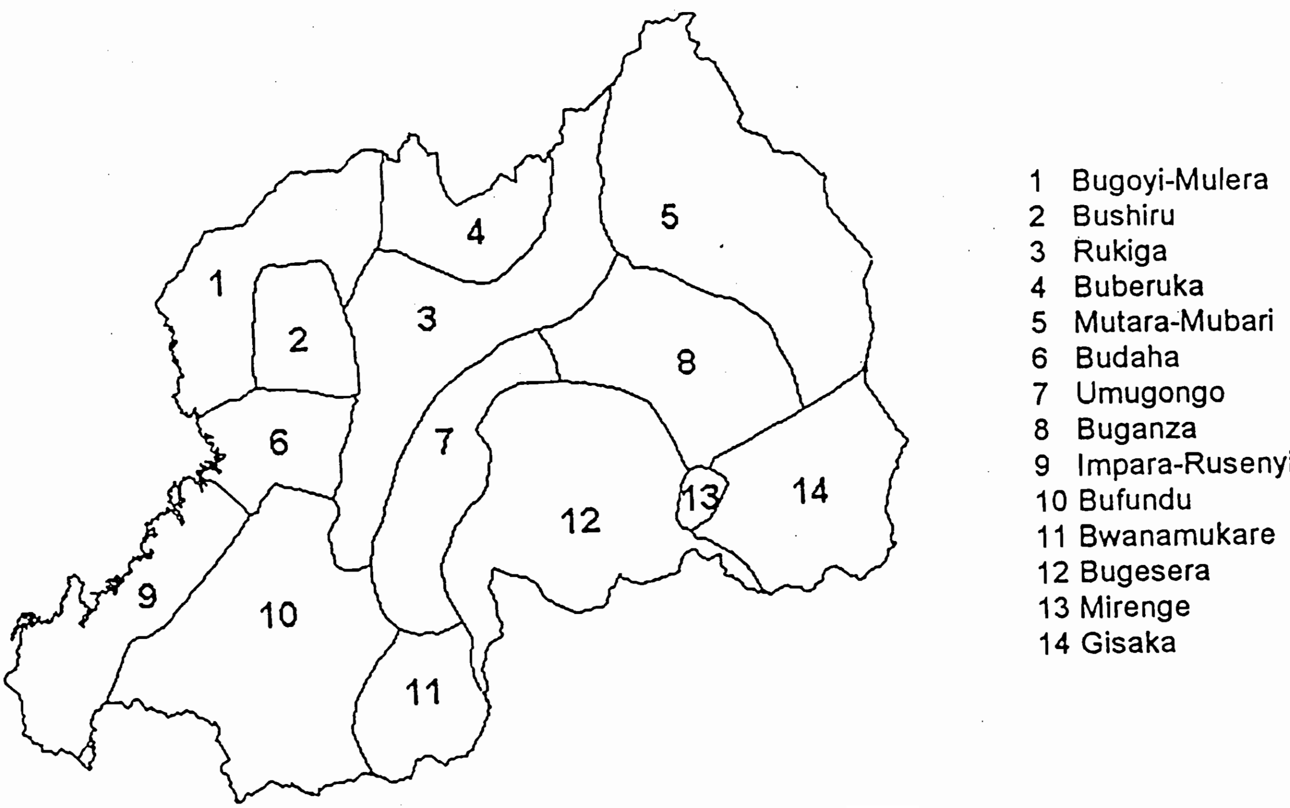
The Nyungwe Forest forms a physical barrier between two separate farming systems on either side, the Lake Kivu Shore and the Gikongoro farming systems. This difference between the east and west of the forest is unexpected since the entire area falls within one agro-climatic zone, the Zaire-Nile Ridge, and has generally similar conditions for crop growth (Delepierre 1975). Historical cultural, social and economic legacies continue to affect crop and animal production patterns. They overlay the physical environmental variables and have led to farming system regions dividing similar agro-climatic zones. Indeed, the farming system regions presented here, created with recent crop production data, unexpectedly resemble the old cultural regions (Map 11). The cultural regions were accepted as the standard regionalization of the country until the 1970's, and their names are still in common use by

[4]Based on Olson, 1994a

FARMING SYSTEM REGIONS



Map 10 Farming System Regions (source: Olson 1994a).



Map 11 Cultural Regions.

Rwandans. The eastern side of the forest is within the old Bufundu region and west of the forest was in the Impara-Rusenyi region (Nzisabira 1989).

The differences between the farming systems of Lake Kivu Shore and Gikongoro are reflected perhaps best in the relatively minor crops and animals the two regions produce. Gikongoro, for example, is the site with the highest concentration of pig production in the country whereas Lake Kivu Shore has very few pigs. Similarly, Gikongoro produces much more eleusine (a grain), sheep, sweet potatoes and wheat than Lake Kivu Shore. On the other hand, Lake Kivu Shore produces more coffee, goats, maize, bananas and soybeans than Gikongoro.

The difference in crops and animals reflects some external factors, such as the introduction of pigs by Catholic missionaries in Gikongoro before World War II. Similarly, wheat production in Gikongoro is the result of a recent governmental program. The distribution of other crops reflects different cultural preferences, perhaps, such as millet in Gikongoro and maize in Lake Kivu Shore.

The diffusion of new crops and animals, such as pigs, wheat and soybeans, within the old cultural region boundaries, indicate that the farming systems continue to evolve within older cultural, economic and political processes. The differentiation of the farming systems on the eastern and western sides of Nyungwe Forest is also reflected in other decisions made by the farmers. Differences in land use, levels of development and income, and tree use and tree planting are all distributed along a east/west divide.

2. *Pressure on Resources*

Population Pressure

Rapid population growth is the factor most commonly mentioned as the cause of pressure on resources as increasing numbers of people cultivate a limited amount of land. This has been an important factor in Rwanda which at its peak period of growth in the late 1970's experienced a growth rate of around 3.7 percent or a doubling of the population every 19 years (MINIPLAN 1982).

Rising population numbers, and subsequent increasing population densities, have been important factors in the southwest of Rwanda. The population started to grow rapidly after World War II with the introduction of new crops and new agricultural techniques, a decline in diseases due to improved medical care and hygiene, and the abandonment of traditional forms of child spacing with the conversion to Catholicism (ONAPO 1990). Population densities rose from 127 km^2 in 1948 to 327 km^2 in 1978 and finally to 495 km^2 in 1991 in Cyangugu. In Gikongoro, the rise was less dramatic but nevertheless very rapid with a growth from 105 km^2 in 1948, through 242 km^2 in 1978, to 302 km^2 in 1991 (Prioul and Sirven 1981; MINIPLAN 1982; MINIPLAN 1992). The rise in population densities have resulted in an increase in land being put under cultivation, since as described below, farming remained the primary means of livelihood for rural people due to the slow development of the non-agricultural sector. Substantial short-distance movement occurred as nearby pasture, valley and forest land was converted to cultivation. This resulted in a loss of grass for pasture, fuelwood, medicinal plants, grasses for making baskets, and to use as green manure, etc., from communal land that had been maintained for hundreds of years for those purposes. Finally, with a cultural system in which each son inherits an equal amount of land from his father, each generation has seen a shrinking of farm sizes in areas where supplemental land to clear or buy is difficult to obtain.

Other factors in combination with rapid population growth have had a profound effect aggravating the *in situ* production pressure on constrained resources (Figure 2). These other factors have been political, socio-cultural, economic and environmental in nature.

Loss of Communal Lands

Before independence in 1962, most of the population was confined to the foothills of the western highlands by a tightly-controlled, hierarchical political system in which the Hutu farmers had little power; access to land was controlled by the cattle-owning Tutsi (Newbury 1988). Population densities built up in the foothills of the western highlands while the savanna East was reserved as pasture for the Tutsi king's cattle (Prioul and Sirven 1981). Even in the West, entire communes (e.g., Musange in Gikongoro) were reserved as pasture. The unequal distribution of land regionally was a major force behind the waves of out-migration that started after independence in 1962 when a power reversal resulted in the Hutu coming to power and opening the East to settlement by farmers (see Section III). These historical inequities in land distribution have been followed by relatively minor, but nevertheless disturbing, disparities at the local level with some farmers in the West able to maintain woodlots and hire laborers whereas many others are near-landless.

The independent government continued to control access to land. In the area surrounding Nyungwe Forest, a large proportion of the land has been allotted to parastatal tea plantations and to economic development cum forest preservation, projects financed by foreign governments (Table 8). The government appropriated land that had been used in an extensive manner *by local farmers* for seasonal pasture, fuelwood and/or crop production. In contrast, the plantations and development projects were intended to generate foreign exchange *for the government*, either directly through foreign assistance and the export of tea or indirectly through an increase in tourism. Local farmers have gained little direct benefits from the plantations or the projects. The income earned by youths picking tea leaves on the Mata tea plantation, for example, is extremely low at between 700 and 1000 Rwandan francs per month ($4 to $6/month). Adult men earn 100 francs per day (60¢/day) for their work. Research conducted among households near a tea plantation in the northwestern Rwanda concluded that on-farm tea production is less profitable than

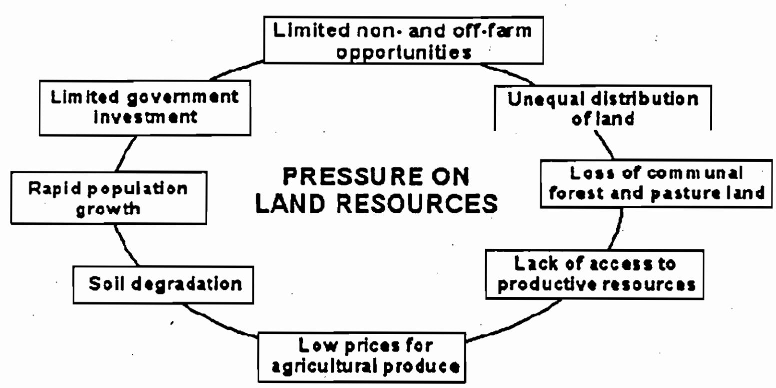


Figure 2 Proximate Causes of Production Pressure on Constrained Land Resources.

food crop production, and that households with a member working on the plantation have actually less food to eat than other households (Laure 1986; von Braun et al 1991) . Farmer interviews near the Crête Zaïre-Nil (CZN) project in northwest Gikongoro indicate that farmers are extremely bitter at the project and the government for having appropriated their land without recompense (actually, 2,624 families were relocated but to extremely marginal land) and then having seen jobs and other benefits of the project go to people from outside the area. In answer to a question put to them concerning whether they gain employment in the project, they replied (Muko 1992):

> On commence du premier au dernier sans être reçu. C'est de là que nous venons! On nous a répondu négativement. Et d'ailleurs, nous n'avons qu'un seul projet, celui du FED dont le personnel se compte dans les dizaines. On y trouve pas de travail sans qu'on ait donné des pots de vin. Il y a toute une semaine que nous nous rendons là-bas.
>
> *We are the last to be accepted. We are just coming from there! They responded (to our request for work) with a no. Anyway, we have only one project, that of the EEC, which employs tens of people. No one gets a job with them without giving a bribe. We have been going there now for an entire week.*

The CZN, financed by the EEC, was designed to be economically profitable through the development of a high-technology, commercial ranch. It was started in 1982 as a pioneer in Rwanda in the practice of sylvopastoralism, an extensive system to raise

Name of Project	Start	End	Zone	Source of Funds	Amount (Frw.)
DANK (Projet de Développement Agricole Nshili-Kivu)	5/10/1986	July 1988	Headquarters: Munini Address: B.P. 50 Butare B.P. 1211 Kigali	Germany Rwandan Govt	264.907.000 46.373.000
Projet d'Animation Rurale Mudasomwa	1981	1990	Headquarters: Mudasomwa Address: B.P. 513 Butare Zone: Commune Mudasomwa	Belgium Rwandan Govt	44.201.000 4.210.000
Projet Café et Cultures Vivrières au bord du Lac Kivu (P.C.C.V.)	1981	1988	Headquarters and Address: B.P. 54 Kibuye 3 zones: Rubavu-Nyamyumba-Kayove. Rutsiro-Gishyita-Rwamatamu. Gatare-Kirambo-Kagano-Gafunzo-Gisuma-Kamembe-Cyimbogo-Gishoma.	IDA Rwanda (Devel. Budget) Rwanda (Regular Budget)	882.000.000 475.600.000 142.100.000
Projet de Développement Rural de la Zone Centrale de la Crête Zaïre-Nil (C.Z.N.)	October 1983	1988 to 1989	Headquarters: Gatare Address: B.P. 582 Kigali Zone: Gikogoro:Muko-Musebeya Zone: Kibuye:Gisovu	EEC Rwandan Govt Food Aid FAC	1.173.000.000 13.200.000 25.000.000 42.200.000

Table 8 Development Projects Around Nyungwe Forest.

