Central Africa

Global Climate Change and Development

Synopsis

Biodiversity Support Program

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A more detailed summary of the technical papers, entitled *Central Africa: Global Climate Change and Development—Overview Report*, was also produced. The *Technical Reports* and the *Overview Report* are available from:

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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

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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 socioeconomic 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 socioeconomic 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 *Synopsis* reviews the main findings of these technical papers.

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.[1] 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 change. 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.[2] 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 the 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 of 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 (Figure 1). 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 the 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.

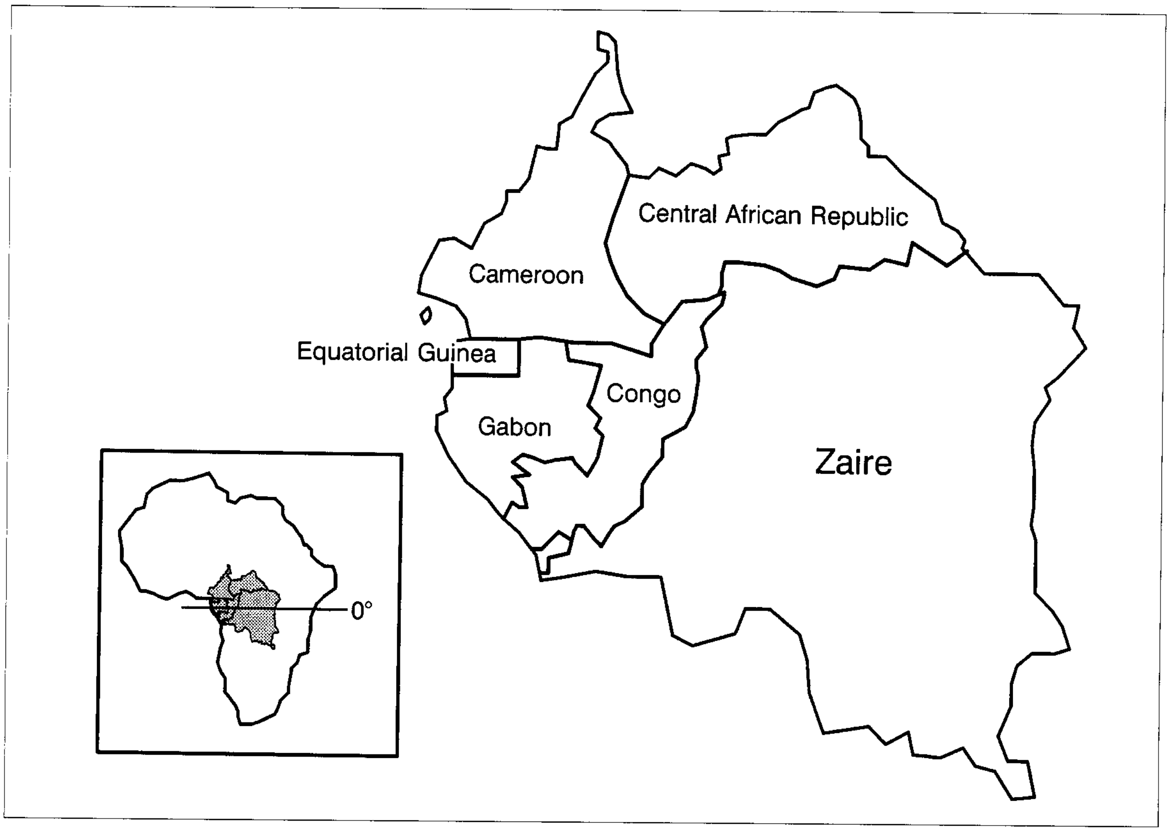
The main findings of the Study are presented in this document. The current state of central Africa's forests, greenhouse gas emissions from deforestation and biomass burning in the region, and the potential impacts of global climate change on the region are discussed in the next section. This is followed 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 brief review of conclusions and recommendations completes this report.

THE FORESTS OF CENTRAL AFRICA

Estimates of Area and Rates of Change

Central Africa's abundant rainfall, year-round high inputs of solar energy, and generally favorable geologic and topographic features have resulted in the formation of the world's second

Figure 1. The nations of central Africa.



largest contiguous expanse of moist tropical forest. This immense biome represents about 15 percent of the world's remaining tropical forests.[3] Contained within its boundaries are the entire countries of Gabon, Equatorial Guinea, and the Congo, most of Cameroon and Zaire, and a small part of the Central African Republic.

Accurate statistics on forest areas, extent and distribution of vegetation types, and clearing and reforestation rates are sorely lacking. Moreover, methodological differences among the few existing studies preclude meaningful comparisons. For example, the United Nations Food and Agriculture Organization (FAO), the most frequently cited source, estimates combined "closed and open broadleaved forest" areas in 1980 at 2.8 million square kilometers[4] (Table 1). On the other hand, a recent study using remote sensing imagery estimates the 1986 combined "forest" and "woodland" areas at 3.17 million square kilometers.[5]

Estimates of rates of deforestation also vary widely. The FAO estimates that 5,730 square kilometers were cleared annually in central Africa between 1981 and 1985[6] (Table 2). Myers estimates that annual clearing rates in Cameroon, Congo, Gabon, and Zaire combined increased from 4,200 square kilometers in 1980 to 7,300 square kilometers in 1989.[7] Both studies indicate that the greatest area cleared each year is in Zaire, which contains over 60 percent of the region's forest area. Cameroon, however, is losing the largest proportion of its forest each year.

