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CENTRAL AFRICA:
Global Climate Change and Development

PN-ABP-067

Central Africa

Global Climate Change and Development

Technical Report

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—Technical Report.

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A detailed overview of the *Technical Report*, entitled *Central Africa: Global Climate Change and Development—Overview* and a summary of the overview entitled *Central Africa: Global Climate Change and Development—Synopsis* were also produced. They are available from:

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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 Report document, both of which are intended to respond to the informational 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.

NASA/Goddard Space Flight Center staff provided the "Improved Information and Information Management: Remote Sensing and GIS" chapter and produced the remote sensing images in the document. Principle authors were Chris Justice (University of Maryland), Ned Horning (STX Corporation), and Nadine Laporte (University of Maryland). In conjunction with the research at NASA/Goddard, Jules Wilmet, Michel Massart, and Eléonore Wolff at the Université Catholique de Louvain and staff at the Katholiek Universiteit Leuven in Belgium produced comprehensive cartographic, photographic, and other data bases on Zaire. Elizabeth Cook and Louis Iverson of the Illinois Natural History Survey, and Dan Harder, of the Missouri Botanical Gardens, also contributed work on change detection analysis in collaboration with NASA/Goddard staff. Jean-Claude Thomas of the U.S. Geological Survey in Reston, Virginia provided technical assistance on the production of the ortho-photo image map.

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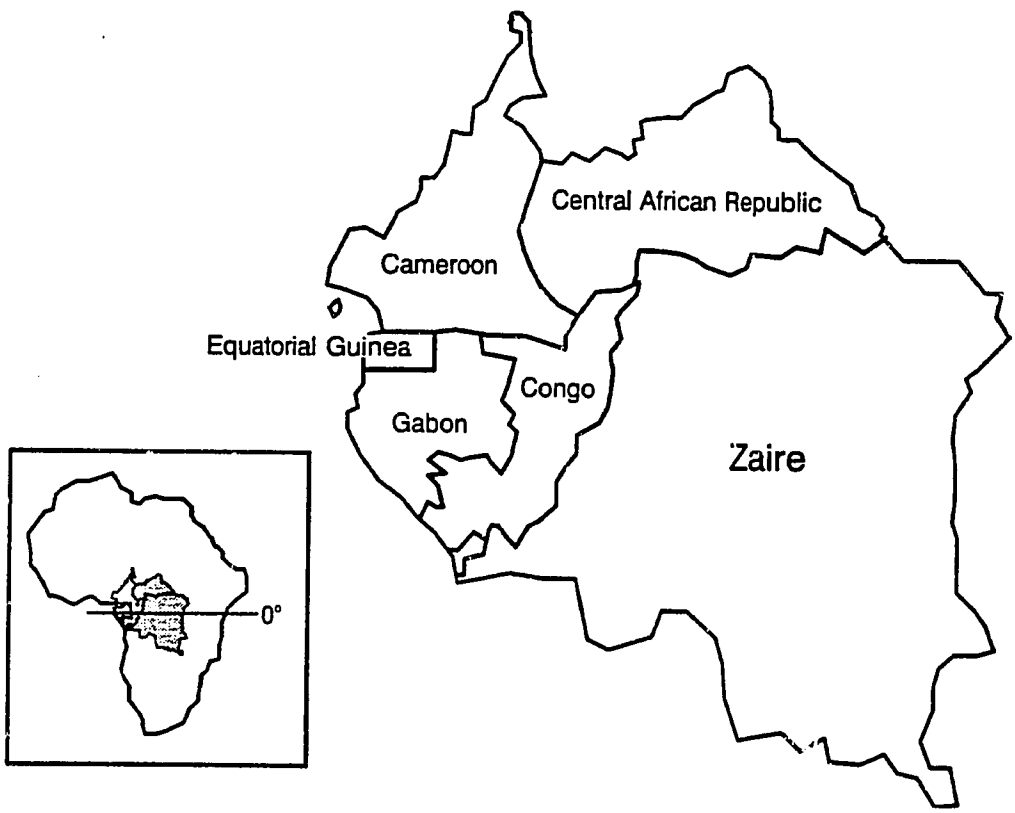
Dr. Chris Justice, University of Maryland, Ned Horning, Hughes STX and Dr. Nadine Laporte, University of Maryland

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, this series of technical papers was produced and printed. An *Overview*, printed under separate cover, reviews the main findings of this *Technical Report*.

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.

This volume contains the original reports in their entirety and is intended as a companion volume to *Central Africa: Global Climate Change and Development Overview*, which includes the overall conclusions and recommendations of the study.

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BIOGEOPHYSICAL SETTING AND GLOBAL CLIMATE CHANGE

Dr. David S. Wilkie
and
Dr. Mark C. Trexler

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1 BIOGEOPHYSICAL SETTING CENTRAL AFRICA: POTENTIAL EFFECTS OF GLOBAL WARMING

1.1 Delimiting Central Africa from a Global Climate Change Perspective

Central Africa (Figure 1), which includes Cameroon, Central African Republic, Equatorial Guinea, Gabon, Republic of Congo and Zaire, extends from 12°N to 13°S and 10°E to 31°E and covers 14% (4.08 million km^2) of the continent. Other than their central geographic location, what makes the nations of Central Africa constitute a discrete, identifiable region within the African continent, and what features make this region of particular interest from a global climate change perspective?

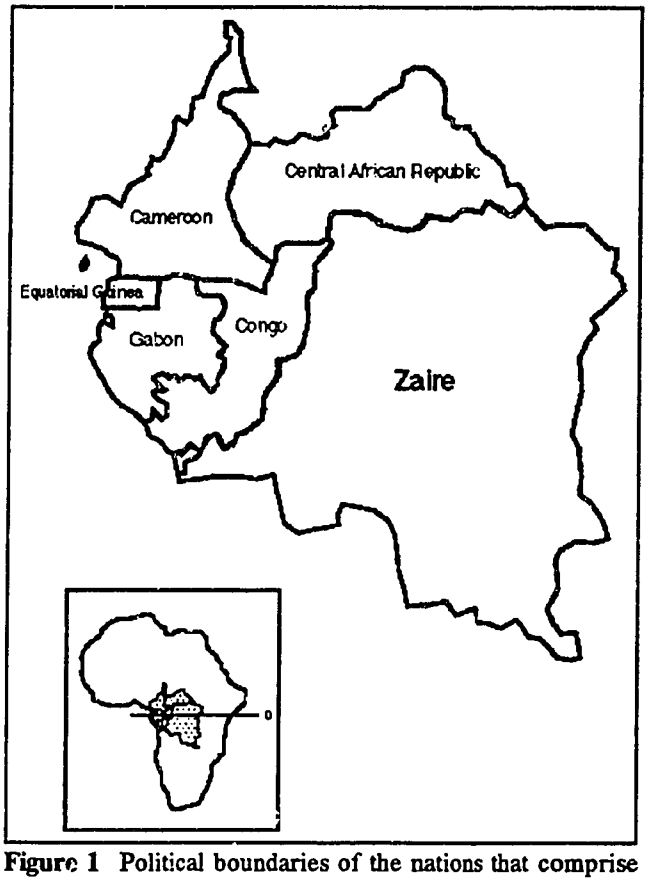

Figure 1 Political boundaries of the nations that comprise central Africa

Examining a generalized map of Africa (Figure 2) that delimits areas having adequate soil moisture for year-round plant growth (Lewis and Berry, 1988; p2) shows that, whereas Africa for the most part is a dry continent (Livingstone, 1975; p250; Nicholson, 1989; p46), central Africa is almost exclusively humid or subhumid, with precipitation exceeding or equalling retention (evapotranspiration and interception) throughout most of the year (Lauer, 1983; p41, Brinkman, 1983; p92). Suitability of the central African climate for year-round plant growth, coupled with geologic, topographic, and soils features of the region, and a complex feedback between vegetation and climate, has resulted in the formation of the largest contiguous area of tropical moist forest in Africa (2.8 million km^2; FAO-UNEP, 1981), constituting 12% of the world's remaining tropical moist forest (UNESCO, 1978). While climatic conditions over much of central- and West Africa indicate that the landscape is capable of supporting tropical moist forest, only in central Africa has the forest escaped the loggers chainsaw and the farmers axe.

Africa's largest remaining expanse of moist forest and the drier woodlands that bound it constitute a vast reservoir of carbon and, depending on human land-use practices may act as a substantial source of carbon dioxide. Thus, from a biogeophysical perspective, the feature most relevant to global climate change that distinguishes central Africa from the rest of the continent is the extensive forests and woodlands that blanket the landscape. To evaluate the importance of central Africa as an actor in global climate change we, therefore, must have a thorough understanding of the biogeophysical factors that are responsible for the

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development, perpetuation, and decline of the moist and seasonally dry forests.

1.2 The Climate of Central Africa

The climate of a region is the long-term average of daily weather patterns. Unlike a region's weather, its climate is usually more stable and predictable. This does not mean that climate is static, rather changes are manifest across a historical rather than daily or annual time scale.

According to the Trewartha's system for characterizing climate, central Africa falls within the (A) tropical rainy climate group, and the (f) and (w) subgroups. (Af) is a tropical rainy climate with no dry season, with the driest month having over 60mm of rain; and (Aw) is a tropical rainy climate that is dry during the period of low sun (winter) with the driest month having less than 60mm of rain. The (Af) region, as delimited by Trewartha, coincides approximately with the areal extension of the tropical rain forest, the distribution of multi-colored Oxisols, and an area of substantially convective rainfall averaging over 1700mm per year. This continuously humid region is elevation limited and coincides with the 18°C isotherm of the monthly average of the coldest months of the year (Brinkman, 1983; p89).

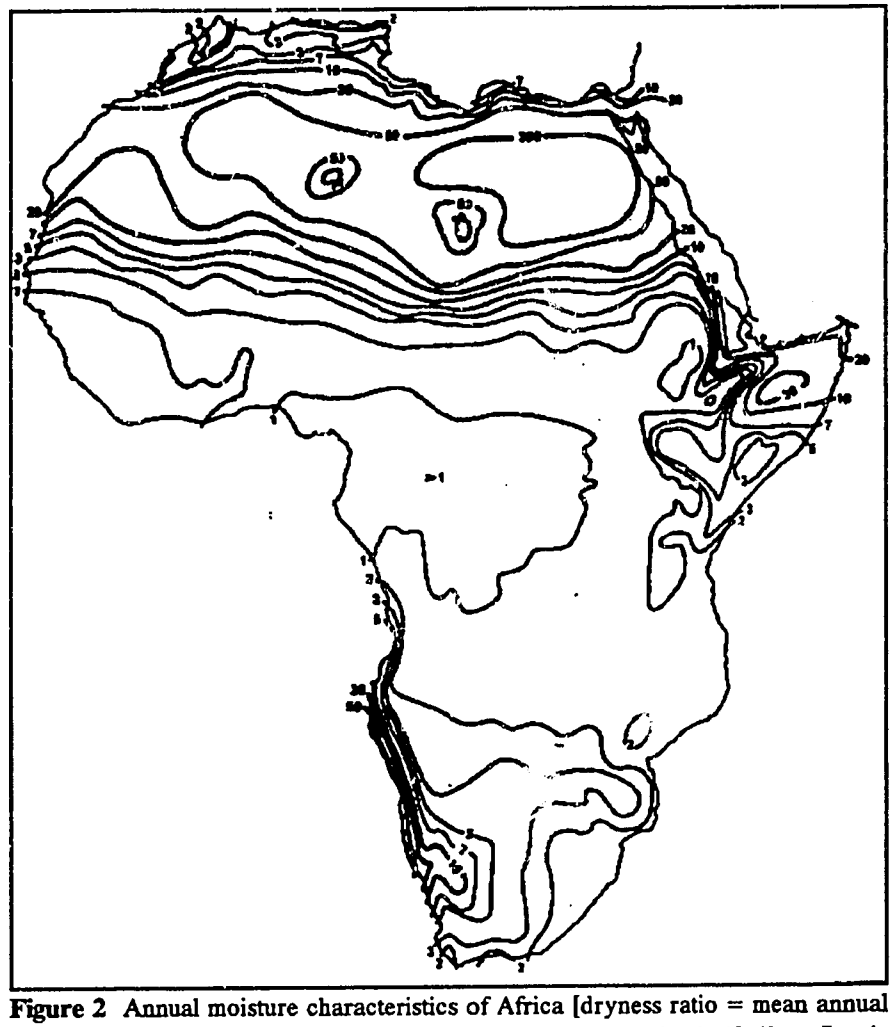

Figure 2 Annual moisture characteristics of Africa [dryness ratio = mean annual net radiation/(mean annual precipitation x latent heat of vaporization)]. (from Lewis and Berry, 1988; p2)

Although solar radiation drives all the Earth's weather, within central Africa seasons are dominated by rainfall pattern (Griffiths, 1972; p7) and not by temperature, that varies little within the region (yearly mean 25°C; Griffiths, 1972). The spatial and temporal distribution of rainfall and its intensity are assumed to be determined largely by Atlantic sea surface temperatures (SSTs, Nicholson, 1989; p54), by biosphere feedbacks, and by the

behavior of the Intertropical Convergence Zone (ITCZ) and the unstable masses of moist air associated with it (Jackson, 1989; p17-20).

Formation of the ITCZ and its role in moderating the timing and distribution of rainfall

Central Africa is subject to constant year round high inputs of solar energy (Figure 3: Lauer, 1983; p9). This results in large quantities of water vapor evaporating from the warm southern Atlantic Ocean and from the land. Sensible heating of the moist air masses over the land surface causes them to rise upward in the atmosphere. The rising moist air expands and adiabatically cools as air pressure declines with altitude. Water vapor within the rising, cooling air mass condenses into droplets that form clouds. As water vapor condenses latent heat is released, which causes further ascent of the air mass and considerable turbulence (Jackson, 1989; p18), triggering intense localized rainfall. Ascent and condensation of warm air around the equator results in an air-pressure gradient from the tropics to higher latitudes, forcing a shift of the air masses toward the poles (Lauer, 1983; p20). As the poleward moving air loses heat by radiative cooling, it subsides in a zone of high air pressure within the subtropical latitudes (the Saharan and South African anticyclones). The subsiding air mass returns toward the equator as a ground current of varying depth (< 2,000m) (Griffiths, 1972; p260), that absorbs heat and moisture from the surface as it moves into the equatorial trough where low pressure prevails. Since air masses from both hemispheres flow together at the Equator, the Intertropical Convergence Zone (ITCZ) or Intertropical Confluence (ITC) is formed. This closed equatorial to subtropical circulation of air was recognized by Hadley in 1735 and is called the Hadley Cell (Figure 4: Lauer, 1983; p20-21; The thermally directed Hadley Cell extends to about 30°N; the Ferral cell is thermally indirect and occupies the region from 30°N to 60°N; the polar cell is a rather weak circulation. The arrows on the hemispherical semi-circle indicate the direction of surface winds).

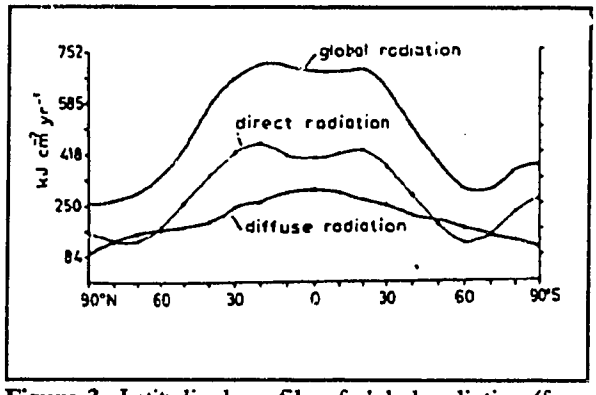

Figure 3 Latitudinal profile of global radiation (from Lauer, 1983; p9)

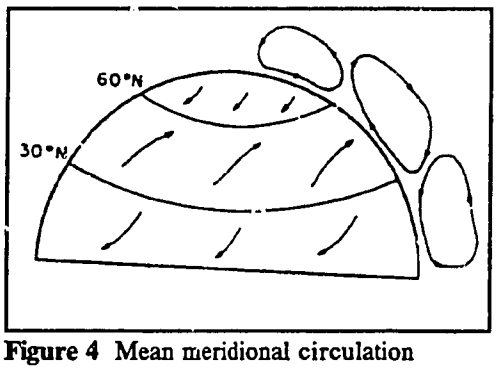

Figure 4 Mean meridional circulation

Except for eastern Zaire and west central Cameroon mountain ranges and extremes of relief are uncommon within the region. Rainfall in central Africa, therefore, is primarily associated with convective rather than orographic (associated with landscape relief) ascent of air. Seasonal migration of the ITCZ as it follows the zenithal position of the sun (Figure 5: Balek, 1977; p24) has a profound effect on rainfall timing and extent within the region

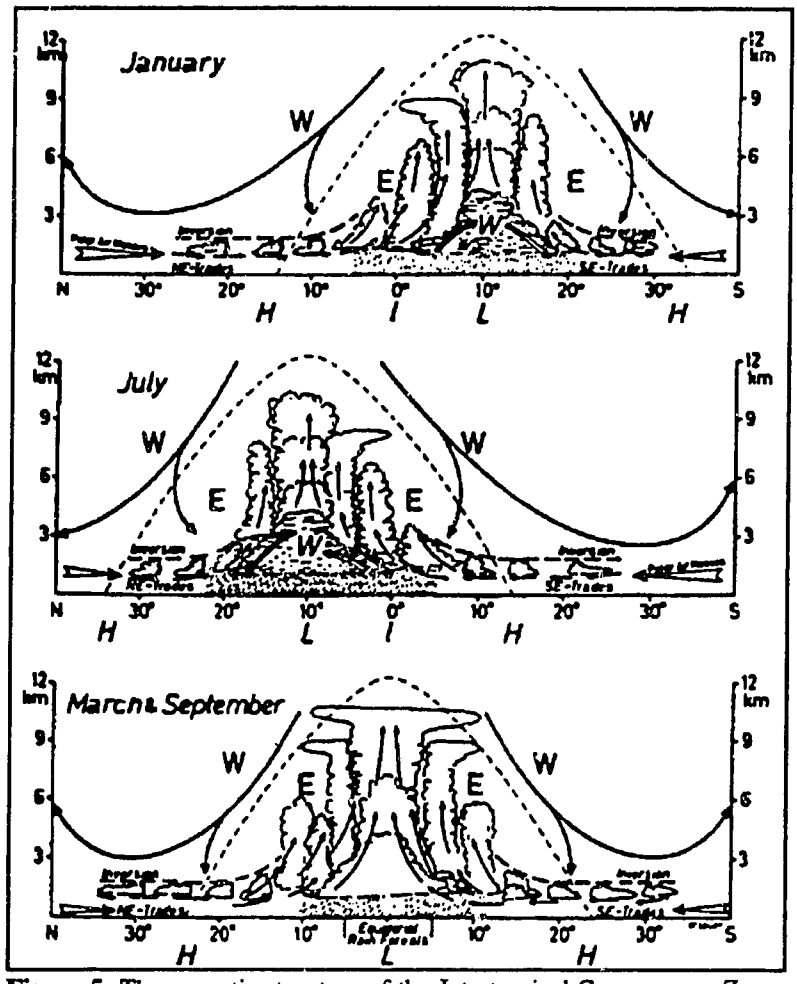

Figure 5 The synoptic structure of the Intertropical Convergence Zone; W = west wind, E = east wind. (from Lauer, 1983; p21)

(Balek, 1977; p25). Rainfall accompanies the equatorial trough as it moves toward the respective summer hemispheres. Simultaneously, the reinforced subtropical anticyclone of the respective winter hemisphere directs hot and dry continental air toward the equator (Harmattan winds associated with the Saharan anticyclone). Both these factors result in cessation of rain at the receding edge of the equatorial trough. At the equator there is a double rainfall maximum that coincides with the sun at zenith, but no real dry season. Moving poleward results in a progressive increase in the duration and severity of long and short dry seasons associated with the influence of the autumnal and vernal equinox respectively (UNESCO, 1978; p36). The asymmetrical distribution of the continents and the resultant asymmetry of the atmospheric circulation results in the ITCZ penetrating deeper into the northern hemisphere (mean annual location 5°N; Jackson, 1989; p11). This may explain the greater extent of moist forest north of the equator.

