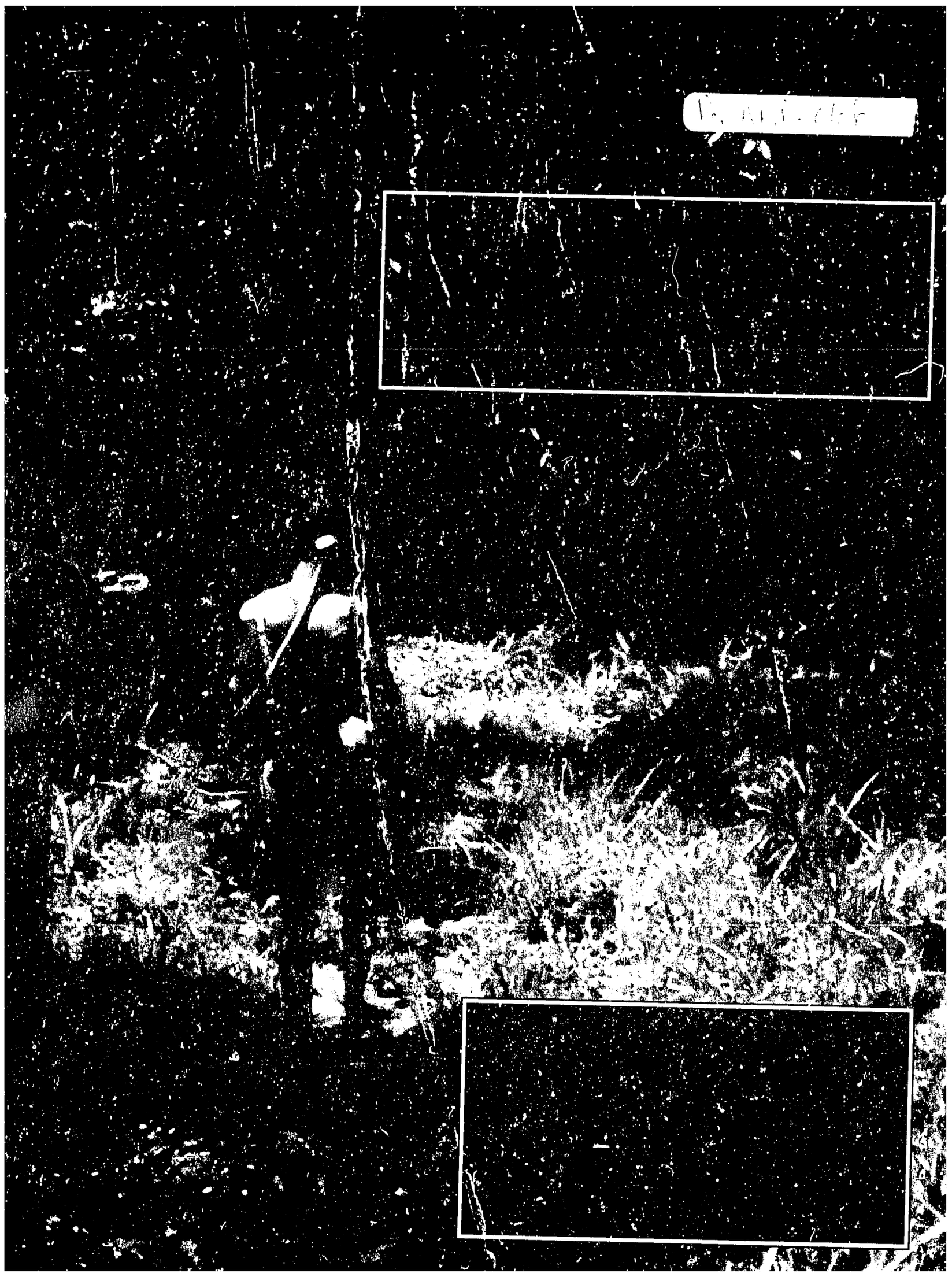

PN-ABP-166

CENTRAL AFRICA:
Global Climate Change and Development

PN-ABP-060

Central Africa

Global Climate Change and Development

Overview

Biodiversity Support Program

A Consortium of World Wildlife Fund,
The Nature Conservancy, and World Resources Institute

WWF

The Nature Conservancy

Funded by the U.S. Agency for
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Central Africa: Global Climate Change and Development—Overview.

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A summary of this overview document, entitled *Central Africa: Global Climate Change and Development—Synopis,* was also produced. The *Technical Report* and the *Synopsis* are available from:

Biodiversity Support Program/Africa
c/o World Wildlife Fund
1250 24th St., N.W.
Washington, D.C. 20037 U.S.A.

Telephone: (202) 293-4800
Telefax: (202) 293-9211.

Contributors

The Central Africa Global Climate Change Study was a collaborative undertaking building upon the work of three principle organizations and many individuals studying various aspects of climate change. The Biodiversity Support Program (BSP) was responsible for coordination and management of the study, and for organizing the information produced by the core team into the comprehensive Overview and an associated Technical Reports document, both of which are intended to respond to the information and strategic needs of policy makers and donors in the U.S. and abroad. The following are the major contributing organizations and their staff.

The World Resources Institute/Center for International Development and Environment (WRI/Center) produced the chapters entitled "Central Africa: Biogeophysical Setting and Global Climate Change", and "Human Interactions with the Forests of Central Africa: Trends and Conditions." Mark Trexler (independent consultant), and David Wilkie (Tufts University) wrote the "Biogeophysical" chapter. The principal authors of the "Human Interactions" chapter were Kirk Talbott (WRI), and J. Frederick Swartzendruber and Marshall S. Berdan (WRI consultants). Contributing authors were: Jennifer Green (WRI), and Keith Openshaw, Christine Haugen, Roberto Martin, David Groenfeldt, and William Boyd (WRI consultants). Internal support from WRI staff was provided by: Sheri Dean, Faye Kepner Lewandowski, Lauren Morris, and Forrest Swick. Peter Alpert, American Academy for the Advancement of Science Fellow at the U.S. Agency for International Development, also contributed to the "Biogeophysical" and "Human Interactions" chapters.

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EXECUTIVE SUMMARY

There is growing consensus among the international scientific and policy communities that greenhouse gas emissions resulting from human activities must be reduced. Global climate change is likely to result in severe adverse impacts, particularly in regions already under stress. If actions are not taken to reduce emissions, the average temperature of the Earth is expected to increase by 0.2-0.5°C per decade during the next century (Houghton *et al.*, 1990). These rates are in excess of any experienced over the last 10,000 years.

Unlike industrialized countries, in which the primary sources of greenhouse gases are industrial activities (production and consumption of fossil fuels, production and use of CFC's, high-input agriculture), in the countries of sub-Saharan Africa, it is the transformation of the biotic environment through deforestation and savanna burning that is currently the major source of greenhouse gas emissions and is potentially the major source in the future.

This preliminary study focuses on the six countries of central Africa which contain the largest remaining contiguous block of closed forests in sub-Saharan Africa: Cameroon, Central African Republic, the Congo, Equatorial Guinea, Gabon, and Zaire. The carbon in the vegetation and soils in these moist tropical forests and surrounding seasonal woodlands constitute the greatest potential source of future carbon dioxide (CO_2) emissions from sub-Saharan Africa. This study also considers the importance of savanna burning, although in less depth since the small savanna area in central Africa precludes this activity from being a large regional source of emissions.

Recognizing that global climate change research requires both an understanding of the physical world, as well as an understanding of human behavior, and that goals and objectives can best be achieved through mutually reinforcing research activities, a collaborative, multidisciplinary approach was adopted in this study. Analysis of biogeophysical and socioeconomic issues relevant to global climate change, and research containing both space-based and ground-based components, were undertaken. This was essentially a U.S.-based study, although preliminary collaboration with European and African researchers was established.

The overall goals of the study were:

(1) To assess the present understanding of current and potential CO_2 emissions from deforestation in central Africa, and assess methods for improving this understanding;

(2) To determine the socioeconomic factors driving human activities in the forests and options for reducing CO_2 emissions from these activities; and

(3) To assess potential impacts of these activities and of global climate change on the environment and peoples of the region.

In summary, the main findings of the study are as follows:

- **The contribution from central Africa to global greenhouse gas emissions is currently small, but could become significant if deforestation rates continue to accelerate.**

The forests of central Africa have so far experienced lower overall rates of clearing than other tropical forests, although in certain areas high rates of localized clearing occur. Deforestation results primarily from unsustainable agricultural practices, although fuelwood and charcoal consumption around densely populated areas and inappropriate logging practices also contribute to clearing. Rapid population growth, urban migration, unfavorable economic conditions, and inappropriate government policies are driving these practices, and are believed to be resulting in increased rates of forest clearing.

Currently, deforestation in central Africa releases less than 1% of the estimated global CO_2 emissions from all sources (fossil fuel combustion, deforestation, and cement production), or about 4% of the CO_2 released from deforestation globally. If not carefully managed, accelerated rates of forest clearing in central Africa could result in a release of regionally and globally significant quantities of CO_2. Burning associated with deforestation also releases significant quantities of methane, nitrous oxide, carbon monoxide, oxides of nitrogen (CH_4, N_2O, CO, and NO_x, respectively), and particulate carbon.

Savanna burning is a minor source of greenhouse gas emissions in central Africa, however for Africa as a whole this practice represents one of the most significant sources of greenhouse gas and particulate carbon emissions. Rates of savanna burning are believed to be increasing, and are likely to continue to increase if extensive areas of forests are converted to savanna. However, data on this activity are extremely sparse and uncertain. Future work on climate change in Africa should be expanded beyond central Africa so that the role of this activity can be adequately assessed.

- **Retaining the forests in central Africa is not only significant from a global climate change perspective, but more importantly, is critical to the region for environmental and socioeconomic reasons.**

Reducing deforestation rates will not only decrease the region's contribution to the atmospheric accumulation of greenhouse gases, but, more importantly, will minimize potential environmental degradation associated with land-use change and global climate change. Biomass burning and unsustainable forest clearing have direct, negative environmental consequences, including regional climatic change, loss of soil fertility, and elevated levels of tropospheric ozone, particulates, and acid rain. Massive deforestation is likely to severely disrupt the region's hydrological cycle.

Global climate change will have the greatest impacts in regions already under stress, and will accentuate existing environmental degradation. Peoples of developing countries are especially vulnerable to climate change because they are so dependent upon natural resources for survival and because they lack the technical and financial resources with which to adapt and respond to changes brought about by global warming. Also, the ability of the region to withstand the impacts of future climate change will likely be severely compromised if the forests continue to be degraded and destroyed.

- **The potential impacts of global climate change in central Africa can best be avoided by reducing greenhouse gas emissions, by maintaining forests, and by understanding and preparing for these impacts.**

Greater and more effective participation by Africans in international global climate change policy discussions will enable the central African countries to influence decisions that will determine future greenhouse gas emissions from all nations of the world. Reduction of future emissions from within the region can best be achieved through improved resource management. Improved resource management, especially conservation of existing forest ecosystems, will also moderate the potential impacts of global climate change, and will contribute to sustainable development. Improved understanding of impacts, through research and increased involvement in international impacts research, will enable these countries to plan their development more effectively.

- **Addressing global climate change in central Africa is essentially a challenge to develop sustainable and robust agricultural practices and natural resource uses.**

Choices made by the central African nations regarding management of their forests will determine the magnitude of future greenhouse gas emissions from the region, and the nature and severity of potential impacts of global climate change on the region. Agricultural activities, a primary contributor to greenhouse gas emissions, are likely to be more threatened by global climate change than other human activities.

The relatively intact forests of central Africa represent a unique opportunity to central African policy makers to promote and apply effective forest management strategies, and thereby avoid the social, economic, and environmental costs of forest loss and degradation. Efforts to manage the forests will probably need to emphasize controlling the rate and pattern of loss of the remaining forest rather than trying to plant new trees. Reforestation efforts in central Africa have yielded minimal success. These forests represent a huge economic resource that <u>will</u> be utilized -- the challenge is to choose development alternatives that are economically, socially, and environmentally sound over the long term. Sustainable practices that contribute to increased levels of prosperity for the people without depletion of overall carbon stocks or environmental degradation must be implemented.

- **A better understanding of central Africa's current and potential future greenhouse gas emissions is important to both the regional and global communities.**

For central African countries, understanding the magnitude, location, and causes of clearing and burning, as well as the potential for future emissions, is a critical first step in designing appropriate natural resource management approaches and tools. Understanding the sources and magnitude of their emissions is also necessary if these countries wish to be active and effective participants in the global climate change science and policy arena. Decisions made within this arena will have long-lasting repercussions over all sectors and economic classes of the world. Lastly, the global science and policy communities which are addressing climate change issues require improved and more extensive information.

- **Existing biogeophysical and socioeconomic information relevant to climate change science and natural resource management are often inadequate and of poor quality.**

Well-defined, targeted efforts are needed to collect new, improved biogeophysical and socioeconomic data, and to compile existing data that are currently difficult to access. Satellite remote sensing analysis offers a unique potential for developing accurate, up-to-date regional land-use data bases. Long-term monitoring sites should be established to collect baseline measurements for understanding and detecting change. Geographic Information Systems are an effective tool for spatial management and analysis of data. A broad network of underutilized agricultural and research stations exists within the region, which, if revitalized, could provide a much-needed operational base for the collection, assimilation, and management of data.

- **The region's institutional capacity is inadequate to address climate change at national, regional, and international levels.**

The long temporal scale of global climate change necessitates a long-term commitment at all levels of institutional capacity, for understanding both contributions to, and effects of, global climate change. National ministries and organizations responsible for forest protection and production, agricultural research and extension, and climate change research and monitoring require additional personnel, institutional strengthening, and technical and financial support. Regional authorities need to be established to foster collaboration and coordination of national activities and to strengthen the region's involvement in the international climate change arena.

- **To improve local and global understanding of climate change issues in central Africa, and design effective response strategies, a coordinated, multidisciplinary approach is recommended.**

Improved understanding of the causes of deforestation and savanna burning, and of the effects of these activities on the environment, is necessary to develop improved resource

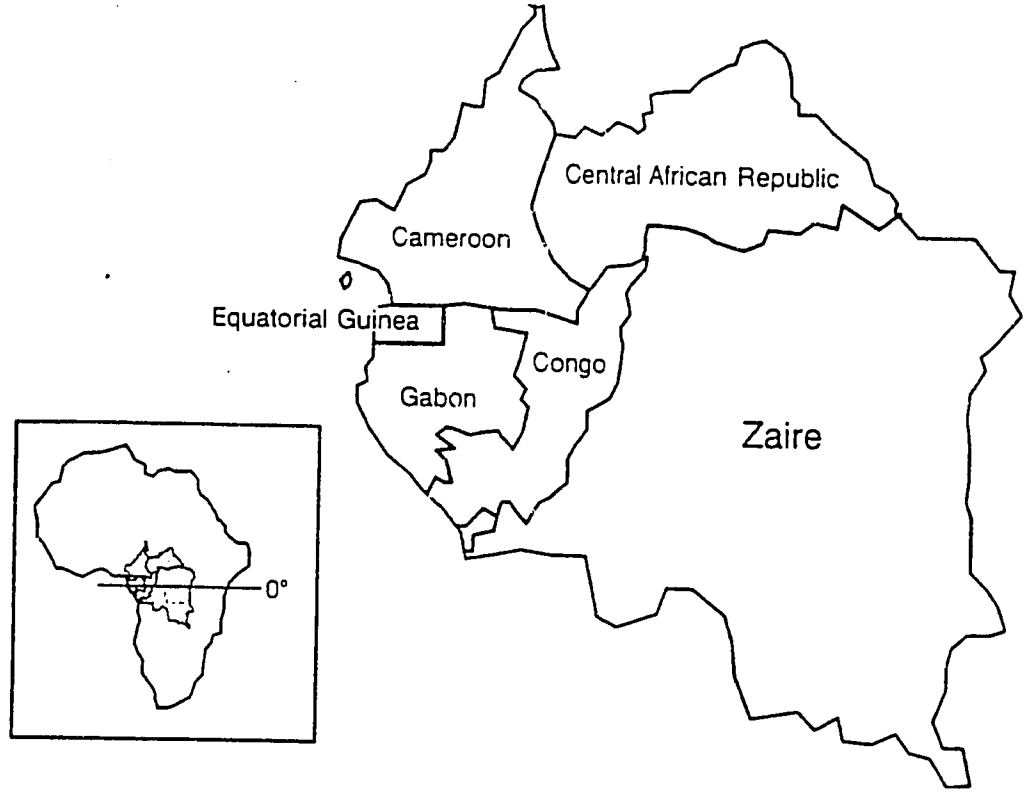
management techniques which result in mitigation of emissions as well as environmental degradation. This understanding requires expertise on both the physical world and human behavior.

The key to an effective, efficient program is collaboration between various development, scientific, and resource management institutions and specialists in Africa, Europe, and North America. Each institution's respective area of expertise (local knowledge, long-term project continuity, scientific and technical expertise) would complement those of the others, resulting in a mutually beneficial, comprehensive, and collaborative program.

I. INTRODUCTION

The six countries of central Africa--Cameroon, Central African Republic, the Congo, Equatorial Guinea, Gabon and Zaire--contain the largest remaining contiguous expanse of moist tropical forest on the African continent and the second largest in the world. This moist forest and the drier woodlands that bound it hold a vast reservoir of carbon. The pressures on this immense resource, largely due to rapid population growth, inappropriate macro-economic policies, economic downturns, and weak management and administration capacities, are causing deforestation rates to increase. If clearing rates continue to rise, a substantial amount of carbon will be released into the atmosphere in the form of carbon dioxide (CO_2), thus contributing to global climate change.

Of more immediate importance to the inhabitants of the region, however, are the direct environmental impacts resulting from deforestation, including altered soil moisture, runoff, and soil surface temperature, as well as potential shifts in local precipitation. These changes could significantly damage the agricultural and economic productivity of the region, placing a heavy burden on rural populations who rely almost entirely on the natural resource base for their subsistence. In addition, continued deforestation will reduce the region's ability to withstand the potential environmental and socio-economic impacts of global climate change.



This study, *Central Africa: Global Climate Change and Development*, was designed as a first step in understanding the complex dynamics of the causes and effects of global climate change in central Africa. The study provides an initial baseline of information to guide future collaboration with, and support to, African colleagues working on this important issue.

The objectives of the study were: 1) to assess the present understanding of current and potential CO_2 emissions from deforestation in central Africa, and assess methods for improving this understanding; 2) to determine the socio-economic factors driving human activities in the forests and the options for reducing CO_2 emissions from these activities; and 3) to assess the potential impacts of these activities and of global climate change on the region.

To meet these objectives, a series of technical papers was produced and printed under separate cover. This *Overview* reviews the main findings of these *Technical Reports*. A brief *Synopsis* report summarizing the *Overview* was also produced.

Background

International scientific and policy communities agree that greenhouse gas emissions from human activities must be reduced. If actions are not taken, the global average temperature of the Earth is expected to increase by 0.2-0.5°C per decade during the next century (Houghton, J.T. *et al*, 1990). These rates of warming are greater than any experienced during the last 10,000 years. Significant climatic changes, including changes in precipitation, are expected to occur in association with this warming.

Although the magnitude, rate, and geographic distribution of future climate change are uncertain, the impacts are likely to be far-reaching and damaging over the long term. Increasing temperatures, changes in precipitation patterns, and associated environmental changes such as sea level rise are expected to cause ecological communities to shift geographically and change composition. If rates of change are rapid enough, or if migration corridors are not available because of fragmentation or loss, individual species as well as entire communities may not be able to survive. Both natural and man-made (e.g., agricultural) systems will be affected.

Peoples of developing countries, who are dependent on natural resources for survival and who often live at the margins of subsistence, are especially vulnerable. Environmental and social problems in regions already under stress will only be exacerbated by global climate change. In addition, most developing countries lack the technical and financial resources with which to adapt to, and protect themselves from, the impacts of climate changes. Agriculture, food security, indigenous culture, energy supply and demand, human health, and social and economic stability are all likely to be negatively affected.

In recognition of the potential impacts of climate change on all aspects of life, the U.S. Congress mandated in 1990 that the United States Agency for International Development (USAID) "pursue a 'Global Warming Initiative' which [would] ... emphasize the need to reduce emissions of greenhouse gases ... through strategies consistent with economic development" (Public Law 101-513). This initiative would, *inter alia*, focus energy and tropical forestry assistance programs on those developing countries expected to release large amounts of greenhouse gases.

In response to this mandate, the USAID Bureau for Africa commissioned Oak Ridge National Laboratory (ORNL) to conduct an assessment of current and potential future greenhouse gas emissions from sub-Saharan Africa (Graham, R.L. *et al*, 1990). The ORNL analysis found that CO_2 is the most significant gas emitted from the region and that deforestation is, and will continue to be through the end of this century, by far that largest regional source of CO_2. Moreover, the study concluded that the greatest potential source of future CO_2 emissions from sub-Saharan Africa is the forests of central Africa, which contain over half of the vegetation carbon in sub-Saharan Africa.

The *Central Africa: Global Climate Change and Development* study was initiated by the USAID Bureau for Africa in April 1991. The study focused on the forests of the six countries of central Africa: Cameroon, the Central African Republic, the Congo, Equatorial Guinea, Gabon, and Zaire. Three U.S.-based desk studies were undertaken. These desk studies described and assessed the current understanding of: (1) the climate, hydrology, soils, and vegetation of the region; (2) socioeconomic factors underlying human use of forest, and the causal relationships between policy, demographics, economics, and land-use change; and (3) the present and potential role of remote sensing in providing information relevant to climate change studies in the region and the role of Geographic Information Systems (GIS's) in managing and analyzing data for regional climate change research. The remote sensing component also included demonstration exercises that illustrated the utility of remote sensing image analysis in climate change research.

The main findings of the study are presented in this document. The current state of central Africa's forests, greenhouse gas emissions from deforestation and biomass burning in the region, and the potential impacts of global climate change on the region are discussed in the next section. This is followed by an overview of human interaction with the forests, and then a discussion of the role of remote sensing and GIS's in improving the quality of information and information management in the region. A review of conclusions and recommendations completes this report.

II. THE BIOGEOPHYSICAL SETTING

INTRODUCTION

Central Africa's year-round high inputs of solar energy, abundant rainfall and its generally favorable geologic, topographic, and soil features, have resulted in the formation of the second largest area of contiguous moist tropical forest in the world, and the largest such expanse in Africa. Central Africa's forests cover an estimated 2.8 million square kilometers, accounting for roughly 20% of the world's remaining moist tropical forest reserve.

Despite their regional and global significance, the moist tropical forests of central Africa are perhaps the least understood of the Earth's remaining tropical forests. Estimates of area, vegetation composition and distribution, rates of clearing and degradation, carbon storage, and carbon dioxide (CO_2) emissions are highly uncertain. Nevertheless, the biomass and soils within these moist forests, and the drier woodlands that surround them, constitute a vast reservoir of carbon that, depending on human land-use practices, have the potential to become a substantial source of atmospheric CO_2 in the future.

PAST CLIMATE

Today, the six countries of central Africa constitute an almost exclusively humid or sub-humid enclave in a predominantly dry continent. This has not always been true. Central Africa experienced wide shifts in rainfall during the past 100,000 years (Nicholson, 1989); some periods were considerably wetter than at present, others considerably drier. As Europe glaciated and deglaciated, air temperatures in central Africa fluctuated. For much of the time between 20,000 and 70,000 years before present (ybp) central Africa was affected by "ice-age" weather conditions of varying severity, resulting in temperatures 4 to 6°C lower than at present. As a result evaporation declined, rainfall dropped by as much as 30% (Bonnefille *et al.* 1990), and moist forest area diminished. Conversely, warmer periods (Table 2.1), associated with deglaciation in Europe, resulted in increased rainfall and recolonization of forest over central Africa (Hamilton, 1983).

Variations in climate have continued during the past 3,000 years, but not at the same magnitude as observed over a more distant time scale (Nicholson, 1989). Africa was significantly more humid between the tenth and thirteenth centuries when caravans traversed the desert along routes now impossible for lack of water. These conditions recurred during the sixteenth through eighteenth centuries (Nicholson, 1989), with the exception of several severe periods of drought in the 1680's, 1740's, and 1750's. At the end of the eighteenth century, marked desiccation commenced over much of Africa, and the decline in rainfall culminated in a period of severe drought in the 1820's and 1830's (Nicholson, 1989). Historic droughts were rather analogous to those occurring presently in the Sahel, with rains returning and a relatively humid period persisting from the 1870's to the 1890's. Fluctuating rainfall has continued to the present day. In fact, the unusually wet period between the 1950's and early 1970's may have prompted recently independent African nations to have

Table 2.1 Late quaternary climate in central Africa relative to average conditions

Period (ybp)	Climate
60,000-35,000	Dry
50,000	Brief/Humid
35,000-22,000	Cold/Dry
27,000	Brief/Humid
22,000-16,000	Warm/Humid
16,000-12,000	Extreme/Dry
12,000-8,000	Warm/Humid
6,000-3,000	Dry
3,000-present	Drier

(after Livingstone, 1975)

been overly optimistic in regard to agricultural production, and may have resulted in the settlement and cultivation of areas that appeared green at the time but which had much lower long-term average rainfall prospects.

PRESENT CLIMATE

In central Africa, at present, yearly mean temperatures vary little, averaging around 25°C. Annual rainfall in the region averages between 1,000 and 2,000 mm. Most rain falls as convective showers in sporadic, localized rainstorms. Areas outside the tropical forest ecosystem, such as in northern Cameroon, northern Central African Republic, and southern Zaire receive less rainfall, while the areas around Mt. Cameroon and on the southern edge of insular Equatorial Guinea receive as much as 10,000 mm annually as a result of the combined effects of coastal topography and the cold Benguela current. Throughout the region, rainfall is generally sufficient for a positive water balance (i.e., precipitation exceeds evapotranspiration) during most of the year.

The most striking aspect of rainfall within central Africa is the source of the water vapor that leads to the convective precipitation characteristic of the region. Although the South Atlantic Ocean provides considerable water vapor to the hydrological system, between 75 to 95% of the rainfall is from recycled water generated by evapotranspiration within the region (Balek, 1977; Brinkman, 1983). The importance of this small hydrological cycle is much greater than in the Amazon Basin, for example, where it is estimated that only about 50% of precipitation comes from terrestrial evapotranspiration (Salati, 1987). Southeast Asia, in comparison, has run-offs exceeding 80% in some locations (Brinkman, 1983).