Despite the lack of accurate statistics, it is clear that the forests of central Africa have experienced relatively low rates of clearing overall compared to other tropical forests. Approximately 0.2 percent of central Africa's closed forests are cleared annually, while in West Africa, over 4 percent of the closed forest area is lost each year. In Côte d'Ivoire, which has already lost over half of its forest area,[8] 6.5 percent is currently lost annually.[9]

Because central Africa contains such a large forest resource, reforestation efforts have been minimal. Also, these efforts have consisted primarily of commercial plantation activities rather than reforestation of logged-over or degraded areas. FAO estimates that approximately 900 square kilometers of tree plantations have been established in central Africa, with varying degrees of success.[10] Many plantations in Cameroon, Gabon, and Zaire have failed due to lack of maintenance and poor management.[11]

Table 1: Forest areas—1980 (10^3 km^2).

	Forest Type		
Country	**Closed**	**Open**	**Total**
Cameroon	179.2	77.0	256.2
CAR	35.9	323.0	358.9
Congo	213.4	—	213.4
Eq.Guinea	13.0	—	13.0
Gabon	205.0	0.8	205.8
Zaire	1056.5	718.4	1774.9
Total	1703.0	1119.2	2822.2

Note: Closed forests, as defined by FAO, have a high proportion of crown cover, and do not have a continuous dense grass layer. Open forests have a continuous grass cover and more than 10 percent crown cover.

Source: FAO (Food and Agriculture Organization of the United Nations), 1988, *An Interim Report on the State of Forest Resources in the Developing Countries*, FAO, Rome.

Carbon Storage and Greenhouse Gas Emissions

While fossil fuel combustion is the primary source of CO_2 emissions globally, in central Africa, deforestation is by far the largest source

Table 2: Annual rates of deforestation—1981–1985 (areas in 10^3 km^2).

	Closed + Open Forest	
Country	**Area**	**Percent**
Cameroon	1.10	0.4
CAR	0.55	0.2
Congo	0.22	0.1
Eq.Guinea	0.03	0.2
Gabon	0.15	0.1
Zaire	3.68	0.2
Total	5.73	0.2

Source: FAO (Food and Agriculture Organization of the United Nations), 1988, *An Interim Report on the State of Forest Resources in the Developing Countries*, FAO, Rome.

GREENHOUSE GAS EMISSIONS

The primary greenhouse gases that are accumulating in the atmosphere due to human activities are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs). Carbon monoxide (CO), non-methane hydrocarbons (NMHC), and oxides of nitrogen (NO_x), although not, strictly speaking, "greenhouse gases," contribute indirectly to global climate change through chemical reactions in the atmosphere. Although all of these gases except CFCs have natural sources, it is the human-caused, or anthropogenic, emissions that contribute to global climate change.

A large number and wide variety of human activities result in the release of greenhouse gases. Carbon dioxide emissions, which currently account for over half of the "greenhouse effect," result from fossil fuel combustion, deforestation, and cement production. Anthropogenic CH_4 emissions result from agricultural production (wetland rice cultivation and raising of livestock), biomass burning (burning associated with deforestation, savanna burning, fuelwood use, and agricultural waste burning), coal mining, natural gas leakage and venting, and landfills. The primary anthropogenic sources of N_2O are nitrogen fertilizers, land clearing, fossil fuel combustion, and biomass burning. CFCs are a class of industrial chemicals that are released through their production and use. Fossil fuel combustion and biomass burning are the primary anthropogenic sources of CO, NMHC, and NO_x.

In developed countries, the principal sources of greenhouse gas emissions are industrial activities, especially fossil fuel combustion and the use of CFCs. In central Africa, emissions result primarily from deforestation and biomass burning, although the magnitude of emissions released from biomass burning is highly uncertain and has not been quantified for individual countries.

When forests are cleared, the carbon contained in the vegetation and some of the carbon in the soils on that cleared land is released to the atmosphere as CO_2. Carbon dioxide emissions from deforestation in the tropics result from a combination of burning and decay. Clearing by burning results in immediate emissions of CO_2. When vegetation is left on the ground to decay, the release occurs over months to years. If the forest is allowed to regrow, the carbon that has been released is reabsorbed by the growing vegetation, and over time, CO_2 uptake will equal CO_2 emissions. If forests are cleared or degraded permanently, however, or if forests are not allowed to regrow to their original biomass density (organic matter/unit area), net CO_2 emissions occur.

Burning associated with deforestation as well as other forms of biomass burning (savanna burning, fuelwood use, and agricultural waste burning), releases other trace gases in addition to CO_2, including CH_4, N_2O, CO, NO_x, and NMHC. Unlike CO_2 emissions from land clearing, which may not be a net release to the atmosphere, emissions of these other gases are net transfers from the biosphere to the atmosphere. Savanna burning and agricultural waste burning, however, are not a net source of CO_2 emissions because the carbon released through burning reaccumulates in vegetation during the next growth cycle. Fuelwood use may or may not release net CO_2 emissions, depending on the sustainability of the activity.

Biomass burning also releases particulate carbon, which counteracts the warming effects of trace gas emissions. The degree to which particulate carbon emissions from biomass burning negates the trace gas contribution to global climate change, however, has yet to be determined.