Jackson (1989) warns however about simple generalizations regarding the behavior of the ITCZ. The ITCZ does not, in reality, form a continuous low pressure trough, nor does it move in a highly predictable manner. Rather it fills and reforms to produce a chain of major disturbances causing variable rainfall regimes throughout central Africa. While annual precipitation at sites within central Africa may be consistent from year to year, the unpredictable behavior of this largely convective weather system means that the daily and monthly patterning of rainfall at any given location within central Africa can vary considerably (Figure 6: Lauer, 1983; p34).

Rainfall

Annual rainfall averages between 1,000 and 2,000mm in central Africa (Figure 7). Areas in northern Cameroon, northern Central African Republic and southern Zaire may receive less rain, whereas areas in central Zaire average over 2,500mm. Mt. Cameroon (Debundscha) and the southern edge of Fernando Póo (Ureka) are two "of the few stations

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around the world with an annual rainfall in excess of 10,000mm" (Griffiths, 1972; p285, p288). The anomalously high quantities of rainfall received by these areas results from the combined effects of orography and the warm Benguela current. Rainfall is sufficient throughout much of central Africa for there to be a positive water balance (i.e. precipitation exceeds evapotranspiration) during most months of the year.

As most of the precipitation within central Africa is convective and as rainfall is not associated with frontal systems as it is in higher latitudes, rain tends to be local. A rainstorm develops, rain falls for a while and then stops. There is little movement of a storm to another locality. (Livingstone, 1975; p 252). Spatial and temporal distribution of local disturbances that result in cumulus cloud and storm development are unpredictable. Thus daily rainfall patterns at any location within central Africa are highly variable.

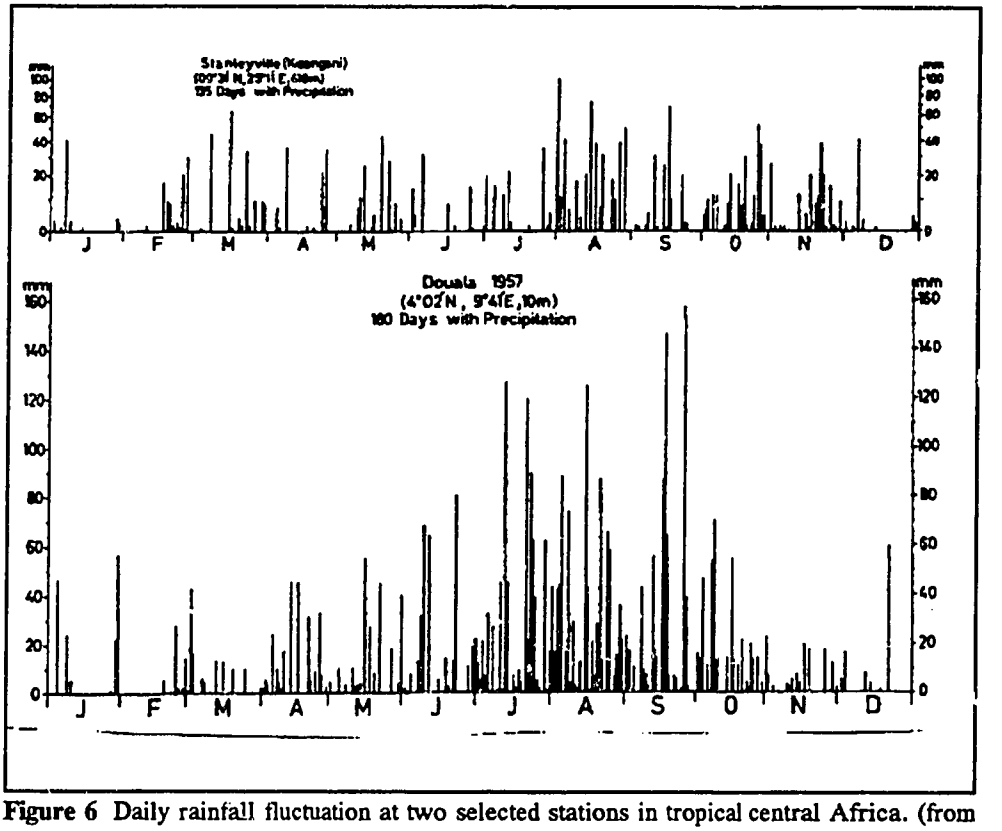

Figure 6 Daily rainfall fluctuation at two selected stations in tropical central Africa. (from Lauer, 1983; p34)

Current Climate

Solar Radiation/temperature

Solar radiation in central Africa has a daily mean of approximately 0.02 J cm^{-2} sec^{-1} and varies annually in a modest sinusoidal way with maxima during the vernal and autumnal equinoxes (March 21 and September 22 at the equator) and minima at the summer and winter solstices (Balek, 1977; p22). Seasonal temperature variations (1-2°C) are less than diurnal variation (5-10°C). Only "the desert areas of the marginal-tropical and subtropical arid regions" (Lauer, 1983; p9) receive more solar energy than moist equatorial regions of Africa. The proportion that direct and diffuse radiation contribute to total radiation received at ground level within central Africa varies according to the occurrence and vertical thickness of clouds, and the content of water vapor in the atmosphere. Areas in the central basin of

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Zaire and around Mt. Cameroon that receive rainfall in excess of 2000mm yr^{-1} often receive over 50% of solar energy as diffuse radiation, whereas during dry periods in southern Zaire and northern Cameroon and the Central African Republic, diffuse radiation only constitutes 20% of solar energy that reaches ground level (Griffiths, 1972; p. 263). Mean monthly sunshine hours is between 35-55% of daylight hours, (Griffiths, 1972; p262) with day length ranging between 12h at the equator to 11.6-12.7h at 10° N and S (Balek, 1977; p22).

Source and "recycling" of rain within the Basin

The most striking aspect of rainfall within central Africa is the source of water vapor that leads to the convective precipitation characteristic of the region. Although the southern Atlantic Ocean provides considerable water vapor to the central African hydrological system (Lauer, 1983; p37), between 75-95% of rainfall is from recycled water (i.e., runoff ranges from 25-5% Balek, 1977; p105-107, Brinkman, 1983; p93). The importance of the, so called, "small hydrological cycle" in central Africa is much greater than that of the Amazon, where it is estimated that only 50% of the precipitation comes from terrestrial evapotranspiration (Salati, 1987; p292). Southeast Asia shows the least "recycling" of all tropical regions, with runoff exceeding 80% in some locations (Figure 9: Brinkman, 1983; p93). The shape of the Zaire River basin, and the extensive rain forest and wetland systems within the region force the bulk of rainwater to be regionally recycled into the tropical atmosphere. Rainfall within much of central Africa is therefore generated largely within the region itself. Although this is a surprising finding, it must be couched in the knowledge that hydrological and meteorological data for central Africa are sparse. Discussion and conclusions drawn from these data are at best course approximations.

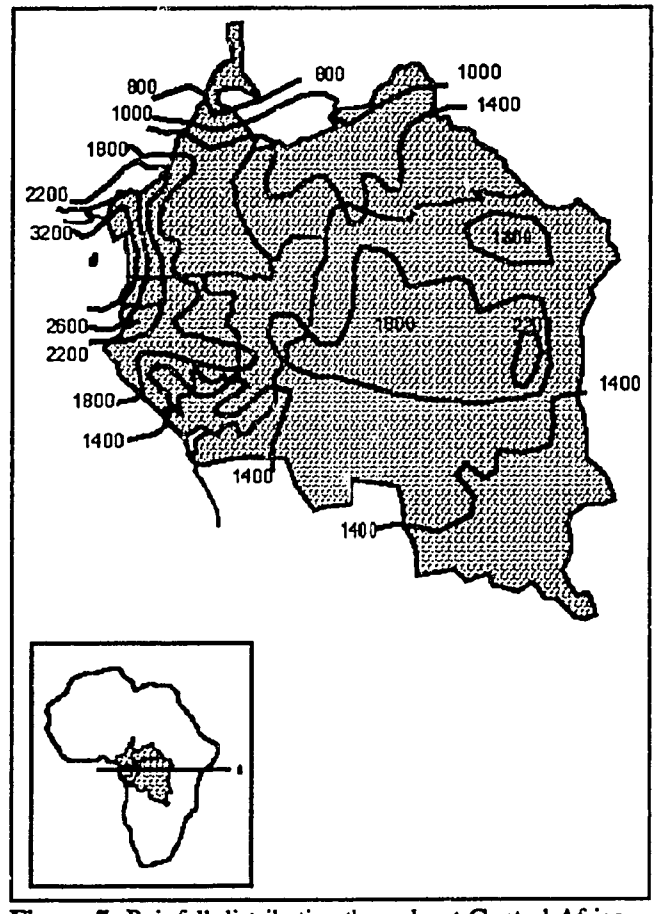

Figure 7 Rainfall distribution throughout Central Africa.

No data are available on the extent that moist forested regions of central Africa contribute to extra-regional precipitation. Central Africa is most likely a closed system in regard to rainfall, with some areas such as the eastern Zaire highlands receiving a somewhat higher proportion of "small cycle" rainfall as a result of orographic cloud formation. Movement of the ITCZ during the year and thus transport of evapotranspiration water vapor

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out of the system may be important at the forest periphery. However, Lauer (1983) notes that the "small water cycle has a transfer time of only 1 to 2 days *after which it falls to the ground as rain*", and that air masses within the ITCZ are stagnant. Both these factors will restrict how far the recycled water could be transported out of the region.

Past Climate

Central Africa, like large parts of the continent, experienced "wide fluctuations in rainfall during the Pleistocene" (Nicholson, 1989; p46-47); some periods were considerably wetter than at present, others considerably drier (Lewis and Berry, 1988; p41, Livingstone, 1982, p530; Moreau, 1963, p26; Hamilton, 1981; p 3, Hamilton, 1983; p153). As Europe glaciated and deglaciated, air temperatures in central Africa fluctuated (Bonnefille, Roeland, and Guiot, 1990). 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 (Moreau, p361), resulting in temperatures 4-6°C lower than at present (Bonnefille, Roeland, Guiot, 1990; p347). Lower temperatures would be associated with a shift in the 18°C isotherm. As a result evaporation would have declined, as would have rainfall (30% reduction according to Bonnefille et al. 1990; p347), and the extent of mesic (moist) forests. The presence of extensive Kalahari sands in the central Zaire basin is evidence of extremely arid conditions between 75-52,000 ybp. Warmer periods (Table 1), associated with deglaciation in Europe, would have resulted in increased rainfall and expansion of forest over larger areas of central Africa (Hamilton, 1983; p153).

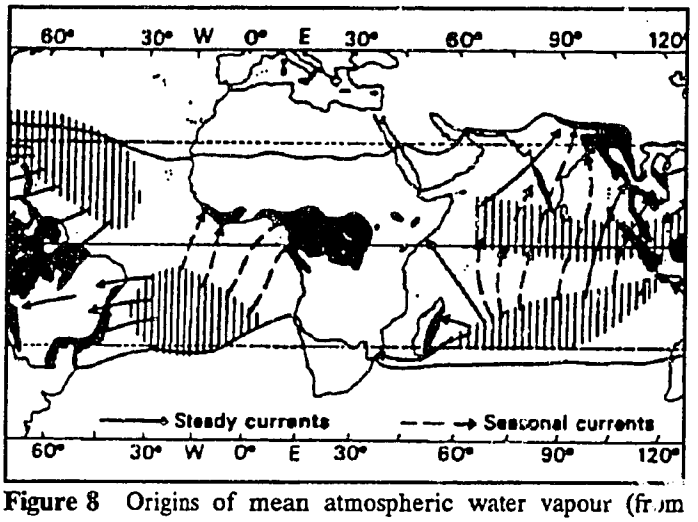

Figure 8 Origins of mean atmospheric water vapour (from Lauer, 1983; p37)

Variations in climate have continued over the last 3,000 years, but not at the same magnitude as observed over a more distant time scale (Nicholson, 1989; p47). "Two periods are particularly worth noting: a relatively humid one in northern Africa at the time of the 'medieval warming' in Europe and elsewhere (10th-13th centuries), and a recent period of rapidly changing conditions which affected most of the continent in the late nineteenth and early twentieth centuries" (Nicholson, 1989; p47).

Africa was significantly more humid between the tenth and thirteenth centuries when caravans traversed the desert along routes now impossible for lack of water, and lake levels were several meters higher than present. These conditions recurred during the sixteenth through eighteenth centuries (Nicholson, 1989; p47), with the exception of several severe periods of drought in the 1680's, 1740's, and 1750's. Evidenced from data on lake levels, historical landscape descriptions, and sporadic meteorological data "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;

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Table 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
12,000-8000	Warm/Humid
6000-3,000	Dry
3,000-present	Drier

(after Livingstone, 1975)

p47). Droughts were rather analogous to those presently occurring in the Sahel, with rains returning and a relatively humid period persisting from the 1870's to the 1890's. Water levels in Lake Chad, that had previously dried up, rose by several meters during this period. Fluctuating rainfall has continued to the present day. Carruthers and Kydd (1989; p44) point out that the unusually wet period between the 1950's and 1971 may have prompted recently independent African nations to have 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."

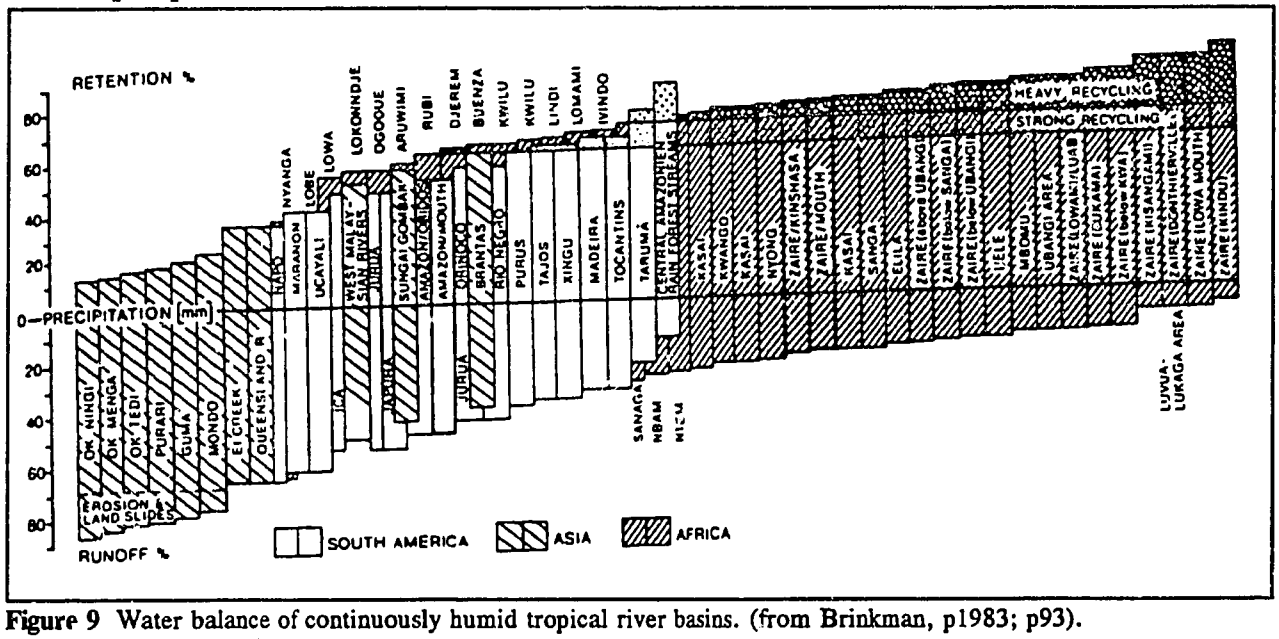

Figure 9 Water balance of continuously humid tropical river basins. (from Brinkman, p1983; p93).