Name of Project	Start	End	Zone	Source of Funds	Amount (Frw.)
Protection et Reboisement de la Forèt de Nyungwe (Karengera) UGZ n° 4	March 1987	1990	Headquarters and Address: B.P. 159 Cyangugu Zone: Karengera/Forèt de Nyungwe	CCCE FAC	40.000.000 452.400.000 45.240.000 497.640.000
Protection et Conservation de la Forèt Naturelle de Nyungwe (GBK II)			World Bank	World Bank	2.950.000.000
Projet de reboisement en commune Mudasomwa	1/4/1984	1988	Headquarters: Mudasomwa Address: B.P. 513 Butare Zone: Mudasomwa commune	Belgium (Gift)	33.641.260
Unité de Gestion de la Zone I de la Forêt Naturelle de Nyungwe (U.G.Z.I.)	1986	1990	Headquarters and Address: B.P. 29 Kibuye Zone: Forêt Naturelle de Nyungwe Gisovu, Gatare, Kirambo, Kagano.	Switzerland (Gift + 2 Tech.Asst.) Rwanda	173.000.000 5.000.000 178.000.000
Appui au Service Forestier Préfectoral de Kibuye (SFPK)	1988	1990	Headquarters and address: B.P. 1 Kibuye Zone: All communes in Kibuye Prefecture (9)	Swizerland (Gift + 1 Tech. Asst.) Rwandan Govt	93.600.000 18.900.000 112.500.000

Source: Agriculture Rwandaises: Problematique et Perspectives by Jean Bosco Nezehose. INADES-Formation- Rwanda, 1990.

Table 8 Development Projects Around Nyungwe Forest (continued).

animals in a pasture under scattered trees planted for timber production. This system was thought to be one of the few profitable enterprises possible in the high-altitude, acidic soils around Nyungwe Forest that conformed to the law of 1988 to conserve trees. The project planted Grevillea, Calliandra, Sesbania and Leucaena tree species on the grassland (DGF 1991). Selected farmers/pastoralists were invited to sign a contract to allow them to graze their animals on the 850 hectares of improved pasture that was planted on former forest or fern lands (Gatali 1992). The project complained of non-selected farmers grazing their animals "illegally" and local farmers complained that the farmers who were selected were the rich from Kigali (Muko 1992). In another aspect of the project, imported brown Swiss cattle, requiring special pasture grasses, supplemental grains and intense veterinary services, were placed on newly planted, improved grasslands (Gatali 1992). The CZN project also planted a green belt around Nyungwe Forest Reserve of exotic tree species (pines, cypress, eucalyptus) for wood production and to reduce encroachment by farmers onto Nyungwe Forest (see Section D below for an examination of the impact of the greenbelt on local farmers).

The project had an agricultural component designed to help develop local farmers. The most visible outcome was radical terraces built on surrounding "pilot" hills with project financing (costing Frw 90,000 to 100,000 per hectare, or around $600 per hectare, for labor). Due to the high cost, complete project financing was later abandoned in favor of paying only half the labor costs, with the farmer to supply the rest, but farmers had responded "reticently" since they didn't have the manure or other inputs to make the new topsoil productive. Similarly, a program of enforced digging of erosion ditches and planting grass lines (enforced by fines or prison) was almost abandoned since farmers would later destroy the ditches (Mutabaruka 1992). A more general problem was that their encouragement of commercial agriculture, selling improved varieties of wheat or white potatoes grown with chemical fertilizer and lime, was unprofitable due to the high cost of the inputs and the lack of commercial outlet (Mutabaruka 1992). Overall, then, the CZN project increased the pressure on land resources felt by farmers in northwestern Gikongoro without helping them to adjust by, for example, supplying them with tree seedlings to replace their access to wild tree products.

We have less information on the other projects surrounding Nyungwe Forest (Table 8) but several were helping local farmers to produce their wood needs on-farm. The Projet de Reboisement de Mudasomwa does have a component of agroforestry (planting trees on farms as part of the agricultural system). The Projet Agricole de Kibuye (in Gisovu and five other Kibuye communes) works with an agricultural research station of ISAR to research potential agroforestry systems, produces and supplies tree seedlings to farmers, maintains an agroforestry demonstration field and trains extension agents on agroforestry techniques (Gahamanyi *et al.* 1988).
The Projet Unité de Gestion Zone 1, (le Centre Forestier de Ruzizi) was financed by the Swiss and was focussed not on agricultural development but on wood production

and conservation of the natural forest. The project had started a small experiment with sylvopastoralism using local sheep since they are less destructive of the vegetation than either cattle or goats. The World Bank's UGZ3 project concentrated almost exclusively on information gathering of land cover types within the forest. The project used air photo interpretation of 1980 photos at 1:20,000 and forest inventory to characterize forest ecosystems. They then digitized their findings into a GIS (World Bank 1993a).

Low Prices for Agricultural Produce
A third factor in the increased pressure on land resources has been the low revenues gained by farmers, intensifying their poverty and desperation (Ben Chabaane 1992; World Bank 1993b). Unfavorable terms of trade, a limited national market for agricultural products and declining coffee prices on the international market have resulted in low prices at the farm gate. Again, regional differences are important with areas able to produce and sell high-value produce doing much better than the others. The large commercial farms of the East, for example, are linked to the external market network and they can easily sell their high-value bananas or sorghum. Farms of the Northwest can sell their white potatoes to traders from the capital city. In contrast, the Southwest is less tied to the nation-wide commercial network and produces less of the high-value crops. Some areas of the Southwest with highly acidic soils, as in highland Kibuye and Gikongoro, are also suffering from severe soil degradation and declining productivity, further increasing their poverty (Olson 1994a). Lack of access to productive resources (Blaikie and Brookfield 1987), including animals for manure, improved seeds, and fertilizers, is also felt differentially between households within regions depending upon their ability to afford the inputs.

Limited Non- and Off-Farm Opportunities
The low farm revenues and declining availability of farm land have led to agriculture alone being unable to support the rural population in much of the West. This has increased the importance of the role of non- or off-farm sources of income in rural areas. The availability of these opportunities differed, again, between regions and between people in regions. The East, well tied in to the external market and with large commercial farms, had agricultural wage labor employment possibilities. The Northwest had been the recipient of many development efforts in the form of new schools, a university campus, new roads, agricultural projects etc. since the early 1980's. This was due to the former President Habyarimana and the people he had selected for important governmental posts concentrating governmental funds in their home region (Newbury 1992). Some rural people were presumably directly employed by or otherwise benefitted through economic multiplier effects from these activities. Again, the Southwest had fewer opportunities. Within the Southwest, Cyangugu was somewhat favored with trade opportunities with Zaire and Burundi. Farmers in Gikongoro and Kibuye, however, were relatively isolated from any trade network or other opportunities outside of subsistence agriculture. The regional differences in

non-agricultural economic activity was captured by Ben Chabaane *et al.* (1991) who created a multi-variable "development" index (Map 12).

This concentration of "proximate causes" of pressure on resources in the Southwest relative to the rest of the country are reflected in this area having the lowest incomes (Map 13) and experiencing some of the worst symptoms of stress such as poor child nutrition and soil degradation (Von Braun *et al.* 1991; Tardif-Douglin *et al.* 1992; Olson 1994a). The Northwest had actually a higher rate of population growth and higher population densities than the Southwest, but because other proximate causes were less severe the situation in the Northwest was much less critical. The limited opportunities for profitable agricultural intensification and non- and off-farm employment in the Southwest has led to high adoption rates of responses to pressure on resources.

D. RESPONSES TO PRODUCTION PRESSURE ON LAND RESOURCES[5]

1. Introduction

Grigg's construct of responses to population pressure is useful to understand the pattern of changes that have occurred in Rwanda over the past 40 years (Figure 3). The first, and perhaps most important response, has been a change in the agricultural system itself with a process of agricultural intensification. The intensification process began early in Rwanda due to the restricted land area allotted to farmers before independence. Population densities built up in the foothills of the Western Highlands. Many intensification techniques were adopted independently by farmers. They developed a system of double, then triple, and then the current strategy of near-continuous cropping. Farmers perform intense crop maintenance, have switched to higher-yielding crops (tubers instead of pulses and grains) and invested in "landesque capital" (Blaikie and Brookfield 1987) such as incorporating manure and grasses into the soil, mulching, maintaining erosion ditches and grass lines and planting trees. The amount of land in fallow declined as a higher proportion of land was placed under crops. As part of this process, communal land that had been patches of forest remnants and grass were brought under cultivation, reducing the availability of wild tree products and pasture for animals. The colonial and now the post-independence governments have enforced other intensification techniques such as the digging of erosion ditches and planting grass lines, and have introduced new crops such as cassava and the climbing bean (Bart 1993). The intensification process has continued to evolve.