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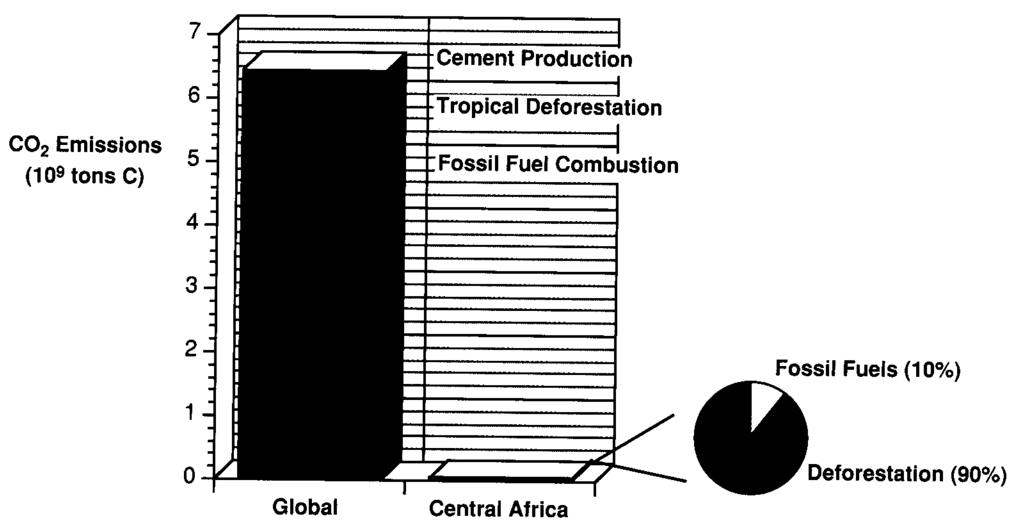
of CO_2, accounting for about 90 percent of the annual release from the region[12] (Figure 2).

Based on estimated clearing rates for the early 1980s, deforestation in central Africa releases 20–60 million metric tons of carbon as CO_2 into the atmosphere each year, although estimates vary significantly among studies (Table 3).[13] Given uncertainties in rates of clearing and regeneration, biomass densities, and soil carbon contents and loss rates, these estimates must be treated with caution.

Current CO_2 emissions from deforestation in central Africa account for about 4 percent of the release from deforestation in all the tropics, or less than 1 percent of global CO_2 emissions from all sources.[14] The vegetation and soils of the remaining forests of central Africa, however, contain a vast store of carbon that will be released to the atmosphere if clearing continues. This forest carbon "inventory" is about 1,000 times greater than current CO_2 emissions from the region[15] (Figure 3), or about 10 times greater than current, annual, global emissions of CO_2 caused by burning fossil fuels. Clearing rates and associated emissions in central Africa are believed to be increasing at present, and given the current demographic and economic dynamics of the region, are likely to continue to increase.

Figure 2: Central Africa's contribution to global CO_2 emissions.



Carbon dioxide emissions from central Africa account for less than 1 percent of global CO_2 emissions from all sources. Approximately 90 percent of the CO_2 emitted from central Africa results from deforestation.

Sources: See endnote #12.

Table 3: Estimates of annual CO_2 emissions—early 1980s (10^6 tons C/year).

Country	Houghton *et al.*	Graham *et al.*	Hall and Uhlig
Cameroon	15.6	7.3	3.63
CAR	3.6	1.9	(2.69)
Congo	3.4	2.0	0.14
Eq.Guinea	0.3	0.3	(0.75)
Gabon	2.2	1.6	(0.30)
Zaire	35.0	33.4	19.87
Total	60.1	46.5	19.90

Note: ( ) = uptake due to net regrowth.

Source: See endnote #13.

Although this study focused on deforestation in central Africa and associated CO_2 emissions, the importance of biomass burning as a continental source of other greenhouse gas emissions was recognized. Biomass burning is a significant global source of a variety of gases (Table 4). Although estimates are highly uncertain, sub-Saharan Africa is estimated to release over half of the global emissions of these gases that result from burning.[16] Savanna burning, while not a source of CO_2, is by far the most important of the three types of burning activities in Africa, responsible for over 85 percent of the biomass burned annually on the continent.[17]

Table 4: Percentages of global anthropogenic emissions due to biomass burning.

Trace Gas	% Contribution
Carbon Monoxide (CO)	11–36
Methane (CH_4)	3–13
Oxides of Nitrogen (NO_x)	7–20
Nitrous Oxide (N_2O)	4–15
Non–Methane Hydrocarbons (NMHC)	15–52
Particulate Carbon	40–50

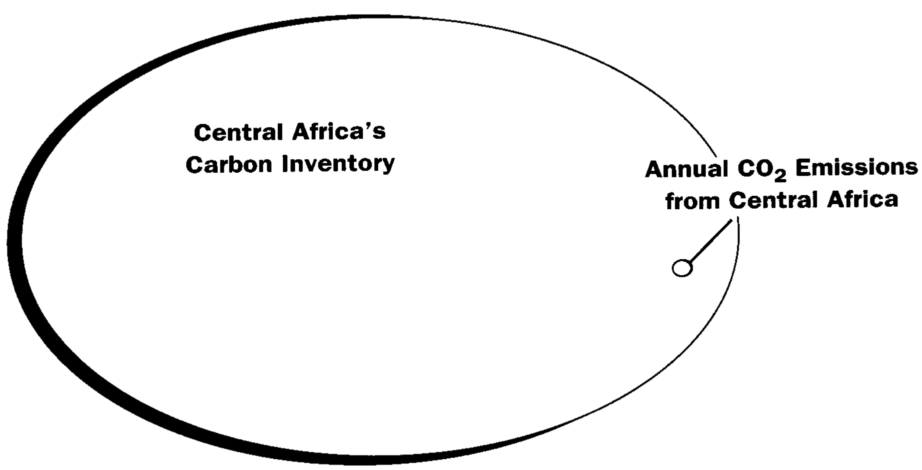
Sources: See endnote #21.

Impacts of Global Climate Change

If emissions of greenhouse gases continue at present rates, the average global temperature of the Earth is expected to increase about 1°C above the present value by 2025 and 3°C before the end of the next century.[18] The greatest rates of temperature increase will occur at high latitudes. A mean increase in precipitation in the tropics is expected to occur in association with this warming, although both precipitation increases and decreases are anticipated.