Recent historical rainfall fluctuations in Africa appear to occur on a continent-wide rather than regional scale, and thus "patterns of rainfall variability clearly imply that large-scale circulation changes, and not regional-scale phenomena such as desertification, impose the dominant control on rainfall" (Nicholson, 1989; p53). While the causes of long-term rainfall fluctuations in Africa are poorly understood, the continental pattern of supra- or subnormal rainfall refutes the "well-known hypothesis that the recent droughts have been anthropogenically produced, a result of desertification caused by poor land management practices" (Nicholson, 1989; p53), and suggests that global SSTs and the El Niño-Southern

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Oscillation (ENSO) are primarily responsible. 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; p54). Paucity of meteorological data[1] makes discussions on rainfall fluctuations in central Africa largely conjecture. We must, therefore, be very careful about assuming that we can predict the impact of 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.

Future Climate

Over the extreme long term the climate of central Africa, like that of the rest of the globe, will continue to be regulated by: variation in the output of energy from the sun; the orbital changes of the earth around the sun (the Milankovitch Cycles, Anon, 1990); and the influence of the north Atlantic conveyor and associated global ocean circulation (Nicholson, 1989). Of more immediate concern is how human activities might influence central African and global climate in the short-term. Human activity can alter a region's climate by changing atmospheric composition, and by altering the physical and biological properties of the surface (Jackson, 1989; p 268).

Extra-regional emissions of trace gases are likely to cause an average global warming of 1°C by the year 2050 and 3°C by 2100 (1.5-4.5°C with a doubling of CO_2) and will result in alteration of rainfall patterns at a regional level. In contrast, land surface transformation associated with agricultural and timber exploitation practices within central Africa will alter soil moisture, runoff, evaporation, and soil surface termerature, all of which affect climate at the local level. Assessing the relative impact of these regional and more local factors is extremely difficult as they are all apt to have synergistic effects.

The human activity within the tropics that has drawn the most attention in regard to its potential impact on regional and global climate is deforestation. In central Africa, this is almost certainly the primary factor that could possibly play a role in climate change in the region in the near future. Yet, pleas to prevent deforestation because it results in droughts and floods are, according to Hamilton (1983; p123), based on "the four Ms (myth, misinterpretation, misinformation and misunderstanding)." Pereira (1973; cited in Hamilton, 1985; p 681), who compiled research conducted primarily on temperate forests, showed that there was little or no relationship between presence or absence of trees and precipitation falling on that area. For central Africa however, it is overly simplistic to say "forests occur where water is available to support them" (Pereira, 1989; p58). If over 80% of the water vapor that falls as rain on the moist forested regions of central Africa results from evapotranspiration, then the trees themselves play a vital role in regulating precipitation, and must to some degree govern the distribution and extent of moist forest.

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[1] Sharon Nicholson has however accrued a reputedly substantial corpus of meteorological data for central-south Africa, and notes that while data have and are still being collected, obtaining these data is often difficult.

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Although rainfall recycling must influence the extent and distribution of moist forest within central Africa, the deforestation = drought contention is a gross simplification that may be unjustified for most of the region. Inappropriate land use practices once the forest has been cleared, are much more likely to determine the water retention capacity, and long-term botanical composition of a given locality, than deforestation alone.

Modelling the Direct Impact of Deforestation on Regional Climate

The role of forests in 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 water cycle" (Lauer, 1983; p38) 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? The only clues we have to answering this question are the results of global climate modelling studies that attempted to simulate the impact of forest removal within rain forest regions of the world (Potter et al, 1975) and specifically within Amazonia (Lettau et al., 1979; Henderson and Gornitz, 1984, Lean and Warrilow, 1989, Shukla, et al., 1990). 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 higher latitudes), showed a wide range of change in surface temperature (+/- 0.5°C; Lean and Warrilow, 1989 showed a 2.4°C change in surface temperature; Shukla et al., 1990 temperature change from 0.5-2.5°C), and resulted in a reduction in precipitation of 75-800mm y^{-1} (Henderson-Sellers, 1987; p468-469, Shukla et al., 1990; p1323). However results from Amazon specific simulations may not be directly applicable to central Africa, as recycling in the Amazon is considered only to contribute about 50% of basin precipitation (Salati, 1987; p292).

The model that simulated the least change in albedo (Lettau et al, 1979), corresponding to a change from rain forest (albedo 9-10%) to degraded forest/woodland (albedo 12-16%), showed the least change in rainfall (75mm y^{-1}). The most extreme model (Potter et al., 1975), that used an albedo increase of 18% where all forest was converted to sparse grassland, resulted in some of the most extreme climate changes. Although simulation models suggest that changes in albedo may influence climate, an empirical study of devegetation in West Africa (Gornitz, 1987) questions the importance of this variable. Gornitz (1987; p66) notes that "anthropogenic vegetation changes in western Africa do not appear to have affected regional climate, as seen from historical records." Further, reduction in soil moisture capacity, associated with reduced organic matter in the soil, places plants under increased stress during dry periods. Thus land use practices may simulate climatic desiccation (Gornitz, 1987) when the rain gauge may show otherwise.

A cautionary extrapolation from global and Amazon specific models suggests that with complete deforestation of the Zaire basin, rainfall may be insufficient to support redevelopment of moist forest. Yet, anthropogenic savanna woodlands within central Africa that were derived from the historic clearing of forest still receive 1200-1600mm of rain per year (White, 1983; p 58, 76, 84). Whether reestablishment of woody vegetation in these previously deforested regions would increase evapotranspiration sufficient to raise the contribution of the "small water cycle" such that precipitation levels could once again promote the development of moist forest is unknown. Simulations to examine specifically

the climatic consequences of central African deforestation have not been constructed[2].

Scorched-earthed models that completely deforest a region are important from a heuristic 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. Thus, is it reasonable to assume that extreme changes in rainfall, soil moisture, and river flows are unlikely to occur even when deforestation continues at its present, accelerating extent?

Contrasting regional and local scale changes in climate

If we assume that the majority of forest clearing within central Africa in the future will stem from the slash-burn-fallow practices of subsistence farmers, then deforestation is likely to result in less radical changes than the scorched-earth models predict. According to a state-of-knowledge conference on tropical watershed forest influences research (annotated bibliography by Williams and Hamilton, 1982), localized deforestation results in: a) increased rain water runoff and total water yields over the year; b) decreased stream flow during dry periods; c) reduced water infiltration capacity if soil exposure is of sufficient duration to result in disaggregation and raindrop compaction of the soil matrix; d) reduced transpiration; e) increased diurnal variation in soil temperature; and f) reduced soil moisture capacity, as a result of reduced soil organic material, (Hamilton, 1983; p28). In addition Jackson (1989; p268-280) adds the following factors: 1) an increase in surface albedo (from 9% for rain forest to 20% for active agriculture); and 2) release of CO_2 and particulates into the atmosphere.

That the results of these empirical studies (conducted on a watershed rather than regional level) conflict with those of regional and global deforestation models is revealing. Local (small-scale) deforestation appears to result in increased runoff and increased stream flow with no reduction in local rainfall, whereas regional (large-scale) deforestation modelling reduces rainfall and consequently reduces runoff and assumedly stream flow. The impact of deforestation will thus depend on: 1) the scale and spatial patterning of forest clearing (Hamilton, 1983; p20-21), 2) whether the cleared area is allowed to reforest after a brief cultivation cycle (Ruthenberg, 1971) or remains with a high albedo, 3) the degree that soil texture and organic content are degraded by subsequent land-use practices, and 4) the relative contribution of SSTs-ENSO, versus land surface transformation, to local, regional and global climate fluctuations (Nicholson, 1989).

Is already changing climate an important variable in the region?

Paucity of meteorological stations and scarcity of long-term data make it difficult to establish with any degree of certainty if, and why, the climate of central Africa is changing (Griffiths, 1972; Balek, 1977; Lewis and Berry, 1988; c.f. Nicholson, 1989). Similarly ,as climate models are only as good as the data and assumptions upon which they are built, then scarcity of meteorological data, and theoretical inadequacies of the models will limit the predictive power of climate modelling of the region. To establish if there is a link between

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[2] Shukla is in the process of examining the impact of deforestation on the climate of Central Africa

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human land-use practices, landscape change and climate at a local or regional scale extensive long-term studies would need to be undertaken; a task that is clearly beyond the resources and priorities of the nations that comprise central Africa. Yet, the need for more extensive climate data for the region is of utmost importance if we are to assess the impact of human land-use on local and regional weather patterns, and on the long-term productive capacity of the landscape. However, by the time sufficient data have been accumulated to evaluate the role of rainforest in climate regulation there may be little forest left standing if central African deforestation follows the pattern of west Africa. Given this, while data are being collected to address deforestation-climate interaction questions, it would appear a sound precautionary measure to instigate immediately forest conservation policies, deforestation mitigation strategies, and reafforestation/agro-forestry efforts.

Could global warming significantly alter regional climatic patterns?

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 it is at present. Seasonality would, however, not be affected; there would just be an increase in the amount of precipitation that occurred at any given time (Lauer, 1983) in any given location. With a doubling of CO_2 and a concomitant global temperature rise of 1.5°C to 4.5°C, rainfall throughout the region may, 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 reafforestation within the region without a concomitant change in 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 less unambiguous (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. Sections of central Africa are subject to a mean increase in precipitation while others show a mean decrease in rainfall. The simulated patterning of rainfall within central Africa is widely different according to each model.

Although analogies from palaeoclimatological studies may be untenable because of the predicted rate of present changes in climate, results from global circulation model simulations are not much more enlightening when assessing the impact of global warming on the rainfall patterns of central Africa. Regional averages suggest an overall increase in precipitation

within central Africa although the spatial patterning of such rainfall may result in some areas suffering a decrease in precipitation (Mitchell, et al., 1990).

1.3 Central Africa Resource Base
Soils and their role in local and regional climate change

Central Africa soils, in general, have developed under "high and constant soil temperature, a udic soil regime characterized by a dry season of less than four consecutive months, and an original tropical rain forest or seasonal semi-evergreen tropical forest vegetation" (Sanchez, 1983; p73).

The most abundant soils of central Africa are the Oxisols (Ferrasols or Latosols according to respective FAO and USDA classifications; Kellogg and Davol, 1949), that are "generally well-drained red or yellowish ... with excellent granular structure and little contrast between horizon layers." They are acidic, are associated with aluminum toxicity, and are low in nutrients such as phosphorus, calcium, magnesium, sulphur, and zinc. "Consequently, most of the physical properties of Oxisols are excellent from an agricultural perspective, but their chemical properties are poor" (Sanchez, 1983; p74, Kellog and Davol, 1949; p10). In addition to Oxisols, soils of moderate to high fertility and high organic content, locally known as hydromorphic soils, are the dominant soil type within the seasonally inundated regions that border the Zaire River, the Oubangi, and their larger tributaries in the central basin region of Zaire and Congo. Hydromorphic soils are also common in the estuaries associated with the Sanaga, Ntem, Benito, Ogoué, and Zaire Rivers. Moormann and Greenland (1980; p55-78) (see also Sanchez p78) consider these soils, that are used intensively for rice production in Asia, to have considerable agricultural potential. Soils (D'Hoore, 1964) of volcanic origin are also highly fertile, and are associated with areas of dense population in southwestern Cameroon and eastern Zaire (Sanchez, 1983; p78; D'Hoore, 1964). The least fertile soils of the region are the deep sandy Entisols (Psamments) that lie over loose sediments (wind-blown Kalahari Sands). They are very acidic, have poor water retention capacity, and Sanchez (1983) warns that clearing of these soils is not recommended, as they become exhausted after a very brief period of cultivation. The largest expanses of these soils are in the south and central portions of the Zaire River basin in Zaire (D'Hoore, 1964).

Contrary to popular belief, organic content of tropical forest soils is similar to that of temperate forests (Sanchez, 1983; p84). When considered over the whole of central Africa, soil organic material constitutes a substantial reservoir of carbon. As areas of forest are cleared for cultivation, soil carbon is lost through oxidation. When cultivation is part of a forest-fallow cycle, then once the cultivated area is abandoned and succession vegetation becomes established, soil carbon is replaced and rapidly returns to predisturbance levels (Schlesinger, 1986). If, however, a forested area is cleared for permanent agriculture, or anthropogenic savanna is regularly burned, then soil carbon loss results in a net addition to atmospheric CO_2. Soil disturbance also releases nitrogen, usually in the form of NO_3, and results in reduced CH_4 uptake.

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

Most central African soils are acidic and are associated with aluminum toxicity. Acid rain, a common consequence of annual savanna burning, may decrease the pH of the region's already acidic soils, thus dissolving toxic quantities of aluminum salts that could inhibit plant growth and potentially cause acute poisoning of rivers resulting in sizeable fish kills. Conversely, savanna burning, by oxidizing some of the soil carbon, may inadvertently increase the proportion of nitrogen in the soil and thus result in improved plant growth and crop production.

Laterite formation after clearing is considerably less common than believed, as lateritic soils are uncommon in forested regions, although somewhat more common in savanna or wooded savanna areas. Yet, it is undoubtedly true that "once formed, the hard laterite is exceedingly resistant to weathering" and can have dramatic adverse effects on agricultural production (Kellogg and Davol, 1949; p50-51). "Another commonly held view is that tropical forests essentially feed themselves, since most humid tropical soils are very poor in nutrients..... Nutrient cycling studies that include the entire soil profile, however, show that most of the ecosystem's nitrogen and phosphorus are located in the soil and not in the [plant] biomass" (Sanchez, 1983; p84). See also reviews by Jordan, 1985; and Salati and Vose, 1984 (cited in Sanchez, 1983; p84-85). The reverse, however, is true for calcium, magnesium, and potassium in Oxisols and Ultisols (Sanchez, 1983; p85,87)

"The relative distribution of soil constraints in the humid tropics is rather similar to that of the southeastern US where agriculture and forestry are both profitable and stable" (Sanchez, 1983; p86). The major constraints of central African soils are associated with their chemical rather than physical/structural properties. In conclusion, the soils that characterize much of central Africa are generally low in nutrient reserves, are associated with aluminum toxicity, and suffer from high phosphorus fixation (Sanchez, 1983; p87). Without external inputs of nutrients, soils typical of central Africa do not have a high agricultural potential.

Erosion potential after forest clearing is a function largely of the relief, and the size of the area that is deforested. As most of central Africa is topographically flat, this is a minor issue for all but a few areas in eastern Zaire and western Cameroon. Similarly, traditional agricultural schemes where 0.4-2.0ha of land are cleared on an annual basis, show little overall soil loss, as the tree-root mat continues to stabilize the soil for the brief period when the soil is exposed to the direct impact of rain and erosional runoff, and more importantly, surrounding fallow fields are able to trap what soil does erode. Maintenance of riparian forest strips does, however, substantially reduce soil erosion even from subsistence scale agriculture.

Water

Central African hydrology is dominated by the Zaire River Basin (Figure 10), which is the largest of 15 major drainage systems in Africa (Balek, 1977; p89), and the second

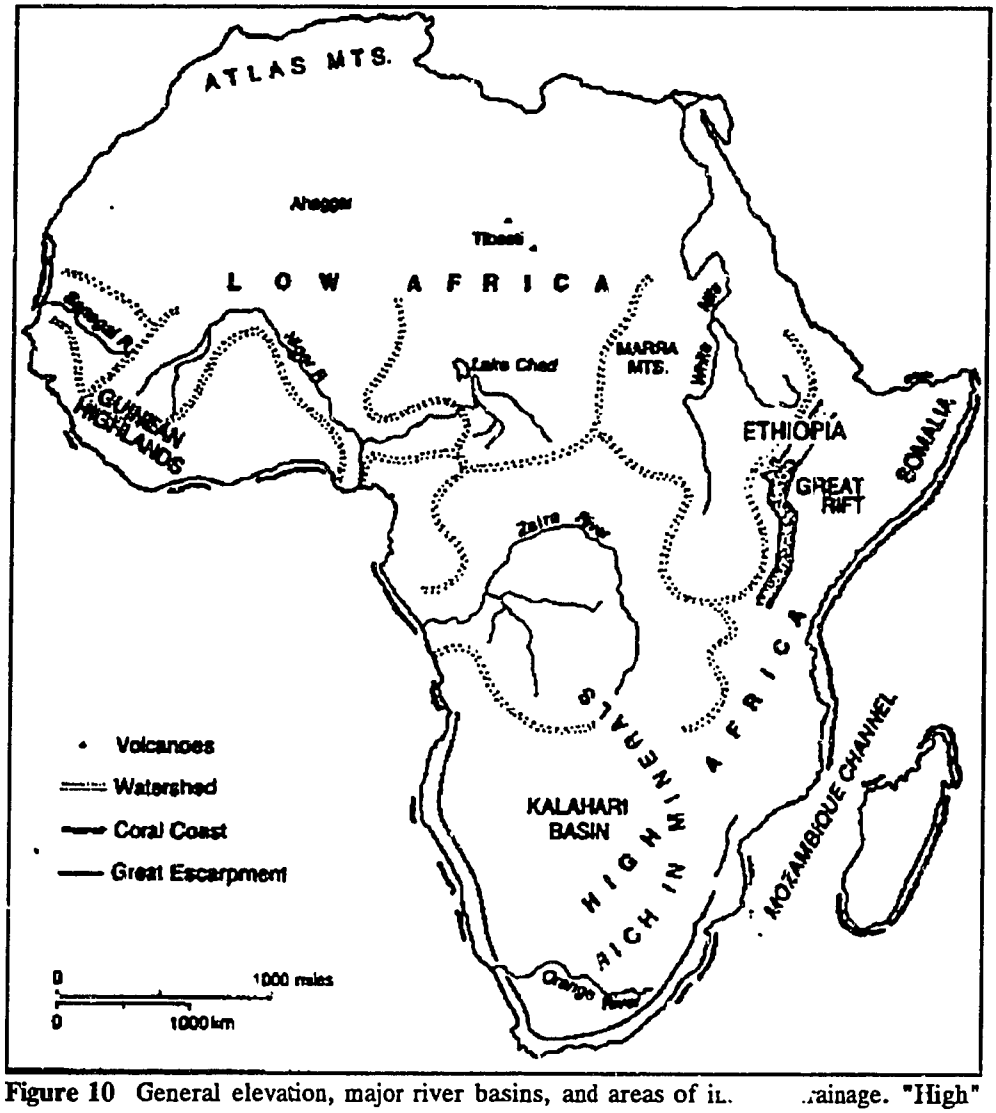

Figure 10 General elevation, major river basins, and areas of i.. ..rainage. "High" Africa areas approximately 1000m above mean sea level. (from Lewis and Berry, 1988; p6).

largest in the world, exceeded only by the Amazon. The Zaire River drainage covers 3.6 million km^2 (Balek, 1983; p123, 88% of central Africa), and includes all of Zaire, all but the southwest of the Republic of Congo, south and central Central African Republic, and southeastern Cameroon. The Sanaga, Ntem, Benito, and Ogoué rivers form a basin that drains southern Cameroon, Rio Muni, and Gabon. Northern Central African Republic is drained by the Chari river that flows into Lake Chad. Northern Cameroon is drained by the Bénoué that flows west into the Niger River Basin, and by the Logone that flows north to Lake Chad.