Little data are available on the role and extent that central Africa's moist forested regions contribute to extra-regional precipitation. The region is probably mostly a closed system in regard to rainfall, with some areas, such as the highlands of eastern Zaire, receiving a somewhat larger proportion of the small hydrologic cycle rainfall as a result of orographic cloud formation.

Hydrology

Central African hydrology is dominated by the Zaire River Basin, the largest drainage system in Africa (Balek, 1977) and the second largest in the world. The Zaire River drainage covers 3.6 million km^2 (Balek, 1983) and includes almost all of Zaire, all but the

southwest corner of the Congo, south and central Central African Republic (CAR), and southeastern Cameroon. The Songa, Ntem, Benito, and Ogoué Rivers form a basin that drains southern Cameroon, Equatorial Guinea, and Gabon. Northern CAR is drained by the Chari River flowing into Lake Chad. Northern Cameroon is drained by the Bénoué that flows into the Niger, and by the Logone flowing north to Lake Chad.

Table 2.2 Mean annual discharge of the Amazon, Zaire, and selected tributaries

River	Average annual discharge (m^3/sec)	Drainage area/km^2	Length km^2
Amazon	203,904	7,180,000	6,250
Zaire	38,805	3,690,000	4,600
Sangha	2,471	nd	nd
Ubangi	5,936	nd	nd

(Balek, 1977)

Although water balance is positive throughout most of the year, water stress occurs in all but a few locations in central Africa at some point during the year; its length and severity increasing with latitude. Water stress is considered a fundamental reason that the total flora of the region is smaller than that of other tropical forest ecosystems, although floristic diversity is comparable (Richards, 1952).

Substantial flows, and the fact that the underlying geology of the area has led to the formation of steep falls or rapids near the coast, means that the rivers of central Africa have tremendous hydropower generating potential. Although data are not adequate to make firm predictions, one outcome of regional changes in rainfall, as a result of global warming and deforestation, would be a change in flow patterns and perhaps total discharge, that in turn would impact hydropower generation and navigation.

As with rainfall, better information on river discharge would enable much better assessment of the current hydrological cycle in the area and assist in the prediction of future changes as a result of global warming.

Vegetation

Vegetation's role as a major actor in micro- and macro-climate change within central Africa stems in large part from the following factors: 1) woody vegetation constitutes a reservoir of carbon, that typically has been accumulated over a long period of time, but could be released rapidly into the atmosphere; 2) vegetation can constitute a short-term sink for atmospheric carbon; 3) vegetation affects the albedo (solar reflectance) of the area; 4)

combustion of vegetation releases other trace gases and particulates into the atmosphere; and, 5) vegetation modifies hydrological cycles by regulating rainfall retention (evapotranspiration + interception) and runoff. Data on the past, present, and projected composition, distribution, and successional status of central African vegetation are therefore important to our understanding of its contribution to global, regional, and local-scale climate change.

A number of different forest types occur in central Africa. Broadly speaking, there are two basic types of moist tropical forest in the region. Mixed, moist semi-evergreen forests are characteristic of the vast Zaire River Basin and cover approximately 3.46 million square kilometers. The second, a hydrophilous (moisture-loving) evergreen rainforest, is found along the coasts of Cameroon, Equatorial Guinea, Gabon, and the Congo, a region of exceptionally high rainfall. On the peripheries of these two and in transition zones is found a drier semi-evergreen forest and woodland which is assumed to be largely anthropogenic in origin (Kendrik, 1989).

Not all of the region, however, is forested. Apart from the various categories of woodland, over 10% of the region is classified as natural grassland or swampland and 30% of the area is classified as montane vegetation, though much of this last category is forest land.

Archeological evidence suggests that a human presence in the forest dates back roughly 40,000 years. Given the practice of shifting cultivation that has prevailed over that time period, most, if not all, of the forest of central Africa has probably been cleared at some time. Also, many areas that were once forest have long since been turned into savanna-woodland under bush-fallow agriculture. The Teke plateau in the Congo and much of southwestern Zaire are examples of such anthropogenic transformation. Clearing of open forest for agriculture, followed by regular burning, has effectively prevented the establishment of woodlands in large areas of central Africa.

Estimates of forest areas by types vary significantly among studies because of different classification systems, methodologies, and periods of study. The United Nations Food and Agriculture Organization, using country surveys, estimated 1980 closed and open broadleaved forest area in central Africa to be 1.7 and 1.1 million square kilometers (km^2), respectively (FAO-UNEP, 1981). A study by Millington *et al.* using satellite imagery and a different classification system, produced estimates for 1986 of 1.55 million km^2 of forest and 1.62 million km^2 of woodland. The discrepancies between these two sets of data, presented in Table 2.3, illustrate the uncertainty in knowledge about vegetation in the region.

Soils

Since the end of the last glacial period in Europe when moist conditions returned to central Africa (12,000 ybp) the soils of the region have developed under a high and constant ground temperature, a soil moisture regime with a dry season of less than four consecutive months, and relatively undisturbed tropical rain forest or seasonal semi-evergreen tropical forest vegetation (Sanchez, 1983).

Table 2.3 Forest extent in central Africa

Country	Closed Forest 1980 Area km²	Open Forest 1980 Area km²
Cameroon	179,200	77,000
C.A.R.	35,900	323,000
Congo	213,400	?
Eq. Guinea	12,950	?
Gabon	205,000	750
Zaire	1,056,500	718,400
Total	1,702,952	1,119,152

Source: FAO-UNEP, 1981: Total 2.82 million km²

Country	Forest 1986 Area km²	Woodland 1986 Area km²
Cameroon	205,871	122,727
C.A.R.	102,018	321,440
Congo	181,798	69,294
Eq. Guinea	19,287	633
Gabon	144,908	21,763
Zaire	897,002	1,084,415
Total	1,550,884	1,620,272

Source: Millington *et al.*, in press: Total 3.17 million km²

The most abundant soils are the Oxisols, soils with good physical properties, but acidic and low in nutrients such as phosphorus, calcium, and magnesium. In seasonally inundated areas along the major rivers, hydromorphic soils of moderate to high fertility and high organic content predominate. The least fertile of the region's soils are the deep sandy Entisols which occur mainly in the south and central portions of Zaire.

Contrary to popular belief, the organic content of these tropical soils is similar to that of temperate soils, and they are a substantial store of carbon. When forest areas are cleared for cultivation, much of this carbon is lost through oxidation. If cultivation is part of a forest-fallow cycle, then once the cultivated area is abandoned and successional vegetation becomes established, soil carbon is rapidly regenerated and returns to prior levels (Schlesinger, 1986). If a forested area is cleared permanently, however, the result is a net loss of soil carbon. Soil disturbance also reduces CH_4 uptake, and releases nitrogen, usually in the form of N_2O.

Loss of soil organic material also reduces water retention capacity which can result in water-stress for plants even during relatively brief dry periods. As many tree species within central Africa are extremely moisture dependent, even brief spells of water-stress can inhibit their growth or prevent their re-establishment. Reduced water retention capacity will, in turn, increase stream flow and may lead to downstream flooding.

Constraints to agricultural productivity from most central African soils result more from their chemical than their physical properties. In general, the soils are low in nutrient reserves, and are characterized by aluminum toxicity and high phosphorus fixation. External inputs of nutrients are needed before intensive agriculture is possible.

FUTURE CLIMATE

A region's climate can be altered by 1) changes in gaseous composition, water concentration, and particulate content of the atmosphere, and 2) altering the physical and biological properties of the surface (albedo, surface roughness, evapotranspiration, water runoff and retention, etc.). What impact may changes in atmospheric composition and land-use have on the climate of central Africa?

Impact of global climate change

Based on palaeoclimatological evidence, it appears likely that an increase in global temperature would result in an increase in the temperature of the southern Atlantic and an increase in overall evapotranspiration in the region (Bonnefille, Roeland, and Guiot, 1990). As a result, we would expect central Africa to become wetter than at present. Seasonality however, would not be affected; there would just be an increase in the amount of precipitation that occurred at any given time in any given location (Lauer, 1983). With a doubling of CO_2 and a concomitant global temperature rise of 1.5°C to 4.5°C, rainfall throughout the region could, based on palaeoclimatological data, increase by as much as 30%. An increase in precipitation would facilitate the development of moist forest in areas unable at present to sustain such forests. Expansion of the area under moist forest assumes that sufficient propagules are available for both successional and mature forest species to invade these once drier regions, and more importantly, that human land use in these regions would allow forests to become established. Given the extent of anthropogenic savanna already present, and current rates of population growth, it is highly unlikely that an increase in regional rainfall would promote afforestation or reforestation within the region without a concomitant change in human land-use practices.

Although palaeoclimatological studies suggest that precipitation will increase in central Africa with a global rise in temperature, results of three high-resolution general circulation models are ambiguous (Houghton *et al.*, 1990). High resolution climate models of the Canadian Climate Centre, the NOAA Geophysical Fluid Dynamics Laboratory, and the United Kingdom Meteorological Office that simulated the equilibrium response to a doubling in atmospheric CO_2, predict a mean increase in precipitation in the tropics, although certain areas such as central Africa show a slight decrease in precipitation during some months in the year. Changes in the patterning of rainfall within the tropics vary inconsistently from model to model. Some areas of central Africa are subject to a mean increase in precipitation while others show a mean decrease. The simulated patterning of rainfall within central Africa is widely different according to each model.

Impact of deforestation

The role of forests in controlling climate and the quantity and distribution of rainfall within central Africa is complex and poorly understood. This uncertainty is reflected most in the role of the small hydrologic cycle in local and regional precipitation patterns. If 80% of

the rainfall within central African forests is recycled by the forest itself, what impact might forest clearing have? Global climate modelling studies have attempted to simulate the impact of forest removal within rain forest regions of the world (Potter *et al.*, 1975) and specifically within Amazonia. All models (even those that completely removed all forest) showed little or no change in Walker and Hadley atmospheric circulation patterns (thus Amazonian deforestation was predicted to have little effect on weather patterns of higher latitudes), showed a wide range of change in surface temperature (Lean and Warrilow, 1989: 2.4°C; Shukla *et al.*, 1990: 0.5 to 2.5°C), and resulted in a reduction in precipitation of 75 to 800mm/year (Henderson-Sellers, 1987; Shukla *et al.*, 1990).

A cautionary extrapolation from global and Amazon models suggests that with complete deforestation of the Zaire basin, rainfall may be insufficient to support redevelopment of moist forest. However, results from Amazon simulations may not be directly applicable to central Africa, as rainfall recycling in the Amazon is considerably less (50%) than in central Africa (80%; Salati, 1987). Similarly, although climate models assume that changes in albedo will influence climate, an empirical study (Gornitz, 1987) in west Africa showed that anthropogenic vegetation (that affect surface albedo) changes appear not to have affected regional climate, as seen from historical records.

Scorched-earth models that assume complete deforestation of a region are useful from an analytic standpoint, but are probably unrealistic given the expected rates of land-use change in central Africa. Even the most recent projections of deforestation within central Africa (Barnes, 1990) do not result in total denudation of the region.

The rapid rate of present changes in climate, and the still poorly understood role of human land-use practices in determining regional rainfall patterns, limits the value of analogies from palaeoclimatological studies. Furthermore, results from global circulation model simulations are not much more enlightening when assessing the impact of global climate change and land transformation on the rainfall patterns of central Africa. The continental pattern of supra- or subnormal rainfall suggests that global sea surface temperatures and the El Niño-Southern Oscillation, and not human land-use practices, are primarily responsible for central Africa's rainfall patterns. Yet, there is evidence that landscape change (land surface transformation in the Sahel, for example) can reinforce the atmospheric conditions which initially reduced rainfall (Nicholson, 1989). Thus, while global climate change studies suggest an overall increase in precipitation within central Africa, the spatial patterning of such rainfall and escalating land transformation could result in some areas suffering a decrease in precipitation in the future (Mitchell *et al.*, 1990).

It is clear that we must be very careful about assuming that we can predict the impact of global climate change and large-scale land transformation (largely deforestation) on local, and regional climate. Central African weather monitoring and forecasting, and our ability to relate human land use with climate variability, will improve only if a network of meteorological stations is supported throughout the region and the data from present stations are made more widely available.

CENTRAL AFRICA AND GLOBAL CLIMATE CHANGE

Although fossil fuel combustion is the major anthropogenic source of carbon dioxide globally, land-use change accounts for the bulk of carbon dioxide emissions in many developing countries, including the six countries of central Africa (WRI, 1990). An understanding of the dynamics of land transformation in central Africa is important, therefore, for two reasons: first, in terms of the impact of land-use change on the future resource base and hydrological system of the region; and second, in terms of the current and potential contribution of the region to global climate change.

Table 2.4 Anthropogenic greenhouse gas emissions for Africa in 1985 in millions of tons CO_2 equivalency

	CO_2	CH_4	N_2O
World	25,949	7,707	2,020
Africa	2,005	635	180
Zaire	132	28	15

Source: USAID, 1990

CO_2 equivalency attempts to control for the differential radiative forcing effect of a molecule of carbon dioxide, methane and nitrous oxide

Future carbon dioxide emissions from central Africa will continue to result primarily from land-use change, which is also responsible for the emission of other greenhouse gases such as methane (CH_4) and nitrous oxide (N_20). Although the processes associated with the release of these gases in central Africa are less well understood, emissions of these other greehouse gases may be more significant in proportion to total global emissions than are emissions of carbon dioxide (Table 2.4).

Estimating greenhouse gas emissions from central Africa

Assessing emissions of greenhouse gases resulting from anthropogenic deforestation, forest degradation, and biomass burning currently taking place in central Africa, and that may accelerate in the future, requires: 1) an accurate assessment of carbon stocks within the region; 2) an accurate assessment of the rate of land-use change; and 3) the ability to convert, accurately, estimates of land-use change to quantities of greenhouse gas emissions.

Biomass inventories for central Africa: estimating carbon stocks

To estimate carbon stocks within central Africa, accurate data are needed on the land cover composition of the region, and the carbon content of each land cover type and associated soils. To date, central Africa lacks a comprehensive, empirical, fine-grained regional survey of land cover. Present estimates of forest cover within central Africa (forests are estimated to contain 90% of biotic carbon) are based primarily on data compiled by the United Nations Food and Agriculture Organization in 1981 (Tables 2.3 and 2.5), and for most countries are of uncertain accuracy and course-grained at best.

Table 2.5 Forest extent, deforestation, and reforestation within central Africa

	Forest Area (10^3 km^2)							
	All Forest		Dry Forest		Moist Forest		Deforestation	Reforested
	P	%	P	%	P	%	per year	Area
							km^2	km^2
Cameroon	185	59	30	69	155	56	2000-5000	280
CAR	279	55	147	51	133	59	500-600	0
Congo	174	49	0	0	174	49	200-700	300-500
Eq. Guinea	13	50	0	0	13	50	30	?
Gabon	173	35	0	0	173	35	150-600	300-500
Zaire	832	57	91	54	741	57	2000-4000	400-600

P = 1980's extent of forest, % = % deforested

Sources: WRI, 1990; IIED, 1988; Myers, 1989; World Bank, 1989

Table 2.6 Tons Carbon/hectare for representative ecosystems

	tons C/ha	tons C/ha
Tropical Humid Forest	210	180
Tropical Seasonal Forest	125	81
Low Tree-shrub savanna	33	36
Grass Dominated Savanna	11	18
Dry Savanna Thorn Forest	7	na
Dry Thorny Shrub Savanna	3	na

Sources: Ajtay et al., 1979; Olson et al., 1985

As estimates of the extent of closed forests, open forests, and woodlands vary, so do estimates of the amount of carbon stored in the region's land cover types. Biomass density on a given hectare of land is dependent upon a number of factors, particularly rainfall, and the degree and history of human and natural disturbance. The mosaic of old growth and secondary forest typical of large areas of the central African forest makes estimation of biomass and consequently carbon stocks exceedingly complicated. Commonly used global data sets for converting land cover types to carbon content per hectare (Table 2.6) are based on formulas to convert timber survey data to total biomass. These data sets are dependent on notoriously inaccurate logging inventories, and the ability to extrapolate from commercial wood volume estimates to total biomass. Accurate carbon density estimates will only be possible if the biomass of representative land cover types is actually measured by destructive sampling. Few such studies have been conducted to date. Given the uncertainty associated with current biomass density estimates, depending on the carbon loading factor used for a given land cover type, carbon inventory estimates for the same geographical area within central Africa may vary by as much as 100%.

Table 2.7 Estimated Present Stocks CO_2 (10^6 tons)

	ORNL	Millington
Cameroon	2,120	1,500
CAR	1,560	1,190
Congo	2,340	1,270
Eq. Guinea	130	120
Gabon	2,540	940
Zaire	17,390	8,620
Total	25,960	13,640

Sources: Millington et al. (in press); Graham et al., 1990 (ORNL)

The two available studies that tabulate carbon inventories by country (Table 2.7) differ markedly in their conclusions. Although estimates of the two models are similar for Equatorial Guinea, they differ by 200-300% for the larger countries. Millington *et al.'s* satellite-based estimates conclude that 13.64 GT (gigatons; one gigaton = 10^9 tons) of carbon are present in Zaire River Basin vegetation. The ORNL estimate of 25.96 GT is virtually twice as high.

Despite the wide discrepancy, there is no reason to conclude that reality lies somewhere between the two. Recent changes made to the volume-to-biomass conversion factors, if applied to the two models, would significantly increase both numbers. Hall and Uhlig's 1991 estimates of carbon levels within several forest categories also appear significantly higher than the equivalent biomes in the ORNL and Millington *et al.* estimates on a per hectare basis.

This suggests that using the new volume-to-biomass conversion factors with the "old" land-use estimates would yield significantly higher carbon inventories. Therefore, both the ORNL and Millington *et al.* studies can serve only as the roughest guide to central African carbon inventories. True carbon levels could conceivably be several times those estimated by the two studies. In any case, there is little doubt that, given population growth and changes in land-use practices over the past 100 years, carbon inventories in central Africa are lower today than they were in past centuries, quite possibly by a significant fraction.

Land-use change: converting biomass to carbon dioxide

There is little doubt that anthropogenic land-use change in the form of deforestation and forest degradation is the primary source of CO_2 emissions in central Africa. As is discussed in the next section, the causes of deforestation are varied and complex. They include: commercial logging, road construction both to facilitate logging and for other access purposes, extension of subsistence agriculture, and cutting for fuelwood and charcoal, especially near urban areas. Attempts to assess deforestation extent and rate over central Africa have been made (Table 2.5). Yet, given the paucity of information on forest area, forest composition, and the form and rate of land transformation, all estimates are of questionable accuracy. The clear conclusion is that while deforestation obviously is occurring, assessment of the rate and impact are, at present, imprecise and perhaps unknow-

able. Better information regarding forest extent, condition, and rate of transformation (deforestation and reforestation) is a compelling need.

Carbon dioxide emission estimates

The biotic carbon cycle involves interactions between basin soils, vegetation, and the atmosphere. A holistic carbon accounting requires quantification of carbon release from deforestation, forest degradation, biomass burning, and soil carbon oxidation, and carbon uptake resulting from natural regeneration of cleared lands, plantations, forest growth, soil uptake, and CO_2 fertilization among others.

Houghton *et al.* (1987) conclude that 40% of the carbon released in Africa comes from clearing of closed forests, 33% from clearing of open forest or woodlands, and the remaining 27% from the conversion of forest-fallow land to permanent agriculture. Each of these landcover types is characterized by a different biomass density, thus estimates of carbon emissions as a result of land transformation will be highly sensitive to estimates not only of land-use change, but of previous land-use cover. Given the uncertainty of the past and present extent of primary forest, and of the rate and extent of deforestation, resulting carbon emissions estimates must be viewed with caution.

Estimates of CO_2 emissions from sub-Saharan Africa, not surprisingly, reflect a considerable range. Because not all the emissions estimates are available on a country-by-country basis, only regional estimates are summarized here. In their 1990 study which relied heavily on estimates by Houghton *et al.* (1987), ORNL concluded that sub-Saharan Africa emitted some 411 million tons of carbon in 1985 (Graham *et al.*, 1990). Hall and Uhlig (1991), however, concluded that in 1980, Africa released between 92 and 113 million tons of carbon. Myers (1989) uses a figure of 224 million tons. It should be noted, however, that clearing rates, biomass densities, and treatment of soil carbon varied among these studies.

Table 2.8 depicts the three most comprehensive estimates of recent carbon dioxide emissions in central Africa on a country-specific basis. The data sets used in the formulation of these estimates are based on separate estimates of biomass densities and rates of deforestation. As would be expected, there are some significant differences in the results, though both ORNL and Houghton are on the same order of magnitude. Hall and Uhlig, however, suggest that total emissions are roughly half of the ORNL and Houghton figures.

Even more uncertain is predicting changes in soil carbon within the region, because oxidation and deposition of soil organic matter depend on several parameters including land cover type, land-use, soil temperature, porosity, and structural stability (Cerri *et al.*, 1991). Conversion of forests to agriculture can result in the loss of 0 to 70% of soil carbon (Schlesinger, 1986; Bramo, 1971; Brown and Lugo, 1990). Although Houghton *et al* (1987) and Hall and Uhlig (1991) include estimates of soil carbon loss in their CO_2 emissions estimates, these studies do not explicitly state the amounts of carbon released as CO_2 from soils in individual countries or regions.

Table 2.8 Estimated Carbon Dioxide Emissions 10^6 tons C/year

	ORNL 1985	Houghton 1980		Hall & Uhlig 1980	
		Low	High		
Cameroon	7.3	9.6	21.5	2.9	4.5
CAR	1.9	2.2	5.0	-2.6	2.7
Congo	2.0	2.6	4.7	+0.0	0.3
Eq. Guinea	0.3	0.2	0.4	-0.6	0.8
Gabon	1.6	1.4	3.0	-0.2	0.3
Zaire	33.4	21.6	48.2	+18.6	21.4
Total	46.5	37.5	82.8	18.1	22.5

Sources: Hall and Uhlig, 1991; Millington et al., in press; Graham et al., 1990 (ORNL)

(+) = emissions, (-) = uptake

Other greenhouse gas emissions: the role of savanna burning

At the continental level, biomass fires are an important variable in the emissions of several greenhouse gases. Savanna fires are believed to account for almost 90% of the total emissions from combined savanna and forest burning and for almost one third of the total global emissions from biomass burning (Andrae, 1991). According to one estimate, annual savanna burning takes place on approximately 600 million hectares of sub-Sahara African land (Goldammer, 1988). This burning is the primary source of greenhouse gas emissions from Africa for gasses other than CO_2.

Hao *et al.* (1990) estimate that almost 1.7 GT of carbon are emitted annually via savanna burning. From a carbon cycle perspective, however, the burning of firmly-established savanna is largely irrelevant since the released carbon is reincorporated during the following growing cycle (Andrae, 1991). Only when the burning leads to further encroachment into woodland or forest is there likely to be a significant net release of carbon over the year. No quantification of the level of such encroachment, however, is available.

ALTERNATIVE FUTURES AND ZAIRE RIVER BASIN GEOCHEMICAL CYCLES

Despite their uncertainty, existing data suggest that central Africa is, at present, a relatively small contributor to global emissions of the primary greenhouse gases. Deforestation is modest, with annual estimated carbon emissions for the mid-to-late 1980s ranging from 20 to 80 million tons per year. To the extent that methane and nitrous oxide emissions

have been quantified for the region, they are also modest, and relatively less important than CO_2 emissions.

Carbon dioxide appears likely to remain the most important greenhouse gas linked to land-use change in central Africa, given the relatively small area of savanna. In the absence of truly large-scale land-use change, (e.g., one that would see forest replaced with savanna over large areas), carbon dioxide seems likely to remain the primary greenhouse gas released from central Africa. Large-scale efforts to mitigate global climate change (e.g., promoting regeneration and tree planting), could even reduce the importance of CO_2 relative to CH_4 and N_2O emissions.

In conclusion, the implications of these rough estimates for the future are hard to quantify. It is clear that for the globe, central Africa's forests constitute an enormous potential source of carbon dioxide and other greenhouse gases. It is important that we obtain a better sense of the nature and dynamics of this carbon reservoir. While such an effort is important for the global community, it is also very important for the future economy of the region, because 1) the forests of central Africa contain a wealth of timber and soil nutrients which, if used wisely, can provide sustained economic development; and 2) extensive and permanent clearing of these forests is likely to result in changes in regional rainfall patterns and hydrology, and lower long-term natural resource and agricultural productivity.

III. HUMAN INTERACTION WITH THE FORESTS OF CENTRAL AFRICA: TRENDS AND CONDITIONS

INTRODUCTION

By far the largest proportion of anthropogenic greenhouse gas emissions in central Africa results from activities associated with land-use change, particularly the clearing of forested areas for agricultural use. In sharp contrast are industrialized nations where the burning of fossil fuels constitutes the primary source of greenhouse gas emissions. Fossil fuel consumption is the greatest single source of greenhouse gases on Earth. Compared to fossil fuel use in industrialized nations, land-use change in central Africa is but a modest contributor to global emissions, accounting for less than one percent of the world's net carbon dioxide emissions in 1990 (WRI, 1990).

An estimated 70% of land-use change in central Africa comes from clearing for agricultural purposes. The figure also highlights another significant fact: together, Zaire and Cameroon account for 88% of the estimated emissions attributable to land-use changes in central Africa. These two countries also account for 87% of the region's population.

It is therefore important to understand the major elements of the processes and dynamics responsible for land-use change in central Africa. This chapter discusses the effects of human activities on the region's forests. The first section offers a brief assessment of the historical, economic, and political context within which present day human activities take place. The second section focuses on a variety of ways in which the people and governments of the six countries interact with the region's forests.

Land-use change in central Africa takes a variety of forms. Road-building, mining, and agricultural clearing can permanently remove tree cover; over-logging and intensive fuelwood collection can degrade a forested area, damage the remaining trees and seedlings, and leave it vulnerable to soil erosion; and seasonal burning to prepare fields for cultivation or to flush wild game can prevent natural regeneration along the edges of the forest and in recently opened areas. The clearing, burning, and conversion of forested land is associated with a variety of indirect factors including: rapid population growth and changing settlement patterns, inappropriate macro-economic policies, inefficient and wasteful production methods, and weak management and administration.