A second response to increased pressure has been to engage in non- and off-farm income generation as much as possible by trading, working as agricultural laborers on near-by farms and performing temporary migration to other rural areas or to the

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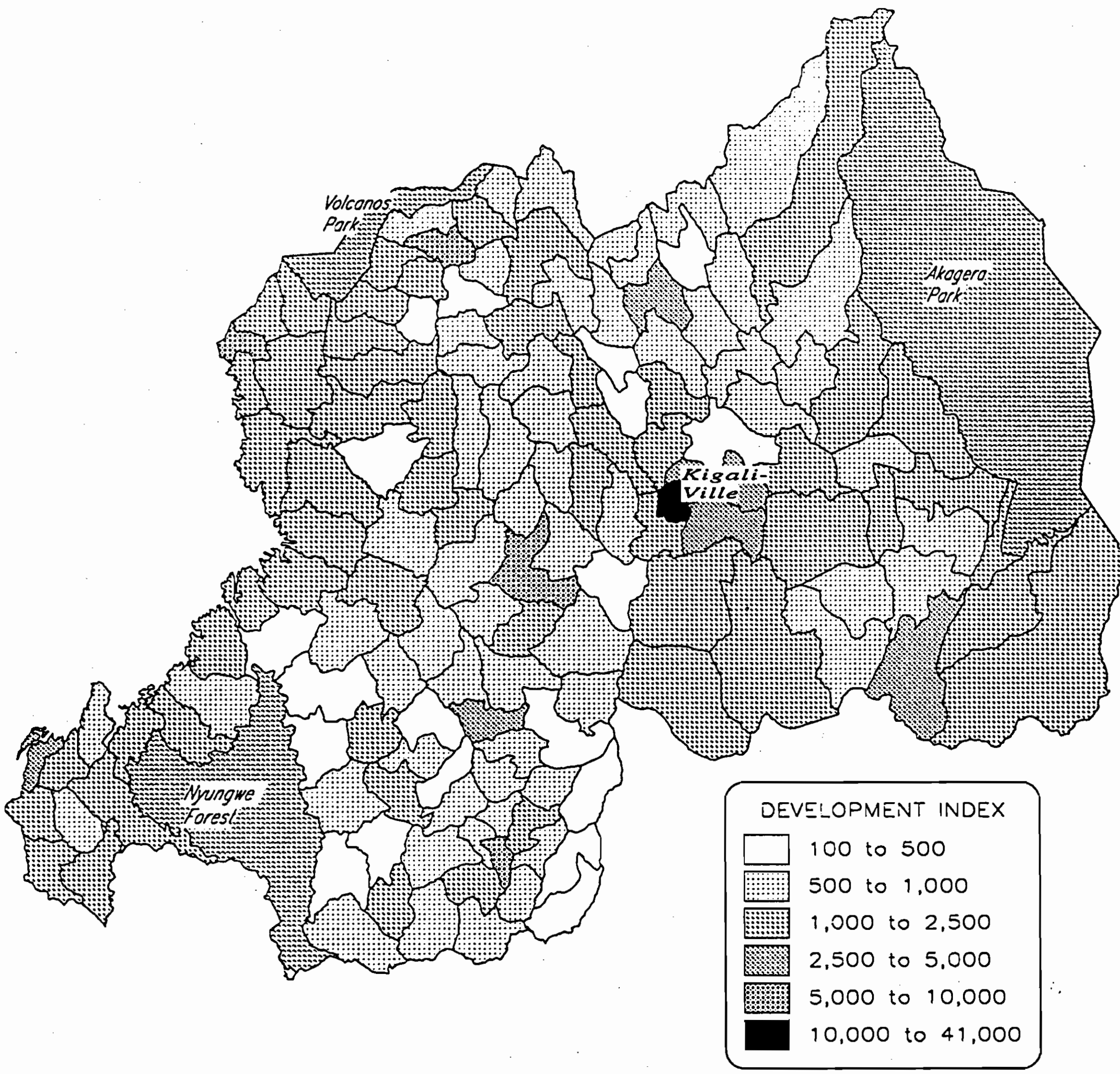
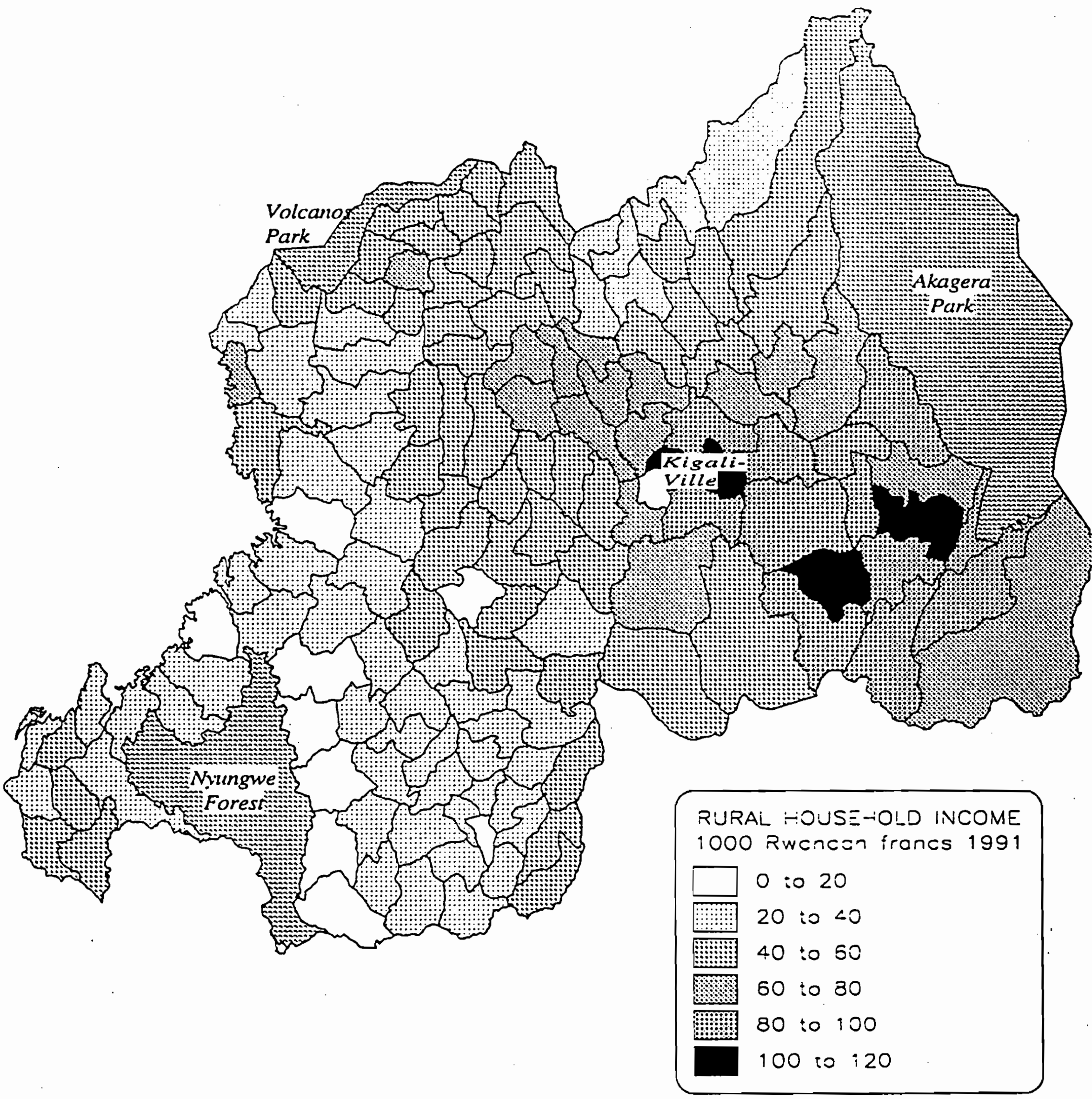
[5]Based on Olson 1994b



Map 12 Index of Development Activites and Infrastructure, 1991.



Map 13 1991 Rural Incomes per Household (Agricultural plus Non-Farm).

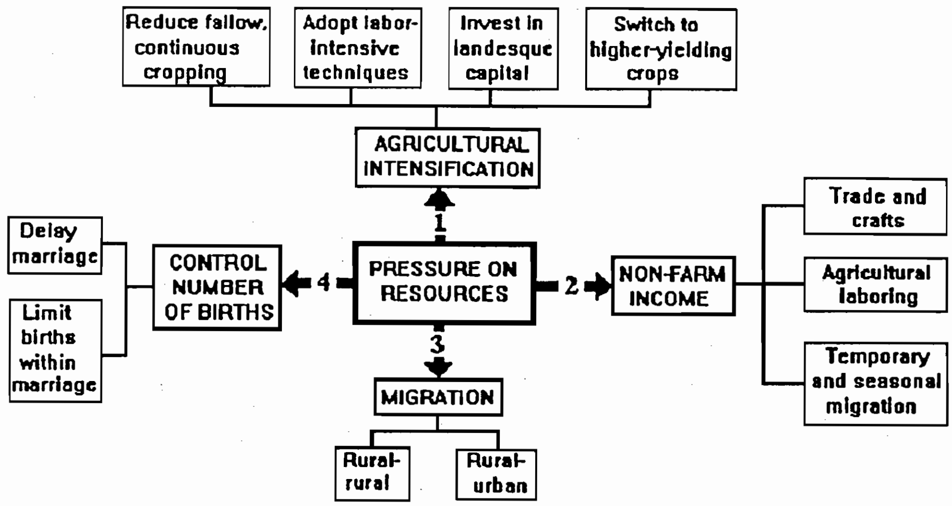


Figure 3 Sequential Responses to Pressure on Resources (adapted from Grigg 1980).

capital city. These non- or off-farm activities were conducted by more than half of all rural households in the country (Clay *et al.* 1989). The most common form of off-farm employment was agricultural labor, an extremely low-paying activity, conducted especially by people from the smallest farms. Other common off-farm activities included small-scale trading and making handicrafts (Clay *et al.* 1989).

The third and fourth responses to the pressure on resources are demographic in nature, out-migration and reducing the number of births. Migration will be discussed below.

The adoption of these four responses has been, in general, sequential with each new response adding cumulatively to the evolution of the rural systems. The adoption of the responses has depended upon the degree and nature of pressure felt and the opportunities available locally to reduce the pressure.

The intensification response has affected how farmers apportion their land among the elements of the "triad" of agriculture in Rwanda, crops, animals and trees. This report will focus on the tree component of that triad since tree products have been the major use of the forest by farmers. The response of migration will also be closely examined since it has led to a potentially important change in land use/land cover on the forest edge.

2. *The Evolving Crop/Animal/Tree Triad Over Time*

In the hierarchical structure before independence, one group of people, the Tutsi, had the privilege of owning cows and held most of the political and economic power. The second group of people, the Hutu, rarely owned cows but often raised the Tutsi's cows in return for the male offspring, milk, and manure. They also cultivated crops around their homesteads, the *urugo*. This cultivated land nearest the *urugo* received manure and household and agricultural residues, as well as intense maintenance, so the soil grew fertile through this human-induced process, whereas the pasture land was eroded and relatively infertile (Schyns 1988). The owners of the cows, the rich Tutsi, however, had power over access to land and most land was reserved for pasture. Only a small amount of land was cropped and trees were confined to forest residuals in marshy valleys (Loupias 1903; Johanssen 1915). When the Europeans arrived, therefore, they found a grass-covered landscape that was the result of continual land management.

The German and then the Belgian colonialists maintained and solidified political power in the hands of the Tutsi who kept complete control over land use and access to land (Maquet 1954; Newbury 1988). Therefore the political and cultural system which placed such importance on cattle and cattle ownership was reinforced. As health programs for both people and cattle were implemented and new food crops adopted, the human and animal populations increased substantially beginning in the 1940's. The build-up of the farming population was, of course, confined to a restricted area by limited access to land.