Rivers within central Africa can be classified as multimodal or unmodal according to their peak flow regimes. Rivers at the equator tend to have bimodal peak flows corresponding to the rainfall maxima in February and March south of the equator, and July and August north of the equator. The Zaire River is a classic example of a bimodal peak flow river as it drains areas in both hemispheres. Rivers gradually transform to a unimodal peak flow pattern as they drain primarily from one but not both hemispheres, the Sanaga River in Cameroon for example.

Water balance (precipitation = runoff + retention, retention = evapotranspiration + interception) is positive throughout most of the year. Water stress does occur, however, in all but a few locations with central Africa, its length and severity increasing with latitude. Water stress at some time during the year is considered a fundamental reason that, although

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floristic diversity is comparable, the total flora of African moist forests is less than that of central and south American, and southeast Asia (Richards, 1958).

Retention is almost exclusively water recycled back into the atmosphere by evapotranspiration (Brinkman, 1983; p 92). Water balance statistics for central Africa are approximate because of "the lack of a representative distribution of meteorologic and hydrologic stations" (Brinkman, 1983; p 92). Water balance is controlled by "the amount of annual rainfall and its spatial/temporal distribution patterns; the exposure of the drainage basin to orographic units such as steep-slope mountains, mountain foot-hill zones, and lowlands; and the abundance of swamps, wetlands, seasonally flooded forests, and lakes in between the respective orographic units" (Brinkman, 1983; p92). central Africa, when compared to other continuously moist tropical regions, is orographically homogenous and has a higher retention capacity than any Amazonian or Asian system (Figure 9: Brinkman, 1983; p93). Even though central Africa is characterized by heavy recycling and relatively low runoff, rivers like the Zaire and its major tributaries (Table 2) have substantial hydropower potential (Lewis and Berry, 1988; p141, Balek, 1977; p107). However, insufficient information is available on the hydrology of the major rivers within central Africa to allow rational use of these waters (Lewis and Berry, 1988; p138, Balek, 1977) for irrigation and energy production.

The impact of global warming and regional land transformation on the hydrology of central Africa is difficult to assess. According to some of the most recent global circulation model simulations, an increase in global temperature may result in increased precipitation within central Africa (Mitchel et al., 1990). Conversely, based on models of the impact of deforestation on rainfall in the Amazon, large-scale deforestation in central Africa is likely to result in a decrease in precipitation (Lean and Warrilow, 1989) within the region. Similarly, even though global warming may result in an increase in precipitation within central Africa as a region, an increase in convective rainfall is likely to increase the intensity of local rain storms at the expense of more widescale persistent rainfall associated with larger scale disturbances (Noda and Tokioka, 1990). The intensification of local rain storms would undoubtedly increase local runoff and stream flows, but may be balanced by a decrease in stream flows in other regions.

The complex feed back interactions of rainfall, evapotranspiration, vegetation, soil carbon content, topography, land use, soil surface temperature, and runoff makes it almost impossible to predict the simultaneous impacts of global warming and deforestation, on the hydrology of central Africa.

Sound empirical data collected over the long term from a set of hydrological stations distributed throughout the region would be invaluable in deciphering the conflated impacts of land transformation and global warming on the regions hydrological system.

Table 2 Mean annual discharge of the Zaire river and selected tributaries

River	m^3/s
Zaire	38,805
Sangha	2,471
Ubangi	5,936

(Balek, 1977)

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Vegetation

Vegetation's role as an 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 accumulates over a long period, but could be released into the atmosphere very rapidly, 2) vegetation can constitute a short-term sink for atmospheric carbon, 3) vegetation affects the albedo of the area, 4) combustion of vegetation releases 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 vegetation within central Africa are therefore important to our understanding of the contribution of vegetation to regional and local climate change.

Past distribution of vegetation

As the climate of central Africa oscillated during the late Pleistocene (Table 1), so too did the distribution of vegetation (Hamilton, 1983; p159, Moreau, 1963; Livingstone, 1975). Extrapolating from work by Kendall (1969), who worked on pollen cores from Lake Victoria, and that of Moreau (1960) and Livingstone (1975), it appears that forest may have disappeared from much of central Africa prior to the end of the last glacial period (12,500bp). Only those areas of orographic precipitation within central Africa remained mesic (moist). These Pleistocene refugia sustained and preserved the plants that depend on a constant hot (27°C), humid (80%), rain-drenched (1800mm yr^{-1}) environment. As the last ice age gradually receded, rainfall increased, and the boundaries of the refuge forest in Guinea, Gabon, and eastern Zaire expanded to fill the vast central basin. That the central region [of central Africa] was recently

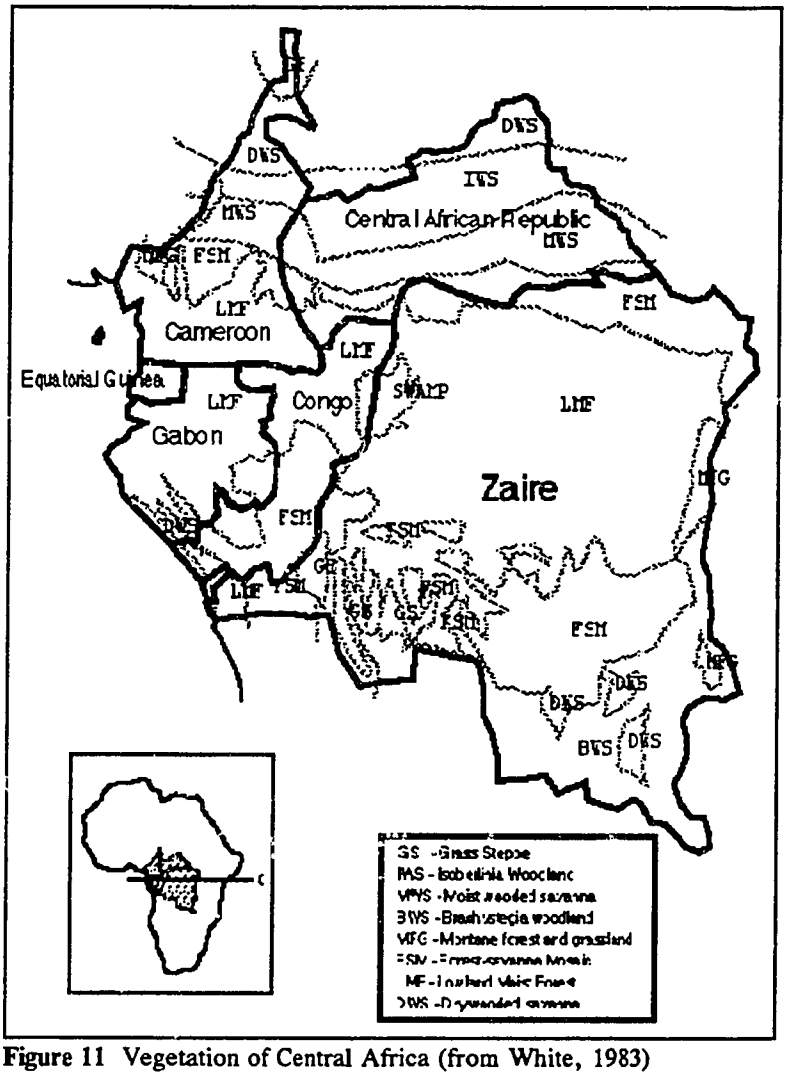

Figure 11 Vegetation of Central Africa (from White, 1983)

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(in a geological sense) savanna scrubland is reflected by its much lower variety of plants and animals compared to the Pleistocene refuge areas.

Tropical evergreen forest (moist forest) was "more extensive ... during the early part of the Holocene" (Livingstone, 1975; p270) reaching its zenith around 8,000 ybp. Subsequent drier conditions are assumed to have resulted in a gradual retreat of the moist forest boundary. However, the pollen "record of the past few millennia is complicated by changes in human land use that might produce vegetational changes similar to a dry climate. Agricultural deforestation since the beginning of the iron age might be mistaken for a drought-induced retreat of forest in the pollen record, but it should not be associated with falling lake-water level" (UNESCO, 1978; p 71). Agriculture enhances run-off rather than reduces it, thus lake level would be expected to rise as a consequence of agricultural deforestation. As the lake sediments, from which pollen counts are established, indicate falling water levels during this period the relative contributions of a desiccating climate, and human agricultural practices to the presumed retreat of the forest boundary are unclear.

While advent of agriculture during the neolithic (10,000-5,000 ybp) have confounded palaeopalynological studies of the region, human land-use is also almost certainly responsible for present reduction of forest cover throughout central Africa. Hall and Swaine (1981) believe that much, if not all, forest within central Africa has at sometime been cleared by humans. In addition, many areas that were once forest, and climatically could still support forest, such as the Teke plateau in the Congo and much of southwestern Zaire, are now anthropogenic savanna-woodland under bush-fallow agriculture. Thomas (pers comm.) notes that with rapid urbanization and the abandonment of agriculture in rural areas in the Congo, parts of the Teke plateau are rapidly reforesting. Although all wooded areas could potentially be converted to permanent savannas, it is the open woodlands that are most susceptible to such transformation. Clearing of open forest for agriculture, followed by burning at >1 year intervals has very effectively prevented reestablishment of woodlands in large areas of central Africa. Burning of wooded-savannas occurs for various reasons: clearing for agriculture, hunting, and pest control.

Present distribution of vegetation

"Although the flora of tropical Africa as a whole is considered relatively well studied, floristic studies and inventories of tropical forests within central and west equatorial African states of Angola, Burundi, Cameroon, Central Africa Republic, Republic of Congo, Rwanda, and Zaire are still incomplete, and the floras are known better physiognomically than floristically" (Kendrick, 1989; p205). Thus, while we may know, in very general terms, how the flora of central Africa are distributed, we have very little empirical, quantitative, up-to-date information with which to accurately map vegetation composition and distribution throughout the region.

The main vegetation types used to characterize the vegetation in the UNESCO/AETFAT/UNSO map are listed in Table 4 (White, 1983, p46). "Broadly speaking, there are two major types of rain forest within the Guineo-Congolian phytochorion. The mixed moist semi-evergreen forest of central Africa are characteristic of the vast Zaire River Basin, which measures about 1300km in diameter, sprawls over an area of some 3.46 million km^2" (Kendrick, 1989; p207) and extends into all the nations [of central Africa].

Table 3 Characteristics of main vegetation types used in UNESCO *Vegetation map of Africa* (White, 1983; p46)

Formations of regional extent:	
1. Forest	A continuous stand of trees at least 10m tall, their crowns interlocking
2. Woodland	An open stand of trees at least 8m tall with a canopy of 40% or more. The field layer is usually dominated by grasses
3a. Bushland	An open stand of bushes usually between 3 and 7m tall with a canopy cover of 40% or more
3b. Thicket	A closed stand of bushes and climbers usually between 3 and 7m tall
4. Shrubland	An open or closed stand of shrubs up to 2m tall
5. Grassland	Land covered with grasses and herbs, either without woody plants or the latter not covering more than 10% of the ground
6. Wooded grassland	Land covered with grasses and other herbs, with woody plants covering between 10% and 40% of the ground
7. Desert	Arid landscapes with a sparse plant cover, except in depressions where water accumulates. The sandy, stony or rocky substrate contributes more to the appearance of the landscape than does the vegetation
8. Afroalpine	Physiognomically mixed vegetation occurring on high mountains where night frosts are liable to occur throughout the year
Transitional formations of local extent	
9. Scrub forest	Intermediate between forest and bushland or thicket
10. Transition woodland	Intermediate between forest and woodland
11. Scrub woodland	
Edaphic formations	
12. Mangrove	
13. Herbaceous fresh-water swamp and aquatic vegetation	
14. Halophytic vegetation	
Formation of distinct physiognomy but restricted distribution	
15. Bamboo	
Unnatural vegetation	
16. Anthropogenic vegetation	

"The second major variant of rain forest - a hydrophilous [moisture loving] evergreen rain forest of high endemism - is localized in these countries along the humid coast of Cameroon... [Equatorial Guinea, Congo, Gabon and Nigeria] where rainfall averages up to 3000mm per year. On the peripheries of the two major rain forest types and in transition zones, a drier semi-evergreen forest extends into .... Angola and the Shaba region of Zaire" (Kendrick, 1989; p207) and north into the Central African Republic and northern Cameroon. Transition zone vegetation is considered derived from moist closed forest (FAO-UNEP, 1981; p 31), and is assumed to be largely anthropogenic in origin.

Table 4 Major vegetation zones within Central Africa

	Sudanian	Transition	Guineo-Congolian	Transition	Zambezian
Congo			100%		
Gabon			100%		
E.Guinea			100%		
Zaire		10%	55%	20%	15%
Cameroon	20%	35%	35%		
C.A.R.	45%	50%	5%		

10% of Cameroon lies within the Sudanian-Sahelian transition zone

According to the UNESCO/AETFAT/UNSO vegetation map by White (1983) the Guineo-Congolian regional center of endemism, and the transition or mosaic zones north, east, and south of the Guineo-Congolian region that become the Sudanian and Zambezian phytochoria (region of plant taxa distribution) dominate the landscape of central Africa (Figure 11; Table 3). These zones like all those described in White (1983) are a combination of physiognomic (growth form/architecture) units based on the characteristic structure of the vegetation such as height, density, etc., and chorological units that correspond to the geographic boundaries of floral taxa. Each major phytochorion within the classification has more than 50% of its species confined to it and contains more than 1000 endemic species. The White (1983) classification evolved from the Yangambi 1956 classification (Aubreville, 1965) and from that of Greenway (1973) (see FAO-UNEP, 1981; p 24; White, 1983; p44).

Total area of central African forest, estimated from the 1983 UNESCO/AETFAT/UNSO vegetation map and reported by FAO-UNEP (1981; excluding Angola) is 2.8 million km^2 (Table 5). This includes 1.7 million km^2 (80% of tropical Africa) of humid closed forest excluding fallows within the Guineo-Congolese phytochorion (FAO-UNEP, 1981; p40 - closed broadleaved forest), and 1.1 million km^2 (23% of tropical Africa) of forest-savanna mosaic within the Guineo-Congolese, Sudanian and Zambezian phytochoria (FAO-UNEP, 1981; p 45 - open broadleaved forest). In contrast, a recent AVHRR study by Millington et al. (in press) estimates the forest area in central Africa to be 3.17 million km^2. Table 5 allows only very limited comparison as forest was categorized somewhat differently in each study, and the accuracy of the White map was never verified, and the veracity of the Millington study is questionable given the spatial and spectral resolution of the data used. Approximate areas of vegetation classes within central Africa as delimited on the 1983 UNESCO/AETFAT/UNSO map are shown in Table 6.

Species composition and distribution within major regions

White (1983) divided the Guineo-Congolian phytochorion into rain forest, short and scrub forest, swamp and riparian forest, transition woodland, elfin thicket, edaphic grassland, secondary and wooded grassland, and transitional rain forest. These major categories are

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Table 5 Forest extent in Central Africa

Country	Closed Forest Area km²	Open Forest Area km²	Fallow Area km²	All Area km²
Cameroon	179,200	77,000	16,900	317,200
C.A.R.	35,900	323,000	41,000	399,900
Congo	213,400	?	11,000	224,400
Eq. Guinea	12,950	?	11,650	24,600
Gabon	205,000	750	15,000	220,750
Zaire	1,056,500	718,400	184,000	1,958,900
Total	1,702,950	1,119,150	323,650	3,145,750

(FAO-UNEP, 1981)

Country	Forest Area km²	Woodland Area km²	Agric-Fallow Area km²	All Area km²
Cameroon	205,871	122,727	102,440	431,038
C.A.R.	102,018	321,440	198,609	622,067
Congo	181,798	69,294	56,543	307,635
Eq. Guinea	19,287	633	1,581	21,501
Gabon	144,908	21,763	77,094	243,765
Zaire	897,002	1,084,415	208,831	2,190,248
Total	1,550,884	1,620,272	645,098	3,816,254

(Millington et al., in press)

further divided into subcategories, for example rain forest is subclassified into: hydrophilous coastal evergreen rain forest, mixed moist semi-evergreen rain forest, single dominant moist evergreen, semi-evergreen rain forest, and drier peripheral semi-evergreen rain forest. Given the mapping scale and the interdigitated nature of natural vegetation formations, vegetation categories are usually represented under a range of conditions. For example, Guineo-Congolian rain forest appears as mapping units (1a) wetter rain forest, (2) drier rain forest, (3) mosaic of 1a and 2, (8) swamp forest, (9) mosaic if 1a and 8, (11a) mosaic of 1a and secondary grassland, (12) mosaic of 1a, Isoberlinia woodland and secondary grassland, (13) mosaic of 1a secondary grassland and montane elements, and (14) mosaic of 1a, Zambezian dry evergreen forest and secondary grassland.