The causes of deforestation in central Africa vary from one site to another, yet a general pattern of contributing factors can be identified. This is especially true in heavily settled areas where forest assets are tapped to meet rapidly expanding human needs. The cross-sectoral nature of local deforestation pressures is highlighted in the three case studies presented in the boxes found on the following pages. These case studies illustrate the point that the removal of forest cover is the result of a set of pressures common within the region, and what changes in forest cover, in accordance with the particulars of local conditions, are the permutations of these factors.

To date, reforestation efforts in central Africa have yielded minimal success. Efforts to mitigate greenhouse gas emissions will probably need to emphasize controlling the rate and pattern of loss of the remaining forest rather than trying to plant new trees. A high priority should also be assigned to efforts to increase agricultural productivity. This could be done through a combination of options such as: higher farmgate prices, land tenure reform, more efficient infrastructure and storage facilities, appropriate use of fertilizer, and improved training and extension services by governments and NGO's. If current trends of forest loss and conversion are to be reversed, governments must place much more emphasis on the agricultural sector and treat it as a principal engine for economic growth.

The region has rich potential for sustainable development, much of it due to the immense, and still largely intact, humid forest ecosystem, the world's second largest. If central Africa's forest system is to avoid the fate of West Africa's largely degraded forests, 75% of which have been lost this century (Martin, 1991), current conditions and trends in the region need to be understood and development priorities reformulated.

HISTORICAL, ECONOMIC, AND POLITICAL BACKGROUND

Early Inhabitants

According to recently unearthed archeological evidence, humanity has been making use of the forests, woodlands, and savannas of central Africa for at least 40,000 years (Wilkie, 1988). The present forest dwelling hunter-gatherers of the region, roughly 200,000 in number, are assumed to be the direct descendants of these early inhabitants (Beauclerk, 1990). Although economic and cultural assimilation have adversely affected many communities of these original forest dwellers, in most cases their culture and religion continue to reflect the value of the forest as the ultimate provider of both material and spiritual sustenance (Hart and Hart, 1986).

The hunter-gatherers are not the only ancient residents of the forests of central Africa. Farming cultures began moving into the forests from the bordering savanna lands some 2,000 to 4,000 years ago. These two groups evolved a symbiotic relationship, in which agriculturalists provided crops, pottery, and tools in exchange for the bushmeat, medicines, and forest products gathered by the hunter-gatherers (Wilkie, 1988). One key to the survival of the early farmers was the development of shifting cultivation, a technique which was often the most practical form of agriculture given the soil qualities of the forests and technologies available.

The agriculturalists began to thrive, establishing villages and trading routes along the edges of the forest and astride navigable waterways. Their descendants are the approximately 50 million Bantu people who comprise the vast majority of modern day central Africans. Sharing the region's abundant and naturally replenishing resources, a mutually beneficial relationship between agriculturalists and hunter-gatherers lasted for centuries.

Permanent disruption of this customary relationship between different forest dwelling groups came with the slave trade and the subsequent colonial era. By the close of the nineteenth century, fortune hunters from France, Belgium, England, Spain, and Germany had laid claim to vast portions of the region. Large tracts of forests were assigned by the colonial authorities to trading firms exporting forest products such as hardwoods, vines, fruits and nuts, and animal products such as ivory, skins, and feathers. Extracting these natural resources, and establishing control over the lands from which they came, quickly brought the Europeans into conflict with the resident hunter gatherers and Bantu farmers.

Land-Use Rights and Responsibilities: Conflicts and Contradictions

In general, the colonial rulers decreed forest tenure policies that were based upon the Roman law principles that prevailed in Europe. These held that any "unoccupied" land for which written ownership documents did not exist (as they clearly did not in the African culture) belonged to the colonial state. Thus deprived of legally recognized ties to the land, Bantu villagers were channeled into providing labor for public works projects, especially road and railroad construction. By the early twentieth century, many communities were required to cultivate export crops such as cotton, cocoa, and coffee. Many of the region's hunter-gatherers were absorbed into the colonial enterprise as providers of logistical support, and also supplied field labor for the Bantus who were no longer able to tend their own fields (Beauclerk, 1990).

The tenurial policies of the colonial era remain in force in various forms today. The only legally secure titles to land in modern Zaire, for example, are those officially registered as private concessions and granted by the national government. These account for only a small percentage of the national territory. Secure private titles or leases can be obtained only through written application. Individual titles are granted by the state for an initial five-year period; definitive title can be acquired once the land has been shown to be "developed", a term which usually means converting primary forest to agricultural usage (Salacuse, 1985). A similar presumption of state ownership over forest lands characterizes the land-use laws of the other central African countries (Riddell and Dickerson, 1986).

A priori written ownership requirements are a common feature of land tenure in many developing countries and frequently lead to adverse ecological consequences (Bromley and Cernia, 1989; Lynch and Alcorn, 1991). In many cases, the less secure an individual's title to the land, the less likely the land is to be put to sustainable, long-term use. What predominates instead is a pattern of exploitation for immediate gain, regardless of long-term ecological consequences.

De facto authority over use and management of the region's forests is a complex mix of customary forest use practices and rules, modern statutes and laws, and legal and business agreements with foreign entities in the form of timber and mineral concessions. In addition, a wide variety of culturally and socially influenced local tenurial arrangements between different ethnic groups frequently comes into play (Peterson, 1990a).

Contradictions between oral customary law and the various written codes, regulations, and statutes that concern tenure rights to forests and other natural resources are exacerbated by conflicting interests between local people and government authorities. Functionaries are charged with increasing government revenues, especially in the wake of recent economic downturns. Local forest dwellers, on the other hand, depend on the forest resources for their livelihoods and survival. These conflicting interests may undermine the willingness of local resource users and government authorities to work out equitable arrangements to manage the forests for sustainable use and conservation.

Local Resource Users Overlooked

Compounding the problem is the dearth of information about the number, practices, and perspectives of the people living in, or dependent on, the forests. Even well-intentioned development initiatives such as credit programs for small-scale investments, extension activities, and agroforestry training are often designed and implemented without local input or regard for customary laws and land-use patterns (Talbott, 1991). Without the participation of those who will be most affected, such initiatives have little chance of success. Central governments unilaterally enact laws asserting public ownership rights or impose zoning regulations over vast forest areas. Commercial rights are then allocated to extractive enterprises, many times without regard for the long-term, ecological consequences and without input from local residents.

At the same time, national governments have been largely unable to effectively supervise activities within vast forest areas. A particularly severe constraint is the inability of governments to staff, train, or pay officials responsible for forest surveying, conservation, and management (Winterbottom, 1990).

Multilateral, bilateral, and other development organizations have also failed to encourage the development of systematic, suitable, and environmentally sound strategies that address tenurial issues related to improved forest management (Colchester and Lohmann, 1990). Large-scale, donor-initiated development projects are being planned in the region that could have major impacts on the forests (Horta, 1991). Timber and mining projects, railroads, roads, and large-scale cash crop activities continue to be put forward with little attention to the local communities' vital role in promoting long-term forest management.

Demographic Patterns and Trends

Although data from the region are unreliable, estimates place the present population of the six central African countries at roughly 54 million. Annual growth rates range from 2.3% in Equatorial Guinea to 3.5% in Gabon. Central Africa's population is projected to reach 140 million by the year 2025, a nearly threefold increase over the next thirty-five years (WRI, 1990 (from UNDP sources)). The following figures should be treated with caution, however, as demographic statistics for the region are generally of unknown reliability and in many cases are merely estimates or extrapolations from colonial era figures.

TABLE 3.1: Demographic Overview
(in millions)

Country	Estimated Population 1990	Estimated Population 2025	Annual Growth Rate (1985-1990)	Density per km²	% Urban	Annual Population Growth Rate
Cameroon	11.2	26.2	2.6%	23.5	49.4	6.8%
CAR	2.9	6.8	2.5%	46.6	46.6	4.5%
The Congo	2.0	5.0	2.7%	5.7	42.2	3.3%
Eq. Guinea	0.4	1.0	2.3%	15.3	64.5	5.1%
Gabon	1.2	2.9	3.5%	4.4	45.7	5.1%
Zaire	36.0	99.5	3.2%	15.4	39.5	4.7%
Regional Total	53.7	141.4	3.0%	14.9	42.2	5.1%

Source: WRI, 1990

The abundance of forest resources in the region was able to meet the needs of the indigenous population for hundreds of centuries. The colonial period, which introduced the exploitation of natural resources for distant consumers, began a slow process of reducing the surplus between indigenous needs and natural supply. For many of the region's people living in sparsely settled rural areas, the forest continues to sustainably meet most human needs. Rapidly expanding urban populations, however, are exerting heavy localized pressures on the forest.

Today, central Africa is not considered overpopulated; extensive areas of the forest remain virtually uninhabited. There is little doubt, however, that some areas are already overpopulated, and that the natural resource base is coming under increasing pressure. One of the most conspicuous of these is the Kivu region of eastern Zaire, where rich, volcanic farmland has attracted displaced farmers, many of them from neighboring Rwanda, Uganda, and Burundi, to an area already straining to support its own swelling population. Such pressures inevitably lead to substantial deforestation. (See Box 1: "Population Pressures: The Kivu Region of Eastern Zaire").

Export-oriented trade and the legacy of centralized colonial administration have resulted in a substantially urbanized culture in central Africa. Forty-two percent of the regional population live in cities and larger towns. With annual growth rates averaging just

BOX 1: POPULATION PRESSURES: THE KIVU REGION OF EASTERN ZAIRE

Over the past 30 years, human impacts on parts of the central African forest have increased significantly. In the Kivu Region of eastern Zaire, for example, a new road, an influx of political and economic refugees, changing land-use practices, and natural resource marketing reforms have combined with an above average population density and a deteriorating national economy to make the Kivu Region one of the most susceptible areas in central Africa to forest clearing and degradation.

The nearly completed road connecting Bukavu to Kisangani on the Zaire River, was built to expedite the transportation of agricultural products from the densely populated Kivu Region down river to the Kinshasa area. A major impact of the road is that it has also opened up a sparsely populated, underutilized lowland forest to the human forces that lead to extensive clearing. Families desperate for new homesteads and entrepreneurs in search of coffee and timber concessions (Mugangu and Hunter, 1990) are moving up the road, bringing "civilization" with them. Products are now exported from the forest. Studies have found charcoal and bush meat supplies increasing in both the Kisangani and Bukavu markets (Hall, Peterson, pers. comm.). The demand for bush meat may affect the existing tree species mix in the forest, as there will be fewer seed-eating animals to disperse the seeds in the forest.

Liberal immigration policies in Zaire have allowed relatively free entry to people fleeing civil unrest and critical land shortages in neighboring Uganda, Burundi, and Rwanda. As the rich highland areas of eastern Kivu become overpopulated, or are taken up by private commercial interests, residents and immigrants from the east have been migrating further west into the lowland forest areas. Recent research near the Kivu Region's northern border has shown that, in general, immigrants from the east practice different forms of agriculture than the forest's indigenous farmers, who continue to use traditional and relatively sustainable shifting cultivation methods. The immigrants' commercial agriculture requires a permanent conversion of primary forests to agriculture (Peterson, 1990b).

Artisanal mining has spread throughout the region since the government legalized free trade of gold in 1982, also contributing to forest clearing. The Bukavu-Kisangani road provides easy access to previously isolated gold mining areas (Hart, pers. comm.). Gold digging can be destructive to the forest as miners clear new settlements, and as run-off from the mines are settling in the area: gold brings them in, but new cultivatable land encourages them to stay (Peterson, 1990b).

In isolation, each of these factors would probably have little long-term effect on the forest. In combination, however, they have had a dramatic impact on the forests of the Kivu Region in eastern Zaire.

over five percent, the urban population is expected to more than triple to 90 million within the next 35 years.

Almost half of this urban growth results from the influx of rural peoples to cities and towns. With agricultural productivity in decline, young men seek their fortunes in the capitals and industrial centers, which also provide the social and cultural amenities of modern life.

In addition to the social and economic problems to which it contributes, urban migration has sometimes compromised the surrounding land's ability to provide food, fuelwood, and building materials. The strain currently being exerted on the resource base leads to localized deforestation and agricultural degradation. Particularly hard hit are the forests near the largest cities: "urban halos" of deforestation now extend as far as 150 kilometers from Kinshasa, Brazzaville, and Yaoundé. (See Box 2: "Urban Halos: Growing Cities and Deforestation in Zaire").

BOX 2: URBAN HALOS: GROWING CITIES AND DEFORESTATION IN ZAIRE

While most of Zaire remains sparsely populated, the major urban centers are expanding into surrounding savanna, woodland, and forest areas. The expanse of denuded land surrounding major cities has become an increasingly prominent aspect of the landscape. Seen from the air, Zaire's major cities appear to be surrounded by a ring or "halo", as the lighter colored soils of the cleared land stand out in contrast to gradually receding wooded and forested areas.

Zaire's urban halos are expanding. In 1981, most of the trees around Kinshasa had been cleared to a distance of 60 to 100 kilometers (USAID, 1981). By 1990, the radius of deforestation had been extended to 150 kilometers (Winterbottom *et al.*, 1990). In 1973, the deforested area around Lubumbashi was estimated to be 230 km^2; in 1981, it was estimated at 1,600 km^2. Recently, the deforested area was estimated at 1,800 km^2 (Castiaux et. al., 1991).

Urban population growth is clearly the major factor driving this process. In 1960, only 3.5 million of Zaire's total population of 16 million were urban dwellers. By 1990, the total population was 36 million, with 14 million living in towns and cities. Recent estimates indicate that by 2025, Zaire's population will be nearly 100 million, and urban areas will account for 64 million persons, nearly two-thirds of the country's population and more than four times the present urban population (UN data cited in WRI, 1990).

Peri-urban deforestation is largely a function of the growth in demand for food, building materials, and fuelwood needed by city dwellers. Commodities in urban markets are normally supplied by the surrounding countryside--the city's economic "catchment area." As cities grow, this catchment area expands. As limited transportation networks and tenure systems provide little incentive for sustainable land management, the most accessible resources tend to be overexploited and eventually depleted. This process drives further expansion of the resource catchment area. Land-use planning has been unable to keep up with this process, notably in the peri-urban areas where low income settlements have evolved into major residential zones, but also in the outlying resource catchment areas.

It is increasingly recognized that fuelwood collection generally occurs in conjunction with other activities, such as logging and preparation of new land for crops, that initiate the clearing process. Since peri-urban tree cutting is not driven solely by the need for fuelwood, then peri-urban fuelwood plantations, which have been found to be costly and difficult to implement, are unlikely to halt the expansion of urban halos. Stabilizing urban growth, and appropriate land-use planning and management in the rural catchment areas, appear to be necessary for mitigation of peri-urban deforestation, along with the solution of urban energy problems.

Economic Profile

The extraction of natural resources from the vast forest storehouse has long been the hallmark of central African economies. This pattern began at very modest levels with the original hunter-gatherers who secured what they needed from the forest and traded the surplus to nearby Bantu agriculturalists. During the colonial era, the region became a major world supplier of timber, copper, palm oil, coffee, and cocoa.

With the worldwide economic growth of the 1960's and '70s, the newly independent African nations were well positioned to profit from high levels of demand for the raw materials they produced. Favorable trade balances were the norm, especially with the development of coastal petroleum deposits in the 1970's and '80s. During this period, petroleum became the most valuable regional export, often dwarfing the value of other export earners. In Cameroon, Gabon, and the Congo, crude oil exports fueled sharp rises in government expenditures; in Zaire, petroleum sales offset a drop in revenues from other minerals, particularly copper.

The emphasis on petroleum generally came at the expense of other economic sectors, particularly agriculture. Only in Cameroon has the agricultural sector avoided the serious deterioration experienced in the other five countries. But even there, soil erosion and declining productivity, especially in western Cameroon with its high population density, are becoming serious problems. In the Congo and Gabon, where urban migration has been particularly pronounced, stagnation in the rural sector has aroused concerns for the long-term supply of food for urban populations.

In the 1990's, central African nations are finding it increasingly difficult to finance their imports through the sale of raw materials, due to depressed prices on world commodity markets. Oil-rich Gabon, which enjoyed a per capita income of nearly $4,000 in 1980, saw this figure decline to $2,830 in 1988 (World Bank, 1990a). During the same period, foreign debt has grown dramatically, further aggravating the macro-economic situation. Agricultural subsidies, particularly in the European Community countries with whom most of the region's trade has historically occurred, have also played a role by placing central African producers at a significant price disadvantage.

Faced with substantial revenue shortfalls and unrelenting debt payments on the one hand, and increasing populations on the other, the countries of central Africa have begun to reemphasize the importance of the forest sector. Economic planners are counting on boosting timber exports in order to cope with the debt crisis, even though world prices for commercial hardwoods have also been in decline. The fact that central Africa continues to emphasize export-oriented, extractive industries over whose markets it has little control is an indication of the structural weaknesses of the region's economies, and of their limited capacity to cope with worsening terms of international trade.

Political Instability

Compounding the region's economic problems are the debilitating consequences of political instability, in part another unfortunate manifestation of the colonial era. After independence, leaders representing the interests of Paris, Brussels, London, and Madrid were replaced by factional leaders concerned primarily with self-enrichment and with promoting the interests of their own ethnic group. In many cases, the resources of the country have been exploited primarily for the benefit of ruling elites while large segments of the population remain, two decades after independence, effectively disenfranchised.

Until recently, political power in central Africa seemed resistant to pressures for change: entrenched national leaders clung tenaciously to power, often acquired via coups d'état or civil wars. The combined effects of economic deterioration, capital flight, and political repression, however, have begun to destabilize the region. Frustrated by their continued disenfranchisement, rival groups have sought to overthrow incumbent leaders. The worldwide trend toward political pluralism that has accompanied the collapse of communism has also made an appearance in central Africa. During the past two years, demands for political and economic liberalization have begun to erode once-solid power bases.

Faced with mounting opposition, the Congo abandoned its Marxist orientation in June of 1991. Gabon, Cameroon, the Central African Republic, and Zaire have also initiated national conferences in an attempt to address the groundswell of political and economic dissatisfaction. Only in Equatorial Guinea has the political system avoided such pressures to date.

These national conferences are an encouraging development. They should not, however, be expected to produce immediate results, and it is unclear whether political reforms will bring about solutions to deep-seated economic problems. With substantial foreign debts, scarce investment capital, and a worldwide slowdown in the demand for export commodities, prospects for sustained growth are not encouraging. In the short-term at least, there is little doubt that troubled economies and increasing political pressures will continue to foster the dissatisfaction that is evidenced by Cameroon's recent general strike, and the civil unrest that flared up in Zaire in September of 1991.

What effects political and economic developments will have on the future of the natural resource base, and particularly the forests, is difficult to discern. In the absence of any improvement in the basic economic picture, both worldwide and regionally, changes in leadership would not necessarily produce better management of the natural resource base. Continued political instability could result in further institutional weakness, potentially threatening large-scale development plans that governments such as Cameroon, Gabon, and the Central African Republic have prepared for their forest resources. At the same time, governmental inability to oversee and coordinate natural resource exploitation could result in an increased attitude of short-term individual gain at the expense of the long-term viability and equitable sharing of the benefits of the forest.

DEVELOPMENT POTENTIAL AND FOREST MANAGEMENT

Whatever macro-economic and political conditions prevail, the people of central Africa remain dependent upon the region's vast forest resources. The primacy of the forest as a supplier of shelter, food, and energy for millions of people in the region remains a fact. In addition, national economies remain dependent upon the forests as the source of the timber, upon which much of their foreign trade is based. Any practical agenda for the future must, therefore, ensure that this natural resource system is managed in the most productive and sustainable way possible.

Agricultural Practices and Land-Use Change

The greatest extent of deforestation has occurred in the region's largest country, in Zaire: some 4,000 square kilometers per year according to one estimate (Myers, 1989). Cameroon, however, is apparently losing the highest proportion of present forest cover: with a deforestation rate of 1.2% per year, this level is half again as high as the Congo's, and three times that of Zaire. At present, the leading source of deforestation and forest degradation in the region is the encroachment of agriculture, particularly of the slash-and-burn variety. Yet, it is important to note that shifting agriculture is not always a destructive practice. This mode of agriculture has represented a sustainable way of utilizing forest resources over countless generations in central Africa as well as in other parts of the world (Conklin 1963, Dove, 1985; Lynch and Alcorn, 1991). Problems arise when demographic pressures, poorly planned infrastructure projects, and inequitable land tenure regimes undermine traditional agricultural systems, or when migrants or settlers from other regions introduce different slash-and-burn practices which may be unsuited to local conditions. The major portion of this clearing comes from the traditional sector. Such clearing, in turn, represents the major source of greenhouse gas emissions as foliage and undergrowth are burned, primarily to permit planting, but also as a source of much-needed short term fertilizer inputs.

The cultivation of agricultural products on previously forested land means that the carbon released during clearing is not entirely lost from the system. What percentage is replaced, or "sequestered", by this cultivation depends upon the original coverage and the particular agricultural usage. After a few cropping seasons, the diminished fertility of the nutrient-poor soil may preclude further production. Under the traditional forest fallow system, such land would then be abandoned to natural regrowth. Over the long term, the carbon previously stored in the forest would eventually be sequestered in new growth. The net effect to the carbon system would thus be zero. However, the area subject to shifting cultivation is presently expanding, due primarily to population growth, and fallow periods are being reduced; the result is a net addition of carbon to the atmosphere.

Agricultural production in the region is growing, though at modest rates. For example, average annual output in the Congo has risen by 0.53%, and in the CAR by 2.05%. However, due to population growth, food production has declined in each of the six

countries on a per capita basis: from -1% per person/year in Cameroon to -6.8% in the Congo (FAO, 1991). Unfortunately, because per-hectare agricultural productivity in central Africa is very low by world standards, much of the rise in total output has been the result of expansion into previously forested areas.

It should also be noted that the central African data on agricultural conditions and trends are little better than other statistics for the region. In particular, little is known about the output of the traditional subsector, whose behavior is a critical factor in forest degradation and forest clearing.

Table 3.2 Agricultural Overview

Country	Ag % of GDP	Ag % of Pop.	% of Land Cult.	Arable & Perm.Crop '000 ha	Perm. Pasture '000 ha	Foods Imports as % of total
Cameroon	28	63	15	7,008	8,300	16
CAR	40	65	3	2,006	3,000	8
The Congo	14	60	1	168	10,000	15
Eq. Guinea	46	58	8	230	104	15
Gabon	10	69	2	452	4,700	17
Zaire	30	67	3	7,850	15,000	26

Sources: FAO, 1991; World Bank, 1991

Exacerbating the supply shortfall is the fact that urban dwellers have come to prefer items that domestic agriculture does not produce, (i.e., wheat for bread), or can produce only at a higher cost than the international market price (i.e., rice). Together, these two trends have caused food imports in general to rise significantly in recent years. With the exception of the Central African Republic, central African countries import a substantial share of their food needs: from 15% in Equatorial Guinea and the Congo to 26% in Zaire. During the 1970s and early 1980s, when export revenues were high, the growing importance of food imports was not considered a problem. The recent slump in export revenues has now made food imports a substantial strain on national balance sheets.

Contributing to the problems in the agricultural sector are seasonal labor shortages in rural areas. Though still the largest component of domestic employment, the decreasing financial returns from labor-intensive farming have encouraged many young men to seek their fortunes in the cities. This is especially true in Gabon and the Congo, where the petroleum industry has created a large wage discrepancy between the public and private

sectors and between urban and rural areas. As a result of this rural exodus, an even heavier burden falls on women farmers who now have less access to male labor during the plowing and harvesting seasons.

With greater pressure on the land and less labor to clear new plots, fallows are decreasing from traditional periods of 20 to 25 years to periods of 6 to 10 years and less (World Bank, 1990b). Under such circumstances, agricultural productivity declines as soils no longer have time to recover through revegetation, and pest cycles transcend the short fallow periods. Many farmers then relocate to new areas that have already been opened up by logging roads or other infrastructure development. The result is an agricultural frontier that advances at the expense of a steadily receding forest.

Three other factors: poaching, insecure land tenure, and inadequate extension services also contribute to the threat to central Africa's forests. Commercial poaching reduces the supply of bushmeat in the more accessible areas, giving farmers an added incentive to move further into the forest since bushmeat remains an important component of the subsistence diet. Lack of secure land tenure constitutes a disincentive to making permanent improvements to the land. Finally, agricultural extension services are poor to non-existent in most areas, depriving farmers of technologies and inputs needed to increase their productivity.

With the exception of foreign-funded projects, research capacity is also minimal. The lack of knowledge and research emphasis about shifting cultivation as an agricultural system precludes effective assistance in improving agricultural productivity. The region's agricultural research centers have tended to neglect the practical realities of central African farming. Not only is local and traditional knowledge about land use not utilized, it is also being rapidly lost as people migrate from their customary lands into new areas, where different techniques may be appropriate.

The key to slowing down the rate of deforestation is increasing unit agricultural production, that is, crop yield per hectare. If average cereal crop productivity for the region could be increased to that of Gabon's, regional cereal output would be increased by 35%. Similarly, if the region achieved the world average, unit productivity would more than double. In this case, no additional land clearing would be required to meet the cereal requirement of the population through the year 2015.

USAID and other donor organizations, through their work on farming systems in various parts of central and East Africa, have demonstrated that it is possible to stabilize production on areas once subject to shifting cultivation cycles. This can be realized through agroforestry, along with modest inputs of artificial and natural fertilizer to increase soil fertility and improve soil structure. The technologies to increase production also exist; whether they can be achieved in practice is the question. The keys to increasing productivity probably lie in setting adequate producer prices, assuring that the necessary inputs are available and affordable, and that marketing infrastructure is adequate.

Energy Resources and Needs

Central Africa is well-endowed with energy resources. The Zaire River system constitutes one of the world's major hydropower resources, though at present, it is largely underutilized. The Gulf of Guinea contains significant petroleum reserves; Gabon, the Congo, Cameroon, and Zaire are all net oil exporters, while Equatorial Guinea has recently begun producing natural gas. Additional petroleum deposits are believed to exist in the interior of Zaire and the Congo, and beneath Lake Tanganyika. Deposits of methane are found in the depths of volcanic lakes in Cameroon and eastern Zaire, though the environmental consequences of using this resource are not known. Uranium ore and coal are mined in Gabon and Zaire, respectively. Finally, solar and geothermal energy may also offer long-term potential as sources of energy for the region.