Long-held resentments of the Tutsi and the Belgians led to the eruption of the Social Revolution and Independence in 1962. The Tutsi lost to the Hutu all political power and control over access to land and other resources (Lemarchand 1970). The pent-up demand for cropping land was released as land previously reserved for pasture became available to farmers. Two immediate impacts of the revolution were 1) reserved pasture land locally in the West and the entire East of Rwanda was opened up to farmers for settlement, and 2) colonial policies towards agriculture were reconsidered by the newly independent government. These political events, as well as demographic and economic changes, led to a major shift in the relative proportion of land devoted to crops, trees and animals.

One policy initiated very early by Belgian colonialists, and then continued in the 1980s by the post-independence government, was exotic tree plantings with *umaganda* (forced communal labor) on government woodlots and along roads. The eucalyptus, cypress and pines were to produce construction materials for the government buildings and churches and to reduce erosion from the hilltops. After independence, tree planting was encouraged on farms but the organized tree planting programs began especially in the mid-1980's. The government prompted tree planting on arbor day starting in the early 1980's. Expatriate agro-forestry projects and governmental programs established tree nurseries and actively promoted tree planting, such as grevillea and eucalyptus, as part of an anti-erosion campaign. The results include an increase in availability of seedlings and knowledge of tree planting, more trees in government woodlots, and more trees on private farms. The governmental extension efforts have been coincident with an increase in the demand for tree products (fruit, fodder, medicines, wood etc.) as the population increased and as forest remnants were converted to crops.

In these regions, therefore, there has been a large increase in planted trees on large and small farms as the few wild trees that had been managed in forest remnants disappeared. Farmers had previously often planted fruit trees and euphorbia around their houses, but now trees are also planted on field boundaries and elsewhere on the farm (den Biggelaar 1994). This increase in numbers of trees with an increase in population densities is similar to what occurred in Machakos District, Kenya (Tiffen *et al.* 1994). There has been an increase in biodiversity in Rwanda's human landscape.

The extremely wide diversity of tree species and tree management techniques currently found on farms speaks to the rapid development of this new knowledge by farmers due to new needs and increasing demands for tree products (den Biggelaar 1994). Trees have become similar to other crops in terms of their economic importance, and indeed have replaced cattle as a source of long-term savings. Trees are carefully managed and provide a constant source of food, fodder, medicine and fuel, and small to medium-sized poles which can be sold (den Biggelaar 1994). Trees play a different role in the household economy from that of crops, however, since they are owned by men and usually provide an infrequent if larger sum reserved for major purchases or to repay debts.

3. Trees: On versus Off-Farm

The most common use of Nyungwe Forest resources by neighboring farmers was probably the collection of wood products, especially fuelwood. There are many other purposes for which farmers use trees, including for medicines, yeast for beer production, stakes for climbing beans, etc. Some of these uses require certain species of trees, whereas the requirements for fuelwood, the primary use of trees, are more flexible.

The importance of tree products for farmers' daily life is thus critical. Changes in availability of tree products are, therefore, quickly and intensely experienced. An examination of responses of farmers near the Forest to questions on availability of tree products may illuminate changes in their relationship with the Forest. This hypothesis was tested by examining responses of rural heads of household and their spouses to a household-level questionnaire, the 1991 Ministry of Agriculture's Survey of Agroforestry (see Methods section for more information on the survey). The 228 households were categorized according to the distance between their homes and Nyungwe Forest, and again according to their prefecture of residence. The consequent small number of households in each category do not provide statistically valid results but provide a general indication of how responses vary between areas. The results of the analysis are summarized in the following tables, number 9 to 13.

Table 9 concerns the collection of fuelwood, the major employment of trees by farmers. A comparison of farmers near the forest with those that are farther away provide findings that are counter-intuitive. Farmers near the forest walk farther and spend more time in the collection of wood than farmers elsewhere who live too far to benefit from forest resources.[6] This difference is particularly true of the farmers in Gikongoro who live less than five kilometers from the forest. They said they walk approximately six kilometers to collect fuelwood, an indication that they are probably traveling to the forest, the nearest large source of trees, to harvest wood. This use of the forest results in them walking farther and spending more time collecting wood than other farmers who must depend on other sources. A comparison of their sources of fuelwood explains this anomaly: those households farther from the forest depend on trees growing on their own farms or on neighboring farms, whereas households near the forest collect their wood from public or communal lands. They are careful to not admit to the enumerator that they collect wood from the natural forest, an indication that they are aware of government rules forbidding such collection. Nevertheless, this contrast between households near the forest, especially those in Gikongoro, who depend on trees grown on public lands, and other households who depend on trees grown on private farms, is revealing.

Table 10 examines this anomaly further in an analysis of how fuelwood availability has changed over time. Again, the results are counter to what is expected. Households near the forest are experiencing a much greater lack of fuelwood than those farther from the forest. This situation has apparently developed over the past five years despite the area near the forest having lower population densities and, of course, proximity to the trees in the forest. The reason behind the unexpected findings is provided in the answers to questions on changing availability in the past five years. Apparently, farmers near the forest had access to off-farm sources of fuelwood in the past but they have since lost this access, due particularly to changes in land and tree property rights. Without additional farmer interviews it is difficult to determine exactly what changes in land tenure rights the farmers were referring to, but it is known that greenbelt projects appropriated tracts of land surrounding the forest during this period. The projects apparently did reduce farmer access to the forest by this appropriation of land. The greenbelt projects, in other words, seem to have been successful in creating a physical and proprietorship barrier preventing local farmers from collecting fuelwood in the forest. Unfortunately, not all projects provided a substitute source of fuelwood to the farmers, as illustrated by the large

[6]The distance farmers walk to collect fuelwood was determined from their answers given in minutes. The minutes were converted to kilometers by assuming they walk four kilometers per hour.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
DISTANCE FROM HOUSE TO FUELWOOD (km)							
Mean	2.6	6.0	2.3	.6	2.3	.7	1.5
Median	2.0	6.0	2.0	.7	2.0	.7	1.0
Maximum	6.0	12.0	20.0	1.0	8.0	2.0	6.0
TOTAL	100%	100%	100%	100%	100%	100%	100%
HOURS/WEEK SPEND COLLECTING FUELWOOD							
Mean	7.4	10.9	6.1	4.6	7.3	4.9	9.1
Median	7.0	8.0	5.0	4.0	2.0	3.0	6.0
Maximum	17.0	30.0	28.0	7.0	40.0	30.0	30.0
TOTAL	100%	100%	100%	100%	100%	100%	100%
WHERE OBTAIN FUELWOOD (2 responses possible)							
Own farm	59%	25%	79%	100%	44%	85%	65%
Neighboring farm	69%	88%	40%	38%	88%	61%	48%
On this hill	41%	25%	42%	38%	63%	15%	40%
Public woodlot	9%	50%	25%	0%	0%	9%	9%
Natural forest	6%	0%	2%	0%	0%	0%	6%
Market	0%	0%	0%	0%	0%	1%	0%
Other	3%	0%	0%	0%	0%	0%	0%
TOTAL	100%	100%	100%	100%	100%	100%	100%
N households	32	16	48	16	16	80	80

Table 9 Collection of Fuelwood.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
LACK FUELWOOD?							
No	31%	13%	56%	75%	88%	78%	64%
Yes	69%	88%	44%	25%	13%	23%	36%
TOTAL	100%	100%	100%	100%	100%	100%	100%
AVAILABILITY OF FUELWOOD IN PAST 5 YEARS							
Large increase	3%	13%	19%	13%	38%	25%	18%
Small increase	9%	0%	31%	38%	25%	26%	23%
No change	13%	6%	8%	6%	6%	29%	13%
Small decrease	31%	31%	25%	44%	13%	13%	29%
Large decrease	44%	50%	17%	0%	19%	8%	19%
TOTAL	100%	100%	100%	100%	100%	100%	100%
REASON FUELWOOD DECLINED (2 responses possible)							
Land scarcity	83%	62%	60%	86%	75%	63%	58%
Higher demand for fuel	58%	38%	70%	100%	0%	56%	34%
New land property rights	42%	54%	25%	0%	0%	6%	13%
Pests and diseases	0%	0%	5%	0%	0%	0%	26%
Theft of fuelwood	4%	8%	0%	0%	0%	0%	3%
Wastage of fuelwood	4%	0%	20%	0%	50%	0%	11%
New industries	0%	0%	0%	0%	0%	0%	5%
Other	0%	31%	5%	0%	0%	19%	11%
TOTAL	192%	192%	185%	186%	125%	144%	161%
N households	32	16	48	16	16	80	80

Table 10 Availability of Fuelwood.

percentage of these farmers experiencing a lack of fuelwood. The planted trees in the greenbelts were clearly governmental or project property that local farmers could not harvest.

The appropriation of land by greenbelt projects partially explains the reduction of availability of fuelwood in areas near the forest. Other areas, however, have experienced different factors reducing sources of fuelwood as population densities have increased, farm sizes have shrunk and wild trees have been cleared as the land has been converted to crops. Households in these areas did not, however, express the same lack of fuelwood and declining availability of fuelwood as households near the forest. Their ability to cope with the incremental loss of trees on public lands is linked to a major effort to plant trees on their own farms. This shift of location of trees from common to private land, and an actual increase in numbers of trees coincident with the intensification of agriculture, is similar to what occurred in Machakos District, Kenya (Tiffen *et al.* 1994).

Table 11 illustrates this trend in tree planting. Most households throughout the Southwest have increased the number of trees grown on their farms, with the exception of farms in Muko, Gikongoro near the forest. The absence of tree plantings in Muko may be tied to the previous lack of need for on-farm tree planting since these households in the past had been able to collect their fuelwood from the forest. It is also tied to the low presence of governmental or project services providing seedlings and extension of how to plant trees. This is illustrated by the source of seedings. Elsewhere, governmental or project nurseries play an important role in providing seedlings to farmers. In Muko, there are apparently no governmental or project nurseries and the seedlings farmers plant originate from friends and neighbors or are collected in the wild.

The reasons given for why trees were planted provide an important insight to the role of trees on-farm compared to off-farm. The primary reason given in all sites except in Muko is to produce tree products, especially wood. This indicates that farmers can no longer meet their wood needs through harvesting trees off-farm. Muko farmers, on the other hand, planted trees primarily to mark field boundaries. Presumably, they had been able to collect sufficient tree products off-farm, very likely from the forest, and in the past had no reason to plant trees on-farm. Many Muko farmers are interested in planting trees on-farm in the future, however (Table 12), and for most, a lack of land is not a major constraint to tree planting.