Because the climate models used to assess the magnitude, rate, and geographic distribution of future climatic change are gross in scale and differ in results, only very general predictions of the impacts of global climate change on central Africa are possible. Both increases and

Figure 3: Central Africa's carbon inventory versus annual emissions.



The amount of carbon contained in the vegetation and soils of central Africa is about 1,000 times greater than current annual emissions of CO_2 from the region.

Sources: See endnote #15.

decreases in precipitation and soil moisture are expected for central Africa, and the simulated patterns of change within the region are widely different according to each climate model. Nevertheless, it is clear that the ability of the region to withstand the impacts of future climate change will be compromised if the forests continue to be degraded and destroyed.

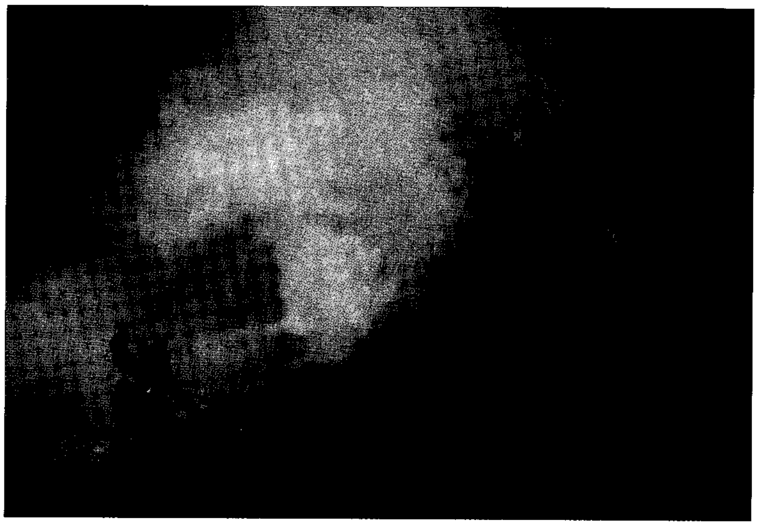
Of more immediate importance to the region, however, are the direct environmental impacts of continued deforestation and biomass burning. Deforestation alters soil moisture, runoff, evaporation, and soil surface temperature, all of which affect climate at the local scale. Forest destruction and degradation also results in loss of valuable biological diversity and disruption of associated ecological processes. Biomass burning contributes to air pollution and acid rain. Perhaps the most striking potential regional consequence of deforestation stems from the fact that 75 to 95 percent of the rainfall in central Africa is recycled.[19] In comparison, only about 50 percent of the precipitation in the Amazon Basin is generated within the region itself.[20] Massive deforestation in central Africa may disrupt its hydrologic cycle and prevent reestablishment of vegetation.

HUMAN INTERACTION WITH THE FORESTS

Land Use and Its Impact on the Forest

Although overall rates of forest clearing are relatively low in central Africa, localized areas are experiencing extensive damage or loss as a result of a variety of activities. Agricultural clearing, mining, and road-building permanently remove tree cover; over-logging and intensive fuelwood collection degrade forest areas, damage remaining trees, and leave areas vulnerable to soil erosion; and seasonal burning to prepare fields for cultivation and grazing, or to flush wild game or control pests, degrades forest edges and prevents regeneration in recently opened areas. The clearing, burning, and conversion of forest areas are directly and indirectly associated with several key factors, including rapid population growth and demographic shifts, inappropriate macro-economic policies, economic downturns, technical shortcomings that result in waste and inefficiency, and weak management and administrative capacities.

The root causes of deforestation are readily discernible. Annual population growth rates of 2.4 to 3.5 percent, combined with insufficient financial, technical, and institutional capacity for more productive land use, result in increasing requirements for land and forest resources to meet food, energy, and building material needs. Hardest hit are those forests most accessible to urban populations that are growing at rates greater than national averages.



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If clearing rates continue unabated—or worse, accelerate—central Africa might find itself facing the same unfortunate consequences of extensive deforestation that plague West Africa. If deforestation on this scale occurs, central Africa will not only become a globally significant source of CO_2 emissions, but will be much more vulnerable to the potential negative impacts of global climate change.

Agricultural Clearing

Clearing for agricultural purposes constitutes the largest source of deforestation in central Africa. The centuries-old practice by indigenous farmers of shifting cultivation, however, is not an inherently destructive practice *per se.* In fact, it has proven to be a sustainable way of utilizing forest resources, not only in central Africa, but throughout the world.[22] Environmental degradation results when demographic pressures, poorly planned infrastructure projects, and inequitable land tenure regimes undermine traditional shifting agricultural systems, or when migrants or settlers from other regions introduce agricultural practices that are unsuited to local conditions.

As it has been for centuries, the vast majority of the people of central Africa are directly dependent upon the productivity of the land for their food and basic sustenance. Increasing populations are putting greater pressure on this valuable natural resource. Many farmers have no choice but to use land unsustainably in order to survive. Shortened fallow periods lead to reduced agricultural productivity as soils no longer have time to recover through revegetation and pest cycles transcend short fallow periods.

Faced with these diminishing returns, many farmers choose simply to relocate to areas that have been opened up by logging or infrastructure development. The result is an agricultural frontier that advances at the expense of a receding forest. In the Kivu region of eastern Zaire, for example, deteriorating agricultural conditions and a steady stream of refugees from neighboring Burundi and Rwanda have caused people to use a new road through the forest to establish farms in previously inaccessible areas.