The most important energy resource in central Africa, however, continues to be biomass. The tropical forest system which covers up to 40% of the region represents a massive source of renewable energy. Even when seasonally inundated or inaccessible areas are eliminated from the account, central Africa's fuelwood resources exceed its hydropower potential in terms of total available energy content. The prevalence of forest resources, combined with the generally low level of economic development, makes biomass the largest source of consumed energy in central Africa. Most of this consumption takes place in the household sector.

One source of regional deforestation comes from meeting household energy needs, especially fuelwood and charcoal for cooking. Urban areas are growing rapidly, and where the supply of wood is low and harvesting practices are unsustainable, the demand for energy puts increasing pressure on nearby forest areas which supply the urban fuelwood and charcoal markets.

When biomass is burned and replaced by new growth in a sustainable cycle, as in traditional rural fuel use patterns, there is no net addition of carbon dioxide to the atmosphere. The carbon released through combustion is offset by carbon sequestered by new plant growth. Other trace gases, such as carbon monoxide, methane, and nitrous oxide, are released by biomass combustion, however, and are net additions to the atmosphere. This scenario of no net emissions is probably still valid in most rural areas. Reliance upon fuelwood as the primary source of energy would thus probably not contribute significantly to a build-up of atmospheric carbon in much of the region.

Urban growth, however, has already reached levels of demand such that consumption now exceeds regeneration. (See Box 2: "Urban Halos: Growing Cities and Deforestation in Zaire). Where localized deforestation takes place to meet urban fuelwood needs, more carbon is added to the atmosphere through combustion than can be sequestered through new growth.

Fuelwood makes up the largest share of biomass fuels in central Africa, and is traditionally collected from public or communal lands rather than purchased in markets. In rural areas, fuelwood is usually collected by children and women, and seldom involves the actual cutting down of trees. Instead, dead trees and fallen branches are gathered, as dry wood is more easily collected, burns more efficiently, and with less smoke. Trees cleared from agricultural plots are another important source of fuelwood.

In contrast, urban areas tend to be supplied by fuelwood and charcoal markets. Fuelwood is used not only by households, but also by small businesses such as bakeries, restaurants, and brick kilns. Charcoal, a compact and lightweight fuel, is produced in wooded rural areas primarily for urban markets. Although charcoal has twice the energy value of wood on a weight-for-weight basis, the growing urban demand for this fuel can mean significant waste because of its high processing losses. On the average, it takes five to seven units of wood to produce each unit of charcoal. In the aggregate, charcoal constitutes a wasteful depletion of forest resources. Reducing the predominance of fuelwood and charcoal as an energy resource, especially in urban areas, has the potential to alleviate the pressure put on nearby forests.

Economic growth generally leads to a shift to the use of more modern fuels such as kerosene, electricity, and liquified petroleum gas (LPG). Movement up this fuel substitution "ladder" is commonly associated with rising incomes: the cleaner, more convenient and more efficient forms are adopted by people with greater discretionary incomes. Given the present economic stagnation in much of central Africa, however, it is unlikely that biomass consumption will decrease in the foreseeable future. From a carbon emissions perspective, on the other hand, slowness to adopt use of fossil fuels may be beneficial if biomass consumption can be maintained on a sustainable basis.

Increased use of central Africa's immense hydropower potential represents another means of controlling deforestation pressure. In the long run, this energy source could substitute for some portion of both fossil and biomass fuels. On the demand side, constraints include the high cost of electric appliances, and the difficulty of fostering new tastes and habits among a populace long used to traditional fuelwoods. On the supply side, the high cost of building new generation, transmission, and distribution infrastructure has kept hydropower well below its potential as an energy source.

Although some studies have been done of the supply and demand for commercial energy in central Africa, notably by the World Bank in connection with power sector loans, there is a serious lack of detailed knowledge of the household and small-commercial sectors, which generally represent the largest share of energy consumption. These sectors rely heavily upon consumption of biomass energy, but little is known about the sources of their supply and the sustainability of output over time. A better understanding of conditions and trends among the users of traditional fuels (wood and charcoal) is required, particularly where localized deforestation ("urban halos") is to be brought under control.

Exploiting Forests

Even though it ranks behind agricultural clearing and biomass energy consumption as a source of greenhouse gas emissions in central Africa, the commercial timber industry is a significant source of deforestation. Despite the vast extent of central African forests and their immense capacity for natural renewal, existing and potential logging practices pose a serious threat to the forest resource base. Unsustainable practices, technical inefficiencies, inappropriate forest policies, and underfunding and staff shortages in the forestry sector all contribute to the ongoing problem.

Present trends in central Africa suggest that the potential exists for deforestation on a scale previously seen in West Africa, and in the Amazon Basin. This potential is brought closer to reality by national economic recovery plans calling for intensified logging to offset declining export revenues. (See Box 3: "Logging in the Forests of Cameroon's Eastern Province").

An important factor determining logging patterns ever since the colonial period has been proximity to rivers and ocean transportation routes. The areas closest to the coast, or adjacent to the extensive network of navigable rivers, were the first to be logged. As need and technological options increased, roads and railroads were built. After a century of commercial logging, the most accessible forests have been intensively logged for commercial species several times, while the more remote ones have been logged in proportion to their accessibility.

To compensate for declining harvests in previously logged areas, new transportation routes have been extended into previously inaccessible areas. Railroads in Cameroon and Gabon have been built into forested areas specifically to provide access to new sources of timber and to extract tree species that do not float.

Logging Practices

Commercial logging in central Africa is dominated by large, foreign operators with a short-term attitude toward extraction of the region's timber resources. Although the forests of central Africa are remarkably diverse, with over 500 species growing to timber size (IIED, 1988a), commercial logging has traditionally concentrated on only a small fraction of that number, with the major emphasis falling on fewer than ten. In each country, one to five species generate the vast majority of export revenues.

The region's commercially valuable species tend to grow at very low densities. Not only are these species the only ones harvested, such harvesting also tends to be wasteful and inefficient. In general, loggers fell trees with the maximum amount of usable timber - tall, old growth trees with straight, clear stems that branch out into the canopy of the forest. The industry practice known as "high-grading" depletes the genetic stock of the remaining forest by "creaming" the best specimens, and also needlessly damages or disturbs large areas of

BOX 3. LOGGING IN THE FORESTS OF CAMEROON'S EASTERN PROVINCE

With an average of only four people per square kilometer and an area of 108,000 km^2, the Eastern Province of Cameroon has the lowest population density of any of the ten national provinces. It also has the most tropical forest cover. Its thick lowland forests extend from southeast of Yaoundé to the borders of the Central African Republic, Gabon, and the Congo. Many view the Eastern Province as a limitless source of timber. In 1985, the Eastern Province produced three times as much timber as any other province. If sustainable logging practices are not instituted, however, the province's forests could soon become a threatened resource.

In an effort to compensate for revenue losses in oil, coffee, and cocoa, Cameroon's traditional export revenue earners, the most recent Tropical Forestry Action Plan (TFAP) calls for investments of $136 million over the next five years. A total of 58 projects in forestry, land use, and forestry-based industry are geared to accomplishing the TFAP's ambitious plans of doubling the annual cut of roundwood to 4 million cubic meters by the year 2000, and to 5 million cubic meters by 2010 (World Bank, 1990b). Much of this activity will be focused on the Eastern Province.

Despite the scope of this plan, neither the government nor the timber industry have put any emphasis on sustainable logging practices. Up to 25% of each tree is left to rot in the forest (Gartlan, 1990). Processing efficiency at the sawmills is as low as 50%. Logging is generally carried out far from villages and towns, limiting the potential market for wood residues. As in the rest of central Africa, poorly trained staff operate the sawmills, and equipment is often old and in poor condition. Government foresters, faced with the enormous challenge of law enforcement and general oversight of logging operations, lack vehicles, fuel, and are inadequately motivated and trained.

Cameroon's reforestation law requires logging companies to pay a reforestation tax to finance government replanting in harvested areas. Due to weak administrative and extension services, however, little reforestation actually takes place. It is estimated that the present rate of country-wide deforestation is ten to eleven times higher than the rate of forest regeneration. Areas with trees remaining after large-scale loggers have harvested the most valuable species and moved on are generally considered commercially worthless and are neglected by government foresters. The typical result is gradual encroachment by agriculturalists and settlers, eventually ending in deforestation.

If the forest of the Eastern Province are to remain rich in timber and biological diversity, and be more than merely a one-time mined resource for the government and industries, sustainable logging must take precedence over the present approach of "cut, carry, and cash".

forest in order to harvest a small volume of timber. In addition, only the best wood, from the top of the buttress to just below the first branches, is removed for export. The rest of the tree is left to rot on the forest floor, a substantial waste of timber resources.

In Cameroon, harvested volumes may be as low as five to six cubic meters per hectare, out of a potential commercial volume of 35 cubic meters per hectare (IIEDa, 1988). In Gabon, harvested volumes are even lower: on average, four to five cubic meters per hectare (IIEDa, 1988). (These figures should be viewed with caution, however, as volumes of wood harvested are often under-reported in order to reduce tax liability.) Logging operations often cause unnecessary damage to non-commercial tree species and to forest soils. In some cases, this damage also threatens the regeneration of valuable commercial species.

Central African governments have tended to underestimate the economic value of forest resources, an attitude reflecting in part the region's historic abundance of trees. Financially stressed governments may also view logging concessions as a useful source of rural investment, with concessionaires often building roads, housing, schools, and clinics for nearby villages, and field offices for government forestry staff. In some cases, concessionaires also provide transportation to logging sites for forestry inspectors and even pay their salaries. For these reasons, governments at times have been reluctant to press logging companies to make better use of timber resources.

Corruption has also been a significant factor. With civil service salaries often months in arrears, forestry officials have sometimes been tacitly encouraged to secure whatever they can for the government as well as themselves. Civil service retrenchments and civil disorder have recently reduced staffing levels and budgets of forest sector agencies, further aggravating this situation.

Throughout the region, the price of logging permits is low. Governmental dependency on commercial firms undermines the objectivity of the harvest monitoring upon which forest taxes are assessed. Under-reporting of wood volume results in the loss of government revenues where export taxes, royalty fees, and other charges are based on reported harvest volumes. The end result is that forest taxes generally do not provide significant levels of revenue to the national governments, relative to the importance of the forest sector in national economies. In Gabon, for example, revenues from timber taxes covered less than 20% of the government budget allocated to the forest sector in 1984 (IIEDa, 1988).

The system of taxation is complex, erratically implemented, and frequently abused. Taxes and fees are levied by a variety of state agencies at numerous stages, from logging, to inland transport, to export. In Zaire, for example, a total of 53 separate taxes are levied, at least in principle, for exported timber products (IIEDb, 1988). As well as paying royalty fees to the government, some concessionaires in Cameroon also pay villagers for the right to log in their area as a result of jurisdictional contradictions between formal and customary tenure systems (Gartlan, 1990).

Reform of the forestry tax system would be an important step in improving forest management within the region. By assessing taxes according to standing tree volume, or potential commercial volume per hectare and creating the necessary administrative structures, for example, government revenues could rise significantly. At the same time, loggers would be given a strong incentive to harvest more carefully, utilizing more of the tree and reducing waste. Given the widespread view of trees as an overabundant resource, however, and the lack of capacity to effectively monitor and regulate logging, it may be unrealistic to expect such a transition, at least in the short and medium term.

Even protected forest areas are experiencing increasing degradation. Most of the national parks of central Africa have not been adequately managed or protected since independence. Many protected areas are regularly encroached upon by agriculturalists, loggers, oil explorers, and bushmeat subsistence and market hunters. A lack of field staff and equipment hampers patrolling and protection. The Congo, for example, has 43 guards to patrol 15,000 square kilometers of parks. In addition, field staff live under difficult rural conditions, are poorly and irregularly paid, and may face personal danger in confronting poachers who are often well-armed.

Analysis of the forestry sector is hampered by serious gaps in the data concerning even general forest inventories, as well as the forest degradation that has reportedly followed commercial logging. Also lacking are biomass and carbon inventories and assessments of loss rates, and studies on spontaneous regeneration within secondary forests. These are all critical topics in understanding the status of the central African forest.

Transportation, Infrastructure, and Mining

The transportation system of central Africa is one of the world's poorest. With a few exceptions, it serves only limited portions of the population, and has deteriorated significantly since the colonial period due to poor maintenance and a chronic lack of investment. With the partial exception of Cameroon, this weakness represents perhaps the most obvious obstacle to economic development in each of the six countries. Large areas remain isolated from the mainstream of commercial life. In many cases, these interior zones constitute a frontier whose economic potential, however misguided, is only now beginning to be exploited.

Expanding and improving transportation infrastructure is a high priority for national governments. Several large-scale projects, most notably the Transgabonais railway in Gabon, and the Bukavu-Kisangani road in Zaire, have been carried out during the 1980's in order to improve access to mineral and timber resources.

Infrastructure's most significant effect on the dynamics of land use comes from the indirect role it plays in opening up the forest to a host of economic activities. Until recently, plans for infrastructure development gave little attention to either the direct or indirect effects of road or railway construction upon forest resources. Yet these secondary effects can be

very significant. By some estimates, for every tree cut for timber in Zaire, up to 25 noncommercial trees are cleared in building the roads to get to the logging site (Goodland, 1990).

High unemployment and stagnant national economies are driving increasing numbers of people into previously forested areas to seek livelihoods and sustenance. During the construction of the Transgabonais railroad, it was estimated that eight to ten hectares were cleared by land-hungry settlers for each kilometer of railway (Nicoll and Langrand, 1986). Their homesteading triggered even more economic activity as artisans and tradesmen set up shop, selling their products to merchants, local residents, and railroad passengers. The gradual establishment of human settlements has led to severe environmental effects in some cases. Bushmeat poaching, in the vicinity of the Transgabonais railroad has reportedly decimated the populations of certain wildlife species (Nicoll and Langrand, 1986).

Similar patterns have occurred in other transportation corridors: the opening of the Bukavu-Kisangani road in Zaire has reportedly caused a noticeable increase in agricultural encroachment and commercial activities along the edges of the Ituri Forest. While these effects have not been systematically studied, similar experiences in the Amazon Basin and West Africa have shown that substantial environmental damage can result from the rapid influx of large numbers of people into tropical forest areas. Infrastructure projects are often the catalysts that set this pattern in motion.

Paradoxically, weak infrastructure has perhaps been the most effective safeguard against large-scale deforestation in central Africa. Without the access that infrastructure provides, many economic investments are either impractical, or can only proceed on a reduced scale. Major road building projects are well beyond the means of local communities, and must be supported by the state or by donor agencies, and at present, the states are extremely hard-pressed for investment capital. Many donor agencies, in turn, are becoming more aware of the environmental consequences of major infrastructure projects and, in some cases, have modified or even cancelled plans for new roads in the region.

It is unrealistic, however, to expect that significant areas of national territory containing valuable natural resources will remain isolated for long. Since infrastructure development is a necessary condition for further economic development in the region, it is not surprising that national governments are seeking to make improvements in the geographic coverage and the efficiency of infrastructure, and that donors are interested in facilitating this effort.

Like infrastructure, mining has had both direct and indirect effects on the forest resources of central Africa. The open pit method of mining manganese, copper, cobalt, and uranium employed in Gabon and Zaire requires substantial land clearing, though the vast majority of Zaire's extensive copper mines are located in the shrublands of the southeast. Major mining operations also require the building of rail lines, roadways, and electricity transmission lines to bring in and operate heavy machinery and to transport minerals to

processing centers or ports. With their need for both skilled and unskilled labor, mines attract large numbers of job seekers and can thus become the stimulus for rapid population growth and commercial development in satellite communities.

Low world prices for minerals combined with chronic transportation bottlenecks, high investment requirements, and a lack of investor confidence in local political and economic stability, impede the expansion of central Africa's mining sector. The long-term outlook, however, could be quite different. Much of central Africa has not yet been thoroughly surveyed, and major mineral deposits could yet be discovered, especially in the Central Basin area of Zaire and the Congo. This region is believed to contain substantial petroleum deposits, the exploitation of which will require a massive investment in the transportation sector. This would, in turn, facilitate logging and agriculture in areas which are presently not accessible. The result will be greater penetration into the forest along with the panoply of human activities that comes with it.

SUMMARY

The tropical forest ecosystem of central Africa is still largely intact, but is coming under increasing stress from a variety of anthropogenic sources. Among these are population growth and internal migration, rapid urbanization, pressures on governments to open up new areas for natural resource exploitation and settlement, and inappropriate land-use regimes. The most important single factor appears to be agricultural clearing, both in the plantation subsector and in the shifting or traditional subsector. Plantation agriculture is expanding in response to the need for export crops, while shifting agriculture is accelerating the pace of forest clearing due to population pressure and decreasing productivity. Savanna burning, traditionally practiced for a wide variety of reasons, is inhibiting natural regeneration and contributes to a long-term reduction in the extent and density of tree cover in the region.

An important step toward improving the outlook for central Africa's forests lies in revitalizing the agricultural sector. Improving agricultural productivity could help slow forest conversion while at the same time meeting the demands of growing populations. A prerequisite of any such revitalization, however, is major reform in the existing land tenure and land-use planning systems. Reform in the commercial logging sector is also a vital step toward the sustainable management of the central African forest.

The region's economic problems are exacerbated by a heavy dependency on the export of raw materials for which the terms of international trade have been in long-term decline. National plans for economic recovery call for accelerated investment in extractive sectors such as logging and mining. These industries can be expected to further contribute to deforestation pressures. In addition, the new infrastructure they require will also generate a variety of indirect pressures on the region's natural resource base.

Many of these plans have been deferred due to political and economic crises. In the longer term, however, it is likely that the trend of opening up "internal frontiers" to natural

resource extraction will resume and perhaps accelerate. It remains to be seen whether productive use can be made of the present delays by beginning to introduce some of the policy reforms and technical changes which have been identified in this study as crucial to preserving the viability of the remaining central African topical forest zone.

IV. IMPROVED INFORMATION AND INFORMATION MANAGEMENT: REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS)

INTRODUCTION

An important component of this study has been to examine the role of remote sensing in the provision of data and information for global change research for the central African region, and to review the potential role of GIS. These relatively new techniques for primary data acquisition, management, and analysis offer considerable potential for improving existing data bases and generating new data for the region. The focus on satellite remote sensing, primarily for the study of land cover and land transformation, was justified by the importance of conversion in the carbon cycle, the regional applicability of the data, and the need for current and accessible information.

The approach adopted for this study was to review the availability of satellite data and the status of remote sensing within the region. As a result of this review, a preliminary assessment of current gaps in remote sensing data availability for the region is provided, and an indication of what should be done to fill these gaps. In addition, four remote sensing case studies that examine some of the more important contributions to a climate change program are included. Examples of how GIS can be used for different types of projects at various scales are given. The following section provides a brief summary of the reviews and case studies which are fully described in the Technical Report.

REMOTE SENSING

Satellite remote sensing can provide some of the data sets needed for climate change studies, and a range of remote sensing techniques are currently available to provide data appropriate for different scales of study. A list of current satellite systems for deriving climate parameters, gas, and particulate data for the region are summarized in Table 4.1. A list of planned satellite systems that will provide new data for future study of climate change is in Table 4.2. (Descriptions of these data sets and planned systems are detailed in the Technical Report.)

The availability of Earth resources satellite data is a problem for the central African region. The longest record of data is from the Landsat system, launched in 1972 (Freden and Gordon, 1983). In the early years of the program, there was an effort by the United States Geological Survey (USGS), which was managing the Landsat program, to provide complete cloud-free global coverage using on-board tape recorders (Figure 4.1a). The coverage obtained during this early period has been the source of data for most of the remote sensing studies undertaken in the region (World Bank, 1976). In the mid-1970's, several countries established their own data reception capabilities. The South African receiving station, for example, has actively been acquiring Landsat data of the region since 1982. However, the reception of the South African station is limited to the southern margin of the central African region, below five degrees south latitude. A proposed Landsat receiving

Table 4.1 Satellite Derived Data Appropriate for Climate Change Studies

- Cloud Climatology (Rossow 1991)
- Cloud and acrosol properties (Stowe 1991)
- Radiation budget at regional and continental scales (Jacobowitz 1991)
- Albedo (Arino 1990, Dedieu *et al.* 1987, Wydick 1987, NOAA 1991)
- Land surface temperature (Assad 1986, IGBP 1991)
- Vegetation indices (Townshend *et al.* 1985, Prince *et al.* 1991)
- Rainfall (Snijders 1991, Milford and Dugdale 1990, NASA 1991)
- Tropospheric ozone (Chesters 1991, Fishman *et al.* 1990)
- Distribution of water vapor (Justice *et al.* 1991)
- Aerosol loadings (Kaufman *et al.* 1990)
- Airborne gas measurements (NASA 1992)

Table 4.2 Planned Satellite Systems Which Will Contribute to Climate Change Studies

Landsat 6 (1992)	An Enhanced Thematic Mapper and 15m panchromatic band
AVHRR K,L,M (1994-)	Will include a 1.6um sensor and improved optical sensor gain. Discontinuation of the 3.75um daytime coverage.
SPOT 4 (1996)	Will include a 1.6 km resolution Vegetation Mapping Instrument with two day global coverage.
Radarsat (1994)	C band radar with ground resolution from 10-100m.
Tropical Rainfall Mapping Mission (1994)	Microwave and optical sensors to determine rainfall rates and cloud properties.
MODIS (EOS Moderate Resolution Imaging Spectrometer) (1998)	36 spectural bands from .4- 14.3um. 250,500 and 1000m spatial resolution.
MISR (EOS Multi-angle Imaging Spectro-radiometer (1998)	8 fixed angle cameras providing multi-angle viewing. Four spectural bands from .4-.86um at 240m.
MOPITT (EOS Measurements of Pollution in the Troposphere) (1998)	Four channel correlation spectrometer measuring carbon monoxide rofiles in the troposphere.

station for Nairobi was never established; as a result, data coverage for central Africa has been largely limited to data collected by the on-board tape-recorders, on a by-request basis. The small number of remote sensing studies performed in the region over the last twenty years has resulted in very few requested acquisitions, and poor availability of historical data. An example of more current Landsat acquisitions for the region is shown in Figure 4.1b. (A further description of Landsat coverage is given in Appendix 2 of the Technical Reports.)

The commercialization of the Landsat satellite system in 1984 led to a large increase in the cost of data and in fees for data acquisition. This has effectively precluded the use of the data by most potential users, particularly for the evolving user community within the region, because of the low level of funding available to national resource monitoring agencies and university researchers. Although there were significant improvements in the quality of Landsat data, and the addition of a higher resolution (30 m) sensing system known as the Thematic Mapper (TM), these data have been too costly, and hence, systematic regional coverage has not been acquired.

New developments in the pricing of Landsat data and the operation of future Landsat systems, may lead to an improvement in data policy by providing data at the cost of reproduction for non-profit organizations (Brown, 1991). This would lead to a major improvement in future Landsat data availability and utilization.

The Système Probatoire d'Observation de la Terre (SPOT) satellite has been acquiring high resolution (20 m multi-spectral and 10 m panchromatic) data since its launch in 1986 (Harris, 1987). Although there is nearly complete SPOT coverage of the region, the data were not acquired on a systematic basis. Hence, the historic database represents a patchwork of images acquired at different times. The coverage of SPOT data collected from 1986 through 1990 is shown in Figure 4.2. The SPOT panchromatic data seem to be the popular choice for conducting urban studies (see Figure 4.3a and b); however, its high cost and relatively low areal coverage (60 km by 60 km) prohibit its widespread use for large area applications.

The U.S. National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite sensing system provides daily global area coverage (GAC) at a resolution of 4 km, with local area coverage (LAC) of 1 km available on request (Justice *et al.*, 1985). Its high temporal resolution makes it attractive for regional and global scale environmental monitoring. These data are available from NOAA. In addition, AVHRR High Resolution Picture Transmission (HRPT) data acquired at the receiving stations of Niamey (Niger) and Nairobi (Kenya) are distributed by Eurimage at Frascati, Italy (TREES, 1991). A global dataset of normalized difference vegetation index data (NDVI) derived from the visible and near-infrared channels has been created using the Global Area Coverage (GAC) data by NOAA (Tarpley, 1991). Vegetation index data for Africa have been used for a variety of vegetation studies (Justice *et al.*, 1985; Prince and Justice, 1991; Prince *et al.*, 1990). A typical example of the NDVI data showing vegetation activity for Africa at the peak of the northern and southern hemisphere growing seasons is given in Figure 4.4

Three additional satellite sensing systems currently offer limited coverage of central Africa in their archives, and are able to acquire data over the region on request. They are the Japanese Earth Resources Satellite (JERS-1) (Kodaira *et al.*, 1987), and the Russian Soyuz Carta MK-4, and KFA-1000 (Minshew, 1992). Radar sensors provide the capability of cloud-free coverage and will afford a considerable advantage for remote sensing in the tropics.

Radar sensors which are currently operational include the European Remote Sensing Satellite (ERS-1) (Kodaira *et al.*, 1987), the Japanese Earth Resources Satellite (JERS-1) (NASDA, 1992), and the Soviet Almaz satellite (Space Commerce Corporation, 1991). Several research projects are using ERS-1 radar data to develop techniques to better monitor vegetation; however, due to the absence of a ground station in the vicinity of central Africa, data from this region are currently not being collected (Fea, 1991). A list of current sensing systems suitable for monitoring central Africa and contact addresses for further information is given in Table 4.3.

A summary of current national and international remote sensing activities within the region is given in Table 4.4. This table is far from comprehensive, but gives an indication of the current level of activity. Information was not available for the Central African Republic or for Equatorial Guinea. The central African countries are in various stages of development in the use of remote sensing, but in all of the countries there is a growing interest in the use of these data for environmental monitoring, particularly with respect to forest cover. Major institutional and financial limitations, however, preclude the use of the data to current potentials.