These differential results of changing fuelwood availability and of tree planting between areas is reflected in answers to questions on changing availability of wood generally in the region (Table 13). In contrast to what would be expected in an area of shrinking farm sizes and declining wild tree stocks, most areas are experiencing little change or an increase in wood availability in their region.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
CHANGE IN NUMBER OF TREES ON OWN FARM SINCE ON FARM							
Increased	41%	21%	73%	75%	38%	72%	63%
No change	25%	36%	4%	0%	25%	16%	15%
Decreased	34%	43%	23%	25%	38%	11%	22%
TOTAL	100%	100%	100%	100%	100%	100%	100%
ORIGIN OF SEEDLINGS							
Nursery of sect/comm gov	59%	7%	41%	56%	75%	65%	56%
Private nursery	6%	7%	0%	0%	0%	1%	0%
Grew seedlings self	13%	0%	2%	0%	0%	4%	13%
Neighbor or friend	9%	71%	24%	13%	6%	8%	23%
Wild stock	9%	14%	28%	25%	19%	21%	6%
Other	3%	0%	0%	0%	0%	0%	1%
Don't know	0%	0%	4%	6%	0%	0%	0%
TOTAL	100%	100%	100%	100%	100%	100%	100%
REASON PLANTED TREES (2 responses possible)							
Wood production	84%	29%	76%	94%	81%	82%	79%
Fruit production	41%	36%	17%	25%	69%	18%	19%
Soil conservation	25%	14%	30%	13%	6%	44%	29%
Mark field boundaries	19%	79%	57%	0%	25%	13%	18%
Fence around house	13%	7%	7%	44%	0%	17%	32%
Stakes for beans	13%	0%	4%	6%	6%	0%	12%
Leaves:mulch and org mat	0%	0%	0%	0%	0%	14%	0%
Medicines	0%	7%	0%	0%	0%	0%	0%
Fodder	0%	0%	0%	0%	0%	6%	0%
Other	0%	14%	4%	0%	0%	3%	4%
TOTAL	194%	186%	196%	181%	188%	196%	194%
N households	32	14	46	16	16	72	78

Table 11 Tree Planting on Farm.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
INTERESTED IN PLANTING TREES IN FUTURE?							
No	59%	56%	71%	50%	31%	51%	40%
Yes	41%	44%	29%	50%	69%	49%	60%
TOTAL	100%	100%	100%	100%	100%	100%	100%
CONSTRAINTS TO PLANTING TREES (2 responses possible)							
No constraint	0%	38%	15%	25%	13%	16%	11%
Lack land	97%	44%	77%	63%	81%	74%	71%
Trees compete with crops	38%	0%	21%	0%	0%	11%	9%
Lack labor	6%	25%	0%	19%	0%	5%	9%
Lack seedlings/seeds	9%	0%	4%	6%	38%	4%	21%
Too long before produces	0%	0%	0%	0%	0%	1%	4%
I'm too old	22%	25%	2%	25%	6%	13%	13%
Other	0%	0%	4%	6%	13%	6%	3%
TOTAL	172%	131%	123%	144%	150%	129%	140%
N households	32	16	48	16	16	80	80

Table 12 Tree Planting in Future.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
AVAILABILITY OF WOOD IN REGION PAST 5 YEARS							
Large increase	28%	13%	44%	0%	25%	40%	28%
Small increase	47%	0%	25%	44%	44%	26%	19%
No change	3%	6%	4%	13%	13%	8%	3%
Small decline	16%	6%	17%	44%	19%	11%	25%
Large decline	6%	63%	10%	0%	0%	15%	26%
Don't know	0%	13%	0%	0%	0%	0%	0%
TOTAL	100%	100%	100%	100%	100%	100%	100%
N households	32	16	48	16	16	80	80
WHY WOOD INCREASED IN REGION (2 responses possible)							
Tree planting	88%	100%	88%	29%	36%	64%	81%
Agr. extension to plant	79%	0%	85%	29%	27%	57%	62%
Govt laws to plant	4%	0%	3%	0%	0%	9%	8%
Seedlings available	29%	100%	18%	100%	64%	47%	27%
Other	0%	0%	0%	0%	45%	0%	0%
Don't know	0%	0%	0%	0%	0%	0%	3%
TOTAL	200%	200%	194%	157%	173%	177%	181%
N households	24	2	33	7	11	53	37

Table 13 Availability of Wood in Region.

	Distance from Nyungwe Forest (km)						
	Under 5		5 to 10		Over 10		
	CYANGUG	GIKONGO	CYANGUG	KIBUYE	CYANGUG	GIKONGO	KIBUYE
WHY WOOD DECLINED IN REGION (2 responses possible)							
Land scarcity	100%	91%	77%	100%	100%	57%	66%
Higher demand for wood	14%	82%	62%	100%	0%	86%	29%
New land property rights	71%	0%	0%	0%	0%	0%	5%
Pests and diseases	0%	9%	0%	0%	0%	0%	44%
Theft of wood	0%	0%	0%	0%	33%	0%	0%
Wastage of wood	14%	0%	31%	0%	67%	0%	15%
New industries	0%	0%	0%	0%	0%	0%	7%
Other	0%	0%	8%	0%	0%	14%	7%
Don't know	0%	9%	8%	0%	0%	0%	0%
TOTAL	200%	191%	185%	200%	200%	157%	173%
N households	7	11	13	7	3	21	41

Table 13 Availability of Wood in Region (continued).

The reasons given for the unexpected increase in wood availability is tree planting, often tied to governmental or project programs. A combination of an increase in seedlings available, in extension activities teaching farmers, and at times obliging farmers, to plant trees, and in tree planting itself has led to the increase in wood production. Muko, near the forest in Gikongoro, is again an exception with most farmers indicating wood availability has declined. The reasons given to the enumerator for the decline are ambiguous – land scarcity and a growing demand for wood, factors existing elsewhere as well. In group interviews, farmers were more forthcoming with their observations of the impact of the loss of what was their land to the Crête Zaire-Nil project.

> On a boisé tous les champs. La commune et le projet ont enlevé de force les champs aux paysans. Certains de nous avez trois, quatre champs, on les a tous pris. Que voulez vous... Les pâturages que le projet avait mis à la disposition des paysans, nos riches de Kigali s'en ont approprié. Nous n'avons pas le droit d'amener nos vaches à Munini (là où il y a des pâturages du projet). Ce sont des propriétés privées de nos dirigeants...
>
> *They (the CZN project) planted trees on all the fields. The communal government and the project took the farmers' fields by force. Some of us had three, four fields there, and they were all taken. What can you say... The pasture that the project put at the disposition of the farmers was all appropriated by our rich people from Kigali. Meanwhile we don't have the right to bring our cows to Munini (where the project has pasture land). That is considered the private property of our administrators.*

In sum, it appears that farmers near the forest had, in the past, collected fuelwood from Nyungwe Forest and grazed their animals on land surrounding the Forest. In the past few years, they have lost their access to both the forest trees and the pasture land due to appropriation of land by greenbelt projects. Those farmers in Cyangugu near the forest have compensated for the loss by planting trees on-farm and have therefore somewhat reduced the impact of the loss of their access to the forest. The farmers near the forest in Muko, however, did not benefit from governmental or expatriate programs encouraging tree planting and they have not yet adapted their farming system to planting trees on-farm. On farms farther from Nyungwe Forest, sources of tree products became scarce as unclaimed communal land was cleared and converted to crops. However, farmers planted sufficient additional trees on their farms to the point where they were able to meet their fuelwood needs on-farm.

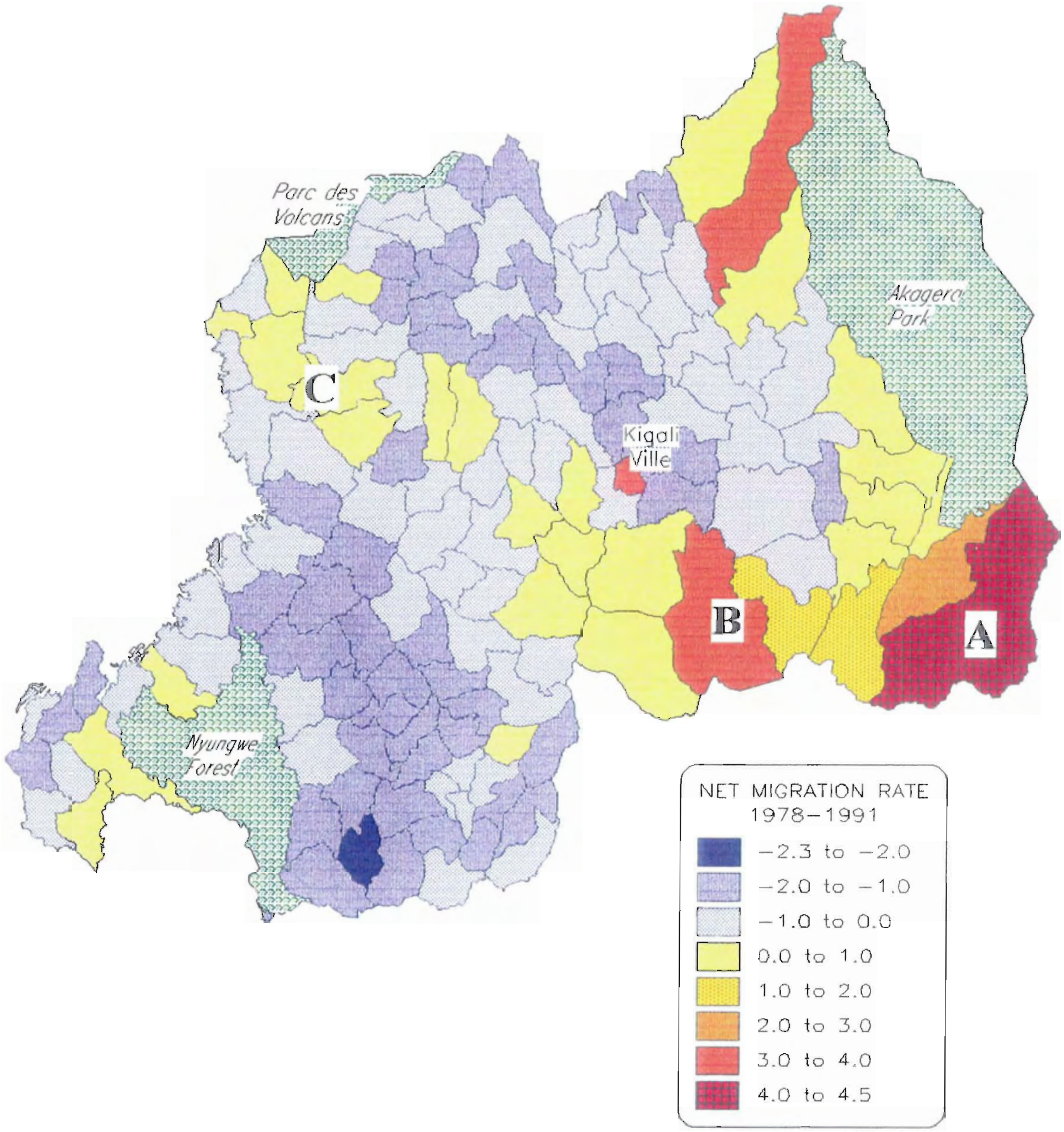
In sum, therefore, the land in the Southwest under grass has declined, that under trees has somewhat increased, and the land under crops has enormously increased. The trend of expansion of cropped land is uncertain since farmers find that there is no longer any uncleared land to be put under crops. Meanwhile, the value of animals remains high since they produce the precious manure for crops. Growing fodder (grass and tree leaves) on-farm is beginning to be a necessary part of the agricultural system. The necessity of planting trees and grasses on-farm has changed the landscape. Grasses had been found in communal or private pasture lands away from the intensely cropped fields surrounding the house, and the rare trees had been in valleys or hilltops on communal lands. Now grasses and trees are planted on the edges of fields as part of the cropping system. Another recently emerging trend is that farmers with extremely degraded cropped land are being forced to convert the land to pasture or woodlots, in a sense completing the cycle. This continuing process of agricultural intensification, coupled with the ecological process of land degradation, may lead in the future to somewhat less land under crops and more under grass and trees.