It is clear that the vegetative formations within central Africa are likely to vary widely in their roles as carbon reservoirs, carbon sinks, and sources of trace gas emissions. Yet, we have very little quantitative data on the extent and distribution of each vegetation category, let alone data on biomass density, rate and mode of transformation (clearing or burning), trace gas emissions on combustion, and associated soil chemistry. One of the most difficult to determine characteristics of any forested vegetation category is the extent of natural or anthropogenic disturbance and thus the relative successional status of a given area of forest. This is particularly important when attempting to assign a biomass density estimate, as forest age and biomass are positively correlated. Similarly, to assess whether a given area of forest is a carbon sink or in equilibrium with the atmosphere, it is important to

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Table 6 Vegetation composition of Central Africa (from 1:5,000,000 scale 1983 UNESCO/AETFAT/UNSO Vegetation Map)

	Cameroon	CAR	Congo	Gabon	Guinea	Zaire	TOTAL
Area $km^2 x 10^3$	475	623	342	258	28	2267	407.9
Vegetation % Cover	%	%	%	%	%	%	%
1a	26	-	21	57	-	27	23
2	13	6	26	15	-	8	11
3	4	-	-	4	100	-	1
4	-	-	-	-	-	1	<1
8	3	-	24	4	-	7	7
9	-	-	-	-	-	9	4
11a	28	46	29	19	-	27	30
19a	3	-	-	-	-	2	2
21	-	-	-	-	-	1	1
25	-	-	-	-	-	16	8
27	8	42	-	-	-	-	9
29a	8	6	-	-	-	-	2
31	-	-	-	-	-	3	2
33	2	-	-	-	-	-	<1
37	-	-	-	-	-	<1	<1
43	<1	-	-	-	-	-	<1
45	-	-	-	-	-	<1	<1
60	-	-	-	-	-	2	1
62	1	-	-	-	-	-	<1
63	2	-	-	-	-	-	2
75	<1	-	-	-	-	-	<1
77	1	-	-	1	-	<1	2
	100	100	100	100	100	100	100
# Vegetation classes	14	4	4	5	1	14	22

Key to Vegetation types

Guineo-Congolian lowland rain forest, wetter types (1a); Guineo-Congolian rain forest, drier types (2) Mosaic of 1a and 2 (3); Transitional rain forest (4); Swamp forest (8); Mosaic of 8 and 1a (9); Mosaic of rain forest and secondary grassland (11a); Undifferentiated montane vegetation (19a); Mosaic of Zambezian dry evergreen forest and wetter miombo woodland (21); Wetter Zambezian miombo woodland (25); Sudanian woodland with abundant Isoberlinia (27); Sudanian undifferentiated woodland (29a); Mosaic of wetter Zambezian woodland and secondary grassland (31); Mandara plateau mosaic (33); Acacia polycantha secondary wooded grassland (37); Sahel Acacia wooded grassland and deciduous bushland (43); Mosaic of East African evergreen brushland and secondary Acacia wooded grassland (45); Edaphic and secondary grassland on Kalahari Sand (60); Mosaic of edaphic grassland and Acacia wooded grassland (62); Mosaic of edaphic grassland and communities of Acacia and broad-leaved trees (63); Herbaceous swamp and aquatic vegetation (75); Mangrove (77)

know what proportion of the trees are fast growing successional species.

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Central African forest as a mosaic of mature and secondary forest

All of the forests within central Africa are composed of a complex mosaic of mature (shade tolerant) and secondary (heliophilous;light demanding) forest patches. The size of the patches depends on the extent of the disturbance. Natural disturbances that result from limb and tree falls, and river bank subsidence are typically 200-800m^2 in area (Oldman, 1978). If a gap is smaller than 500m^2, pioneer species such as Musanga cecropioides and *Trema orientalis* do not become established; instead expansion of the remaining forest crowns, and growth of suppressed saplings fill in the gap. Gaps associated with human disturbance are usually much larger (>0.5ha). If gaps are sufficiently large, fast growing heliophilous species rapidly colonize the area, germinating from the large viable seed bank that usually exists beneath mature forest. Unlike mature forest species that are often ballistically dispersed and have large seeds that germinate rapidly, pioneer species such as *Musanga cecropioides* tend to have small animal-dispersed seeds that can remain viable in the soil for some time. "This is a strategy evolved to utilize a niche that is rare in space and short in duration in natural forest" (Hamilton, 1983; p172). Most pioneer species are relatively short-lived (*Musanga cecropioides* becomes dominant 3 years after gap formation, reaches its optimum after 8-10 years and senesces after 15-20 years), often form monodominant stands, and because they are shade intolerant, are usually unable to regenerate under their own canopy. Most gaps are transient features on the landscape though elephant browsing, repeated human resource extractions, and establishment of dense patches of *Marantaceae* can maintain gaps in a regressive stage of succession where herbaceous material and saplings of pioneer tree species continue to dominate.

Évrard (1968; p96-101) divided secondary vegetation into old and young stages. Species characteristic of young secondary vegetation include herbaceous plants such as *Afromomum spp.*, and *Ataenidia conferta*, and trees such as *Anthocleista spp.*, *Musanga cecropioides*, *Macaranga spp.*, and *Myrianthus arboreus*. Old secondary forest that eventually becomes indistinguishable from mature forest is dominated by semi-heliophilous species that can reach a height of 35m and are moderately long-lived.

Given that the forests of central Africa are composed of a mosaic of mature and secondary forest patches, the composition of a given area of forest will be determined by the frequency and extent of gap formation. Given the relatively small size of natural gap formation (Hartshorn, 1978 - Costa Rica; Hart, 1985 - Zaire), human land-use is likely to be the most significant source of large gaps within central Africa. The proportion of secondary forest within a given area is likely to be a concave function of human population density; that affects the size of gaps created and clearing revisitation period (Wilkie and Finn, 1988). Secondary forest is likely to be maximal at median population densities, reaching minima at low and high population densities.

Edaphic grasslands and secondary/wooded grasslands

Just as forested areas within central Africa are typically a mosaic of mature and secondary vegetation that results from human disturbance, the open woodlands and grasslands of the region show characteristic signs of anthropogenic origin. Two distinct forms of grassland occur within the Guineo-Congolian phytochorion, edaphic grasslands and secondary grasslands. The former occur as small patches surrounded by forest on hydromorphic soils

(White, 1983; p84, Kellogg and Davol, 1949; p51), whereas the latter, derived from cultivation and burning of the forest, are considerably more extensive (White, 1983; p84).

Secondary grassland occurs as a mosaic with small degraded patches of the original forest. Grassland is often 2m or more tall, and is usually burned at least once a year. Secondary grasslands are widely distributed within the transition zones of the Sudanian and Zambezian woodlands. Small patches of secondary grassland also occur deep inside the Guineo-Congolian region. Anthropogenic grasslands that are maintained as such by regular burning will store considerably less carbon (biomass + soil) than the woodlands that they replace. Similarly, grass fires alter the seasonal carbon content of the atmosphere, and result in ozone pollution and acid rain, both of which are likely to alter the floristic productivity of the area. Evidence from Nigeria (Charter and Keay, 1960) and Ghana (Hall and Swaine, 1976) suggests that if fire is excluded from sparsely wooded areas and secondary grasslands, and if propagules are available, forest species will invade and the area will revert to more dense forest.

Country based estimates of ecosystem area, deforestation, and reforestation

Although quantitative data on the distribution and extent of vegetation types within each country of central Africa are incomplete, several attempts have been made to describe

Table 7 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; p306; IIED, 1988; Myers, 1989; World Bank, 1989

the areal extent of forest. World Resources Institute compiled information from a range of primary and secondary sources to produce estimates of present extent of forest and total area deforested within central African countries. These data are shown in Table 7. Given the margin of error associated with the information upon which the table is based, all values should be considered only as qualitative assessments of forest area and extent of deforestation within each country. More recent estimates of the area of specific ecosystems within each central African country were generated from AVHRR NDVI data (Millington et al. in press). Although these data are presented for comparison in Table 8, no confidence measures are

available to establish the accuracy of these figures. The reader should therefore treat all estimates of forest extent, and area of specific ecosystems to be qualitative rather than quantitative in nature.

Table 8 Area estimates for ecosystems within Central African countries

	Biome Area in km^2						
	Cameroon	CAR	Congo	Gabon	Eq. Guinea	Zaire	Total
Grassland	2,687	105	0	422	0	14,122	17,336
Wooded grassland	3,540	105	23,396	7,377	211	6,956	41,585
Shrubland	0	0	1,432	4,005	0	2,002	7,439
Bushland	11,751	790	6,481	4,427	105	26,243	49,797
Low woody mosiac	685	1,212	0	1,475	738	1,001	5,111
Woodland	122,727	321,440	69,294	21,763	633	1,084,415	1,620,272
High woody mosiac	102,440	198,609	56,543	77,094	1,581	208,831	645,098
Forest	205,871	102,018	181,798	144,908	19,287	897,002	1,550,884

Source: Millington et al., in press

To demonstrate further the range of uncertainty associated with estimates of forest extent within central Africa, information for each country is presented.

Cameroon

Cameroon covers 465,000 km^2. A limited forest inventory was carried out in 1967, but none since (Hazlewood and Stotz, 1981; p.35). "Remarkably there is a dearth of sound information on the present status and survival outlook for Cameroon's forests -- all the more regrettable in that they constitute well over two percent of the biome within Africa" (Hazlewood and Stotz, 1981; p.35). Estimates of Cameroon's current land uses vary significantly. Estimates of the remaining forest area, for example, range from 65,000 - 256,200 km^2. This suggests that from half to a quarter of the original forest resource remains (Hazlewood and Stotz, 1981; p.35). One estimate concludes that of roughly 320,000 km^2 of original forest (448,000km^2 according to WRI, 1990), only about 70,000 km^2 is undisturbed productive closed broad-leaved forest, whereas the balance has either been logged-over (100,000 km^2), converted to agriculture (60,000 km^2), is inaccessible (parks or reserves) or unproductive (60,000 km^2), or is productive but in mixed forest-grassland tree formations (30,000 km^2) (WRI, 1985; p.54). Hazlewood and Stotz (1981, p32) estimate that some 70,000 km^2 of rangeland exist in northern Cameroon, much of which has been very heavily grazed and burned for many years. It is generally assumed that this grassland has been derived from the clearing of forest for the planting of crops (Hazlewood and Stotz, 1981; p.21).

FAO reports that the total area of closed forest was reduced by 10,000 km^2 between 1976 and 1986 (Lewis, 1989). It is estimated that by 1992, almost 50% of productive forest will have been cut over at least once (IIED, 1988; p.27). In the southern half of the country, about 20% of the tropical moist forest (40,000 km^2) is thought to be severely

degraded (IIED, 1988; p.26). Current estimates of deforestation continue to vary widely. WRI (1990) states a loss rate of 1,000 km^2/yr for closed forest, and 900 km^2 for open forest. FAO (1981) estimates that between 1981 and 1985, 800 km^2 of closed forest and 300km^2 of open forest were cleared annually. IIED (1988; p27) puts the loss of closed moist forest at 1,500 km^2/yr out of 4,000-5,000 km^2 cleared yearly for agricultural purposes. IUCN takes a middle position, putting closed moist forest loss at 900-1,100 km^2 annually (IIED, 1988; p.27). Myers arrives at an estimate of 2,000 km^2/yr (Myers, 1989).

Overall, estimates of deforestation exceed the annual revegetation of the remaining forest, thus resulting in a large annual net loss of forest resources (World Bank, 1989; p.61)

Reforestation Plantations in the Cameroon are of modest magnitude, although they were undertaken as early as the 1930's (IIED, 1988; p.30). Ebaa (pers. comm.) reports government planting of some 280 km^2. FAO (1981) estimates that 180km^2 of plantations existed in 1980, and that 70km^2 were planted between 1981 and 1985. Most are not maintained, resulting in a tremendous waste of money and effort (IIED, 1988; p.30). Only about 3% of the area that was deforested has been reforested over last decade (Horta, pers. comm.).

CAR

The Central African Republic covers 623,000 km^2. Changes in forest cover and resources are difficult to evaluate due to a lack of forest inventories, the last one having been carried out by Centre Technique Forestier Tropical (CTFT) between 1960-68 (Pinglo, 1988). However, Poulin Theriault, a Quebec-based subsidiary of Tecsult, won a contract to carry out an inventory of the central African Republic rainforest, financed by the World Bank. The three main tasks are to itemize the flora of the dense forest in the south west, establish a tree farming pilot project near Bangui, and improve the administration of natural resources (Economist Intelligence Unit, 1991; p.34). The status of this inventory is unknown.

Estimates of the Central African Republic's past and present forest cover differ considerably in important elements, no doubt partially because of differing methods of classification. One estimate concludes that there are 357,000 km^2 of forest and savanna woodland, but only 34,000 km^2 of true dense forest, all in the south of the country bordering Congo (Worldmark, 1988; p.58). Sudano savanna and dry woodlands cover approximately 90% of the Central African Republic's territory (World Bank, 1989; p.6).

The Central African Republic has lost some 550 km^2/yr between 1981-1985, the equivalent of an annual loss of 0.2% per year (FAO, 1981). Graham et al. (1990) estimated that 630 km^2 would be lost every year up to 2001, but deforestation has reportedly been increasing since 1986 when a major new road opened up (Carroll, pers. comm.).

Reforestation Plantations are virtually absent from the Central African Republic.

Gabon

Gabon covers 257,700 km^2, the majority of which remains under forest cover. Although 60,000 km^2 of Gabon's tropical moist forest have been inventoried, knowledge of

the forests of Gabon is still very scanty, with the exception of the coastal forest dominated by okoume (IIED, 1988; p.13). The majority of inventories were carried out at very low sampling intensities (0.2-0.3%) in the 1960's, and concentrated on the few species deemed exploitable at the time. The lack of knowledge of the composition and ecology of the forest outside the coastal zone can be an important constraint to the development of forest management systems (IIED, 1988; p.13). One of Gabon's forest inventory estimated 300 million m^3 of timber, 100 million m^3 of which is okoume, the principal wood now being logged (U.S. Dept. of Commerce, 1987; p.9).

As in other central African nations, estimates of moist forest extent vary. IIED (1988; p.14) estimated original forest extent to be 209,600 km^2 whereas WRI (1990) set this figure at 266,000km^2. Current forest extent is estimated at 173,000km^2 (WRI, 1990). There is little doubt that forest continues to cover between 70-80% of the country (Myers, 1989). The sparsely populated nature of the country (4.3 people/sq km) is certainly partially responsible for the magnitude of remaining forest cover, but it should be noted that a great deal of logging has occurred. IIED (1988) reports that the majority of Gabon's forests have already been logged at least once (IIED, 1988; p.13) and that only 79,140km^2 of unlogged forest remain. Myers (1989) estimates that 40% of forests have been logged (albeit lightly), and that an additional 35% have been made accessible by railway and will be logged by the year 2000.

Approximately 15% of the area of Gabon is covered by savanna (Nicoll and Langrand, 1986; p10), most of which is of anthropogenic origin. Human land use in the area dates back to the Neolithic (Nicoll and Langrand, 1986; p25). Gallery forest is present throughout the country and shrub formations prove that the forest will regenerate once activities which degrade the forest are halted (Nicoll and Langrand, 1986; p25).

Estimated deforestation rates are within a relatively constrained range. FAO (1981) estimates a loss of 150 km^2/yr for closed forest between 1981 and 1985, with no data available for open forest. This is equivalent to about 0.1% of 1980 closed forest area. Myers (1989) estimates an annual loss of 600 km^2 for 1989.

Reforestation Over time, 250-300 km^2 of okoume have been planted, with varying degrees of success. Approximately 150 km^2 seem to have retained their value, the remainder having gone to waste because of plantation failure or lack of maintenance. An additional 100 km^2 are planted each year (IIED, 1988; p.16).

Equatorial Guinea

Equatorial Guinea is a country of 28,050 km^2. No national forest inventory has been undertaken and surveys from the colonial period have never been updated (Hanan, 1989). FAO (1981) estimates 12,950 km^2 of closed forest and virtually no savanna woodland. WRI (1990) estimates that 50% of Equatorial Guinea's forests have been lost over time. The nation is estimated to have lost only 30 km^2 per year of closed forest during the 1980's, the equivalent of 0.2% of its closed forest. Open forest data are not available.

Congo

Congo is a country of 341,500 km^2, and encompasses roughly 10% of Africa's dense forest (World Bank, 1990; p.1). Estimates of Congo's present forest cover differ. Congo is estimated to contain between 100,000 km^2 (Myers, 1989) and 174,000km^2 (WRI, 1990) of forest.

Deforestation estimates vary considerably for the Congo. FAO (1981) estimates 220 km^2/yr of closed forest were lost between 1981 and 1985. No information is available for open forest. Myers (1989) estimated a loss of 200km^2 for 1980, and 700 km^2 in 1989.

Reforestation In the Congo reforestation appears significant, and is concentrated in the southern part of the country. Private investors are establishing tree plantations, now totalling more than 250 km^2 (Cailliez, 1990; p.6). Another source estimates some 340 km^2 have been reforested in savanna areas over the past 40 years, and 130 km^2 in forested areas (Makelola, pers. comm.).

Zaire

Zaire is a country of 2.267 million km^2, and encompasses more than 50% of central Africa. Zaire contains over half of Africa's rainforests, and about one-tenth of the global tropical moist forest biome (WRI, 1985; p.1). Given the size of the country, it is not surprising that considerable uncertainty surrounds its forest resources. As Myers (1989) notes, "despite its significance, Zaire appears to have produced only rudimentary statistics on its forest estate, less than any other African country." It is clear that the more fertile soils at the eastern edge of the basin have been converted into tea and coffee plantations, or other cultivated areas. In the central basin, fertile soils have been cleared to establish extensive rubber and oil palm, as well as coffee plantations. Rice cultivation has been developed in the areas of the swamp forests (IIED, 1988b; p.34).