PRODUCTS FROM NOAA-AVHRR DATA ANALYSIS

The NOAA-AVHRR provides data which can be used for small-scale environmental monitoring. Quantifying the spatial distribution of tropical forest at regional and continental scales is a necessary step toward understanding the role of the terrestrial system in global climate change. Regional carbon models and global climate models which take account of biosphere/atmosphere interactions, need reliable and up-to-date spatial information on the extent and distribution of major biomes and their rates of change. Data from the AVHRR are appropriate for small-scale vegetation mapping, though their coarse spatial resolution makes it difficult to derive accurate measures of rates of land cover conversion (Townshend and Justice, 1988). Estimating rates of change is best undertaken using data from higher spatial resolution sensors.

Table 4.3 List of Current Satellite Sensing Systems and Sensor Characteristics

Sensor	Repeat Frequency	Spatial Resolution	Number of Spectral Channels	Frame Area	Date Operational
AVHRR	2 times/day day & night	1 x 1 km	5	2700 km x # of lines	1978
Landsat MSS	16 days	80 x 80 m	4	185 x 185 km	1972
Landsat TM	16 days	30 x 30 m	7	185 x 185 km	1983
SPOT XS	approx. 3 days	20 x 20 m	3	60 x 60 km	1984
SPOT PAN	approx. 3 days	10 x 10 m	1	60 x 60 km	1984
KFA-1000	variable	5 x 5 m	2	variable 75 x 75 km	date not known
MK-4	variable	6 x 6 m	4	variable 162 x 162 km	date not known
JERS-1 optical	44 days	18 x 18 m	8	75 x 75 km	1992
JERS-1 Radar	44 days	18 x 18 m	1 - L band 23.5 cm	75 km width	1992 problem with antenna
Almaz	not known	15-30 m	1 - S band 10 cm	20 x 240 km	1991

AVHRR Forest Mapping

Vegetation maps of central Africa are generally old and unrepresentative of the past ten years of anthropogenic pressure. Mapping current land cover for all the tropical belt at one km resolution is an important contribution to global-scale studies by the International Geobiosphere Programme (IGBP, 1992). Assessment of global climate change implies the need for long-term monitoring. A standard one km product of regional vegetation maps from the early 1990's, for the entire tropical belt, will provide a useful basis for such long-term monitoring (TREES, 1991). Knowledge of the spatial distribution of the main vegetation types of central Africa is very important for biophysical modelling, to help determine such parameters as albedo, and to estimate water and energy fluxes. It is also important for national forestry and planning organizations. An up-to-date regional map of forest resources is a step in developing an effective management plan, and should be given high priority by national governments and the international development community. The coarse resolution data set from the AVHRR can provide an interim product on the distribution of forest areal extent, while more detailed and comprehensive high resolution mapping is being developed.

For the central African AVHRR mapping study, interactive thresholding of visible, middle, and thermal infrared channel data was applied to dry season imagery for 1988-89 and 1989-90 to delineate the following categories: dense humid forest, degraded forest, mixed forest/savanna, and savanna. Table 4.5 shows the correspondence between these AVHRR derived vegetation classes and the Yangambi vegetation classification (Trochain, 1957). Thresholds for discrimination were established empirically using Landsat data and field knowledge. The first step of the analysis process involved thresholding middle--infrared, multi-date composite images to delineate the forest-savanna boundary. The composites were maximized over a number of consecutive dates of imaging using the maximum value compositing method described by Holben (1986). A further thresholding was then performed to discriminate between mixed forest-savanna and degraded forest in the transition zone between forest and savanna. Finally, thresholds in the near-infrared band were used to differentiate closed forest from degraded forest in the Guinea-Congolian Zone (White, 1983). The greatest spectral contrast between forest and degraded forest is found in the near-infrared channel. A similar finding was reported for West Africa (Laporte, 1990; Malingreau, 1990).

Table A2.1 Central Africa remote sensing activities

	ORGANISATION	PROJECT NAME	DATA / LOCATION	METHOD	COMMENTS
CAMEROON	1-ORSTOM	Soil cartography in dense humid forest	Airborne Microwave/ South Yaoundé (F) (R)	?	-MSS coverage not complete. -3 RS laboratories will ceated in 1992-93 at Yaounde. -people are in training
	2-University of Dshang	Land use maps (R-P)	SPOT(scene ID:081-339) (F)(L)	(D+A+G)	
	3a-University of Geography Yaoundé	Meteosat receiving station +workstation	Meteosat (F) (R) (N)	?	-Unviversity of Georaphy is interested by Climatic change studies.
	3b- Univ. of Geog	Landuse mapping of West Cameroon	SPOT (F) (L)	A	
	5-ONADEF	Population density maps for South Cameroon	MSS (P)	D	-ONADEF wants to initiate RS activities linked to forest survey
ZAIRE	6a- SPIAF	Synthetic maps of Zaire	MSS from1974 unitl 1989 (N)	A	-Complete coverage of historical MSS imagery -problems of budget due to political instability
	6b-SPIAF	"Routine "forest map production Deforestation rate in Central Africa	MSS & SPOT (L)	A	
	7- ERTS - Zaire	National Remote Sensing Projects	MSS (1980/1990) (P)	A	
			MSS/TM (P)	?	
CONGO	7a-CERGEC	GIS for urban mangement (Brazzaville)	GIS +aerial photos	?	-No complete coverage -will to start RS activities - training planned -people are active in RS with the NEAP and GEF
	7b-CERGEC	potentially SPOT/MSS images for erosion process detection	SPOT/MSS -Coastal Zone	?	
	7c-CERGEC	CARTIS & RS laboratory installation	SPOT+ aerial photos	?	
	7d-CERGEC	Land use map of Congo (PAFT proposition)	Radar + TM + SPOT (F)	?	
GABON	8-Projet OPT-Dietri	Forest inventory maps	SPOT + aerial photos (F) (L)	?	-Complete SAR coverage -no good vegetation maps available at the national level -New SAR is planned to generate precise vegetation maps
	9-British-Gas	Landuse map	Microwave SAR images (AC) (L)	?	
	10-IGN	GIS for urban mangement (Libreville)	SPOT panchromatic + photos	?	
	11a-Min. du Plan	Microwave data acquisition (N)	National campaign completed ?	?	
	11b-Min. du Plan	Land use map of Gabon (PAFT proposition)	?	?	

G: Ground observations
L: Local / R: Regional / N:National
D: Digital/ A: Analogic/ ? unknown
F:Future / P: Present/AC Acomplish

PAFT: Tropical forest Assessmant Plan
NEAP: National Environment. Action Plan
GEF: Global Environemrntal Facilities
R.S:Remote sensing

OPT (Office des POste et Télécommunication)
CERGEC Centre de Recherche Geographique et de production Cartographique
ONADEF Office National et de développement des forêts.

The AVHRR Vegetation Map of Cameroon

The AVHHR Cameroon vegetation map (Figure 4.5) covers the area of Cameroon south of seven degrees north latitude. The area mapped corresponds to the area covered by the FAO Vegetation Map of Cameroon (FAO, 1980). The major areas of degraded forest are located in the Central Province (Yaoundé), the Southern Province (along an east-west axis from Ebolowa to Sangnelima) and along a south-north axis from Buea (Southwestern Province) to Bafousam (Western Province). This latter area was identified as a "hot spot" of deforestation by Letouzey (FAO, 1980). The Eastern Province is less affected by forest degradation (shifting cultivation). The degradation caused by selective logging, present in the Eastern Province, cannot be quantified with one km data.

With the exception of northern Central Province, the pattern of degradation is clearly associated with the road network and is caused by shifting cultivation. The determining factor of degradation in general appears to be population density. This condition is illustrated by the "halo" of degradation around Yaoundé. This degradation follows a centrifugal pattern common to urban areas in the tropical belt. In the northern Central Province, the degradation is mainly located at the fringes of the remnant forest blocks, which is a common pattern of degradation throughout West Africa.

The AVHRR Vegetation Map of Zaire

The AVHRR map of Zaire (Figure 4.6) shows the large block of forest covering the *Cuvette Centrale*. The forest to the north shows a continuously sharp boundary. On the southern margin the closed forest and the open formation is more irregular, where humid forest shows a more complicated spatial "interface" with open forest/savanna.

The largest pattern of degradation inside the closed forest is in the equatorial region centered around Djolu (Mongala Province), in Haut Zaire between Niangara and Ango, and in the Haut Uele Province. Linear patterns of deforestation are well represented in *cuvette centrale* (central river basin of the Zaire River), following the main communication network of rivers and roads. The linear patterns are clearly depicted by the 1 km data and are exemplified by the triangular structure between Kindu-Kasongo Shabunda. Similarly, there are linear features aligned northwest/southeast near Ilebo, Mweka and Lusambo, in the Bandudu Region and in South Kivu Province. A concentric pattern of deforestation can be seen around Kisangani, similar to those found around the urban areas of Cameroon.

Table 4.5

LAC categories	Yangambi Classification from Trochain, 1957	FAO, 1991*
Closed forest: Untouched forest, or old secondary forest Tree Cover [100%]	Closed climatic forest formation: dense moist forest (evergreen & semi-deciduous) mangrove, swamp forest, periodic swamp forest	Closed forest (crown cover >40%) - crown cover 40 - 70 % - crown cover > 70%
Degraded Forest: Shift cultivation areas, young fallows Tree cover [40-70%]	Secondary forest derived by degradation from dense forest, types forest regrowth, forest fallow, cut-over-forest.	Agricultural impact on natural forest: -short fallow cropping ≥ 33% -long fallow cropping < 33%
Mixed Forest/ Savanna: -Mosaic of forest/ degraded forest where savanna formation is dominant -woodland savanna Tree cover [10 - 40%]	Mixed forest-grassland and grassland formation inter mingled with dense forest patches or riparian forest -woodland savanna	Fragmented forest -forest fraction 10-40% -forest fraction 40-70%
Savanna: -Tree and shrub savanna Tree Cover [<10%]	Grass savanna, tree savanna, shrub savanna intermingled in different proportion	-Shrubs

FAO, 1991* : types proposed for the Land Change assessment 1980-1990

fallow cropping are defined by $\frac{\text{culture area}}{\text{Culture area + Fallows area}} \times 100$

Forest Area Estimates and Map Validation

The areal extent of dense humid forest reported by FAO for Cameroon in 1980 was 180,000 sq km. This estimate was based on visual interpretation of Landsat images (between 1973 and 1975) at 1:500,000 and 1:1,000,000 scale, coupled with aerial photo interpretation (FAO, 1980). From the NOAA-AVHRR analysis, the total extent of dense humid forest is estimated at 168,087 sq km. Using these two estimates to derive rate of forest loss, however, is problematic and inadvisable. Firstly, errors associated with the AVHRR estimate resulting from the coarse spatial resolution of the sensor have yet to be fully quantified (see Technical Report). Secondly, the errors resulting from the class groupings in the different classification schemes need to be considered. Thirdly, the errors implicit in the FAO estimate are unavailable. The preliminary area estimates for the AVHRR-derived classes for Cameroon and Zaire (Tables 4.6 and 4.7 respectively) are presented for comparison with the 1980 FAO classes.

The most comprehensive areal estimate currently available for Zaire was produced by FAO (Lanley, 1982) and is based largely on figures and maps produced in the 1950's, in particular, by those of Devred (1958). The Devred map has 37 classes of vegetation, and was based on a series of publications from the 1930's-1950's (e.g., Lebrun, 1936; Lebrun and Gilbert, 1954; Duvigneaud, 1952). A comparison of satellite-derived boundaries with this map shows the core area of moist forest in the *cuvette centrale* to be similar, but the satellite-derived boundaries show considerably more detail at the northern and southern margins. One notable difference is that large areas of the Devred class of dense humid semi-deciduous subequatorial and guinean forest occur within the region of mixed forest and savanna determined from the satellite data. This is most marked in the area north of Kikwit in Bandundu Province. Field observations suggest that the Devred classification is inaccurate for the current vegetation cover in this area, which is predominantly savanna. Similarly, the Devred class of dense humid semi-deciduous subequatorial and guinean forest with islands of guinean savanna occur within the forest class as depicted by the satellite data. This is most evident for an area northeast of Oshwe in Bandundu Province. We have no corroborating data for this location.

The one km resolution of the AVHRR results in an inherent error in the estimate of the areal extent of vegetation classes. Similarly, the classification schemes are obliged to include combinations of single vegetation types. Validation of the accuracy of NOAA-AVHRR classifications is generally based on higher resolution data from Landsat or Spot, or from recent reliable vegetation maps. The TREES project of the EEC is currently using TM data to validate AVHRR LAC forest classifications. For this study, validation of map accuracies was undertaken using three approaches. The first approach was to compare the map derived from the AVHRR with available maps for the country. The general correspondence between previous maps and satellite-derived maps gives an indication of the success in interpreting broad vegetation classes from the AVHRR data. The accuracy of existing maps is insufficient to allow the differences between existing maps and AVHRR maps to be interpreted as changes in land cover. In the second approach, the AVHRR derived map was compared visually with a number of high resolution Landsat and Spot images distributed

throughout the country. Thirdly, vegetation maps from three classified Landsat scenes were compared quantitatively with the AVHRR derived map.

In the last two approaches, Landsat data at more than ten times the spatial resolution of the AVHRR were considered to be an adequate representation of actual vegetation distribution. Similarly, the classes obtainable from Landsat data can be combined to permit direct comparison with those derived from AVHRR. Landsat images were chosen according to a south-north stratification corresponding to the Guinea-Congolian Zone and the Transition Zone identified by White (1983). Inside these vegetation zones, the choice of Landsat images was determined largely by data availability and the access to local knowledge needed to assist the interpretation.

From preliminary results obtained from the Landsat comparison, we have determined that the LAC classification underestimates the areal extent of forest by 20% at the forest margin, whereas in the dense forest domain the LAC data overestimated forest area by 10%. These errors are clearly linked to the discrepancy between spatial size and distribution of forested areas, and the spatial resolution of the sensor. Nevertheless, it is our current understanding that estimation of closed dense humid forest is consistent at a regional scale and an error estimate can be given for different zones. The highest error found for the transition zone (+20%) occurs where mixed formations are present. Most forested areas have an aerial extent smaller than the sensor sampling frequency, thereby inducing a large underestimation of forest area. The error is smaller where the dominant land cover is forest (-10%).

From this study, we conclude that a preliminary estimate of the areal extent of broad vegetation classes is possible using AVHRR one km data. Cloud cover is a major constraint to using optical data acquired at 2:30 pm even with near daily coverage. The early morning AVHRR sensors should be evaluated for reduced cloud cover. Further refinement is also needed to improve current forest area estimates by taking into account inherent errors associated with using the coarse resolution data. In particular, the three sample areas used for quantitative comparison should be extended to cover a wider range of patterns of forest spatial distribution. The AVHRR mapping is being continued for other countries in the region, and the maps are being refined as a contribution to the TREES Project. The one km data from the Niamey receiving station covering the western part of the region have not been used to date for the study. We are currently examining the Niamey archive for cloud-free data to be incorporated in the mapping of Congo, Gabon, and Equatorial Guinea. We recommend that this feasibility study be continued, and that the resulting full resolution maps be made available to a wider community, particularly those within the region, for further evaluation and refinement. In addition, we recommend that the AVHRR data be examined for their potential contribution to delineating further categories of seasonal forest and savanna type. This study should include use of the ten-year-record of AVHRR GAC (4km) data in conjunction with the existing one km data base.

AVHRR data provide a relatively low-cost approach to forest area mapping. In areas where the existing map base is out-of-date, it provides a useful intermediate product prior to completion of comprehensive higher resolution surveys. The results and accuracies of the

one km mapping make the data adequate for input into improved biospheric models within global climate models.

AVHRR Fire Mapping

One of the larger uncertainties in estimating the amount of biomass burned or trace gases emitted from Africa is the lack of knowledge about the spatial extent of savanna burning, or the interannual variability (Hao *et al.*, 1990). Fredericksen *et al.* (1990) observe that about 80% of savanna areas in the Sahelian and Sudanian zones of Senegal were burned during the 1987 and 1988 dry seasons. There is currently no such satellite-derived estimate for the central African region.

Recent development of remote sensing techniques has shown the feasibility of using the NOAA-AVHRR 3.75 um and the 11 um channels to detect fires (Pereira *et al.*, 1992; Setzer and Pereira, 1992). Matson and Dozier (1981) demonstrate a method to determine sub-pixel fire size and temperature under controlled conditions from the AVHRR one km data. This method, however, has limitations for operational implementation on a regional scale. In particular, the method requires an accurate estimate of background surface temperature of the fire pixel. Kaufman *et al.* (1990) show that it is possible to detect fires as small as 10m x 10m using AVHRR sensors. Due to low saturation of the 3.75 um channel (318-320°K) some land areas are hot enough to saturate the afternoon images. Multispectral analysis incorporating thermal channels is required to distinguish between active fires and warm soil saturation effects (Robinson, 1991). In addition to fire detection, the AVHRR data can be used to detect burn scars. A combination of day and night AVHRR data can be used to detect the occurrence of fires on a daily basis. Presence of dense clouds may obscure detection of fires, but a statistical sample of the number of fires occurring over a given period can be obtained (Kaufman *et al.*, 1990). In the tropics, fires are set in the dry season which coincides with the period of minimum cloud cover. Research is needed to determine the accuracy with which a measure of total number of fires in a given area can be obtained. Factors such as timing, duration and size of fires, and frequency of cloud cover, need to be evaluated in terms of the spatial and temporal resolution of the AVHRR sensors. Similarly, the effects of multidate image registration on fire counting accuracy need to be determined when total fires are being estimated over a period of time.

Central Africa Fire Distribution

A preliminary distribution map of active fires (Figure 4.7) detected in January 1988 using AVHRR sensors for the northern-central African region shows that the sharp boundary of active fires coincides with the forest/savanna margin. At this time of the year, very few fires are seen within the forest domain. Figures 4.8 a and b show the areal distribution of burn scars for the southern hemisphere in the early dry season, June 1988 (a) and the late dry season, August 1988 (b).

The next step in the research program is to use these data on the distribution of fires to improve estimates of trace gas emissions from biomass burning. Satellite data need to be analyzed to generate maps of fire distribution and burning extent on an annual basis. These data can then be used to estimate the total area burned for a given vegetation type. Estimates also need to be obtained for average biomass per type, the fraction of vegetation burned, and gas emission ratios. These latter measurements will require ground data collection. The AVHRR fire data should also be used to evaluate information on timing and distribution of fires in the context of possible fire management strategies.

The conclusion from this case study is that NOAA-AVHRR one km data, when used in conjunction with sample high spatial resolution data, can provide a means to improve our current estimate of the spatial distribution of fires within the region and lead to improved estimates of the total area burned each year. These data can then be incorporated in improved estimates of trace gas emissions for the region. We recommend that a program of activity be developed which will provide the necessary ground data to validate satellite-based techniques, and to give representative emission factors for the vegetation-fire types typical of the region. The initial stage for central Africa should be to contribute to a broad, continental scale program which will identify those priority regions for more focused biomass burning studies. From our preliminary evaluations, it appears that the humid forest areas of central Africa contribute very little in terms of burning emissions. Immediate priority should thus be given to the humid savannas.

PRODUCTS FROM THE LANDSAT ANALYSIS

High spatial resolution satellite data such as SPOT or Landsat provide an important means for inventorying and monitoring natural resources, as well as managing them. The existing cartographic map base for large parts of central Africa is out-of-date. This makes effective regional planning difficult. The distribution of agriculture (plantations and shifting cultivation) is poorly known, and the precise location and extent of logging is largely undocumented. Similarly, rates of change in land cover over the past twenty years have been undocumented, thus making estimates of the associated carbon budget difficult to obtain.

In the following two case studies, we examine the feasibility of using high resolution data for an improved cartographic base map and land transformation monitoring.

A Satellite-Derived Cartographic Map Base

The poor state of current baseline cartography for the region is an obstacle to improved regional management. Although extensive cartographic mapping programs were undertaken during the colonial period, the maps produced are, to a large extent, out-of-date. Satellite mapping does not produce the detail available from aerial surveys, but in many cases it is adequate and the cost is substantially reduced. For example, satellite image maps can be used to provide accurate and up-to-date locations of forest reserves, roads, logging concessions, and land ownership. Mapping this information is an important step toward effective

resource management within the region. Information derived from geo-corrected satellite data can be easily entered into spatially referenced data bases such as a GIS.

Ortho-photo images are precision-processed map images which conform to a cartographic map projection. When precision processing is applied to satellite data, the end result is imagery free from distortions related to sensor, satellite, and the surface (Irish, 1990). Two geo-corrected Landsat Thematic Mapper image maps have been produced to illustrate the type of cartographic product that can be made using state-of-the-art, precision processing techniques (Figure 4.9). The creation of these image maps was closely monitored by personnel from the USGS (Reston, VA) and the USGS EROS Data Center (Sioux Falls, SD) and their suggestions were incorporated in the final map. The image was precision-processed by Hughes STX Remote Sensing Services (Lanham, MD). The output map is geometrically corrected to the Universal Transverse Mercator (UTM) projection at a scale of 1:125,000. In addition to systematic sensor and satellite corrections, an adjustment for mean elevation was made using a set of ground survey points from aerial photos obtained from the Institut Geographique National (IGN) in Paris. A contrast enhancement was applied to the image to allow maximum differentiation between forest types. Annotations were added to the map to label major rivers, towns, and country boundaries.

The area selected for this example was the tropical forest area located at the borders of Cameroon, Congo, and the Central African Republic (center; 2.5 degrees north latitude, 17 degrees east longitude). Several national and international organizations are implementing forest conservation projects and studies in this area. These activities will benefit from an improved cartographic base.

This example demonstrates that satellite data can be used to provide an up-to-date map base for the region. It is recommended that the capabilities of national mapping agencies be upgraded to a level at which satellite ortho-photo maps can be generated in-country, and the results integrated into national mapping programs. Copies of sample maps produced in this study are available from the Biodiversity Support Program.

Land Change Assessment

The goal of land cover change assessment is to quantify the rate of change in African landscapes, which is fundamental for global change studies. Combined with biomass estimates, land change information can significantly improve trace gas flux estimates (Skole et al., in press). In this section we: 1) describe methods used for detecting land transformation in central Africa; 2) examine the advantages and disadvantages in using digital techniques to detect land cover change in the region; and 3) compare digital techniques with visual techniques.

Change detection of land cover can be determined using visual, photo interpretation techniques or digital numeric techniques. A comparison between digital and visual change detection techniques indicated that:

- visual techniques can be used in-country by personnel with experience in visual interpretation techniques, whereas digital techniques require an investment in hardware, software, and additional training;

- visual techniques make use of visual cues such as shape, texture, and proximity to other features which can, in most instances, produce a more accurate classification than digital techniques; and

- the output from digital analysis is quantitative and can be directly input into a digital information system whereas the output from visual interpretation must be quantified either by digitizing or manual techniques such as a dot grid analysis.

Change detection methodologies can be developed to survey an area in its entirety (Skole *et al.*, in press), or on a sample basis which provides representative statistics on clearing rates for the entire area (Singh, 1990). A wall-to-wall approach has the advantage of producing a map that illustrates the change situation, whereas the sample approach produces only representative statistics of land cover change. The advantage of a sample approach is that cost of the survey is greatly decreased and accuracy of the change statistics is greater.

In the past, rates of deforestation have been based on national statistical information, such as demographic and land-use records. In a study more fully described in the Technical Report, four Landsat MSS scene pairs were selected to demonstrate a change detection methodology, and to illustrate the problems that need to be addressed when quantifying deforestation within the region. The four areas were selected to provide a variety of land cover types including dense forest, forest margins, and gallery forest. Two approaches were used to quantify land conversion. One approach independently classified each multi-date image into a number of land cover classes (e.g., closed forest, savanna, woodland/savanna complex, rural development, and water). Two classified images were then compared to compute a change matrix. For the other approach, the multi-date images were combined into one image and the resultant image was classified into either a no-change class (e.g., primary forest, secondary forest, non-forest), or a change class (e.g., forest to non-forest, non-forest to forest, non-forest to secondary forest).

Figures 4.10 a, b, and c show a pair of Landsat MSS images (dated 1976 and 1986) used in the change detection study, and the resultant change image. This image covers an area in north-eastern Zaire with low population density. The bulk of the image contains moist tropical forest with savanna patches occurring at the top. On the image as a whole, the rate of change is small (2.3% regrowth and 1.0% forest converted to degraded forest). Within the change class, most of the change is occurring in coffee plantations (bluish, rectangular patches along the roads on the 1976 image) which were abandoned when coffee prices dropped below economically viable levels. The findings from the change detection study are preliminary and the studies are being further refined.

The purpose of the study was to evaluate procedures for change detection associated with cover classes occurring in the study areas, rather than to provide representative

deforestation statistics. However, it is worth noting that at the locations sampled, it would appear that rates of deforestation are low in comparison to those reported from other parts of the tropics.

In general, the data quality of many of the early images was marginal. Many factors, including low dynamic range, line drop-out, and striping contributed to the poor quality, particularly in the earlier Landsat imagery. The narrow dynamic range contributed greatly to the confusion among different cover types and prevented a finer breakdown of land cover classes. This confusion was great in the savanna/woodland and secondary forest classes. The line drop-out and striping did not adversely affect the classification. It did, however, lead to gaps in usable data coverage.

Because this study used imagery from only two dates for each site, it does not allow insight into seasonal vegetation dynamics (phenology) or land-use dynamics. An understanding of these dynamics is important if one is to accurately determine change statistics for an area. Knowledge of phenology is important when selecting a preferred season to acquire seasonal forest imagery. Much of the land cover in the central African region undergoes some seasonal change, such as burning and regrowth at different time scales. An understanding of these cyclic changes, as well as other land-use practices, such as shifting cultivation, is necessary to select images at a frequency which enables one to differentiate between cyclic and non-cyclic changes. It is important to note that limited data availability often restricts the historic data sets which can be used.

Clearly, the greatest limitation for this study was the lack of ground data. Neither of the analysts doing the classification were familiar with the areas being classified, nor did they have access to higher resolution products such as aerial photos or video overflights. For some sites, the analysts were able to consult with persons familiar with the area, thus gaining some insight into the land cover, and cultural practices which affect land cover change.