The Boserupian intensification process appears to have been relatively successful in areas of better soils and in farm households with sufficient resources to invest in the soil. In ecologically marginal areas and in poorer households, however, the intensification process has not provided a sufficient increase in production to support the added number of people, and the process has also resulted in soil degradation.

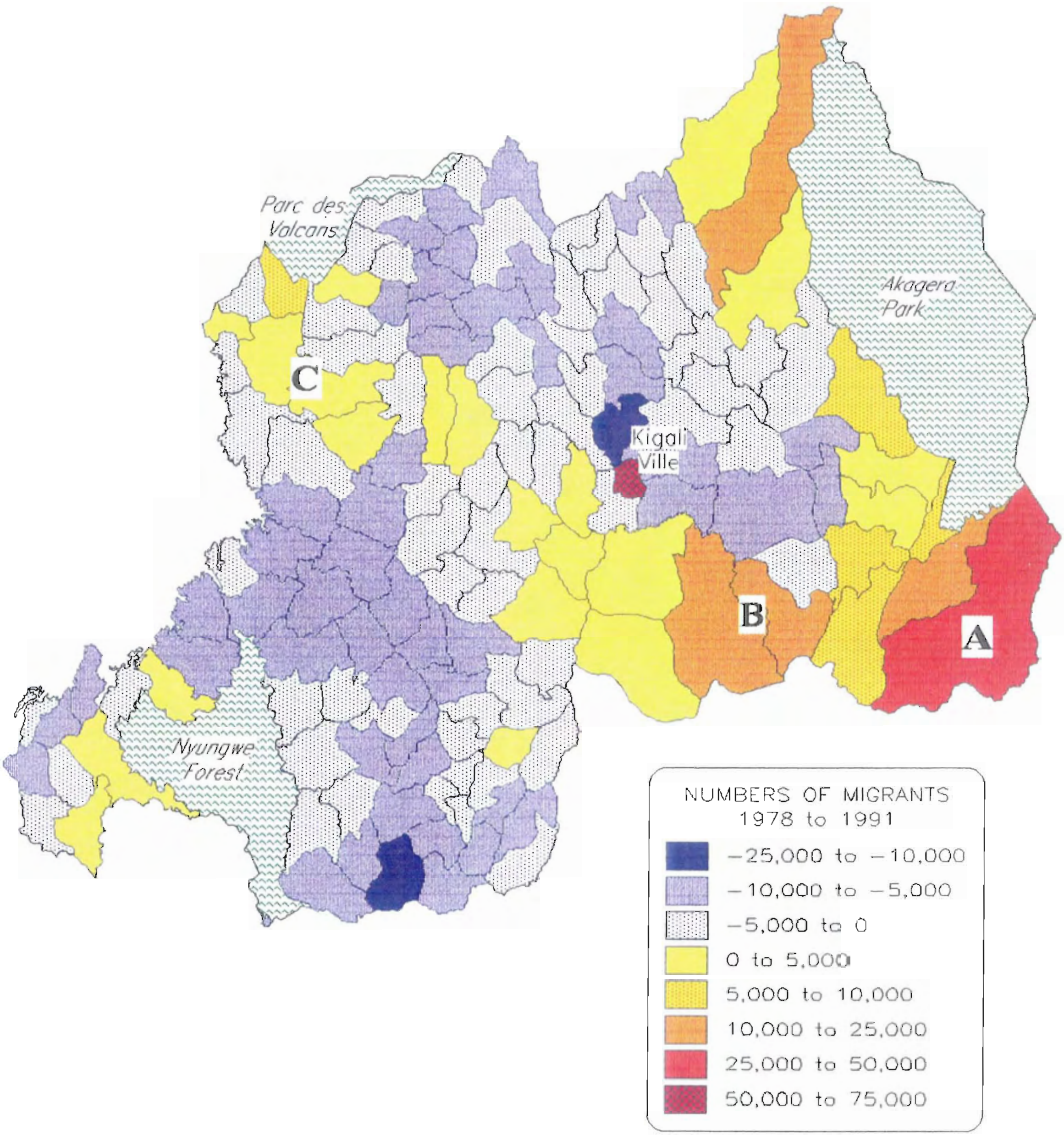
4. Migration

The reality of limited additional agricultural intensification opportunities and rare non-agricultural employment in the Southwest has led to adoption of another strategy, that of migration. Out-migration to the East began after independence in 1962 and by 1980 the population had seemed relatively evenly distributed throughout the country. The results of the 1991 census of the Rwandan population indicate, however, that migration as a response to resource constraints and to perceived regional differences in economic opportunities remained important in the period 1978 to 1991. The results indicate that contrary to what is often assumed, internal migration remained a common occurrence throughout the country with the in- or out-migration rate in many communes exceeding their rate of natural increase (Maps 14 and 15). The possibility of emigration by farmers seeking land had become increasingly impossible due to the unwillingness, and at time hostility, of neighboring governments and farmers of Uganda, Zaire, Burundi and Tanzania to consign their valuable and/or scarce land to foreigners (Sirven 1984; Bart 1993).

The opportunities at the new destination areas in Rwanda are much poorer compared to what earlier generations had enjoyed. The only zones of new land that migrants could claim were in the dry, rocky far East, in marsh land that required draining, or alongside forest reserves. The sole town receiving a large number of migrants was the capital city, Kigali-Ville, but the absence of good opportunities for those less than well-educated meant that rural areas continued to attract substantially more permanent migrants than cities.



Map 14 Net Migration Rate by Commune, 1978 to 1991.



Map 15 Net Numbers of Migrants by Commune, 1978 to 1991.

The extreme concentration of the mass of rural in-migration to a few communes in the far East reflects what many authors have written and what farmers have said, that opportunities for finding new land in Rwanda were extremely limited (Uwizeyimana 1991; Guichaoua 1989; Bart 1993). This migration stream to the East is a continuation of the pattern existing since independence in 1962 as farmers have moved from the densely populated Western Highlands farther and farther east searching for unsettled agricultural land (Olson 1990). The in-migration rate to these few remaining communes attracting migrants is very high, partly because their population sizes were so small before the new migrants arrived (migration rates are calculated by comparing the number of migrants with the resident population and represent the percentage of the population added or lost annually through in- or out-migration). Rusumo in the southeast (labeled "A"), for example, has an in-migration rate of 4.35. These far eastern communes do not have very high agricultural potential. The soils in the extreme southeast are shallow and rocky, and the rainfall is low and often variable. Gashora and Sake communes (labelled "B") are marshy and require drainage (CPR 1992). It is interesting to note that the communes alongside Akagera Park are almost all receiving in-migrants. Whether the new settlers are finding new land outside the Park boundaries, as previous migrants had done, or moved into the Park and hunting reserve, is unknown.

A few rural communes in the Western Highlands are also experiencing a small degree of in-migration. These communes are located alongside forests, indicating that in-coming farmers are probably clearing lands next to the forests or inside the official forest reserve boundaries. This is visible along the Parc des Volcans in the Northwest, the former Gishwati Forest Reserve (labeled "C"), and the *western edge of the Nyungwe Forest Reserve* in the Southwest. Approximately 8,600 net migrants settled along the western edge of the Nyungwe, mostly south of the road (Karengera and Bugarama communes). The in-coming farmers to the eastern edge of the forest were probably short-distance migrants, coming from the surrounding communes, and perhaps some from Gikongoro. Much of the land along the eastern edge of Nyungwe had been expropriated for parastatal projects and this, along with the poor soils and widely-known poverty of local farmers, apparently kept people from migrating to this land.

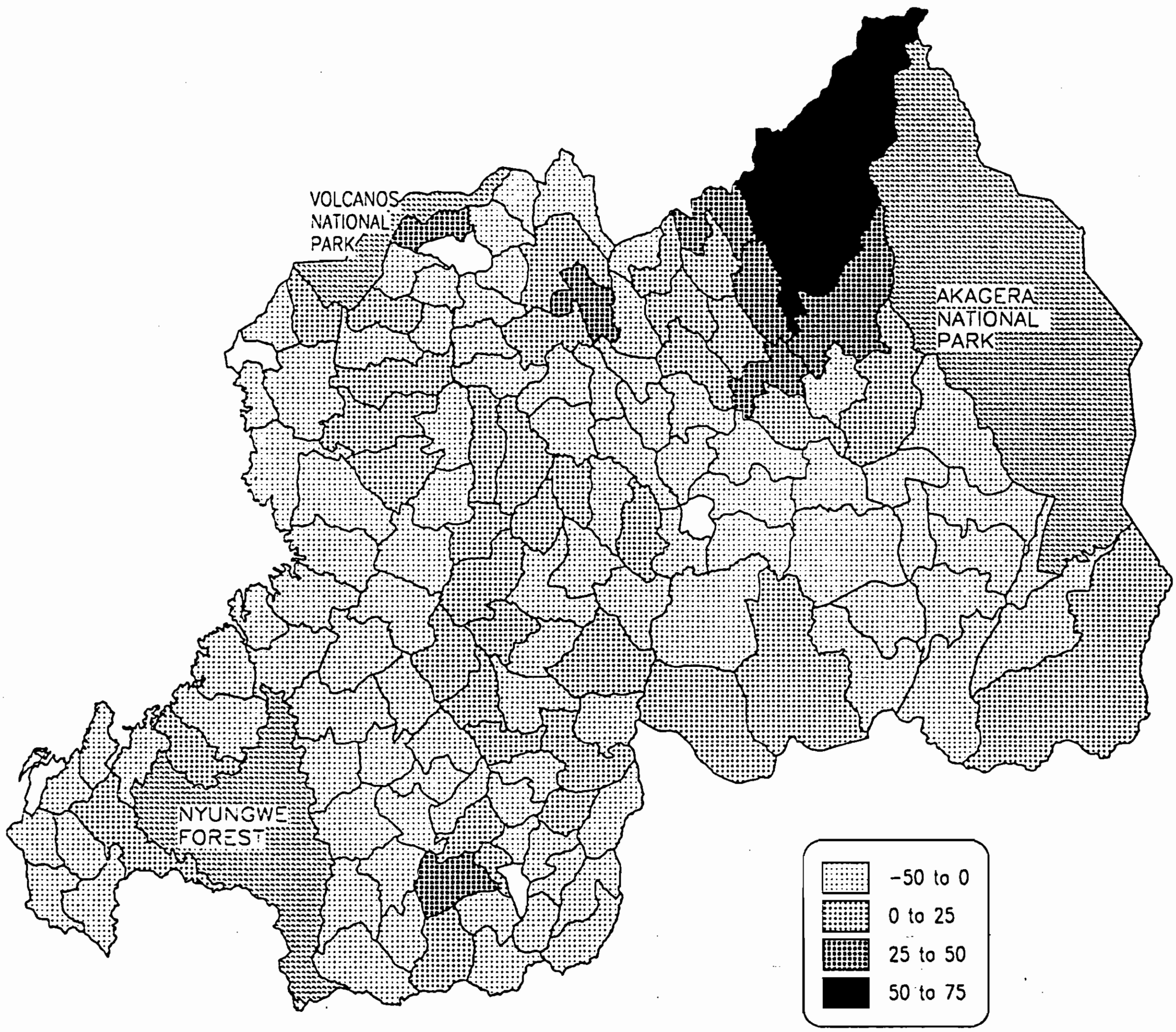
These movements towards the parks were undetected in earlier migration studies (Olson 1990; Cambrezy 1984) either because they are a new phenomenon or because they were not detected in the broader inter-prefectoral movements studied. One indication that they are a new phenomenon is that the 1978 to 1991 inter-prefectoral movements (see below) indicate a new stream of migrants moving from Gikongoro to Cyangugu, probably to those communes along the western edge of Nyungwe Forest receiving in-migrants.