It has been estimated that about 1 million km^2 of forest cover was present in Zaire in 1980 (estimates ranged from 750,000km^2 to 1,774,900 km^2). A recent mapping project, combining aerial photography with satellite imagery, indicates that forest cover of all kinds still amounts to over 1 million km^2 (Myers, 1989, citing Roberts, pers. comm.). This does not mean, however, that forest conversion has occurred over the past decade. Kendrick (1989) suggests that no more than 700,000km^2 of remaining forest is primary. IIED (1988b) estimates that the area of relatively undisturbed or mature forest in the central basin could amount to about 850,000 km^2, although IUCN has estimated that only 50% of the primary forest cover in the Zaire Basin remains (IIED, 1988b; p.34). Aside from closed and relatively mature forest, FAO (1981) estimated that approximately 718,400 km^2 of open forest were present in 1980.

In addition to forests, large areas of southern Zaire are covered by fire-climax savanna (Newberg, pers. comm.). The original forest was cleared long ago and repeated burning has prevented the succession of these areas back into forests (Ames, 1981; p.II-6).

FAO (1981) estimates that between 1981 and 1985, 1,820 km^2 of closed forest and 1,880 km^2 of open forest were lost per year. This is the equivalent of 0.2% of the country's estimated forest cover in 1980. Myers (1989) concludes that some 4,000 km^2 were cleared in 1989.

Reforestation Plantation establishment efforts have been relatively extensive in Zaire. Up to 1960, 400 km^2 were reportedly planted, mostly within designated forest reserves. An additional 200 km^2 were reportedly planted as of the early 1970's. However, it appears that most plantations have either disappeared or are very poorly maintained (Winterbottom pers. comm.; IIED, 1988b; p.51). FAO (1981) estimates that an annual average of 20km^2 of plantations were established between 1981 and 1985.

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2 LAND-USE CHANGE IN CENTRAL AFRICA AND ITS CONTRIBUTION TO GREENHOUSE GAS EMISSIONS

Fossil fuel combustion is the primary anthropogenic source of carbon dioxide. Anthropogenic land-use change, however, is the primary source of carbon dioxide emissions in many developing countries, including the six countries of central Africa (WRI, 1990; p.346). Understanding of the cycles of other radiative forcing (greenhouse) gases, particularly methane (CH_4) and nitrous oxide (N_2O), is much less advanced than it is for CO_2, and is virtually absent at the country or even regional level for Africa. It appears, however, that for CH_4 and N_2O biotic sources such as anthropogenic land use change (e.g. deforestation) and land-use practices (e.g. savanna burning, livestock rearing, and agriculture) are relatively more important to global cycles than are non-biotic or industrial sources.

Any evaluation of the role of central Africa as an actor in global climate change requires that the information and assertions presented are set in an appropriate context, particularly as in almost all cases, the data sets that are essential to the analyses are seriously inadequate. To provide such an appropriate context for this evaluation, the following items are discussed: 1) the carbon cycle; 2) methods for modelling global carbon; 3) problems with assessing carbon storage within the various vegetation communities that characterize central Africa; 4) previous studies that have attempted to assess biomass and carbon dioxide emissions within central Africa; 5) estimates of carbon inventory and emissions within the countries that comprise central Africa; 6) importance of other trace gas emissions; and 7) alternative futures for central Africa trace gas emissions. To provide a better understanding of the verity of existing data and of future data needs, survey methodologies and ources of analytical uncertainty are emphasized.

2.1 Important Components of the Carbon Cycle

The biotic carbon cycle in the Zaire Basin involves interactions between basin soils, vegetation, and atmosphere. After assessing carbon stocks, a holistic carbon accounting requires quantification of carbon emissions (deforestation, forest degradation, biomass burning, soil carbon losses) and carbon uptake (natural regeneration of cleared lands, plantations, forest maturation, CO_2 fertilization).

Deforestation and Forest Degradation

Estimated carbon dioxide emissions from deforestation are highly sensitive to estimates not only of land use change, but of previous land use cover. Given the uncertainty regarding past and present extent of primary forest, and the rate and extent of deforestation, resulting carbon loss estimates must be treated with caution. Houghton et al. (1987) conclude that 40% of the carbon released in Africa came from closed forest clearing, 33% from clearing of open forest or woodlands, and the rest from conversion of forest fallow agricultural land to permanent agriculture. Myers (1989) concludes that 59% of the carbon from deforestation is coming from primary forests.

Deforestation statistics, from which many estimates of carbon emissions are based, may be unable to incorporate effectively carbon emissions resulting from large-scale forest

degradation that stops short of absolute clearing. In Zaire, for example, it is estimated that forest degradation is roughly equivalent to 4,000 km^2 of deforestation, although this is not included in carbon statistics (Myers, 1989).

Early estimates of global biotic carbon releases estimated a range of 4 to 8 Gt (Gt = gigatons = 10^9 tons), but could not exclude the possibility of releases as low as 2 Gt or as high as 22 Gt (Woodwell and Houghton, 1977). More recent estimates of global emissions, based largely on 1980 deforestation data sets, have fallen into a narrow range: 0.9 - 2.5 Gt (Houghton et al, 1985), 0.4 - 1.6 Gt (Detwiler and Hall, 1988), and 0.7 - 2.0 Gt (Hao et al., 1989). The underlying datasets for all these estimates are very similar: land use conversion data from Myers (1980) and Lanly (1981), and biomass densities from Whittaker and Likens (1975), Brown and Lugo (1984), and Detwiler et al. (1985). Global estimates will continue to change, and probably narrow, as data interpretation techniques are agreed upon. In a recent review of the literature, for example, Houghton (1991) concluded that the range of estimates could be reduced to 1-2 Gt when recent refinements to the models are taken into account. Attempting to update the estimates to reflect 1989 data, however, resulted in an estimated emissions range of 1.1-3.6 Gt (Houghton, 1991; p99). The quality of the underlying data, however, remains quite uncertain, and so must emissions estimates. As Hall and Uhlig recently noted, "our results are only as good as the empirical data base, which is frustratingly incomplete" (Hall and Uhlig, 1991).

Estimates of CO_2 emissions from Sub-Saharan Africa reflect a considerable range. Because not all the emissions estimates are available on a country-specific basis, only the regional estimates are summarized here. Oak Ridge National Laboratories in their 1990 study concluded that sub-Saharan Africa emitted some 199.1 million tons of carbon dioxide in 1985 (Graham et al., 1990; p56). Hall and Uhlig, however, concluded that in 1980 Africa released between 92 and 113 million tons of carbon. Houghton (1989) uses a figure of 225 million tons.

Biomass Burning

At the continental level, fires are an important variable in the emissions of several greenhouse gases. Most of this burning takes place in the savanna, some in the forest. Hao et al. (1989) estimate that almost 1.7 Gt of carbon are emitted through just savanna burning. From a carbon cycle perspective, however, savanna burning (once the savanna is firmly established) is largely irrelevant since the released carbon is re-incorporated into savanna vegetation during the following growth cycle (Andrae, in press). 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 such encroachment is available.

Savanna and bushland burning consumes approximately 600 million ha of land every year, sometimes more than once a year (Goldammer, 1988). Savanna burning is the primary source of greenhouse gas emissions from Africa other than CO_2. Savanna fires in Africa are estimated to account for almost 90% of the total emissions from combined savanna and forest burning, and for almost 33% of the total global emissions from biomass burning (Andrae, in press). The importance of savanna burning in Africa reflects both the very large area of savanna coverage, and the proportion burned every year (some 75%) (Andrae, in press). In some areas of central Africa, the savanna is burned twice a year to control pests such as the

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tsetse fly (Newberg, pers. comm.).

The importance of biomass burning in the emissions of several greenhouse and other gases is reflected in Table 9. These figures are highly tentative, and reflect a very weak and small data set. In parts of Africa, the burning of forests and savanna is reportedly generating a large amount of ozone pollution and contributing to acid rain (World Bank, 1989b; p.5). Because of the limited area within which the burning often takes place, and the magnitude of the fires, the result is levels of atmospheric pollution that can exceed those found in industrialized regions elsewhere in the world. This is particularly the case for the precursors to smog, namely hydrocarbons, carbon monoxide, and oxide of nitrogen. These compounds can react with each other to form other pollutants, particularly ozone, a greenhouse gas. Surface ozone concentrations in excess of 40 ppb are frequently measured, especially during the dry season (Cros, et al., 1987). Similar levels have been found to cause temperate forest damage. In addition, ozone concentrations of 80-120 ppb are likely to occur under inversion conditions in some tropical regions, particularly during the dry season (Andrae, in press).

Table 9 Biomass burning as a percentage of global anthropogenic emissions

Trace gas	% Contribution
CO	11 - 36
CH_4	3 - 13
NMHC	15 - 52
NO_x	7 - 20
N_2O	4 - 15
Particulate Carbon	40-50

Source: Hao et al., 1989; Cachier, et al., 1985

Soil Carbon Losses

The fate of organic carbon levels following human intervention remains highly uncertain. Predicting soil carbon changes is difficult due to their dependence on several parameters including soil temperature, porosity, and structural stability (Cerri et al., 1991). Additional research is needed, however, since carbon storage in forest soils can be very significant. In a yellow Latosol in Central American rain forest, for example, organic carbon within 5 m of the surface was estimated at 240 t/ha, of which 50% was concentrated in first meter (Cerri and Volkoff, 1987).

Schlesinger (1986) summarized studies of the loss of soil carbon after conversion to agricultural use, finding that 19 studies of forest conversion yielded a 21% mean loss, with a range from 1.7 - 69.2%, while one study of tropical savanna conversion yielded an estimated loss of 46%. In the case of two West African sites, Brams (1971) concluded that cultivated soils had 40-60% of the soil carbon present in ferralitic soils under secondary forest. Other studies suggest that whatever losses result in the years immediately following land conversion, soil carbon levels have largely recovered within a decade (Cerri et al., 1991). Brown and Lugo (1990) go so far as to conclude that the conversion of tropical forests to pastures result in no measurable loss or accumulation of soil carbon.

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Regeneration and Plantations

Deforestation in South America has been so extensive in past decades that carbon uptake through natural regeneration may exceed ongoing deforestation levels. However, this is much less likely to be the case in a region such as central Africa where deforestation rates are increasing not decreasing. Accurate estimates are impeded by the absence of regeneration statistics, of reliable tree planting statistics, and by a lack of understanding of the carbon accumulation associated with different forms of regeneration and tree planting.

Forest Maturation

Brown and Lugo (1990) suggest that maturation of secondary forest may be, or provide the opportunity for, a significant carbon sink in large areas of the tropics. There are likely to be hundreds of millions of hectares of non-primary forest in central Africa, suggesting a considerable potential for carbon accumulation. There are no reliable data regarding forest type, forest age, and carbon accumulation rates, however, upon which to base an estimate.

CO_2 Fertilization

Although CO_2 fertilization has been hypothesized to be resulting in the uptake of gigatons of additional carbon annually, there are no data on the degree to which this is actually happening in tropical forests in general, much less those of central Africa (Heimann and Keeling, 1989).

2.2 Global Carbon Modelling Methods

Forests are estimated to contain 90% of the carbon stored in terrestrial vegetation, although quantitative estimates vary widely. Estimates today range from under 500 to more than 800 Gt (Post et al., 1990). Olson et al. (1983) estimated that carbon in vegetation has fallen from some 900 Gt prior to anthropogenic land clearing, about half of which was in tropical forests, to about 560 Gt today. Houghton et al. (1983) estimate that 90 to 120 Gt of carbon were released through land-use change between 1860 and 1980 alone. The plausibility of such significant declines is buttressed by estimates of original and present forest cover in selected central African countries (Table 7).

Inherent difficulties with global carbon modelling include: 1) the area of land cleared, degraded, allowed to recover, or reforested annually or over time is highly uncertain; and 2) the quantities of biomass carbon released or taken up through each of these processes are often climate and site-specific, and in general are poorly quantified.

Although estimates of deforestation and other land-use change rates continue to vary considerably over time (Houghton, 1989), estimates of carbon in biomass have been particularly volatile. The weighted averages used for tropical forest bookkeeping have ranged from 188
tons of carbon per hectare (t C/ha, Whittaker and Likens, 1975), to 124 t C/ha (Brown and Lugo, 1982) to 53 t C/ha (Brown and Lugo, 1984). Because the deforestation rate data set used by most modelers is the same, variation in estimates of carbon per hectare explain much of the range in global emissions estimates, which for 1980 ranged from 0.5 to 2.5 Gt/yr. (Houghton, 1989; p.54; Hall and Uhlig, 1991; p.118). Given rising deforestation rates,

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Table 10 Forest area and deforestation rate in Central Africa

Country	Forest Area (km^2) Original	Present All	Present Primary	Deforestation Rate (1989) (km^2/year)
Cameroon	220,000	164,000	60,000	2,000
Congo	100,000	90,000	80,000	700
Gabon	240,000	200,000	100,000	600
Zaire	1,245,000	1,000,000	700,000	4,000

Source: Myers, 1989; p.7 (compiled from many primary sources)

Houghton concludes that the figure for 1989 is likely to be 1.1-3.6 Gt/yr. (Houghton, 1991).

Two approaches are in use to assess the role of terrestrial biota in the global carbon cycle and budget, namely bookkeeping and carbon balance models.

Bookkeeping Models

Bookkeeping models take estimated deforestation, fallow to forest reversion, and reforestation; couple them with estimates of t C/ha lost or gained, and estimate CO_2 flows. Such modelling is represented by Houghton et al. (1983, 1985, 1987, 1991), Brown and Lugo (1982, 1984, 1989, 1991), Detwiler & Hall (1985, 1988), and Hall and Uhlig (1991). Carbon bookkeeping can be undertaken at the global, regional, or national levels, and can be undertaken with relatively sketchy data. Such bookkeeping has often failed to account for carbon lost other through than actual deforestation, e.g. losses associated with forest degradation, and for possible carbon uptake associated with "non-traditional" tree cover such as on-farm forestry, even as such cover grows in relative importance to natural forest inventories in many countries. More recent bookkeeping efforts have explicitly attempted to incorporate some of these variables, most particularly carbon lost through forest degradation. As shown by Houghton (1991), the incorporation of variables such as forest degradation into bookkeeping models can significantly affect conclusions regarding global carbon flows. Most global bookkeeping efforts conclude that tropical forests have been a significant source of carbon emissions for many years, although estimates of magnitude vary widely.

Carbon Balance Models

These models seek to balance the global carbon cycle based on the fact that all carbon released from the terrestrial biota has to end up in the atmosphere, in the oceans, or back in terrestrial vegetation and soils. Numeric values imputed to terrestrial vegetation carbon flows are therefore more dependent on assumptions regarding atmospheric and oceanic dynamics than on empirical terrestrial carbon flow data. Dynamic carbon models such as those of Goudriaan & Ketner (1984), and Esser (1987) are of necessity largely global in nature, but generally suggest that the terrestrial biota is a net sink for carbon. Dynamic

attempts to balance the global carbon budget, however, are subject to significant revision as new information becomes available (Broecker et al, 1979). It was historically assumed in such models, for example, that the oceans constituted the primary sink for fossil fuel and terrestrial carbon releases, but Tans et al. (1990) were unable to actually find evidence of air-sea interactions to support the hypothesis. They postulated that a lot of the "missing" CO_2 must be going into terrestrial ecosystems, and that temperate forests were already absorbing 2 - 3.4 Gt of carbon per year during the 1980's. To explain this, dynamic modelers tend to conclude that heightened atmospheric CO_2 levels are increasing forest growth rates, particularly in temperate and boreal zones, the so-called CO_2 fertilization effect. The hypothesis is hard to verify since increases in forest growth rates have not yet been observable in empirical stand data. Even many dynamic modelers conclude, however, that continuing large-scale deforestation already has or will reverse the direction of the carbon term by increasing the emissions term while reducing the forest area available for further fertilization (Bouwman, 1989; p.47, Heimann and Keeling, 1989).

2.3 Problems with Assessing Carbon Stocks and Flows in Central Africa

The accuracy and precision of both bookkeeping and carbon balance models is linked to the quality of the global data base regarding land-use change, plant biomass, growth and oxidation rates. Research into ecosystem biomass stocks and flows has expanded rapidly over the past decade. Research in Latin America has been encouraged by the high-profile nature of land use change in the Amazon. Research in Southeast Asia is encouraged by the detailed records of land-use change and advanced forest inventories available there (Dale et al., 1991). Central African biomass inventories and flow rates, however, remain highly uncertain. Ecosystem extent and land use change data remain uncertain, and forest inventories are largely absent, making carbon inventory and flow estimation difficult. As Myers notes "[I]n certain countries, e.g., Zaire, the data base is so meager that the result is no better than a partial assessment" (Myers, 1989; p.10)

Appraising Ecosystem Area and Distribution

Considerable uncertainty characterizes estimates of tropical ecosystem distributions, particularly in Africa (Bouwman, 1989; p.29). A recent attempt to quantify Sub-Saharan ecosystem distributions encountered major difficulties in integrating localized or regional estimates and maps due to inconsistencies in quality and coverage, and well as inconsistent soil and vegetation classifications (Graham et al., 1990).