The following preliminary conclusions can be drawn from the digital change detection study described in the Technical Report:

- digital analysis techniques can be used for monitoring land transformations when used in concert with field information;

- success of monitoring is a function of the number of transformation classes that are to be classified. Changes between forest and non-forest classes provide the highest accuracy. Attempts to define more detailed transformation classes lead to decreased classification accuracy;

- detection of land transformation is difficult in areas where land cover change is occurring in small patches or as a gradient;

- temporal dynamics of certain land-use practices (e.g., burning and regrowth) can confuse classification of land transformation;

- general knowledge of the area in question and associated land-use practices is essential when generating land transformation statistics from satellite data for areas of complex land cover;

- ground information is necessary to determine the accuracy of satellite derived land transformation statistics; and

- there is a trade-off between greater number of land cover classes obtainable using visual interpretation techniques, and the higher spatial accuracy obtainable using digital techniques.

Satellite Global Positioning Systems (GPS) and LANDSAT Satellite Imagery Assisted Field Surveys

Information concerning ground conditions ("ground-truthing") should be an integral part of any remote sensing mapping program, particularly when trying to produce or verify land cover classifications in landscapes unfamiliar to the interpreter. Obtaining ground information for these purposes in areas as remote as the primary forests of Zaire is problematic for two reasons: the difficult logistical problem of accessing remote areas, and the difficulty in obtaining accurate geographic location information associated with ground data. In many areas, existing topographic maps are inadequate for precise location. A case study was carried out with the primary objective of assessing the utility and practicality of using satellite GPS in conjunction with Landsat satellite imagery as a tool to assist in rain forest assessments within central Africa.

A GPS is being developed by the U.S. Department of Defense to replace the older Omega, Loran-C, and Transit navigation systems. Once all 21 Navigation System with Time And Ranging (NAVSTAR) satellites are in orbit, the system will provide an accurate geographic location 24 hours per day anywhere on the globe. Each satellite transmits a navigation signal that provides users with location accuracy ranging from 15 m, using one GPS receiver, to one centimeter or less when 2 GPS receivers are "connected" in differential mode.

The approach taken in this study employed an existing network of Private Voluntary Organizations (PVO's) with on-going field projects in the region to provide a preliminary assessment of GPS utility. The second objective of the study was to examine the feasibility of linking data collection activities relevant to climate change in central Africa to ongoing or planned projects of PVO's with experience in the region. Wildlife Conservation International (WCI) was provided with satellite imagery to guide field surveys of lowland gorillas, in exchange for information that would help us to distinguish ambiguous spectral features on Landsat images. A full description of this GPS case study can be found in Appendix 3 of the Technical Report.

This case study comprised a rather severe test of the practicality of: 1) using GPS positioning in conjunction with Landsat satellite imagery as tools to assist in rain forest assessments within central Africa; and 2) linking data collection activities relevant to climate change in central Africa to ongoing or planned projects of PVO's with experience in the region. Extreme transportation and logistical difficulties in the field, the relatively brief period available for field work, topography and vegetation, GPS satellite obscuring, and insufficient time for training of the PVO researcher, conspired to limit the effectiveness of this exercise. Nevertheless, the principle of utilizing the skills and local knowledge of PVO field researchers is sound, and the case study provided much useful information concerning how best to implement future activities of this kind. The strategy for collaborating with PVO field researchers to conduct rapid field surveys of rain forest using satellite image maps and GPS positioning is a direct and positive outcome of the case sites, and provides a very useful model for implementing future activities.

CRITICAL REMOTE SENSING DATA GAPS AND RECOMMENDATIONS

Currently, the biggest remote sensing data gap is the absence of comprehensive, cloud-free, high spatial resolution, optical data coverage (see Technical Report). The twenty-year history of the Landsat program makes it possible to piece together almost complete coverage of the region, but in most cases, the land-use change which has occurred during this period makes the early data inappropriate for assessing current conditions. Lack of comprehensive data coverage for any one period stems, in large part, from the lack of an effective data acquisition policy for the region over the past several years. Persistent cloud cover compounds the problem and is one that cannot be overcome by optical sensing systems. Such comprehensive coverage would satisfy many current needs, for example, for cartography and land cover mapping, and would provide the basis for long-term monitoring of land cover change.

Although nothing can be done to improve the historical record for the region, every effort should be made to ensure that we are not in the same position five years hence. The location of a Landsat receiving station covering the region would facilitate data acquisition. The policies of the organizations currently acquiring data for the region are dictated by data orders. We, therefore, need a comprehensive data order for central Africa to improve the current situation. The current pricing structure for high resolution data makes regional data acquisition prohibitively expensive for all but the major funding agencies. The World Bank Global Environmental Facility (GEF) has received a Landsat proposal which would lead to a comprehensive acquisition policy for 1992/3 and 1997/8 for the region. Similarly, the NASA Landsat Pathfinder initiative (described in Technical Report) will assemble the available Landsat data for two historical epochs and provide an important contribution to improved availability and accessibility to the historical Landsat MSS and TM archives.

The question of remote sensing data gaps is closely tied to the issue of effective data availability. The existence of data does not necessarily mean that those who need the data can afford to obtain them. This raises questions of data pricing and copyright issues which account for some of the current gaps in the use of satellite data. The recent reduction in the price of Landsat data more than two years old to the cost of reproduction by Earth Observation Satellite Corporation (EOSAT), has resulted in some improvement.

It is also difficult for researchers to obtain a clear understanding of current data availability. Information concerning historical coverage of Landsat and Spot data is available from EOSAT, EDC, SPOTIMAGE and the South African Council for Scientific and Industrial Research (CSIR), though there are problems in obtaining accurate cloud cover and data quality information. For example, the "quick-look" products for SPOT data for this region are of poor quality. For the NOAA-AVHRR system, a similar problem exists with partial listings of regional AVHRR one km data availability residing with NOAA, the South African Council for Scientific and Industrial Research (CSIR) and the European Space Agency (ESA). A regional information center providing up-to-date inventory would be a useful solution to most of the current difficulties in assessing data availability. Such a center

could also disseminate information on data availability within the region, facilitate access to foreign data centers, and foster collaboration among national agencies.

When planning remote sensing projects, it is important to obtain information on previous projects and on other projects currently underway, as their experiences can prove invaluable in designing effective new programs. Currently there is no efficient mechanism for obtaining such information. A current listing, with a brief description of past and current national and international projects, giving contact names and a point contact, would be a useful improvement to the current situation.

The cloud cover problem for optical sensors points to the potential utility of microwave data. Currently, there is a data gap in the availability of ERS-1 for the region. It will be some time, however, before the applications research and development will enable the operational use of these data for regional forest mapping. Experience from ERS-1 applications research planned for other tropical forest regions will provide the basis for using these data when they become available for central Africa.

For most climate change research applications, remote sensing data need to be combined with data from non-remote sensing sources. For example, to estimate a regional carbon budget it is necessary to combine remote sensing derived deforestation rates with a map of forest type, and representative biomass estimates for each forest type. When developing a strategy to fill current data gaps, it is therefore important to examine remote sensing data needs in the context of achieving specific research or management objectives. Remotely sensed data alone will not provide the answer to many of the pressing climate change questions which are, by their nature, inherently interdisciplinary.

IMPROVED DATA BASE MANAGEMENT FOR THE REGION

This section is concerned primarily with a form of spatially referenced data bases called Geographic Information System (GIS). Using a system of hardware, software, and various procedures, a GIS allows one to acquire, store, analyze, and display geographically referenced data (Burrough, 1986). GIS is being used in a variety of disciplines and the number of applications is growing. With the introduction of more powerful and less expensive computers, as well as improved software, the advantages of GIS are becoming more widely available.

The countries of central Africa have not made much progress in establishing either regional or national geographic information systems, although there are a limited number of local GIS's being established. A number of other African countries, however, are using GIS's effectively (Nkambwe, 1991; Bwanaali, 1991; Falloux, 1989).

Throughout central Africa, mapping is very heterogeneous. Existing maps are often outdated and of questionable quality. In most countries, the state of mapping is very poor due to a lack of funding, expertise, equipment, and coordination among various institutions.

In addition, standard topographic and thematic maps for most of the region can be difficult to access. Most of the digital maps for this region exist as a subset of a continental or global data set. Most of these digital maps are adequate for working on a global or continental scale, but are marginal for applications on a regional scale, and inadequate for national or local-scale applications (Hastings and Clark, 1991). On national and local levels, there are limited digitized map data available. These data are being produced by various projects in the area.

To illustrate the variety of potential uses of GIS to support climate change projects in central Africa, a number of case studies were explored (see Technical Report). With each case study, the benefits, drawbacks, and lessons learned were discussed in the context of a potential Africa climate change program. The GIS case study applications were:

- Program Impact Evaluation Bandundu, Zaire - United States Agency for International Development (USAID)-(Green-Larson, 1991);

- Land-Use Modeling in central Africa (Lambin, E.-Boston University pers. comm., 1992);

- Land-Use Planning - Collaborative Study of Cassava in Africa (COSCA) Resource and Crop Management Program, Nigeria (Nweke, 1988);

- Biodiversity Inventory/Monitoring - Madagascar (Smith, A. *et al.*, 1990);

- Deforestation/Carbon modeling - Amazon Basin (Skole, D. *et al.*, in press) The Complex Systems Research Center at the University of New Hampshire; and,

- Spatial database of the Africa United Nations Environment Programme/Global Resource Information Database (UNEP/GRID)-(Jaakkola, 1990).

The case study review led us to the following conclusions. GIS technology has improved to the point where it can be instrumental in supporting different applications such as those described above. In addition to the obvious impact of using GIS for managing and analyzing data, are the secondary effects such as data sharing and data gathering, which can facilitate linkages among groups who otherwise would be working in isolation.

As a follow-up to this definition phase study, it will be important to continue to introduce GIS into the region, possibly as a series of experimental pilot studies to support climate change projects. Before GIS projects are started in the region, it is important to conduct an in-depth survey of existing information systems in order to identify potential technical and logistical problems, and to avoid duplication of effort. It is also recommended that support for GIS activities be provided across the range of scales appropriate for climate change studies.

At the local level, GIS could be used to model land-use dynamics as outlined above. Similarly, it would be advisable to build on the experience gained from the Bandundu case study to monitor development efforts, and to incorporate these techniques with long-term monitoring projects to determine the effects of climate change on the region.

At the national scale, a GIS similar to the one described in the Madagascar case study could be established to assist in the inventorying, monitoring, and managing of socioeconomic and ecological conditions. At the regional level, for example, a GIS could be established to support a regional modelling effort to examine the possible impact of climate change on agricultural sustainability, and to support mitigation policy and planning needs, and the related training. Specifically, a regional GIS system which includes up-to-date information on climate change spatial-data availability, such as maps and satellite data coverage, would improve data management in this area.

Recommendations

Satellite derived climate data - It is recommended that current meta-data on available satellite-derived climate data sets be made available to national agencies within the region, and the international donor community concerned with climate change. The IGBP-DIS and WCRP should be encouraged to play an active role in improving knowledge about--and access to--the more important satellite-derived data sets.

Satellite data availability - It is recommended that the current operators of high resolution sensing systems be encouraged to establish a comprehensive and coordinated data acquisition strategy for the region. The existing pricing and copyright policy should be changed to facilitate operational environmental monitoring by the countries in the region. Currently these are the largest obstacles to effective use of remotely sensed data. Meta-data on the current and historical availability of high resolution data for the region should be made more accessible and available in the region. 'One-stop shopping' facilities providing information on data coverage and access for the different sensing systems should be developed in-country.

Remote Sensing Institutions - It is recommended that at least one center be established in the region to provide effective assistance and technical backstopping on remote sensing and GIS technology. The center should have long-term support for staffing and equipment, and a close contact with the international remote sensing and GIS research community. Continuity for such a center is essential to permit close working relationships with the national agencies. The center should serve the needs of national agencies and organizations within the region. This should be done with careful consideration of the successes and failures of regional remote sensing centers outside the region. Potential problems of interagency rivalry between the remote sensing centers and the inventory and monitoring agencies need to be faced. There are several proposals by different donors to establish such centers: it is critical that these efforts be coordinated. One of the prime purposes of such centers would be to evaluate the utility of various new remote sensing systems and techniques prior to their operational

use by the relevant national agencies. This may best be performed through a series of demonstration studies in collaboration with national agencies.

Forest Inventory and Monitoring - It is recommended that the national forest agencies be supported in the integration of remote sensing and GIS in their current and planned programs. A forum for exchanging experience about the use of satellite data between the different agencies in the region would be most valuable. The AVHRR regional study outlined above should be completed, and then made available for evaluation and refinement by national forest agencies. Further evaluation of change detection procedures over a wider range of conditions needs to be performed. Satellite-based analysis of rates of deforestation needs to be conducted in collaboration with those national forest agencies responsible for forest monitoring. These studies should be linked to existing inventory data collected by forest agencies to derive improved estimates of forest biomass. The need for ground data for image interpretation necessitates a supporting field program. The use of PVO's in this process has shown considerable potential. A closer link should be encouraged between national forest agencies of the different countries within the region, and the international programs which are attempting to determine deforestation rates.

Biomass Burning - It is recommended that projects be developed to provide improved emission estimates from biomass burning in the region, and to better understand the potential socioeconomic and ecological impacts of changing fire use practices. The AVHRR should be further evaluated as a means to derive improved estimates of the extent of biomass burning within the region. In addition, ground-based biomass estimates and emission factors should be collected which are representative of the vegetation types and conditions that can be delineated regionally by remote sensing.

Improved Satellite Based Cartography - It is recommended that national mapping agencies be upgraded to a level where satellite ortho-photo maps can be generated in-country, and results can be integrated into national mapping programs. Programs for satellite cartography should be supported within the region. Current maps are a prerequisite for effective land-use management.

GIS - As a follow-up to the definition phase analysis undertaken within this overall study, it will be important to continue to assess the potential role of GIS in the region. It is recommended that a series of experimental pilot studies be developed to support climate change-related projects. Specifically, a regional GIS system which includes up-to-date information on climate change, and spatial-data availability, such as maps and satellite data coverage, would greatly improve the current management and accessibility of data in this area.

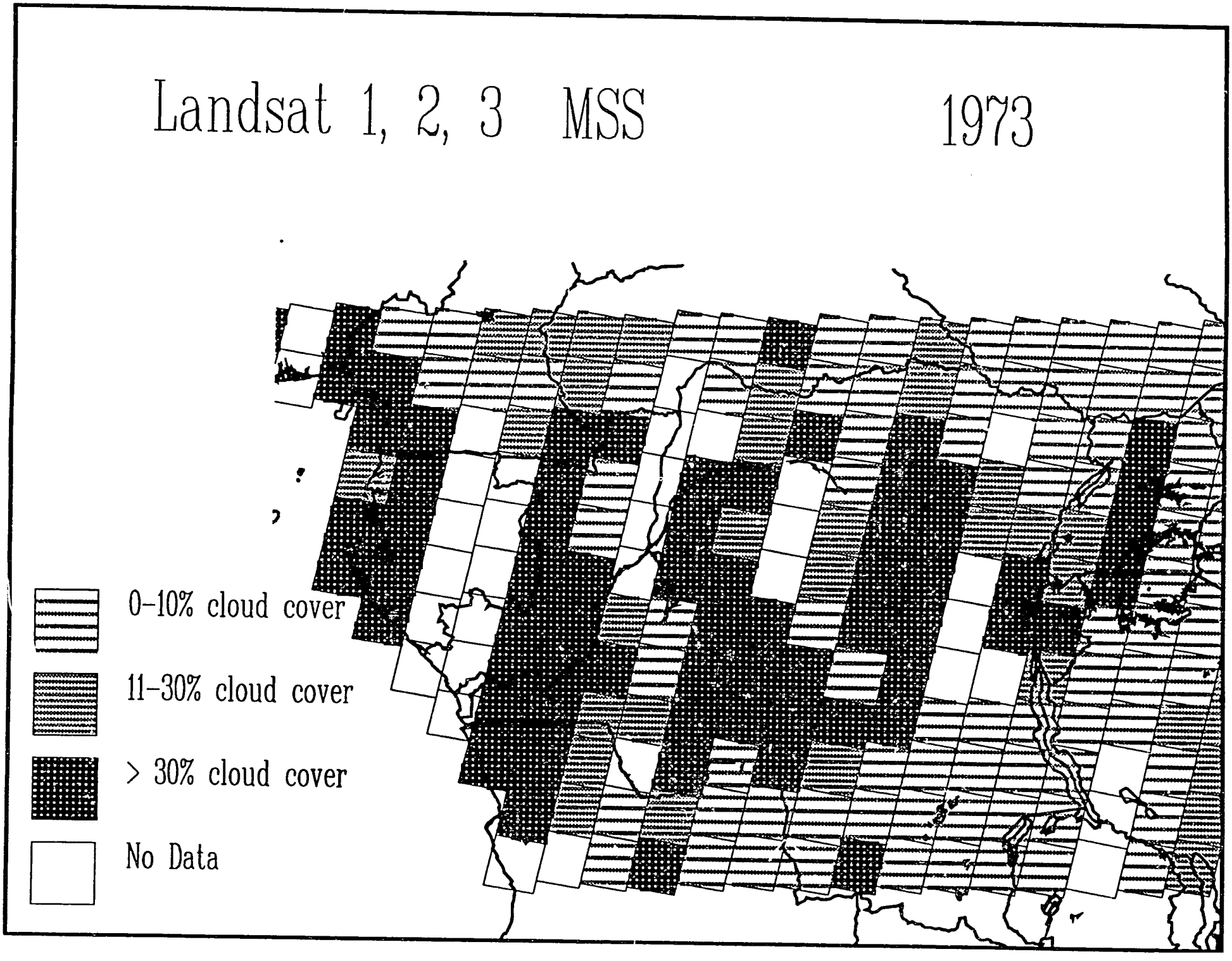


Figure 4.1a - Landsat coverage of central Africa during 1973.

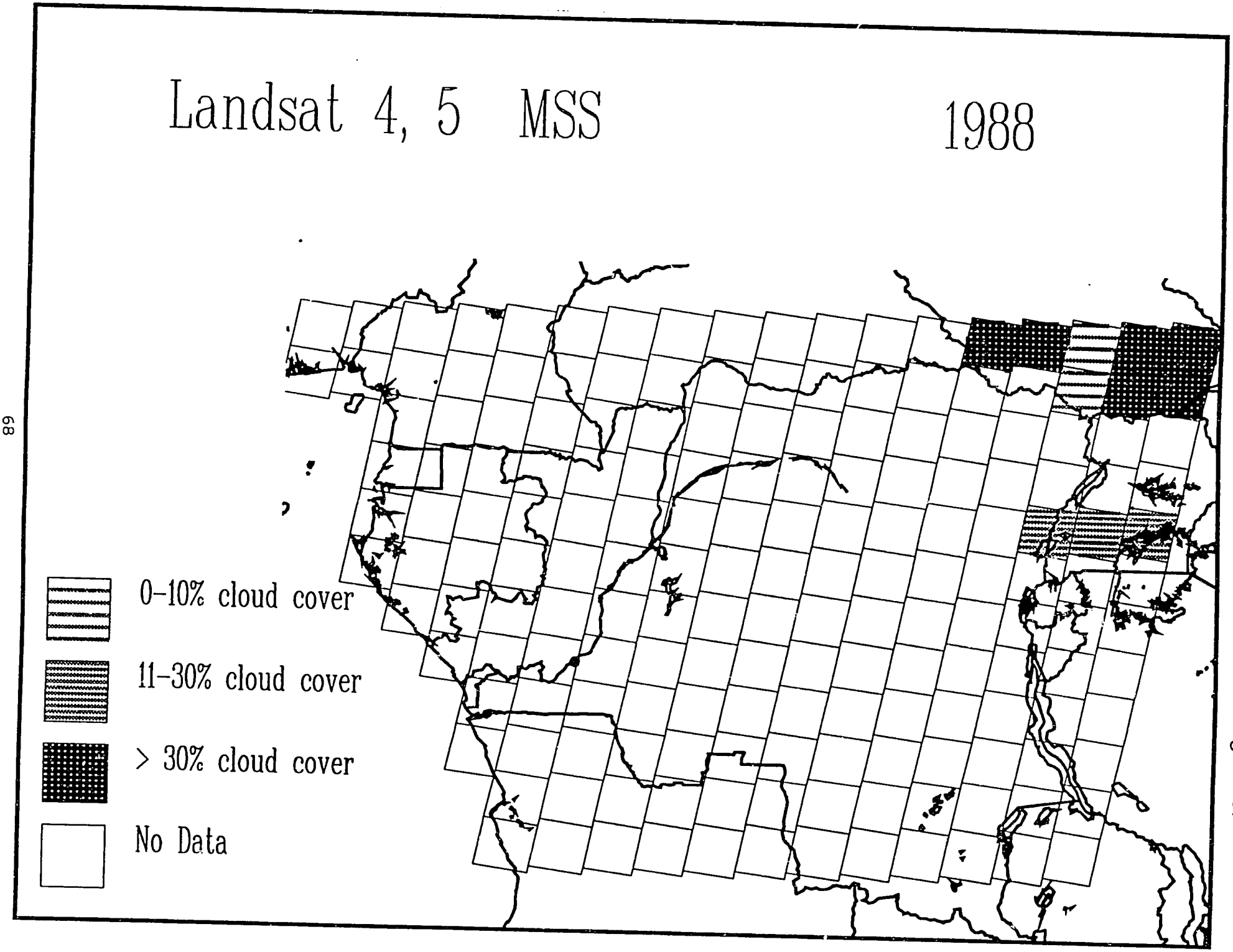


Figure 4.1b - Landsat coverage of central Africa during 1988.

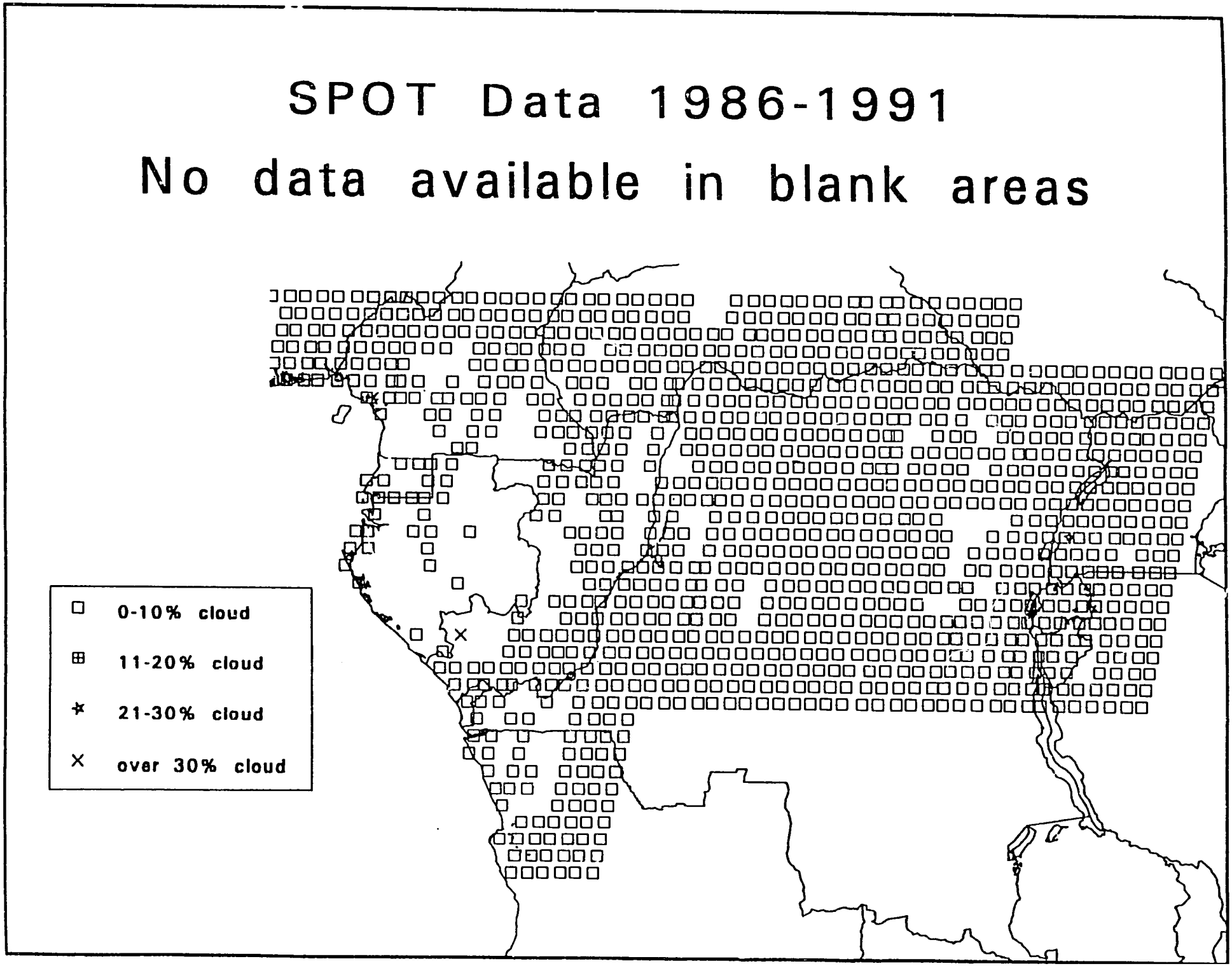


Figure 4.2 - SPOT coverage of central Africa during the period 1986- 1991.

Figure 4.3a—An example of the SPOT panchromatic (10m) sensor. The image was acquired 4 September, 1989 over the city of Brazzaville, Congo. The airport can be seen in the middle of the image, the Congo river in the lower right corner, and the dark patches in the upper left are forests.