A regression analysis was conducted by Brown and Griffith (in press) to statistically examine the 1978 to 1991 communal migration rate. They conducted the analysis within SpaceStat, a spatial statistical program that computes a spatial lag factor to reduce the spatial autocorrelation problems inherent in analyses of attributes of spatial units (e.g., communes). The log of the migration rate variable was used as the dependent and variables indicating relative population pressure, amount of spare land, rural income and levels of urban functions were the independent variables. Population pressure, a rural push factor, was estimated by Brown by calculating the cumulative population density from 1948 to 1991 for each commune. Campbell (1994) computed an approximation of available farm land (Map 16), a rural pull factor, as the proportion of arable land in the commune (i.e. land area less land in lakes, swamps, parks, homes, roads etc.) not used for agricultural activities. The non-farm rural and especially urban pull factor was represented by the development index of Ben Chabaane *et al.* (1991) which measured levels of infrastructure, economic activity, access to markets, etc. Ben Chabanne and Cyiza (1992) also calculated rural income, both a rural push and pull factor, based on agricultural census statistics and estimates of non- and off-farm income.

The resultant spatial lag regression analysis with these four independent variables had a pseudo R^2 of .472. The development index provided the strongest statistical explanation of migration, followed by the amount of spare land, the cumulative population density and finally rural income. The importance of the urban pull factor reconfirms the growing significance of urban-destined migration in Rwanda, and also reflects the regional differences in employment generation and economic multipliers that the infrastructure and economic activities in rural and urban areas generate.

An examination of the residuals revealed important local factors affecting migration activity. In-migration was underestimated in the high-altitude, low-potential communes adjacent to the western parks and forests and in an eastern commune containing the hunting reserve near Akagera Park (probably since the spare land variable had excluded park and forest reserves assuming they were protected areas). In-migration was also underestimated in communes with a large amount of marsh land requiring drainage (Gashora and Sake). Marsh land had also been excluded from the estimate of spare land. These results provide another indication that migrants were having no choice but to settle marginal agricultural land. Out-migration was underestimated in a block of communes located on the main roads directly to the east and north of Kigali-Ville. This unexpected phenomenon may be due to the short distance and ease of transport between these communes and Kigali-Ville. However, it also reinforces the finding that some areas of the previously-attractive East are now zones of constrained opportunity.[7]

[7] The discussion of the regression analysis is based on Brown, in press.



Map **16** Unfarmed Cultivable Area as a Percent of Area Under Crops, Fallow and Pasture for Rural Communes, 1987.

The movements between prefectures from 1978 to 1991, illustrated in the arrow map (Map 17), are an extension of the West to East rural-rural migration pattern that had been occurring since independence. Migrants from throughout the country concentrated their recent land-seeking efforts in a few areas of the extreme far East. The few opportunities that existed in those areas were in the form of marginal agricultural lands situated far from the migrants' origins, but this land still presented more prospects than what the migrant farmers could expect in their origin prefectures or in the city. The small stream of people moving from Gikongoro to Cyangugu is pr obably the first inter-prefectoral movement of people into forest reserve land of suffici ent size to be mapped.

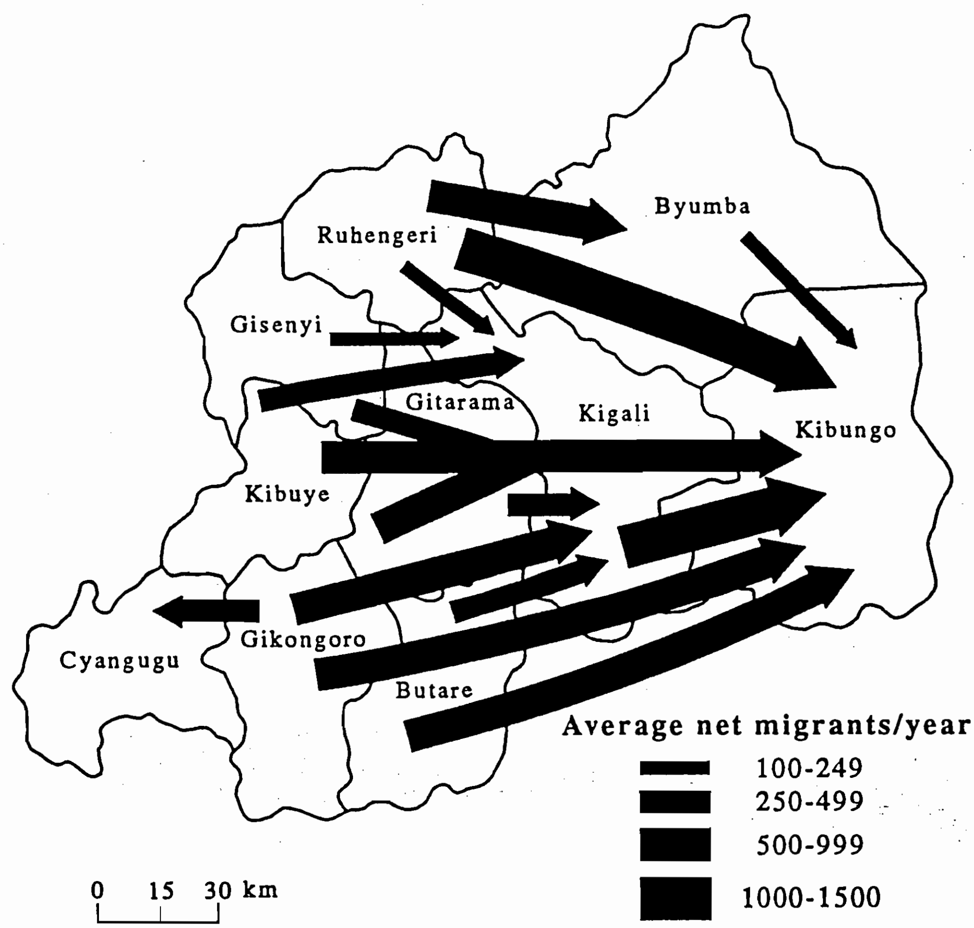
This extension of the historic West-to-East rural-rural flows seems rather final, literally the end of the road. The only unsettled land remaining in Rwanda is found in the 15 percent of country in parks and forest reserves, land set aside initially because it appeared to have little agronomic potential.

VII. CONCLUSION

THIS STUDY HAS FOCUSED ON AN IDENTIFICATION AND EXPLANATION OF LAND cover changes that have occurred over the past 20 years in a small area of South West Rwanda, including a portion of the Nyungwe National Forest. Considerable concern has been expressed in government and conservationist circles over the need to protect the biodiversity of the Forest in the face of a presumed threat from the expansion of agriculture, driven by a rapidly growing population in adjacent areas.

The results of the study indicate that the area of the Nyungwe Forest has declined, but the overall area of forest, natural and planted, has increased by just over 6 percent of the total air photo study area of 763 km^2. The decline in the area of the natural forest is not a consequence of the expansion of smallholder agriculture as would be indicated by the concerns of national policy-makers and donor agencies, but rather it is the result of policies designed to protect the forest through the establishment of government projects along the edge of the forest to act as a buffer against the encroachment of agriculture. The result has been effective in that cultivators have not been able to cut the forest to obtain farm land. They have, however, virtually replaced pasture with cultivation and extended their activities up to the buffer zone.

In terms of conserving biodiversity in the study area, two opposing processes have been identified. First, the area of the natural forest has declined, but we have no information on the impact of the reduction of the area upon the biodiversity of species in the forest. Second, over the same 20 year period, the biodiversity of the



Map 17 Movements between Prefectures, 1978 to 1991.

agricultural landscape[8] adjacent to the Forest has increased as farmers have selected a variety of crops and have planted a large number of endogenous tree species on their lands. The minimum mapping size chosen for the airphoto analysis precluded the mapping of most of the trees that have been planted throughout the agricultural landscape. In consequence, our estimate of the total amount of arboreal vegetation in the study area is an underestimate. Recent research in the area confirms the frequency of tree planting by individual farmers (den Biggelaar 1994; Olson 1994c).

In sum, it is likely that in the area of study, the total forested area and the biodiversity of the forest-agriculture landscape have increased. The finding that agricultural activities have increased on-farm biodiversity and have not contributed to a reduction in the area of natural forest is counter-intuitive.

This outcome of the study illustrates the importance of defining the concept of biodiversity carefully so that appropriate and effective policies can be enacted to maintain it. In the study area biodiversity is represented in a contiguous protected area with significant flora and fauna - the Nyungwe Forest, and also in the trees and crops selected by farmers[9]. Smallholder cultivation and forest protection are not necessarily in conflict, and in this area apparently combine to promote vegetational biodiversity in the landscape.

This raises a question regarding policies for biodiversity conservation - "biodiversity of what and for whom?" Government policy in Rwanda has emphasized the protection of natural areas through the exclusion of human livelihood systems. In the Nyungwe area it has implemented a number of projects designed to create a buffer zone between rural communities and the Forest. This zone has succeeded in minimizing agricultural encroachment into the Forest[10]. However, the projects have reduced the area of the Forest, and also deprived farmers of land they formerly occupied.

Meanwhile, the biodiversity of the agricultural landscape has been enhanced as people have sought to improve their livelihood systems. There may therefore be opportunities for implementing policies that promote the viability of livelihood systems that are already enhancing biodiversity. As Falloux and Talbot (1993) have argued, environmental protection and development can be components of the same process. It should not however, be taken to mean that the forest is secure. The critical threat to NRM in the country and to the Nyungwe Forest in particular, is posed by poverty.

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[8] see Richards and Little (1994) for a discussion of issues related to the biodiversity of Africa's human landscapes.

[9]No analysis was possible of the impact of the reduction of the Nyungwe Forest on insect, animal, and bird species, or of the effect of planted woodlands on these groups.

[10] It can be argued that the Nyungwe Forest owes its existence to the choice of local communities which left it undisturbed while dramatically altering the surrounding area. While not anthropogenic, the Forest is certainly a part of a landscape created by the people of the region.

We have indicated above that there are a variety of strategies being employed to ameliorate rural economic hardships. Many of the options are constrained by the quality of the natural resource base and by the lack of economic opportunity within the broader national economy. In the absence of effective policy to stimulate opportunities in rural livelihood systems the trends towards the use of resources in the parks and reserves will in all likelihood accelerate.

The policy issue is, therefore, one of promoting economic opportunities that both improve the quality of life and preserve biodiversity. Two complementary approaches can be considered for the Nyungwe Forest Region. One is to assess the possibilities of direct economic returns from the biodiversity of the forest through non-timber - consuming activities such as tourism, and the harvesting of medicinal plants (Frumhoff and Bergmark 1993). This would require the cessation of activities that reduce the biodiversity through poaching, or tree clearing activities, such as gold mining, and agriculture. Community involvement would be necessary to ensure both local control of the process and local benefit from the results. The experiences of the CAMPFIRE program in Zimbabwe and of the Kenyan Wildlife Utilization Fees should inform the involvement of local communities in such ventures[11].