Of particular relevance to carbon inventory estimation is the distinction between savanna vs. woodland/forest, and secondary vs. primary forest. Anthropogenic influence on Africa's forest has been very great, though it is difficult to quantify. Chevalier (1948) estimated that at least 66% of forest in the Ivory Coast had been modified by man. Hall and Swaine (1981) conclude it is unlikely that there is any forest in Africa which has not been subject to human interference. Numerous accounts by forest ecologists, searching for primary forests for their studies, mention signs of former human presence. Indeed, most savannas and grasslands in central Africa are unlikely to reflect the climatic or edaphic climax vegetation type. Instead, intentional clearing is thought to have created most of the savannas, and annual or even biannual burning prevents a return to forest cover (Goldammer,

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Secondary forests tend to have accumulated considerably less carbon than primary or virgin forests. With few exceptions, secondary forest extent now exceeds primary forest extent in most tropical countries, totalling over 6 million km^2 (Brown and Lugo, 1990) although the difficulty of distinguishing between primary and late secondary forest has been noted by many authors (Hamilton, 1983; p.176). Brown and Lugo (1990) report that secondary forest now accounts for almost 30% of global tropical forest area. Given the increasing rates of primary forest loss (WRI, 1990; Myers, 1989), and assuming that most areas revegetate rapidly, secondary forest may be expanding considerably more rapidly today, and may exceed 500,000 km^2 in the four central African countries listed in Table 10.

Current carbon cycle models generally assume that mature forest vegetation (i.e. vegetation where photosynthesis balances respiration and decay) prevails over large areas of

Table 11 Old and new estimates of above-ground biomass carbon for selected FAO-UNEP (1981) forest types within Central Africa

	FAO-UNEP Forest Type Tons Carbon/ha					
	Undisturbed		Logged		Unproductive	
	Old	New	Old	New	Old	New
Cameroon	130	141-188	125	136-209	46	64-104
CAR	na	na	135	146-222	23	32-52
Congo	160	174-232	103	112-172	46	63-104
Eq. Guinea	102	111-148	79	85-132	90	123-201
Gabon	116	126-168	102	111-170	93	128-209
Zaire	116	126-168	102	111-170	60	83-136

Old expansion factor = Detwiler and Hall, 1988
New expansion factor = Brown et al., 1989

Source: Hall and Uhlig, 1991

tropical moist forest, and that such vegetation is essentially irrelevant to assessments of carbon emissions and uptake. Lugo and Brown (1986; p.85) argue that neither of these presumptions is correct, and that existing tree ring and ice core data suggest significant fluctuations in atmospheric CO_2 concentrations in past centuries, presumably resulting from relatively rapid changes in ecosystem coverage. They conclude that the extent of secondary forest may in fact be considerably greater than conventionally believed, and that such forests can continue to accumulate carbon for up to 1000 years. Long-term cycles that would prevent achievement of a carbon steady state include: fire cycles, catastrophic windthrows, hurricanes, and human-induced deforestation and reforestation (Lugo and Brown, 1986;

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p.87).

Problems with Establishing Ecosystem Carbon Content

Biomass loading on a given hectare of land in central Africa is dependent on numerous variables, most importantly rainfall and degree of human intervention. Techniques for estimating biomass loading in tropical forests are either imprecise or exceedingly time consuming and costly. Empirical measurement through destructive sampling has been done on a very selective basis. Given the relative availability of data sets, extrapolation from forest stand inventory data to total biomass is prevalent. Increasingly, these estimates are in turn being coupled with satellite imagery techniques in an attempt to estimate biomass levels over large areas, across multiple ecosystems, and through time (Millington et al., in press). It should be noted that neither destructive sampling nor forest inventories biomass estimates reported in the literature will remain accurate measures of ecosystem biomass over time, as either human intervention or natural processes could significantly change actual biomass density by ecosystem types.

Table 12 Variance in estimates of tropical forest biomass carbon per hectare

	Forest Type Tons C/ha				
	Evergr...		Seasonal		All
	D	V	D	V	X
Latin America	176	82	158	85	88
Africa	210	124	160	62	136
Asia	250	135	150	90	112

D = based on destructive sampling (Brown and Lugo, 1982; Olson et al., 1983), V = based on wood volumes (Brown and Lugo, 1984), X = based on new expansion factors (Brown et al., 1989, 1991)

Source: Myers, 1989

When first applied by Brown and Lugo in 1982, the total area subjected to destructive sampling around the world totalled less than 30 hectares. In addition, sampling was almost exclusively biased toward primary forests (Brown and Lugo, 1991). Using this data, Brown and Lugo (1982) estimated a weighted average tropical forest biomass of 328 T/ha for closed forest (range of 60-538 T/ha), and 80 T/ha for open forest (range 40-140 T/ha).

Biomass estimates based on forest inventories are necessarily dependent on inventory accuracy, as well as on the ability to extrapolate from commercial wood volumes (the normal focus of forest inventories) to total biomass. Although forest inventories are much more globally available than are destructive sampling data sets, it is often impossible to assess how complete and accurate are the former. Some central African inventories, for example, focus on just a handful of commercial species of trees, making it very difficult to extrapolate to the forest as a whole. Extrapolation from commercial stemwood to total biomass has varied in

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the literature over time. In their early work, Brown and Lugo (1984) used a ratio of total biomass to stemwood biomass of 1.6:1 for closed forest, and as great as 2.9:1 for open forest. Brown et al. (1989) later calculated new expansion factors, finding that they increased exponentially with decreasing stand diameter. The new factors range from 1.5 - 2.0:1 for undisturbed forests, and to more than 7:1 for highly disturbed or recovering forests. Using the new expansion factors, biomass extrapolations from volume data can increase by 30-50% depending on forest type (Brown et al., 1989). This is exemplified in Table 11, which illustrates the changes made to Detwiler and Hall's 1988 estimates of carbon density per hectare by incorporating the changed expansion factors (Hall and Uhlig, 1991; p.121).

Building upon Table 11, Table 12 illustrates that the different approaches to estimating biomass, as well as refinements to the different techniques, have yielded dramatically different estimates of average tropical forest biomass per hectare over the last decade. The carbon estimates found in Tables 11 and 12 can also be compared to still commonly used global datasets seen in Table 13. Table 14 presents the range of ecosystem carbon loading values used by Millington et al.'s study that is described subsequently. It is important to note that the carbon figures arrived at by Millington et al. appear low (Brown, pers. comm.), but they are the only set of carbon estimates that attempt to differentiate biomass density at the country and forest type level.

These tables illustrate not only the wide range of estimates of carbon loadings by ecosystem type, but also the different ecosystem characterizations found in the literature. The range of carbon loadings suggest that identical land-use change estimates could result in emissions estimates varying by as much as 100%. The range of ecosystem characterizations illustrate the difficulty in rationalizing the different estimates found in the literature.

Benefits and Limitations of Using Satellite Imagery to Estimate Biomass

The level of uncertainty regarding the distribution and types of ecosystems found in Central Africa, including distinguishing between primary and secondary forest, combined with the dearth of reliable forest inventory statistics, make satellite imagery an attractive data source for estimating both ecosystem distributions and accompanying biomass.

Satellites with sensors to measure planetary reflectance in the visible red and near infra-red parts of the spectrum can now monitor almost any area of the globe on a regular basis. Radiation at all wavelengths is either absorbed, reflected or emitted when it strikes the soils and/or vegetation of a given site. A characteristic "reflection" curve for green vegetation or particular land cover type can be derived for any particular

Table 13 Biomass carbon per hectare of tropical ecosystems

Ecosystem	tons C/ha	tons C/ha
Humid forest	210	180
Seasonal forest	125	81
Shrub savanna	33	36
Grass savanna	11	18
Dry wooded-savanna	7	na
Dry shrub-savanna	3	na

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

wavelength, with visible red and near infra-red wavelengths being the most useful for this purpose. In the red region of the spectrum (0.6 to 0.7 um), radiation is absorbed by chloroplasts for use in photosynthesis. This contrasts with strong reflection of near infra-red radiation (0.8 to 1.1 um) caused by leaf cell reflection and refraction (Millington et al., in press).

Spectral reflections can be used to characterize vegetation type, and potentially to derive estimates of vegetation canopy, ground cover, and biomass loading. "Assuming a strong linear relationship between canopy foliage biomass and woody biomass in main bole and tree branches, it would appear that the vegetation index could provide a good estimator of total biomass" (Sader et al., 1989; p.144). Some studies have correlated biomass parameters, such as vegetation cover and above-ground biomass with NDVI (Normalized Difference Vegetation Index). This had led Millington et al. to conclude that "although none of the studies relate to tree or shrub biomass specifically, they do suggest that similar correlations should be found for woody biomass" (Millington et al., in press). Current research is not bearing this assertion out. Sader et al. (1989) compared high-resolution (Landsat-TM) satellite-derived NDVI with actual ground data for some 72 plots in Puerto Rico. Total dry weight biomass ranged between 20 and 160 mt/ha, while the NDVI ranged between .59 and .69. Unfortunately, no correlation between NDVI and biomass could be identified (Sader et al., 1989; p.149). Although the NDVI was significantly correlated with forest age classes, the vegetation index was not a good predictor of stand structure variables (e.g. height, diameter of main stem) or total biomass in uneven age, mixed broadleaf forest (Sader et al., 1989; p.143). Brown and Lugo, leaders in the study of forest biomass, have also been unable to establish a correlation between NDVI and biomass for mixed tropical forests (Brown, pers. comm.).

A primary problem with satellite imagery is one of scale. Much of the satellite data available is at relatively modest resolution requiring that the vegetational attributes of many square kilometers be reduced to a single computer pixel, and ultimately assigned to one or another of the land cover types being quantified. Under these circumstances, the ways in which the data are composited have a profound impact on the eventual result (Gutman, 1991), and the adequacy of the NOAA GVI (global vegetation index) data set for land surface characterization in climate studies has been questioned by Thomas and Henderson-Sellers (1987).

Box et al. (1989) also concluded that increased accumulation of biomass in forests might not result in an increase in forest "greenness," making the use of any "greenness" measures for estimating biomass more difficult to interpret. Box et al. suggest that, at most, satellite indexes can be used to derive a boundary curve reflecting an upper limit to biomass accumulation for mature forest sites. Drier, younger, non-woody, and certain other landscapes, even if not differentiable by satellite, would clearly fall well to the left of this boundary curve (Box et al, 1989; p.81). Box et al. conclude that although "NDVI appears to be a useful index of some surface phenomena, it is still not certain just what biological phenomena the NDVI actually represents" (Box et al., 1989; p.72).

Other analyses raise similar questions about extrapolating from satellite measurements to biomass loading, and the climate of African rain forest regions adds to the difficulty of interpreting satellite indices, since the distribution of rainfall through the year is less even

than in other tropical forests. In one study, the variation observed in spectral vegetation indices from African tropical rain forest areas were consistent with observed vegetation seasonality and climatic data. But because of marked wet and dry periods, sometimes the spectral index for savanna was lower, the same, or higher than for rainforest (Tucker et al., 1985). As a result, "[i]n comparison with temperate and boreal forests, the ecological and physical complexity of tropical forest environments placed limits on how remotely sensed data may be used to estimate forest parameters" (Sader et al., 1990; p.1344).

Deriving land use and biomass estimates from satellite data, particularly in an area such as central Africa, can be characterized as more of an art than a science. Satellite data will become more reliable as finer pixel dimensions are attained, reducing the mix of surface types reflected in each pixel. Ultimately, however, higher spatial and spectral resolution satellite data will have to be coupled with improved ground-truthing and field data, both of which remain rare for central Africa (Box et al., 1989).

2.4 Previous Studies of Regional and Country Specific Carbon Inventory and Emissions

The previous pages have surveyed the difficulties in linking Zaire Basin vegetation to carbon inventories, as well as carbon releases and uptake. There is truly little reliable data that can be used to arrive at anything but the most uncertain of estimates for central Africa. This uncertainty, however, has not prevented recent analyses from attempting to quantify these variables. In this section, the methods of two such studies are discussed, after which their results are reported in country summaries. In addition, general information pertaining to the forest sectors of Zaire Basin countries can be used to arrive at qualitative conclusions regarding the variables of carbon storage and fluxes; such information is also profiled by country.

As no country-specific data are available on the carbon flows associated with forest degradation, soil carbon losses, forest maturation, regeneration, tree planting, or CO_2 fertilization, the country profiles are far from complete pictures of country carbon cycles.

Greenhouse Gas Emissions in Sub-Saharan Africa

In 1990, the Oak Ridge National Laboratory (ORNL) completed a study for USAID estimating carbon inventories and emissions for Sub-Saharan Africa, as part of the primary project goal of estimating the extent to which Sub-Saharan land-use change might be capable of mitigating global warming through additional carbon uptake (Graham et al., 1990). Arriving at carbon inventory and carbon release estimates involved several steps:

1) Vegetation cover was estimated for each country. Graham et al. felt unable to use some of the newer maps as a result of inconsistencies of quality, different scales, and vegetation classifications, etc. Therefore, they relied upon a combination of out-of-date regional maps, as well as the draft FAO vegetation map for Africa, in spite of the fact that selected satellite data showed the draft FAO map to be inaccurate in mapping forest/savanna boundaries in central Africa (Graham et al., 1990).

2) Biomass values reflecting ideal climatic and other conditions were assigned to the different vegetation types. Olson et al.'s (1985) figures were used (See Table 13 above), with the exception of the value for dense forest which was discarded as too high. Olson's data were considered generally in the median range reported by other researchers for specific vegetation types (Graham et al, 1990; 38).

3) A GIS system was used in conjunction with digital maps of available soil, rainfall, and other maps to systematically extract variable values at 0.4 degree intervals in latitude and longitude.

4) Carbon inventory at each data point was estimated based on estimated land use at the point, the presence of human influence, and on the basis of soil fertility, annual rainfall, current vegetation class, zone, and country. A linear relationship was assumed between rainfall and biomass. If the vegetation panorama at the point included "cropland", "forest fallow" or "savanna fallow", then Graham et al. (1990; p50) assumed that native vegetation present at the same point would be degraded and its carbon storage capacity reduced by 35%.

5) Carbon releases were estimated on the basis of land-use change estimates. Data from FAO/UNEP's Forest Resources of Tropical Africa Report (1981) were used to characterize land-use conversion and forest areas. FAO deforestation projections to 1985 were used to characterize initial 1985 conditions in the model runs (Graham et al., 1990; p.38).

6) Country-wide carbon inventories and flows were arrived at by aggregating and averaging values at the GIS data points within each country.

Estimating Woody Biomass in Sub-Saharan Africa

A concern with energy balances and biomass fuel availability in sub-Saharan Africa resulted in a joint UNDP/World Bank Bilateral Energy Sector Management Program assessment of woody biomass standing stock and sustainable yield in sub-Saharan Africa (Millington, et al., 1991).

The basic methodology encompassed:

1) Creation of a database of woody biomass estimates. The biomass values used to correspond to AVHRR land-use classifications were the median biomass values derived from as many published estimates as could be found. In some cases, the median figures chosen hide the huge ranges of measurements identified from the literature (Table 14).

2) Extrapolation of biomass estimates to land cover estimates derived from remotely sensed data. Use of previously published maps would have led to unsatisfactory results since their age, scale variations, and floristic criteria have limited application

in biomass studies. AVHRR data from 1986 was used as a relatively "normal" rainfall year, and because the year appeared to reflect the best data available since AVHRR images became available in 1981.

Table 14 Biomass carbon per hectare estimates for African ecosystems

Ecosystem	All Africa[1] tons C/ha	Central Africa[2] tons C/ha
Grassland	0.3-0.2	1.2
Wooded grassland	0.2-2.4	0.7-1.7
Shrubland	1.8-7.5	5.0
Bushland/Thicket	0.3-17.5	7.0-9.0
Low woody mosaic	0.2-16.8	11.0
Woodland	0.5-111.0	13.4-35.0
High woody mosiac	1.5-8.5	7.8-8.4
Forest	11.4-123.4	51.5-112.0

Source: Millington, et al., in press

[1] reflects range of biomass values of sub-classes that comprise each major ecosystem unit

[2] range of mean sub-class biomass values for ecosytems within central african countries

3) Pixels were aggregated into statistically significant groupings, producing a classification of 60 land-cover classes for all of sub-Saharan Africa. These were then reduced to 43 land cover classes, that were reviewed and further merged due to the inherent uncertainty in using 8 km spatial resolution AVHRR data to assign land-cover (1 pixel = 64 km^2).

The country and biome-specific biomass estimates generated by Millington et al. represent the first effort to regionally estimate ecosystem coverage and biomass loading in such detail. At the same time, the methods used are subject to virtually each of the major error terms previously discussed in estimating biomass. Indeed, simply the use of median biomass values when the range is so large and encompasses so few data points suggests that the actual carbon loadings could be considerably higher or lower than suggested. The differences in the carbon loadings shown in Table 15 with those shown in Table 16 reflect the same conclusions. Millington et al.'s results must therefore be evaluated with considerable caution, and are considered too low by some analysts (Brown, pers. comm.). Nevertheless, as the only country and biome-specific estimates available, they are incorporated into the country profiles below.

2.5 Estimates of Regional and Country-Specific Carbon Inventory and Emissions

Estimates of carbon inventory and carbon emissions of the six central Africa countries are listed in Table 15. All available data show that Zaire's forests contain far higher carbon inventories than all other Zaire Basin countries combined. According to ORNL statistics, the carbon in Zaire's forests is double the combined inventory of Cameroon, Gabon, Congo, Equatorial Guinea, and the Central African Republic.