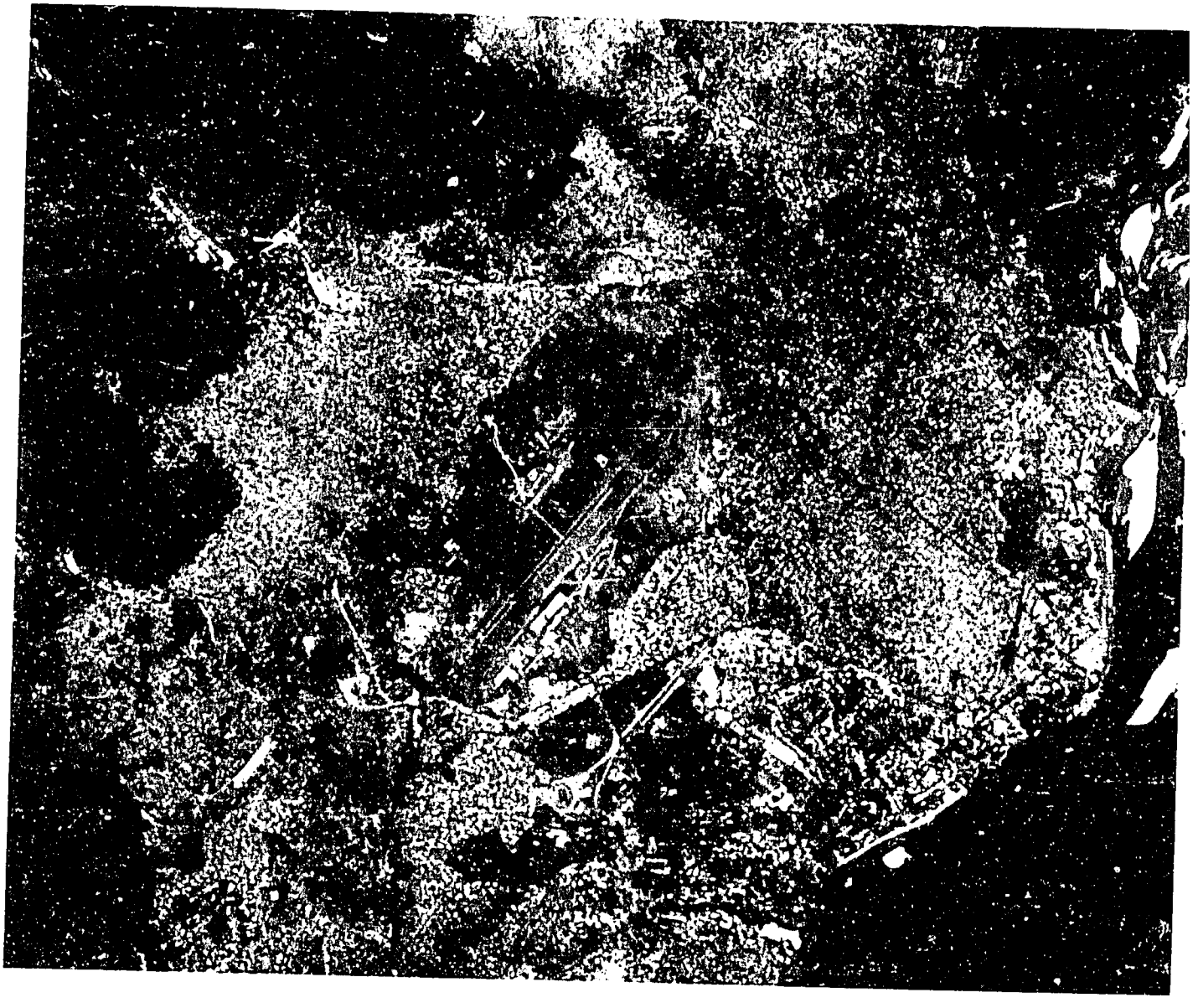


Figure 4.3b—An example of the SPOT multispectral (20m) sensor. The image was acquired on the same date and is coincident with Figure 4.3a.

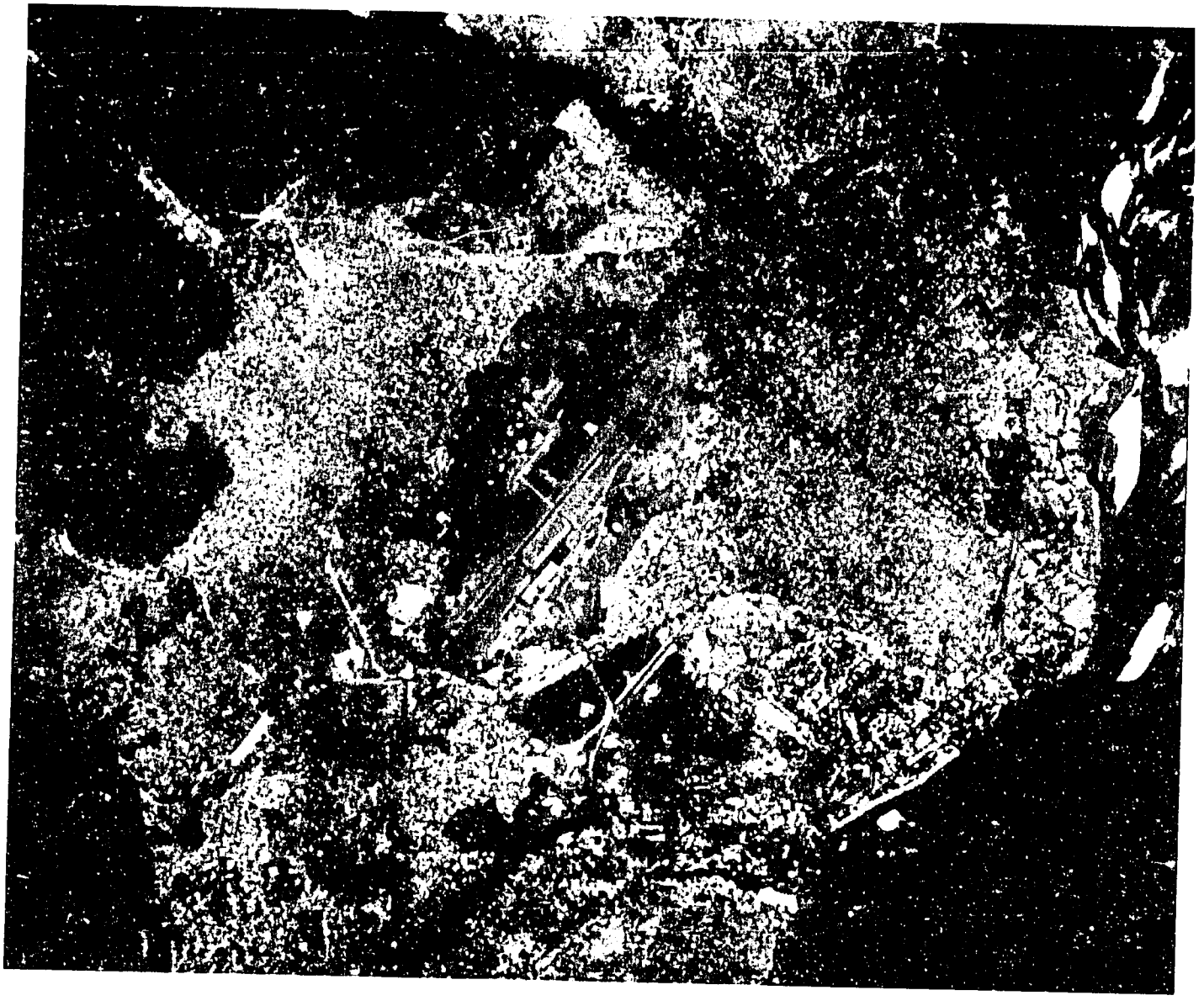
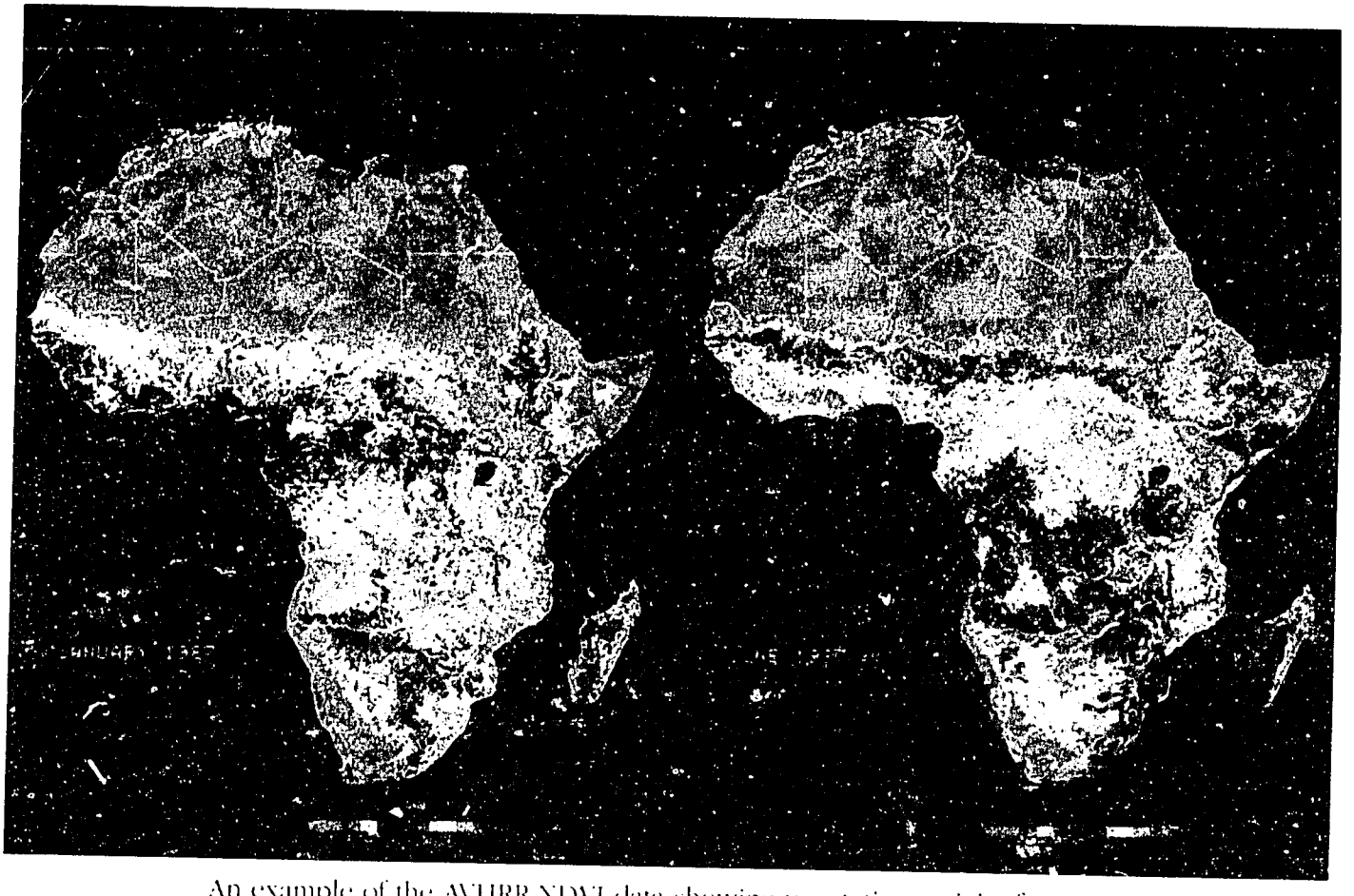
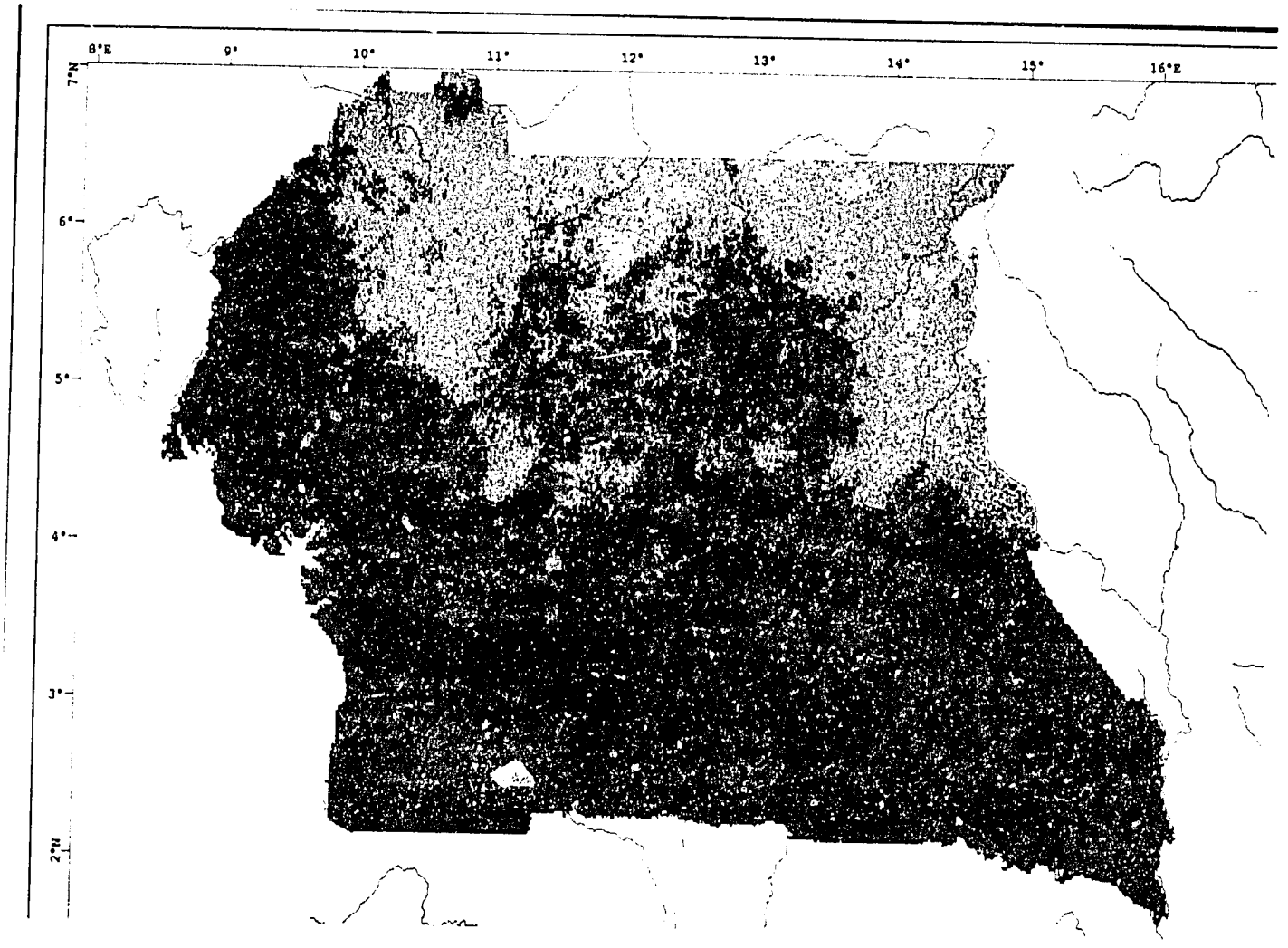


Figure 4.4



An example of the AVHRR NDVI data showing vegetation activity for Africa at the peak of the a.) southern and b.) northern hemisphere growing seasons. The red, purple and white color represent increasing vegetation activity.

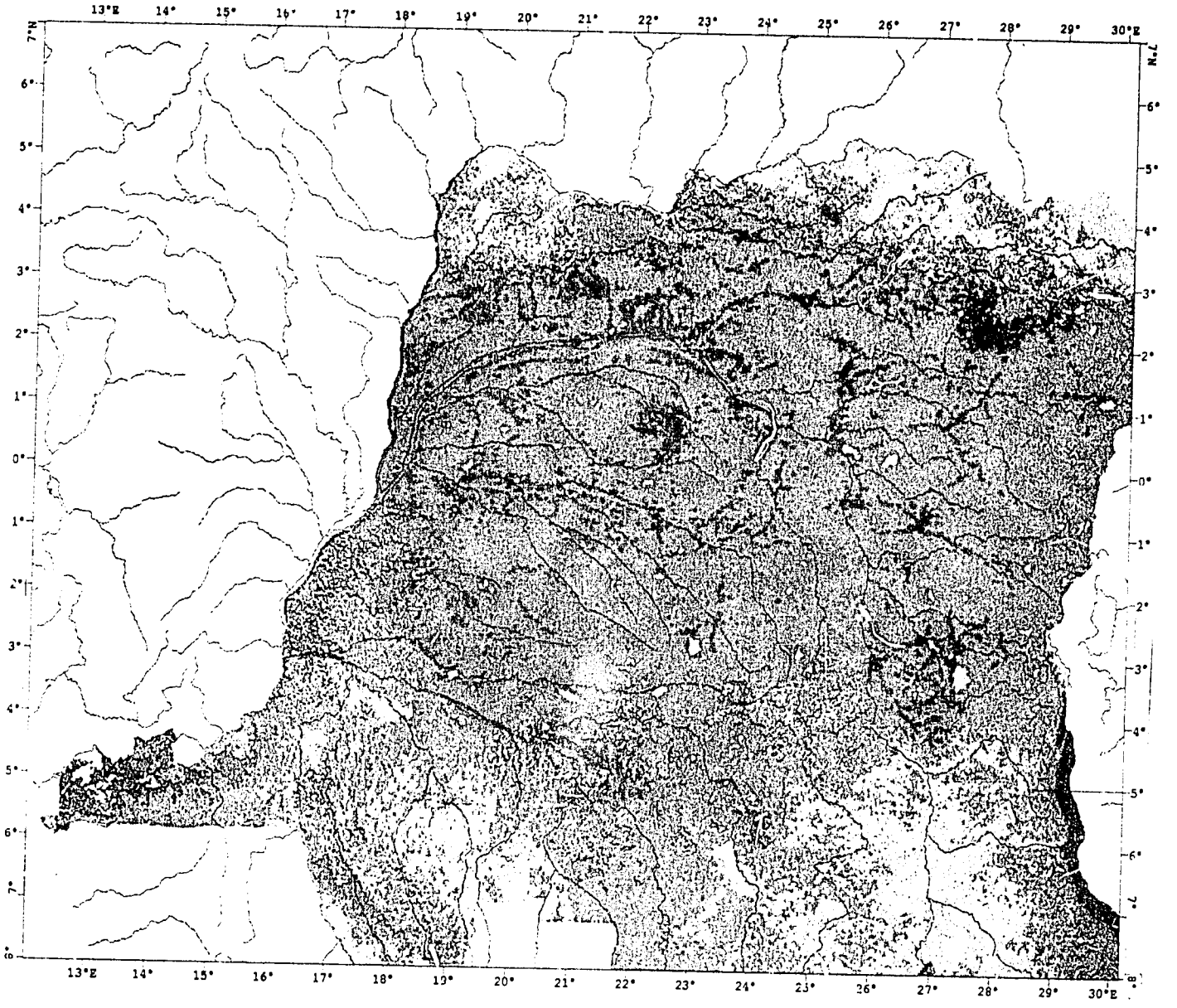
Figure 4.5—Vegetation map of southern Cameroon derived from 1989 NOAA-AVHRR data



Cameroon vegetation

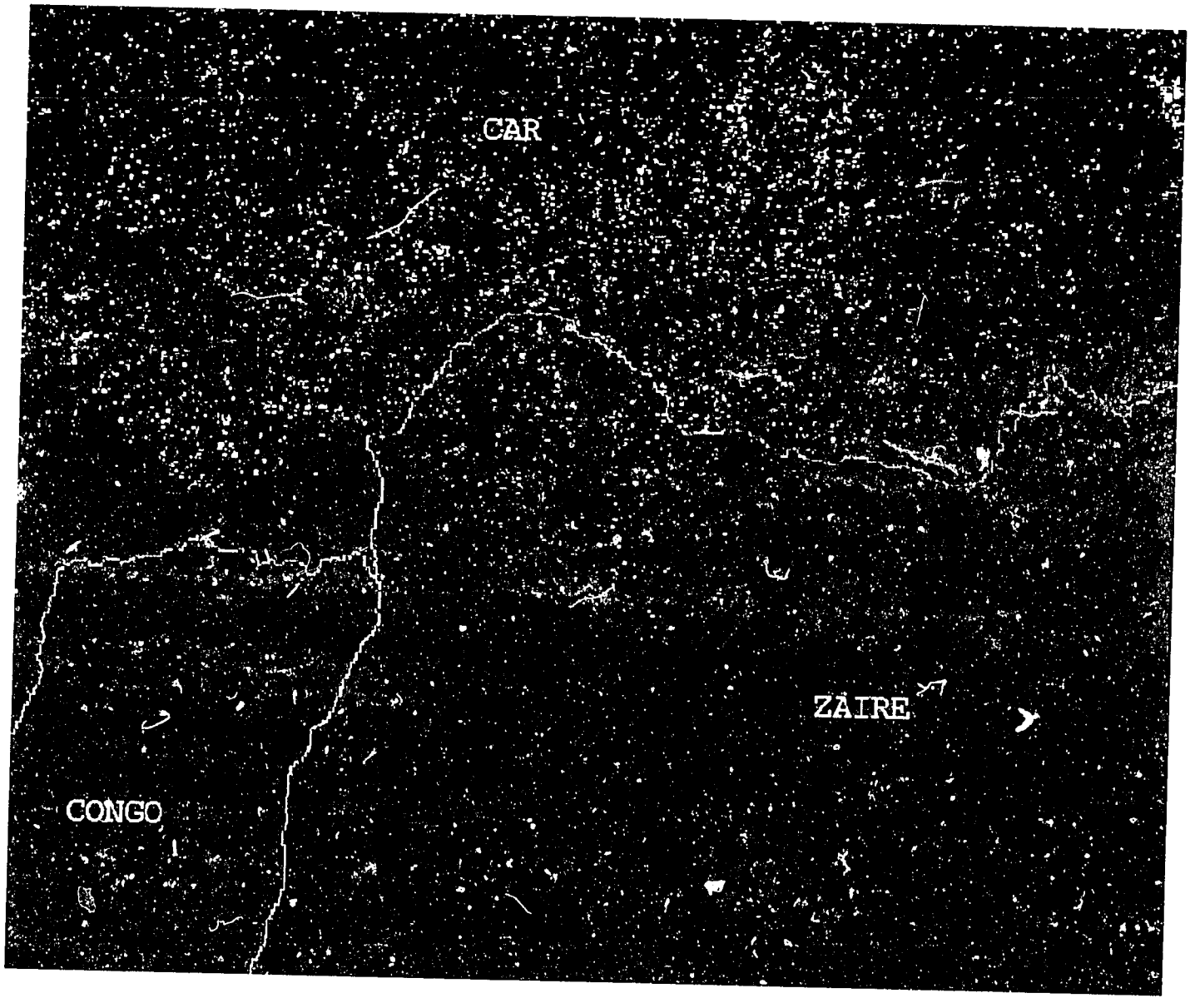
Green = Dense moist forest
Red = Degraded forest
Orange = Mixed forest/savanna
Yellow = Savanna
Blue = Rivers and lakes

Figure 4.6—Vegetation map of northern Zaire derived from 1989 NOAA-AVHRR data



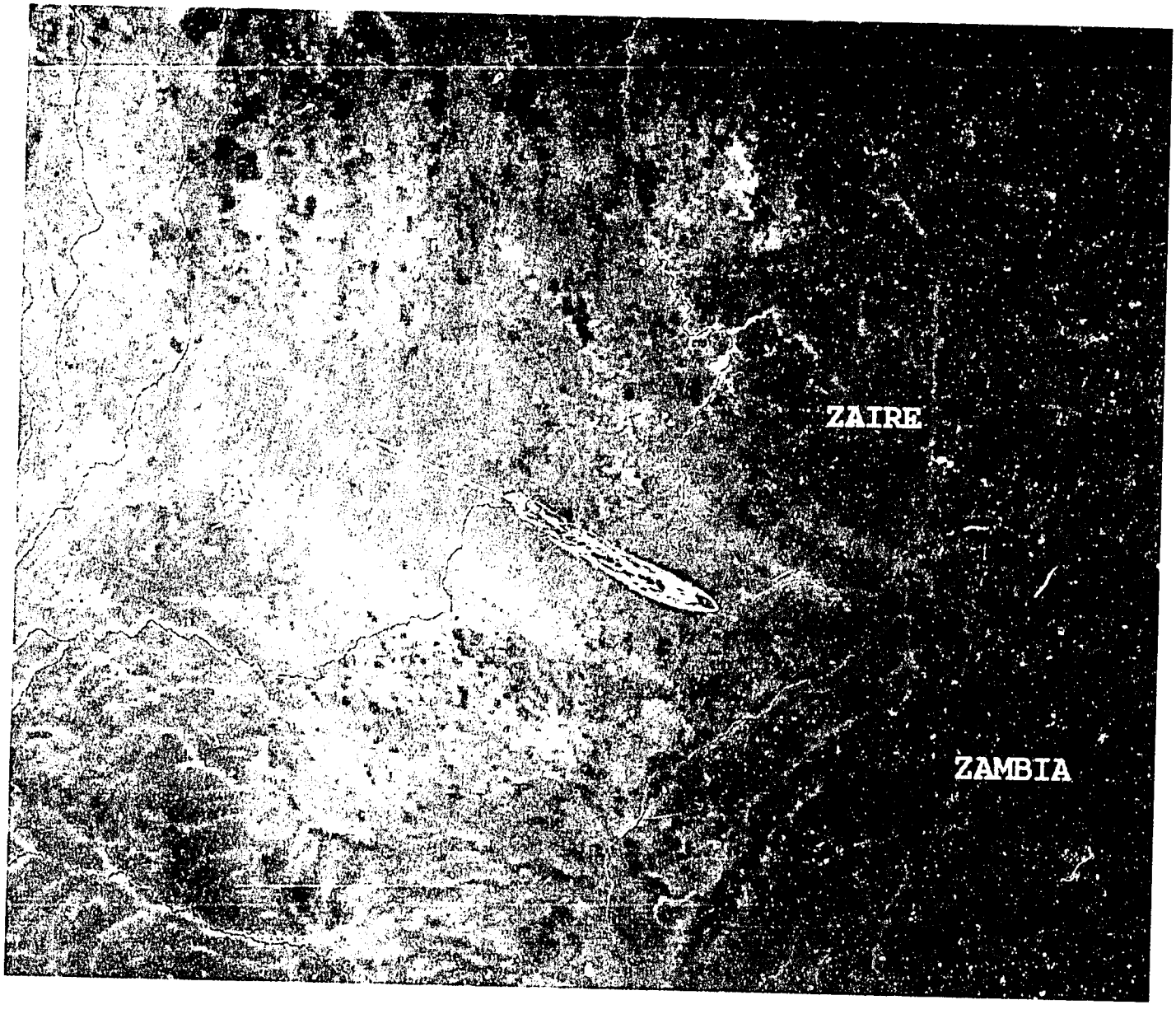
Green = Dense moist forest
Red = Degraded forest
Orange = Mixed forest/savanna
Yellow = Savanna
Blue = Rivers and lakes

Figure 4.7—A preliminary map of the distribution of active fires detected using the AVHRR sensors during the month of January 1989



White dots = Fires
White lines = Country borders
Gray lines = Rivers

Figure 4.8a—The areal distribution of fires and burn scars for the southern hemisphere for the early dry season (June 16, 1988).