Several other agriculture-related factors also threaten central Africa's forests. Commercial hunting in the more accessible areas reduces the supply of bushmeat, an important component of the subsistence diet, forcing farmers to move farther into the forest to ensure an adequate meat supply. Lack of secure land tenure inhibits farmers from making permanent improvements to the land. Finally, poor or non-existent agricultural extension services in most areas make it difficult for farmers to optimize the use of their resources.

Energy Resources and Needs

The most important energy resource in central Africa continues to be biomass, primarily fuelwood. Even when seasonally inundated or inaccessible areas are factored in, the potential energy from central Africa's biomass resources (based on an estimate of annual sustainable yield) exceeds the potential energy from its considerable hydroelectric resources. Biomass accounts for the largest share of consumed energy, most of which is household consumption, especially in the form of fuelwood for cooking.

Growing populations, especially in urban areas where the supply of wood is low and harvesting practices are unsustainable, put increasing pressure on nearby forest areas, especially for fuelwood and agricultural land. In the larger metropolitan areas, such as Kinshasa, Brazzaville, Lubumbashi, and Yaoundé, this pressure has resulted in the formation of distinct "urban halos", concentric patterns of deforestation radiating outward as far as 150 kilometers from city centers[23] (Figure 4).

Commercial Logging

Even though it ranks behind agricultural clearing and biomass energy consumption as a source of greenhouse gas emissions, the commercial timber industry tends to be the most publicized agent of deforestation in central Africa. Despite the vast extent of central African forests and their immense capacity for natural renewal, existing commercial 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 this ongoing and accelerating threat. In addition, logging roads open forests to people who establish farms in previously inaccessible areas.

Commercial logging in central Africa is dominated by large, foreign operators primarily interested in short-term gain. In general, loggers tend to 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 typically engages in the wasteful practice known as "high-grading": taking only the best wood, from the top of the buttress to just below the first branches. The rest of the tree is left on the forest floor.

Pressure to generate foreign export revenues has caused several central African nations to actively promote increased exploitation of forest resources without instituting regulations to monitor logging practices. The result is often unsustainable harvesting of commercial timber.

Infrastructure

Infrastructure development, primarily road building, can have a significant effect on forests by opening them to a host of other economic activities. High unemployment and stagnant national economies are driving increasing numbers of people into previously forested areas to seek livelihoods and sustenance. Infrastructure projects are often the catalysts that set this pattern in motion.

Mitigation Efforts

There is little evidence that reforestation activities have had any significant success in central Africa. This is not to say that tree planting should be abandoned, but that these efforts must be targeted more appropriately (e.g., peri-urban reforestation near good transportation infrastructure, and small-scale agroforestry initiatives rather than large-scale plantations), and must include adequate mechanisms for management. Nevertheless, efforts to mitigate green-

Figure 4: The "urban halo" around Lubumbashi, Zaire.

© CSIR

This Landsat image of Lubumbashi, taken during the dry season, illustrates the "urban halo" of clearing and agricultural encroachment that extends out from the city center into the surrounding forest.

White	=	**Bare soils and city center**
Pink	=	**Bare and rocky soils and patchy vegetation**
Dark Pink	=	**Recent burns**
Yellow-Green	=	**Land cleared for agriculture and fallows**
Dark Green	=	**Forest vegetation**

(Color composite—Landsat MSS (5,7,4) of 14 June 1985, scale: 1/300,000. Processing—M.F. Massart, Belgian Scientific Policy Planning Services, Université Catholique de Louvain, Belgium.)

Mauri Rautkari/World Wildlife Fund

original hunter-gatherers, who secured what they needed from the forest and traded the surplus to nearby farmers. During the colonial era, European landlords appropriated the animal, mineral, and vegetable wealth of the forests to supply consumer demands back home. The region as a whole became a major supplier of timber, coffee, cocoa, and palm oil. Specific countries also became important sources of particular minerals: Zaire for copper and cobalt, Gabon for manganese, and the Central African Republic for industrial diamonds.

house gas emissions will need to focus more on controlling the rate and pattern of loss of the remaining forest rather than planting new trees; in other words, on improved management of the region's existing natural resources. Better resource management of the existing forest will not only reduce emissions, but will also avoid other, more immediate, deleterious environmental consequences of deforestation and will help maintain this valuable economic resource.

A high priority should be assigned to increasing agricultural productivity through such means as pricing policies, equitable land tenure systems, better transportation and storage facilities, and training and extension efforts by governments and nongovernmental organizations. If current trends of forest loss and conversion are to be reversed, more emphasis will have to be placed on the agricultural sector as a principal engine for economic growth.

POLITICAL AND ECONOMIC FACTORS

Economic Profile

Extraction of natural resources from the vast forest storehouse has long been the hallmark of central African commercial economies. This pattern began at modest levels with the

Worldwide economic growth in the 1960s and 1970s enabled the newly independent African nations 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 1970s and 1980s. During this period, petroleum became the most important regional export, its value often dwarfing that of traditional export earners, which in the haste to pursue the oil boom, were frequently deprived of essential reinvestment.

The collapse of world petroleum prices in the 1980s was the first in a series of economic reversals that brought increasing hardship to the region. Global slumps in prices of agricultural and industrial raw materials and increased competition from other regions followed. Faced with drastically reduced export revenues, all six central African nations were compelled to undergo economic stabilization and structural adjustment programs in the mid-1980s. The global economic slowdown of recent years has only prolonged the painful readjustment process.

Faced with substantial revenue shortfalls and unrelenting debt payments on one hand and increasing populations on the other, it is not surprising that all of the countries of central

Africa except Equatorial Guinea are focusing on timber extraction in spite of flat world prices and soft markets for commercial hardwoods. The sheer expanse of the region's forests makes them an obvious choice for government planners anxious to offset declining export revenues. 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 the countries' limited capacity to cope with deteriorating terms of international trade.