To this end a bolder approach to tourism that brought more revenues to the parks and reserves and fostered local economic returns might be considered. For example, the major focus of tourism is the viewing of the gorillas in the Volcanos Park. Visits to Rwanda tend to be a 3-day add on to a safari in Kenya and/or Tanzania. A consumer study might be instigated to assess the costs and benefits of developing an integrated tourist circuit in Rwanda such that those who come to see the gorillas would also go to Nyungwe and/or Akagera. Such a strategy would make Rwanda's gorillas a focus for a minimum 5-6 days in Rwanda and would contribute to economic opportunities and diversification of livelihood systems in rural areas.

The second is to reduce the incentives to look at the forest as a source of income by improving the productivity of agriculture and concurrently promoting alternative livelihood systems that can provide non- and off-farm employment for both present and future generations. At the farm level the critical issue is land productivity. The disruption of the manure cycle is a critical factor and farmers are striving to reconstruct it under contemporary constraints. The land base in its present condition is not meeting the needs of the current generation and offers little to future ones. What was true for pre-1994 Rwanda will be true in the future, both in the areas of established settlement and in areas of new settlement.

Cash to obtain livestock, and hence manure, is seen as crucial and existing livelihood systems are limited in their ability to generate income. Over 50% of rural households

[11]For an in-depth discussion of principles of community-based conservation, and illustrative case studies, see Western and Wright (1994).

depend on off- and non-farm sources of income and additional opportunities for economic diversification are required. It is essential that credit be available to facilitate the purchase of livestock, foster non- and off-farm economic activity, and re-establish trading. One component of the National Social Action Plan was designed to provide small credits for micro enterprises; this provision of the plan should be implemented enthusiastically with the flexibility to encourage a variety of entrepreneurial activities both on- and off-farm.

There is no single opportunity for the people of the area. The approach suggested above would result in a variety of opportunities each affording small gains that accumulate to provide the inputs that can restore the soil resource and promote non land-based sources of income. Prior to the recent crisis rural Rwandans were experimenting with ways of improving their condition. This behavior needs to be supported by a policy framework that offers incentives for improving the land and investing in entrepreneurial activities and at the same time protecting the rich biodiversity resources of the area.

VIII. METHODOLOGICAL IMPLICATIONS OF THE STUDY

THE STUDY SEEKS TO INFORM THE BIODIVERSITY SUPPORT PROGRAM ON appropriate conceptual and methodological approaches to understanding society-environment interaction as it relates to biodiversity issues. Effective policy for the conservation of biodiversity cannot view conservation as an end in itself, separate from the societal context in which it is proposed. In order to assess the role of biodiversity conservation in development it is necessary to understand the complex ways in which environmental and societal processes interact.

This Pilot Project was designed to provide insights to appropriate ways of examining such interactions through a preliminary analysis of society-forest interactions in communities adjacent to the Nyungwe Forest Reserve in Rwanda. The study examined the changes in land use and land cover in the areas of the forest and adjacent to it and looked for explanations for these changes in the processes of national and local development.

The study has attempted to address the following questions:

- has there been a change of forest cover (augmentation/depletion)? If so, where and what type of cover (forest, woodlot, trees on farms)?
- what has replaced forest/ what has forest replaced?
- what processes lie behind the changes?
- what are the implications for the protected forest? For local communities?

The study has shown that an important basis for pursuing such questions is the existence of a conceptual framework that leads the researcher to examine the complex web of linkages that determine the interactions between society and natural resource management. These interactions occur between different scales (global, national, local) over time and space and so researchers have to explore the evolution of these interactions over time both at the local level, and between rural communities and national, and even global, forces.

The study has shown that the adoption of a *historical perspective* is important. A report prepared in 1982 by a team including one of the authors (Berry *et al.* 1982) was influenced by a prevailing perspective at that time among government officials, researchers and donor groups, that rapid deforestation in Rwanda was a relatively recent and active process resulting from rapid population growth. The results of work by Olson for this study, and for her dissertation (Olson 1994c), has demonstrated that the situation is more complex:

- Deforestation of much of Rwanda had taken place long before European intervention in the area over the past century as herders had created a landscape suitable for grazing. Recent changes in land cover as a result of population growth and migration have primarily seen pasture replaced by cultivation.

- Further, in the Nyungwe Forest margins removal of forest has been the result of government policy that established projects, ironically designed to act as a buffer to prevent farmers cutting the forest. These projects have succeeded in restricting cultivation in the forest, though other forms of exploitation, such as poaching and mining, continue.

- Policy has also resulted in an increase in tree cover in cultivated areas as the government promoted the planting of woodlots and trees along roads. These government projects relied mainly on exotic species.

- Further, on their own initiative farmers have increased the numbers of trees planted as they sought to curtail erosion, increase the supply of fodder for animals and provide for their fuel needs. Farmers have planted local species and the biodiversity of trees on farms has actually increased over time (den Biggelaar 1994).

These results also indicate the importance of exploring interactions between scales. This study has indicated the inter-relationships between the activities of local communities and the national policy framework, which in Rwanda has been influenced by international forces, such as structural adjustment, conservation interests, and the NEAP initiative.

The *conceptual framework* thus played a signal role in defining the approach to analysis of land use changes related to biodiversity conservation in the study area. It also clarified the relevant questions for assessing the relationship between societal processes and natural resources management over time. Finally, the framework established the structure for the presentation of the findings. It is an essential component of the methodology used by the project.

The critical questions derived from the application of the conceptual framework defined the information needs of the study. Two broad categories of information were required: information on the extent, location and timing of changes in land cover; and information on the processes that contributed to these changes.

Changes in land cover were determined using information from different sources - LANDSAT MSS imagery for 1975 and 1986 and aerial photography from 1973 and 1990, supplemented by the 1986 topographic map. Several observations concerning the appropriateness of these data sources can be made:

1. For countries like Rwanda where the units of cultural land cover occur at such high spatial frequencies, the use of aerial photography at scales of 1:50,000 or larger is judged to be necessary to correctly interpret detailed land cover changes in terms of social processes.

2. MSS is adequate to interpret level-one land cover types which vary at low spatial frequencies (measured in hundreds of meters) if the terrain is reasonably undissected (broad interfluves and valley bottoms more than 300-500 meters across).

3. Multi-temporal TM imagery is probably required from each of two time periods in order to assess land cover change at level-two or higher.

4. Although difficult to obtain, historical aerial photography does exist for many countries in Africa. This valuable data source should be used more often both as a source of historical ground truth for achieved satellite imagery and as primary data in land cover change analyses as demonstrated in this study.

The chief cause of the problems with the digital classification approaches in this study, both supervised and unsupervised, was the high-frequency illumination differences caused by the dissected topography. These could have been corrected using digital elevation data. One of the more disheartening aspects of this study was that a DEM exists for the whole of Rwanda, but these data were not made available to this project.

The remotely sensed data permit estimates of the extent and the location of major land cover change. The critical question for biodiversity conservation policy is how do we interpret these changes? Effective policy requires an understanding of the fundamental causes of change so that it can address these causes and not merely symptoms.

The conceptual framework guides the exploration of root causes. It focusses the research upon interaction between social, political, economic and natural resource issues across scales and through time. Such interpretation and explanation of societal processes that lie behind these mapped changes in land cover required the integration of information from a variety of sources including:

Historical records
Policy documents for national and international influences on local communities
Interviews - formal and informal; individual, group and experts.

Historical Records. Documentation of past processes that contributed to recent and ongoing changes was obtained from colonial documents, books and reports of scientific research. While some of this material was accessed through standard library searches, some sources were only available from the specialist holdings of the Musée Royale de l' Afrique Central in Tervuren, Belgium.

The level of effort that can be put into archival searches is constrained by the financial resources and time limitations of a project. The availability of information from historical records was essential to this study. Photographs and reports of early European travellers in the region caused contemporary assumptions about past land cover to be questioned. Once these assumptions were shown to be suspect, critical examination of the processes lying behind land cover change became essential.

Policy Documents and Official Reports. These sources of information were found to be available in Rwanda, but were scattered. Project team members had spent considerable effort in collecting an incomplete set of official documents. This was also the experience of the team from WRI that assessed the documentary resources on NRM (Brunner and Tunstall 1992). Their compilation of available information was surprising in its volume and in the fact that this report provided Rwandans with information on NRM documents in the country that had not previously been available.

Policy documents assist in the understanding of official initiatives that have an impact upon conservation issues. Some, such as the NEAP, relate directly, while others, such as economic policy documents, have to use interpreted to reflect the impact of economic initiatives upon resource management.

Government and project reports frequently include data that illustrate specific aspects of rural life. For example, the agricultural census (MINAGRI 1989) contained substantial commune-level information of a variety of issues, including land area, crop production, animal holdings, and nutritional levels. Similarly, the census reports contain detailed demographic data.

The availability of official reports is limited by the fact that they are not centrally archived, nor are they usually shared between government or other institutions. There is an urgent need to explore ways of managing such information in ways which permit it to be accessed more easily and analyzed in a more integrated manner (Campbell *et al.* 1994a; 1994b).

Interviews. The project was fortunate to have been able to draw on a rich body of recent information gathered at the household, and from individuals and groups. The outbreak of civil strife in Rwanda in April 1994 precluded specific survey work for this project.

The interviews were essential to the interpretation of the causes behind changing patterns of land cover. In the absence of interviews, official data would have been relied upon. Yet such data can be misleading if it is not used in an analytical context that accurately reflects the conditions under study. For example, the prevailing explanation for declining agricultural production in Rwanda was that rapid growth of the population had stressed the resource base. Had the study been limited to official data, such as the census, then such a Malthusian scenario could have been illustrated. Measures to limit population growth might have been the focus of remedial policy. The interviews demonstrated this to be a very incomplete view of the situation. Poverty, and its synergistic relationship with the availability of livestock manure were shown to be causes of the declining resource base and, indirectly, as a threat to protected natural areas. The policy implications to be drawn are that the focus should be on strategies to reduce poverty, and to provide opportunities for increasing the availability of livestock manure.

A number of interview strategies was identified. Sample household surveys provide the most detailed information, but are expensive and reflect a significant institutional infrastructure. At the other extreme, Rapid Rural Appraisal may provide significant information if conducted carefully. Group interviews and discussions with key informants were important to this study. While all these can yield useful data, the basis of each needs to be considered explicitly. The findings of this project would suggest that multiple approaches, that provide opportunities for cross-checking and corroborating information, are desirable. Further, the information they provide has to be evaluated and analyzed within a context informed by the historical record and policy framework.

In conclusion, this pilot study has demonstrated that understanding the complex interactions between society and the environment as a basis for effective NRM policy, including conservation of biodiversity, requires an approach that:

- is grounded in an appropriate conceptual framework;
- recognizes the importance of assessing interactions over time and selects a relevant historical frame for the analysis;
- examines the interactions between processes at the global, national and local scales;
- explores local as well as national perspectives on the issue;
- incorporates data and information from a variety of sources on environmental, socio-economic and policy subjects, at appropriate scales to examine the issue under study, and pursues multiple methods of analysis.

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