Red dots = Fires
Green lines = Country borders
Blue lines = Rivers
Black patches = Burn scars

Figure 4.8b—The areal distribution of fires and burn scars for the southern hemisphere for the early dry season (August 7, 1988).

Red dots = Fires
Green lines = Country borders
Blue lines = Rivers
Black patches = Burn scars

Figure 4.9—Improved maps using Landsat imagery

A section of the image maps produced for this Study using Landsat TM imagery from 11 November 1990. This section (scale: 1/250,000) shows the border between Congo and Cameroon at the intersection of the Sangha and Ngoko Rivers. Villages, plantations, logging roads, and airstrips are all clearly visible.

Figure 4.10—Determining changes in vegetation using Landsat MSS imagery.

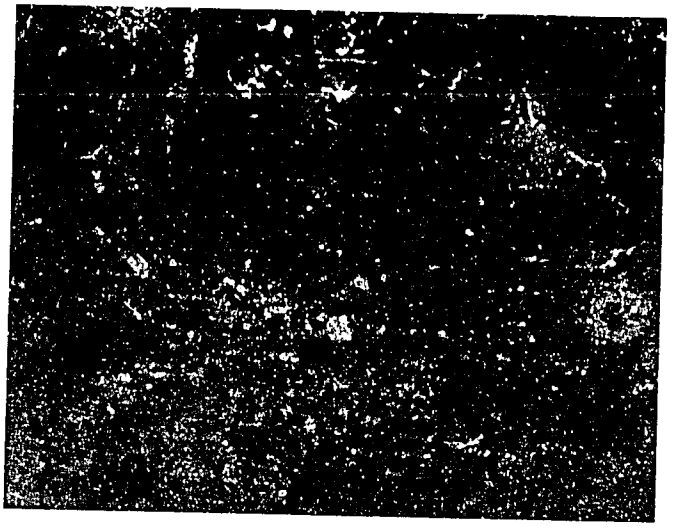
Classified Vegetation Types

No Change:

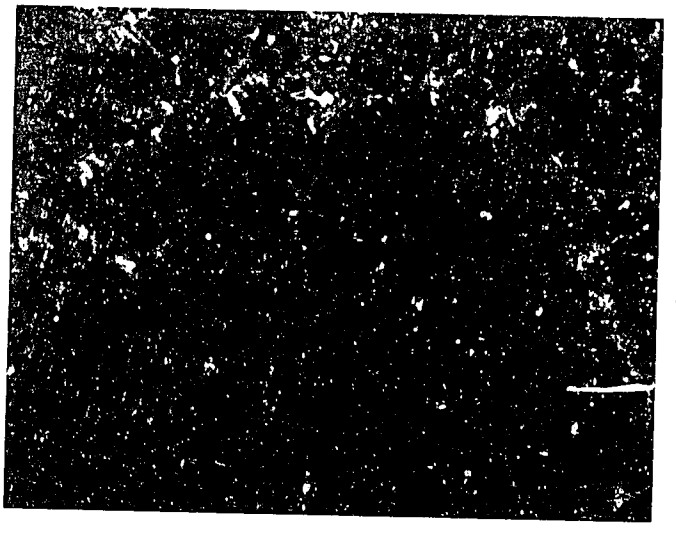
Green	=	Forest
Red	=	Disturbed/secondary forest
Black	=	Shadow/river
Tan	=	Bare soil/ savanna

Changed Vegetation:

Yellow	=	Clearing (disturbed forest to cleared forest)
Blue	=	Regrowth (cleared to vegetated land)

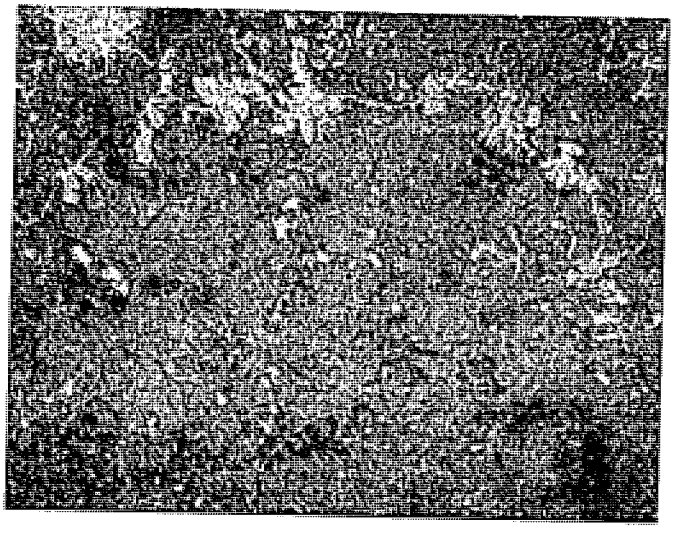


Landsat MSS image, 13 January 1976



Landsat MSS image, 16 January 1986

Change in vegetation between 1976 and 1986.



These three images from the change detection demonstration exercise illustrate the use of Landsat MSS imagery for determining changes in forest vegetation over time. The two Landsat images of the same site (the southern Ituri region in northeastern Zaire), acquired 10 years apart, were overlayed and processed to produce a change image with six classified vegetation types. The change image indicates changes in vegetation over the 10-year period. Much of the clearing and disturbance (yellow) has occurred along roads; much of the regrowth (blue) is believed to be abandoned coffee plantations.

Contact Addresses for more Information and Data Requests

AVHRR -National Oceanic and Atmospheric Administration, National Environment Satellite, data, and Information Service, National Climatic Data Center, Satellite Data Services Division
Princeton Executive Square, Room 100,
Washington, D.C. 20233
tel (301) 763-8400
fax (301) 763-8443

Landsat MSS and TM - Earth Observation Satellite Company
4300 Forses Boulevard
Lanham, Maryland 20706
tel (301) 552-0500
fax (301) 552-0507

SPOT XS and PAN - SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22091-4368
tel (703) 620-2200
fax (301) 648-1813

Soyuz Carta KFA-1000 and MK-4 -
Velon H. Minshew
Central Trading Systems
Satellite Imagery Division
611 Ryan Plaza Drive, Suite 700
Arlington, TX 76011
tel (817) 459-0423
fax (817) 459-0721

JERS-1
Mr. Yukio Haruyama
Director for Earth Observation Systems Program Officer
2-4-1, Hamamatsu-cho
Minato-ku, Toyky
JAPAN 105
fax 81-3-34323969

Almaz-Hughes STX Satellite Mapping Technologies,
4400 Forbes Boulevard
Lanham, MD 20706
tel (301) 794-5020
fax (301) 306-0963

V. CONCLUSIONS AND RECOMMENDATIONS

Deforestation is and will continue to be the major source of greenhouse gas emissions in central Africa, but the direct environmental impacts of deforestation, such as changes in rainfall patterns and decreases in soil fertility, are likely to be more immediate and more damaging over the short term than the indirect impacts that will eventually be brought about through global climate change. This is critical to the people of this region who depend upon the natural resource base for their basic survival and national economic stability. Better management of forest resources is vital, not only to reduce emissions over the long term, but to ensure the prospects for a secure economic and environmental future for the region. The fact that these forests remain relatively intact offers an important opportunity to promote and apply effective forest management strategies, thereby avoiding the social, economic, and environmental costs of forest loss and degradation that other developing nations have experienced.

In addition to deforestation, biomass burning, particularly in savanna ecosystems, is increasingly recognized as a significant continental source of greenhouse gas and particulate emissions. Further analysis throughout sub-Saharan Africa is essential for the development of comprehensive strategies for understanding and mitigating this contribution to global climate change from Africa, as well as instituting better resource management systems.

In both the forest and savanna regions, improved natural resource management options can be developed by increasing both scientists' and policy makers' understanding of the biological, physical, and human dynamics affecting these ecosystems. Research and mitigation activities must be coordinated within a comprehensive program in order to optimize benefits to both the local and global communities. This study found that the baseline scientific data (meteorological, hydrological, land-use change, forest composition and distribution, biomass densities, etc.) and the baseline socioeconomic data (demographics, energy supply and demand, land-use patterns, etc.) are inadequate. Additional data need to be collected and made available through improved information management systems to local and regional planners, environmental managers, and the climate change research community. These activities will contribute to both raising regional awareness of the significance of climate change, and developing in-country climate change research capabilities. These data should also be used to design, evaluate, and implement appropriate climate change mitigation policies for sub-Saharan Africa.

There is still a great deal of scientific and socioeconomic research needed, but a combination of action and analysis is recommended to better understand and address global climate change in central Africa. Enough is known about current land-use change in the region and it's potential impacts, to justify emissions mitigation activities in the form of improved resource management.

To be most effective, both research and mitigation activities should be carried out through collaboration between local governments, bilateral donors, NGO's, and the scientific and resource management communities in Africa, Canada, Europe and the U.S. Each institution's respective area of expertise (local knowledge, long-term field project continuity, scientific and technical expertise) would complement those of the others. All parties can both contribute to, and benefit from, a comprehensive collaborative program. Similarly, it is recommended that these implementing organizations collaborate with other international and development organizations that are supporting environmental monitoring within the region or are involved in climate change research, in order to avoid duplication of effort.

This study provided a baseline of information upon which to begin an analytical and action-oriented program. The following are the conclusions of the study and corresponding recommendations for increasing vital knowledge of the forest, savanna, and human land-use systems, and enhancing the capacity of African nations to mitigate both the causes and potential impacts of global climate change and resource degradation on the region. The conclusions and recommendations are organized into five categories: (1) the impacts of global climate change on the region, (2) greenhouse gas emissions from the region, (3) causes of land-use change in forest and savanna zones, (4) focussed information needs and appropriate data management, and (5) institutional capability for resource management.

Impacts of Global Climate Change

Global climate change is likely to have broad, damaging impacts on the environment and peoples of central Africa.

Without its forests, the region's resilience with respect to many of these impacts will be substantially reduced. In addition, biomass burning and unsustainable forest clearing have direct and negative local environmental consequences, including regional climatic change, loss of soil fertility, and elevated levels of tropospheric ozone, particulates, and acid rain. Perhaps the most striking potential regional consequence of deforestation stems from the fact that 75 to 95% of the rainfall in the region is recycled. Massive deforestation is likely to severely disrupt this important hydrological cycle.

Only very general predictions of the impacts of global climate change are possible at this time, because methods to accurately predict future greenhouse gas emissions are not yet available, and the models presently used to assess the magnitude, rate, and geographic distribution of potential future climatic change are gross in scale and differ dramatically in results. Nevertheless, scientists estimate that increasing temperatures, changes in precipitation patterns, and associated environmental changes such as sea level rise are likely to occur, and would cause ecological communities to shift and to change in composition. If rates of change are rapid enough, or if migration corridors are not available because of fragmentation or loss, individual species, as well as entire communities, may not be able to survive. This includes both natural as well as agricultural systems.

Peoples of developing countries are especially vulnerable to climate change because they are dependent upon natural resources for survival, and because they lack the technical and financial resources with which to adapt and respond to changes brought about by global climate change. Agriculture, food security, indigenous culture, social stability, energy supply and demand, human health, and foreign exchange earnings are all likely to be negatively impacted by global climate change.

The potential impacts of global climate change in central Africa can best be avoided by reducing greenhouse gas emissions worldwide, by maintaining forests, and by understanding and preparing for these impacts. Greater and more effective participation in international global climate change policy discussions, particularly the Intergovernmental Negotiating Committee (INC) and the Intergovernmental Panel on Climate Change (IPCC), will enable the central African countries to influence decisions that will determine future greenhouse gas emissions from all nations of the world. Increased participation of African scientists in international global change research will contribute to both national and global scientific understanding. African countries have historically been unable to fully participate in these international associations for a variety of reasons, including: insufficient information, insufficient communication among themselves and with other groups, limited human and financial resources, and institutional difficulties. Increasing in-country expertise, as well as addressing these other limitations, will enable central African countries to become more active participants in what is one of the most visible and important international policy discussions today.

In summary, reducing permanent deforestation rates through improved resource management would not only significantly decrease the region's contribution to the atmospheric accumulation of greenhouse gases (although admittedly, the contribution is small compared to emissions associated with industrial activities in the developed nations), it would also minimize local environmental degradation, thereby contributing significantly to sustainable development.

Recommendations:

- **Climate change should be given a higher profile in development planning and be treated as a primary concern by all development agencies and national governments.**

Climate change is closely linked to sustainable development and is, therefore, an important issue for African nations. Addressing climate change in sub-Saharan Africa is a challenge to develop sustainable and robust agricultural practices and natural resource uses.

- **It is important to promote the involvement of the central African countries in the international climate change arena, including the INC and the IPCC.**

Support should be provided to national policy makers and technical staff to attend national and regional workshops and conferences that focus on increasing capacities to estimate emissions impacts and response strategies. Wider dissemination of information, and scientific and policy exchanges should also take place. Improved scientific expertise will increase national capacity to actively participate in international climate change discussions, and perhaps influence subsequent international climate change policy decisions, thereby giving them a role in determining how activities in the rest of the world will affect their future.

- **Long-term impacts monitoring and modelling programs at field sites representing different ecosystems should be established.**

Activities to predict and monitor the impacts of global climate change and land-use change on natural and agricultural systems within the region should begin now at long-term (~30 year) monitoring sites representative of natural and anthropogenic ecosystems within the region. A program of conducting baseline measurements should be developed. These activities may best be accomplished in collaboration with NGO's that have established field sites within the region, or at revitalized national research institutions and field stations. The overall coordination of this work could be undertaken through a collaborative research program between in-country institutions and western university departments. In addition, a research program within the region should be developed that will lead to improved models of the relationship between tropical ecosystems and climatic variables.

Greenhouse Gas Emissions

Deforestation and biomass burning are the largest sources of greenhouse gas emissions in sub-Saharan Africa. Compared to the emissions contributed by fossil fuel use in industrialized nations, CO_2 releases from deforestation in central Africa account for a small fraction of the global total. The large remaining forested areas of the region, however, offer significant potential for greatly increased emissions of greenhouse gases if deforestation continues unchecked.

Although the existing land-use change, biomass density, soil carbon, and fire chemistry data for central Africa are inadequate for detailed and accurate assessments, rough estimates of current and potential future greenhouse gas emissions from central Africa can be made. Based on estimated clearing rates for the early 1980's, deforestation in central Africa releases 20 to 60 million metric tons of carbon annually. This is less than 1% of the estimated global CO_2 emissions from all sources in 1985, and about 4% of the global CO_2 released from deforestation. Clearing the remaining forests in central Africa would release approximately 35,000 x 10^6 tons C which is over six times the global release from fossil fuel

combustion in 1988[1]. If all of the clearing is accomplished by burning, methane, nitrous oxide, carbon monoxide, and oxides of nitrogen (CH_4, N_2O, CO, and NO_x, respectively) would be released as well. Combined, these emissions would be equivalent to about 48,000 x 10^6 tons carbon as CO_2.

Biomass burning was not discussed in detail in this study because, for central Africa, it is a small regional source of greenhouse gas emissions. However, biomass burning, particularly savanna burning, is one of the most significant sources of greenhouse gas emissions and particulate carbon from the African continent. Based on available information, sub-Saharan Africa is estimated to be responsible for over half of the global emissions of CH_4, N_2O, CO, NO_x and particulate carbon from savanna burning and burning associated with deforestation, although regional and global emission estimates are highly uncertain. The trace gas emissions from these activities in sub-Saharan Africa are equivalent to about 5% of the global emissions of CO_2 from fossil fuel combustion. Approximately 60% of the particulate carbon released in the tropics is due to biomass burning; the remainder is mostly due to natural emissions from vegetation. This particulate release may negate the trace gas contribution to global climate change to some degree since carbonaceous aerosols scatter and absorb incoming solar radiation.

A better understanding of central Africa's current and potential future greenhouse gas emissions is important to both the regional and global communities for a number of reasons. For the countries in the region, understanding the magnitude, location, and causes of clearing, as well as the potential for future emissions, is a critical first step in designing appropriate natural resource management approaches and tools. The forests of central Africa are an important economic resource that is grossly understudied.

Understanding the sources and magnitude of central African emissions is also necessary if these countries wish to be active and effective participants in the global climate change science and policy arena (e.g., the IPCC, the INC, and the International Global Biosphere Program (IGBP)). Decisions made within this arena will have long-lasting repercussions on all sectors and economic classes of the world.

Finally, a better understanding of central Africa's greenhouse gas emissions is important to the global community for both scientific and policy reasons. The scientific community (e.g., climate modelers, terrestrial ecosystem and global carbon modelers, and atmospheric modelers), as well as the community concerned with designing and implement-

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[1] This number represents an upper bound on potential CO_2 release from central Africa due to deforestation, and is highly uncertain. The number is based on estimates of the carbon in the remaining vegetation and the soils of the region, and assumes that all the aboveground vegetation is cleared, and that 20% of the below-ground carbon (soil and root carbon) is oxidized as a result of clearing. No accounting is made of potential regrowth and subsequent reclearing.

ing appropriate responses to potential global climate change, require improved and more extensive information.

Recommendation:

- **Improved biogeochemical and land-use data must be collected and analyzed in targeted forest and savanna areas of sub-Saharan Africa.**

In order to improve estimations of current and potential future greenhouse gas emissions from deforestation and savanna burning, improved, current biogeochemical and land-use data must be collected, particularly biomass and soil carbon densities, trace gas emission ratios for fires, vegetation composition and distribution, and rates of replanting and regrowth.

Field studies will be needed for improved estimates of biomass and soil carbon densities and trace gas emissions from fires. Field chemistry analyses related to biomass burning are important because of the continental significance of savanna burning as a land management tool, and as a source of greenhouse gas emissions. National forest inventory and monitoring programs (species composition and distribution, rates of clearing and degradation, rates of replanting and regrowth) are important sources of key data and should be supported. Improvement of existing vegetation maps should continue as they are important sources of historical information useful for land-use change analyses.

Causes of Land-Use Change in Forests and Savanna Zones

Permanent deforestation in central Africa according to existing information is primarily due to non-sustainable agriculture. Fuelwood collection and charcoal production around densely populated areas, as well as inappropriate logging practices, are also significant contributors to permanent change in forest cover. These activities do not take place in isolation. Rapid population growth, urban migration, unfavorable economic conditions, and inappropriate government policies are all driving forces.

It is also true, however, that the forests of central Africa have so far experienced much lower rates of clearing than other tropical forests. These forests represent a huge economic resource that will be utilized -- the challenge is to use them in such a way that carbon stocks are not depleted or degraded, thereby avoiding greenhouse gas emissions, permanent loss of biodiversity, and serious environmental degradation. Unlike West Africa, where inappropriate management practices have resulted in the loss or degradation of most of the forests, central Africa presents an ideal opportunity to promote and apply effective forest management strategies.

Biomass burning associated with land-use change (i.e., burning associated with forest clearing and savanna burning) is a relatively minor source of greenhouse gas emissions from central Africa, but is a significant source of emissions from the African continent. Savanna

burning accounts for over 80% of the burning associated with land-use change in Africa. Savannas are burned for a variety of reasons: to generate new vegetative growth for livestock, to flush game, and to construct fire breaks. Rates of burning are not believed to be increasing significantly, nor are they expected to in the future unless extensive areas of forest are converted to savanna. However, data on this activity are extremely sparse.

Improved understanding of the causes and the processes of deforestation and savanna burning in sub-Saharan Africa is necessary to develop improved management of resources and consequent mitigation of permanent forest loss and degradation, thereby reducing greenhouse gas emissions and environmental degradation. Sustainable management of these resources will lead to increased economic returns, as well as increased ability to withstand the potential impacts of global climate change.

Recommendations:

- **In-country analyses of the causes and dynamics of deforestation and savanna burning are critical in order to better understand and predict the present and most likely future patterns.**

A combination of remote sensing and field surveys should be used to identify areas of rapid and permanent change due to human land use, and to develop appropriate management strategies. Critical areas may be found where several factors such as infrastructure development and rapidly increasing population and migration intersect. Past and present clearing and degradation can be identified with remote sensing techniques. Historical data, especially maps and aerial photos, can be used to extrapolate the clearing rates derived from remote sensing data further back in time.

Future trends require in-country analysis and modelling of factors such as current and projected demographic and economic statistics, current and projected energy supply and demand, and current and planned infrastructure development. In-country analyses of the causes of deforestation and savanna burning are required. Further analysis of demographic and economic statistics, government policies, land tenure systems and other socioeconomic factors that contribute to land-use change is also recommended. An assessment of where and why savanna burning takes place throughout the continent is needed to identify areas in sub-Saharan Africa that require more detailed focus.

- **Research and promote sustainable agriculture techniques, improved forest management techniques, more efficient biomass energy use, and alternative savanna management practices.**

In-country analyses of techniques to slow permanent deforestation, increase reforestation, and sustainably use forest resources are required in order to improve forest management. Activities that mitigate forest loss and degradation, and simultaneously increase economic returns, should begin with pilot management strategies and activities. Improved sustainable

agricultural techniques need to be researched and promoted in and around forested areas. Timber exploitation should be better managed through research and testing of natural forest management techniques, examination and modification of existing policies to reduce waste and improve efficiency, and improvement of inventories and institutional capabilities. Biomass energy needs should be assessed, particularly around growing urban areas, with a view toward practices and policies that will increase efficiency. Existing energy supply and demand surveys should be analyzed and used both to develop strategies for improved efficiency and to more effectively plan for future energy demand. The feasibility and appropriateness of reforestation and tree planting programs should be assessed, especially through evaluation of previous programs.

In-country analyses of alternative savanna management practices are also required. Different burning practices can lead to either an improvement in agricultural productivity, or environmental degradation and a decline in productivity, both of which have implications for human habitability and sustainability of land use.

Focussed Information Needs and Appropriate Data Management

Better quality, more current, and well-managed information will provide central African countries with one of the tools necessary for improved resource management.

The national and international scientific and policy development communities need improved data and data management in order to address more effectively the challenge of mitigating climate change and retaining the integrity of the natural system. Data relevant to climate change science and natural resource management are often inadequate, of poor quality, or nonexistent. Some of these data gaps can be filled by satellite remote sensing analysis, which offers unique potential for developing accurate, current, regional land-use data bases (areas by vegetation type, areas burned annually, and rates of clearing and degradation). A wealth of historical data which are poorly developed, underused, and difficult to access also exists. If reworked and made accessible, these data could also fill some of the existing gaps. All data collection should be focussed, and continually evaluated in order to avoid inefficient use of resources. GIS is an effective tool for spatial management and analysis of data, and because of its standardized format can also be used to promote the sharing of data.

Sources of data vary widely in the region. A broad network of underutilized agricultural and biological research stations exists, which, if revitalized, could provide a much-needed operational base for the collection, assimilation, and management of data. There are also a variety of international NGO's and scientists already working in the region on various research and conservation activities that could both contribute to and benefit from improved regional data management. The NGO's are also an important source of local knowledge and long-term project continuity in the field, which could prove invaluable to long-term monitoring efforts.

Data development activities should involve both outside experts as well as national scientists in order to enhance national scientific expertise. Data development will also provide the international scientific and policy communities with improved information so that appropriate and equitable policies can be enacted.

Recommendations:

- **Conduct an in-depth study and evaluation of existing information systems relevant to central Africa and global climate change, and begin coordinated GIS pilot projects.**

GIS projects should continue to be introduced into the region to assist in the inventory, monitoring, modelling, and management of socioeconomic and biogeochemical data. First, however, an in-depth study of existing information systems should be conducted in order to identify potential technical and logistical problems and to avoid duplication of effort. GIS activities should be conducted across a range of scales appropriate for climate change and resource management studies; therefore, it is recommended that a series of autonomous, but coordinated, pilot projects be undertaken initially.

- **Compile and make accessible relevant data in Europe, Canada, and sub-Saharan African countries.**

Better use should be made of the historical data that exist in Europe, Canada, and Africa, as well as data generated by development projects and international agencies that are not readily accessible. These data should be collected, assessed, and compiled into easily accessible data bases for dissemination to local, national, and international communities.

Institutional Capabilities

The region's present institutional capacity is inadequate to address climate change at national, regional, and international levels. The long temporal scale of global climate change necessitates a long-term commitment at all institutional levels to the understanding and mitigation of both contributions to, and impacts of, global climate change.

National ministries and organizations responsible for forest protection and production, agricultural research and extension, and climate change research and monitoring require additional personnel, institutional strengthening, and technical and financial support. Regional authorities need to be established to foster collaboration and coordination of national activities (e.g., data gathering and management, implementation of action plans and other initiatives, policy studies) and to strengthen the region's involvement in the international climate change arena.

Coordination between international donors concerned with natural resource and socioeconomic data collection and management is essential. This will avoid duplication of

efforts and conflicts among programs, and foster collaboration and improved efficiency. NGO's may be able to coordinate activities among donors, national and foreign researchers, and other NGO's.

Recommendations:

- **Support and coordinate efforts aimed at improving the capabilities, both institutional and logistical, of those national ministries and organizations responsible for forest management, agricultural research and extension, and climate change research and monitoring.**

The region's institutional climate change and natural resource management capabilities are weak to non-existent. This is particularly true for national ministries and organizations responsible for forest protection and production, agricultural research and extension, and climate change research and monitoring. Support should be provided through general institutional strengthening and training of personnel. This will contribute to improved national capability in natural resource management, and more effective involvement in international climate change policy discussions.

- **Establish regional coordinating authorities that will address needs and implement climate change activities.**

In order to address the regional needs of climate change research and natural resource management, and assure that the process is efficient and coordinated, regional coordinating authorities should be established. These authorities would address needs and implement activities in data gathering, management, and dissemination; regional action planning; sponsorship and coordination of regional representation at international fora; and coordination of regional donors in these and other global climate change activities.

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