Political Instability

Compounding these economic problems are debilitating political uncertainties. Until recently, national political power in most of the six countries was resistant to domestic pressures for change: entrenched leaders clung tenaciously to power they often acquired through bloody coups d'état or divisive civil wars. The combined effects of continued economic deterioration and political repression, however, have begun to destabilize governments in the region.

Frustrated by their continued disenfranchisement, rival groups have moved aggressively to press for both political reforms and economic liberalizations. Particularly unstable situations have developed in Zaire, where civil unrest has jeopardized Mobutu Sese Seku's more than 25-year rule, and Cameroon, where a major general strike beginning in 1991 has brought one of the region's healthiest economies to a virtual standstill. What impacts these and lesser movements in the other countries may have on the economic well-being of central African nations, and particularly on their forest resources, are yet to be determined.

Institutional Constraints

While central Africa has yet to experience environmental degradation of the magnitude found in other tropical regions, the trends described here suggest that the region's ecological challenges are growing rapidly. National governments are struggling to develop and sustain the institutional capacities of their ministries that deal with forestry, agriculture, and the environment. Given the diminished financial and institutional capacity of the six countries, substantial external support will probably be required to adequately address natural resource planning and management issues.

African countries have historically been unable to participate fully in the global climate change science and policy arena (e.g., the Intergovernmental Panel on Climate Change and the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change). This is for a variety of reasons, including insufficient information, poor communication among themselves and with other groups, limited human and financial resources, and weak institutional support. Decisions made within this arena will have long-lasting repercussions over all sectors and economic classes of the world. Increasing in-country expertise, as well as addressing these other limitations, will enable central African countries to become more effective and active participants in what is one of the most visible and important international policy discussions today.

IMPROVED INFORMATION AND INFORMATION MANAGEMENT

As discussed above, uncertainties surrounding the extent and nature of current forest cover and the rate of transformation preclude an accurate assessment of regional greenhouse gas emissions. Satellite remote sensing and Geographic Information Systems (GIS's), relatively new techniques for primary data acquisition, management, and analysis, offer considerable potential for improving existing data bases as well as generating new information. Higher quality and new information, and improved information management, will not only increase the region's climate change research capability, but will also contribute to the region's ability to optimally manage its resources, from both an economic and an environmental perspective.

Remote Sensing

Although the six countries of central Africa are in various stages of development in the use of satellite remote sensing technology, there is a unanimous and growing interest in using this technology for environmental monitoring, particularly with respect to forest cover. Major institutional and financial limitations, however, prevent the full potential of remote sensing systems from being realized.

An array of satellite and other remote sensing systems suitable for climate change-related studies is available that provides a range of data at different temporal and spatial resolutions. Conventional aerial photography provides the highest spatial resolution and is the most appropriate imagery for conventional local forest inventory. The Landsat Multispectral Scanner (MSS) with an 80-meter resolution, provides the longest record of satellite data for the region—since 1972.[24] Landsat data are suitable for regional forest assessments and monitoring rates of deforestation. Higher resolution satellite data are available from the Landsat Thematic Mapper (TM) (30 meters) and the French SPOT system (30 meters and 10 meters).[25] Imagery from the latter system approximates the resolution of high altitude aerial photography.

The National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite sensing system provides daily global coverage at a coarse spatial resolution of about 4 kilometers, with local area coverage of 1 kilometer available on request.[26] In addition, AVHRR 1 kilometer High Resolution Picture Transmission data for central Africa are acquired at receiving stations in Niger and Kenya.[27] The high temporal resolution of AVHRR makes it attractive for regional scale environmental monitoring and small-scale vegetation mapping. Its coarse spatial resolution, however, makes it difficult to derive accurate land conversion rates.

Radar sensors provide the capability of cloud-free coverage and afford a considerable advantage for tropical remote sensing. Satellite radar sensors currently provide very little data for the region, although airborne radars are being used increasingly for sub-national scale projects in parts of the region.

Satellite data availability is a problem for the region. Data coverage is sparse and no comprehensive or systematic acquisition policy exists. The commercialization of high resolution data in 1984 led to a large increase in the cost of data and in fees charged for data acquisition, effectively prohibiting data access for a large number of potential users. This is particularly true for the evolving, but poorly funded, user community in central Africa. The current acquisition policy is providing poorer spatial coverage than was obtained in the early 1970s. New developments in the pricing of Landsat data and the operation of future Landsat systems, however, may lead to an improvement in data policy.[28] Such improvements, in turn, would result in increased Landsat data availability and utilization for the region.

As part of this Study, five remote sensing demonstration activities were undertaken:

AVHRR mapping of dense moist forest in Cameroon and Zaire; AVHRR monitoring of fires; evaluation of Landsat change detection methodologies; satellite ortho-photo map generation; and the use of Global Positioning Systems to improve ground data collection programs in support of satellite image interpretation.

In summary, the AVHRR proved to be a suitable tool for generating small-scale maps of moist tropical forest (Figures 5 and 6) and new statistics on its areal extent. Estimated dense moist forest areas for Cameroon and Zaire based on this analysis are 168,087 and 1,117,963 square kilometers, respectively. These area estimates, however, have yet to be fully validated, and preliminary assessments indicate that errors in the areal estimates can be as high as 20 percent. The coarse spatial resolution of this sensor makes this an intermediate product that should be superseded by high spatial resolution mapping of the region as the data become available.

The AVHRR is also capable of detecting flaming fires as small as 100 square meters. Daily monitoring provides the means to quantify the distribution and timing of fires within the region. These data, when combined with representative biomass and sample ground-based emission measurements, can provide improved regional trace-gas flux estimates.

High-resolution satellite data were shown to be an appropriate tool for monitoring changes in forest cover. Pairs of Landsat MSS images (one from an early date, e.g., 1976, and one from a later date, e.g., 1986) were acquired at each of four sites in the region, and using digital analysis techniques, changes in forest vegetation over time were assessed (Figure 7). The success of this analysis was a function of the number of vegetation transformation classes that were classified. Changes between forest and non-forest classes provided the highest accuracy; attempts to define more detailed transformation classes led to decreased classification accuracy. The temporal dynamics of certain land-use practices (e.g., burning and forest regrowth) can confuse the classification of land transformation. Ground information is necessary to determine the accuracy of satellite-derived land transformation statistics.

The poor state of baseline cartography for the region is an obstacle to improved regional management. Ortho-photo images are precision-processed map images that conform to a cartographic map projection. When precision processing is applied to satellite data, the result is imagery free from distortions related to the sensor, satellite, and land surface.[29] Two geo-corrected Landsat TM image maps were produced in this Study to illustrate the type of cartographic product that can be made using state-of-the-art, precision processing techniques (Figure 8). The area selected for this product includes the borders of Cameroon, Congo, and the Central African Republic. The results demonstrate that satellite data can be used to provide an up-to-date map base for the region.

Ground data collection is an important component of most remote sensing data analysis methodologies. The problems of ascertaining precise field locations in the region, where maps are for the most part inadequate, can be alleviated by using a Global Positioning System (GPS). Currently, GPS technology can give geographic location to within less than a meter. In this Study an existing network of private volunteer organizations (PVOs) with ongoing field projects in the region was used to provide a preliminary assessment of instrument utility for ground data collection in support of satellite mapping and monitoring activities. The strategy of collaborating with PVO field researchers to conduct rapid field surveys of tropical forests using satellite image maps and GPS positioning is a direct and positive outcome of this demonstration activity and provides a useful model for implementing future activities.

Geographic Information Systems

The inaccessibility of existing maps and data is a major obstacle to those undertaking

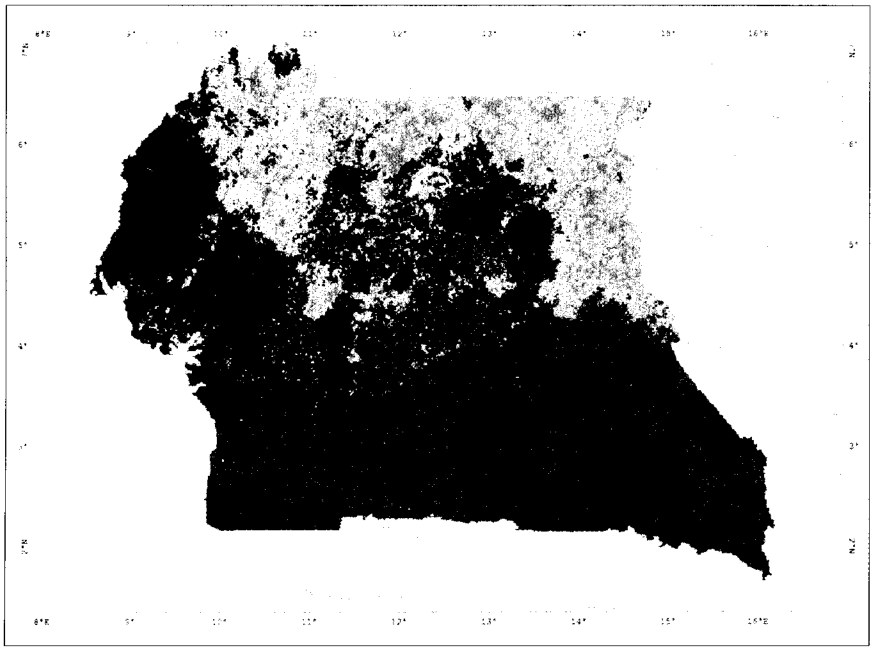


Figure 5: Vegetation map of southern Cameroon derived from 1989 NOAA-AVHRR data as part of this Study.

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

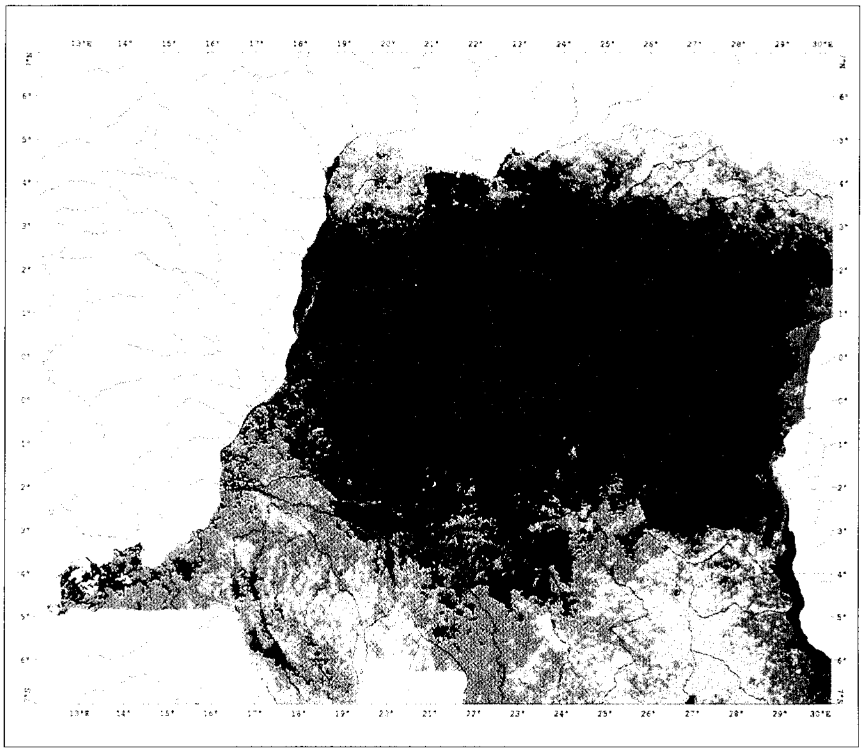


Figure 6: Vegetation map of northern and central Zaire derived from 1989 NOAA-AVHRR data as part of this Study.

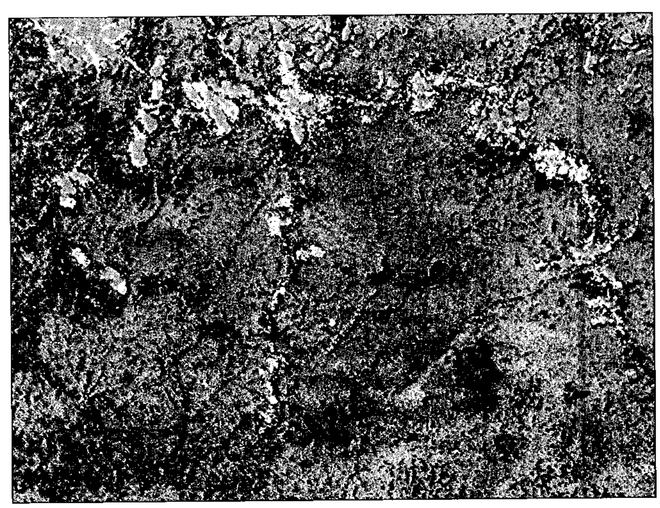
Figure 7: Determining changes in vegetation using Landsat MSS imagery.

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.

Figure 8: 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.

research in the region. Spatially explicit digital data bases provide a means to overcome some current obstacles and provide the existing data in a form that facilitates quantitative analyses. Using a system of hardware, software, and procedures, a GIS allows one to acquire, store, analyze, and display geographically referenced data.[30] At present, GIS's are 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 a GIS have become available to many organizations. For developing countries, a GIS is no longer a prohibitively expensive technology.

Despite successful deployment elsewhere on the continent, the central African countries have been slow to establish either regional or national GIS's, although there are a limited number of local GIS's being developed in the region.

GIS's can be used to manage data at a variety of scales and for a wide range of applications. At a local level, GIS's can be used to model land-use dynamics, to monitor development efforts, and to monitor long-term climate change impacts. At a national scale, GIS's can assist in conducting inventories, monitoring, and managing land use. At a regional level, for example, when used in conjunction with time series analyses of satellite data, a GIS can support modeling efforts to determine carbon fluxes. Similarly, GIS's can be used to examine the possible impact of climate change on agricultural sustainability and to support mitigation policy and planning needs. A regional GIS system with up-to-date information on climate change-related spatial data availability, such as existing maps and satellite data coverage, would provide a useful data base for climate change studies.

Though GIS technology is appropriate at these different scales of application, attention should be paid to the failures and successes of previous GIS projects in Africa. As with remote sensing, GIS is a useful tool to address certain aspects of climate change research and resource management, but is not the solution in and of itself.

CONCLUSIONS AND RECOMMENDATIONS

Deforestation, savanna burning, and global climate change, both causes and effects, should be given a high profile in development planning and should be treated as primary concerns by national governments and development agencies.

Deforestation is and will continue to be the major source of CO_2 emissions in central Africa, but the direct environmental consequences 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. Avoiding these consequences 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, therefore, not only to reduce emissions over the long term, but to ensure the prospects for a secure economic future for the region by avoiding near-term environmental degradation. In addition, without its forests, the region's ability to withstand the predicted impacts of global climate change will be substantially reduced.

The fact that central Africa's forests remain relatively intact offers an important opportunity to promote and apply effective forest management strategies, sustainable agriculture techniques, and more efficient biomass fuel use, 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 recognized as a major continental source of greenhouse gas and particulate emissions.

This study found that the baseline scientific data (meteorological and hydrological data, forest composition and distribution, biomass densities, etc.) and the baseline socioeconomic data (demographics, energy supply and demand, land-use change, etc.) required for climate change analysis and improved resource management are sorely inadequate. Better quality, more up-to-date, and well-managed information is necessary to provide central African countries with the tools they need to develop in-country climate change analysis capabilities and to design, evaluate, and implement appropriate resource management and climate change mitigation policies. Some of the data needs can be filled by satellite remote sensing analysis, which offers a unique potential for developing accurate, up-to-date, regional land-use data bases. A wealth of historical data exists that should be analyzed, and targeted socioeconomic surveys, analyses, and monitoring should be undertaken. Data collection should be focused 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.

Although there is still a great deal of scientific and socioeconomic research needed, a program that combines both action and analysis is recommended. Enough is known about current land-use change activities in the region and their potential impacts, for improved resource management to begin now. Research and resource management activities must be coordinated within a comprehensive program in order to optimize benefits to both the local and global communities. To be most effective, both research and mitigation activities should be carried out through collaboration among national governments, bilateral donors, non-governmental organizations, local communities, the private sector, and the scientific and resource management communities in Africa, the United States, Europe, and Canada.

This Study provided a baseline of information upon which to begin collaboration with African colleagues in a thoughtful and focused manner. Through targeted research and action, programs can be developed to enhance the capacity of African nations to mitigate both the causes and potential impacts of global climate change and resource degradation in the region.

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