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Table 15 Estimates of carbon inventory and carbon dioxide emissions by country

	Present Carbon Stocks 10^6 tons		Estimated Carbon Dioxide Emissions ORNL		10^6 tons C/year Hall and Uhlig
	ORNL	Millington	AID model	Houghton model	Model
			1985	1985 Low--High	1980
Cameroon	2,120	1,500	7.3	9.5 -21.6	+2.9-4.5
CAR	1,560	1,190	1.9	2.2 - 5.0	-2.6-2.7
Congo	2,340	1,270	2.0	2.6 - 5.8	+0.0-0.3
Eq. Guinea	130	120	0.3	0.2 - 0.4	-0.6-0.3
Gabon	2,540	940	1.6	1.4 - 3.0	-0.2-0.3
Zaire	17,390	8,620	33.4	21.6-48.2	+18.6-21.4
Total	25,960	13,640	46.5	37.5-84.0	+18.1-22.5

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

+ = emissions, - = uptake

Inventory Estimates

The two available studies that put forth country specific carbon inventories differ markedly. Although the estimates of the two models are similar in the case of Equatorial Guinea, they differ by 200 - 300% for Cameroon and Zaire. Millington et al.'s satellite-based estimates calculate that 13.66 Gt of carbon are present in Zaire Basin vegetation, whereas the ORNL estimate is almost double that at 26.08 Gt. Clearly the two estimates vary greatly, yet there is no reason to conclude that the true value lies somewhere in between. Recent changes made to the volume-to-biomass conversion factors by Brown et al. (1989), if applied to the two models, would significantly increase both estimates. Overall, both the ORNL and Millington et al. studies can serve only as the roughest guide to Zaire Basin carbon inventories. True carbon loading could conceivably be several times greater, but not less than that estimated by Millington et al. given the apparent conservatism of the estimate (Brown, pers. comm.). In any case, there is no doubt that carbon inventories in Central Africa are lower today than in past centuries, quite possibly by a very significant fraction.

Emissions Estimates

Estimates of carbon losses associated with deforestation vary widely among available studies. ORNL estimates losses in 1985 at 46.5 million tons carbon as CO_2. Under low-high biomass estimates Houghton estimated the loss from 37.5-84.0 million tons carbon as CO_2 per year for 1980. His estimates for 1985 would likely be significantly higher given increased deforestation rates (Houghton, 1991). Both ORNL and Houghton's estimates would also rise significantly if they were to incorporate Brown's new biomass conversion factors. Hall and Uhlig's (1991) estimate, which already incorporates Brown's new conversion factors, nevertheless sets net emissions in 1980 between 18 and 22 million tons carbon as CO_2.

Table 16 Standing stocks of carbon in ecosystems contained within the countries that comprise Central Africa

	Biomass (10^6 Tons C)						
	Cameroon	CAR	Congo	GabonEq. Guinea		Zaire	Total
Grassland	0.3	0.1	0	0.1	0	1.6	2.1
Wooded grassland	0.6	0.2	3.8	1.1	0.1	0.5	6.3
Shrubland	0	0	0.7	2.0	0	1.0	3.7
Bushland	8.4	0.7	5.8	3.8	0.1	28.8	47.6
Low woody mosiac	0.7	1.3	0	1.6	0.8	1.1	5.5
Woodland	163.8	429.1	201.1	64.1	0.9	3,796.7	4,655.7
High woody mosiac	86.3	117.2	46.8	64.0	1.3	163.5	479.1
Forest	1,245.5	591.8	1,017.8	805.4	117.6	4,633.9	8,412.0

Source: Millington et al., in press

This wide range of estimates occurs despite relatively similar underlying land use assumptions. As a result, they could also suffer from a common-mode failure that biases the estimates upward or downward. They are all also unable to incorporate important elements of Central Africa's carbon cycle, namely forest degradation, and forest maturation. Although global estimates are attempting to incorporate more of these variables, country-specific data still do not. As a result, once again these estimates can be taken only as rough guides of what is occurring in central Africa.

2.6 Other Greenhouse Gas Cycles

Carbon dioxide is the greenhouse gas most commonly focused upon due to its relative importance in climate forcing (circa 50%), but methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFC) are also significant gases that directly contribute to radiative forcing. Other gases are linked indirectly to radiatively forcing, such as carbon monoxide (CO) that impedes the natural breakdown of methane in the atmosphere. Khalil and Rasmussen (1985), for example, calculated that the increase of atmospheric methane concentrations over the past 200 years is probably 70% due to increased emissions and 30% due to depletion of OH radicals.

With the exception of CFCs, each of the gases mentioned has biotic sources linked to human activities. These sources include: rice farming, livestock production, landfills, and biomass burning in the case of methane; land clearing, biomass burning, and fertilizer use in the case if nitrous oxide; and biomass burning in the case of ozone.

Methane Cycle

Methane is currently estimated to be the third most important greenhouse gas after CO_2 and CFCs. Pearce (1989) estimates that within 50 years, however, CH_4 could be most significant greenhouse gas given its growing atmospheric concentration and its strong

radiative forcing relative to CO_2. As in the case of CO_2, natural CH_4 cycling is substantial, yet anthropogenic activities are resulting in increased emissions that are contributing to rising atmospheric concentrations.

The sources of CH_4 are fairly well known, although individual contributions remain uncertain. Recent estimates give global emission 407-672 Tg/yr (Teragrams = Tg = 10^{12} grams: Schutz and Seiler 1989), with 286-495 Tg coming from biogenic sources (e.g., rice production, livestock production, and landfills), and 121-177 from non-biogenic sources (biomass burning, natural gas leakage and coal mining).

Estimating net CH_4 emissions from different sources is difficult due to the complexity of the various sources and sinks. It is estimated, for example, that only 20% of CH_4 produced in rice paddies ends up getting emitted since 80% is oxidized to CO_2 along the way (Denmead, 1991; 79). Even then, only a handful of field chamber measurements of CH_4 emissions are available, backed up by some isotopic evidence involving C^{13} and H^2. Measurements over large areas and in Asia where 90% of the world's rice is grown are still lacking, and sufficiently sensitive gas sensors are just now becoming available (Denmead, 1991; p79). Given the complexity of the chemical pathways involved, combined with very limited information about emissions resulting from any given pathway, estimates of regional and national emissions are extremely tentative. Table 17 presents one estimate of the relative importance of methane in terms of African and global greenhouse gas emissions.

The biggest sink for methane is photo-chemical oxidation by OH radicals in the troposphere and stratosphere, estimated previously at 400-600 Tg/yr, with a much smaller biological sink in microorganisms in aerobic soils, estimated at 32 Tg/yr. Evidence suggests that CH_4 oxidation in soils is being suppressed in systems which receive high inputs of nitrogen, either through fertilization, or from atmospheric deposition (Denmead, 1991; p.78).

Nitrous Oxide Cycle

The global nitrous oxide cycle is the least well understood cyle of all the major greenhouse gases. Regional emissions estimates, much less country-specific ones, are highly uncertain. In one example of global emissions from cleared tropical forest, coarse estimates from five study sites were extrapolated to estimate emissions from an area of over 2.5 billion km^2 (Keller et al., 1986), when in reality N_2O emissions are likely to vary widely depending upon underlying gradients of climate, soil fertility, and disturbance (Matson and Vitousek, 1990; p.668).

The principal sink for N_2O appears to be its destruction through photochemical processes in the stratosphere. N_2O is oxidized to NO, a major sink for, and destroyer of, ozone. N_2O oxidation is estimated at 12 Tg N_2O-N/yr, but the observed rate of increase of N_2O in the atmosphere reflects the addition of 3.5 Tg/yr, suggesting that some 30% more N_2O is being added to the atmosphere than is being destroyed each year (Matson and Vitousek, 1990). Atmospheric concentrations of N_2O are increasing at 0.2 - 0.3% per year. As estimates of the N_2O being produced through fossil fuel combustion have declined after the discovery of N_2O production as an artifact of the sampling methodology, biomass burning was put forward as a possible source of the "missing" N_2O. (Denmead, 1991). Forest soils are believed to be the single largest source of biotic nitrogen (circa 6 Tg N/yr; Matson and Vitousek, 1990). Tropical land clearing is also thought to be a potentially important source.

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N_2O production would be associated with the rapid disappearance of carbon leading to high rates of nitrogen conversion from organic to inorganic forms after disturbance (Denmead, 1991; p.77). It remains quite possible, however, that a significant global source has yet to be identified, or other sources have been underestimated (Cofer et al., 1991; p.691).

The chemistry of biotic N_2O formation and destruction is complex and hard to measure. N_2O is produced as an intermediate step in a variety of nitrogen cycle processes, including denitrification and nitrification in soils. Some is also produced by biomass burning, although estimates of the importance of this source have varied widely over time (Matson and Vitousek, 1990, citing a variety of sources). Empirical measurement of N_2O emissions generally has thus far been limited to a relatively small number of chambers studies, despite the fact that point to point variability of soil gas emissions is notoriously large. Such emissions often vary by a factor of two within just a few meters of each other; variations of 10:1 occur frequently. Sampling periods have also been far too short to adequately characterize natural flux events that usually occur over one to many days (Denmead, 1991; p.78, with extensive secondary citations).

2.7 Alternative Futures and Zaire Basin Geochemical Cycles

Although highly uncertain, existing data suggest that the Zaire Basin is 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 1980's ranging from 20 to 60 million tons per year. To the extent that methane and nitrous oxide emissions have been quantified for Africa (Table 17), they are also modest, and relatively less important than CO_2 emissions. This should be particularly true for central Africa, primarily due to the relatively small amount of savanna found there.

Table 17 Anthropogenic greenhouse gas emissions for Africa in 1985 in millions of tons CO_2 equivalency

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

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

Carbon dioxide appears likely to remain the most important greenhouse gas linked to land-use change in central Africa. In the absence of truly large-scale land-use change, (e.g., one that would see forest give way to savanna over large areas of central Africa) carbon dioxide emissions seem likely to remain the primary source of radiative forcing. Large-scale efforts to mitigate global warming (e.g., promoted regeneration and tree planting), could even reduce the relative importance of CH_4 and N_2O emissions by bringing large-scale biomass burning under control.

Estimating future carbon stocks and flows within central Africa is inherently much more uncertain even than estimating today's inventories and flows, neither of which can be performed with any degree of certainty. So many physical, social, demographic, infrastructural, and economic variables are involved in determining future carbon inventories

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and flows that existing estimates are by necessity almost exclusively based in physical rather than practical potentials. These variables are outside the scope of this paper.

The 1990 ORNL report represents the first effort to project hypothetical carbon futures for sub-Saharan Africa. As Graham et al. noted, these estimates are arrived at "exclusive of institutional, socioeconomic, and political constraints." (Graham et al, 1990; 87). In addition, the estimates found in Graham et al. are based on ecosystem distribution and biomass loading estimates previously discussed and found to be highly uncertain. Taking these uncertainties into account, Graham et al. hypothesize that under the most ambitious (and unrealistic) scenario, Sub-Saharan Africa could go from being a source of 154 million tons of carbon per year during the decade 1991-2001 to being a net sink of 172 million tons by the year 2001. For central Africa specifically, carbon emissions under the status quo could potentially go from some 60 million tons per year to a net uptake of tens of millions of tons per year. These figures must be seen as far more optimistic than the actual institutional, socioeconomic, and political constraints would permit. These figures assume both a complete end to deforestation, and large-scale reforestation through a variety of means (plantations and agroforestry). Other ORNL scenarios assume progressively less optimistic assumptions. Thus far, more realistic assessments of potential carbon futures in central Africa are unavailable. Country-specific estimates that attempt to account for these constraints in a preliminary way will be available in the near term (Trexler and Haugen, in press).

Notwithstanding the tremendous uncertainties underlying ORNL and other estimates, several hypotheses regarding physical parameters of Zaire Basin carbon futures can be arrived at. They are grouped below as pessimistic and optimistic. Currently there is little basis for assigning relative likelihoods to the two scenarios:

Pessimistic Outlook:

- Demographic and economic imperatives will encourage much larger scale encroachment into remaining tropical forest regions than has occurred up to this point. Until recently, for example, it seemed likely that Gabon would still possess a large expanse of forest at the start of the next century, much of it in primary form. Severe economic setbacks may change the picture, however (Myers, 1989). Population is estimated to increase from one million people in 1988 to three million by the year 2025.

- Logging will continue to degrade large areas of still intact forest, resulting in large carbon losses (depending to some extent on the disposition of the harvested carbon). Secondary disturbance associated with the settlement and cultivation of logged areas also will prevent the recovery of carbon stocks.

- Savanna burning will continue to prevent the reversion of savanna areas to tree cover, and will continue to encroach on presently forested areas.

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Optimistic Outlook:

- Concerted policy action is directed at stabilizing agriculture on already utilized land, thus slowing deforestation.

- Logging policy is dramatically revised to promote the more efficient utilization of forest areas and of the extracted product.

- Large areas of land are allowed to regenerate from what is now fire-climate savanna.

- Large areas of currently fallow land are allowed to develop into more mature secondary forest due to a displacement of agricultural pressure to permanent sites.

- Large areas of already growing secondary forest are allowed to accumulate cover due to a displacement of exploitative pressure such as logging.

- The existing significant potential for formal tree planting, ranging from plantations to on-farm forestry and other means, is taken advantage of. This can increase carbon inventories, displace demand for forest products out of natural forest, and reduce the need for transient agricultural expansion into the forest sector.

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HUMAN INTERACTION WITH THE FORESTS OF CENTRAL AFRICA

World Resources Institute
Center for International Development and Environment

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Foreword and Acknowledgements

This report is one component of a multidisciplinary AID-funded study entitled the Central Africa Global Climate Change Study. The study is coordinated by the Biodiversity Support Program, a consortium of the World Wildlife Fund, The Nature Conservancy, and the World Resources Institute.

This report is the synthesis of six individual country studies, composed during the summer of 1991 and submitted for review to a team of outside experts, too numerous to mention here, but whose comments were an integral part of the production process. This synthesis document has also undergone a series of reviews, both internal and external. The WRI team would like to extend a special thanks to the following people whose efforts, contributions, and editorial services helped shape this document: Jennifer Green, Roberto Martin, Cheryl Cort, Nels Johnson, Mark Trexler, Christine Haugen, and David Gow (all of WRI), David Groenfeldt (independent consultant), and David Wilkie (Tufts University).

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Kirk Talbott - Project Director
Fred Swartzendruber - Senior Analyst
Mike Berdan - Senior Editor
Keith Openshaw - Senior Technical Advisor

Central Africa Global Climate Change Study

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EXECUTIVE SUMMARY

This desk study was conducted by the World Resources Institute (WRI) as one of three components of an AID-funded report on climate change in central Africa. It focuses on the impact of human activities on the landscape of central Africa, and especially the tropical forests of Zaire, Cameroon, Gabon, the Congo, Central African Republic, and Equatorial Guinea. It provides an analysis of the development conditions and trends affecting the vast carbon reserves that are contained in the largely contiguous, tropical forest system that extends from the highlands of eastern Zaire to the coastal lowlands of central Cameroon. Though the figures are imprecise and subject to debate, there are an estimated 27 billion tons of carbon stored above ground and an additional 56 billion tons in the roots and soil.

The immense tropical forest network of central Africa is exceeded in size only by that of the Amazon Basin. It is vital to the six national governments as a resource base that provides not only livelihoods to millions of people, but a considerable share of export earnings. On the wider stage, it is equally important because of its potential contribution to both local and global climate change and its inherent capacity to mitigate against the negative impacts of that climate change.

Despite the fact that central Africa's tropical forest ecosystem is still largely intact, this study concludes that it is now feeling increasing stress. The forest system of central Africa is threatened by a number of factors, the most important of which include:

* accelerating migration from densely populated regions such as eastern Zaire, Rwanda and Burundi;
* increasing pressure on governments to open up forests to logging and mining enterprises;
* weak or non-existent land use planning, particularly related to agricultural clearing of forests; and
* infrastructural development.

Based on an examination of the history and political economy of the region, the WRI team has identified five primary aspects, or sectors, of human interaction with the forests: forestry, agriculture, infrastructure, mining, and energy. Using this five-pronged analytic framework, this study identifies and assesses those conditions and trends which are currently most significant, or have the most potential to be significant, in transforming the region's landscape through activities which impact on the forest ecosystem and its storehouse of biomass.

This study also identifies a number of historical, demographic, economic, and institutional policy-related trends which have significantly affected relevant development and environmental conditions throughout the region. The following briefly summarizes some of these trends.

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Population growth and developments in the political and economic arenas can play an important role in determining how human activities affect landscape change. For example, the regional trend towards a rapidly growing, low-income population contributes to the carbon emissions that come from landscape change as a result of higher demands for agricultural products, lumber for building materials, and fuelwood and charcoal for cooking. By contrast, a more prosperous population changes its consumption patterns, replacing traditional staples with imported foods, and biomass with fossil fuels. At the same time, however, a more prosperous population is also likely to build larger homes and offices and furnish them with more furniture, two activities that increase the amount of stored carbon.

Government needs for foreign exchange may stimulate investment in export crops, as well as timber and mineral extraction. The construction of railroads, roads, and harbors necessary for enhancing export capacity can, in turn, affect settlement patterns, demands for food and fuel, and local income levels.

Policies relating to commodity pricing and trade practices, environmental legislation and enforcement regulations, in particular, need to be reformed substantially in all the countries in the region if forest management is to be effectively promoted. Land tenure policies as well as farm product pricing and marketing practices play key roles in the agricultural sector. Concession agreements, taxation schedules, subsidies for parastatal agencies, and other government policies are having a significant impact on a wide range of development activities in the forests of the region.

Many of these trends and policies are presently contributing to deforestation, losses in species diversity, degradation of soil and water, the accompanying decrease in agricultural productivity, and the marginalization of many forest-dependent peoples. In addition, they undoubtedly contribute to both regional and global climate change while diminishing the area's capacity to mitigate the effects of regional climate change.

Multilateral and bilateral donor agencies, government ministries and extension services, international and national non-governmental organizations, and thousands of grass-roots community development and religious organizations all offer significant potential in contributing to better forest management and land use practices in central Africa. A critical problem, however, is that the institutions responsible for promoting sustainable development in the region at the international, national, and local levels need to be far better coordinated, and in many cases, strengthened. The policies and agendas also need to be better aligned so as to deal more comprehensively and holistically with the myriad and complex sectoral interactions.

The most important findings concerning trends within the five sectors are summarized below:

The Agricultural Sector. Clearing of forested areas for agricultural use is the single largest contributor to landscape change and thus to the reduction of carbon inventories in central Africa. Indications are that agricultural clearing is destined to continue over the medium term. With the partial exception of Cameroon, regional agriculture has fared poorly over the past twenty years. Declining yields have been the result of a number of factors including reduced fallow periods, loss of soil fertility, inadequate agricultural inputs, and unfavorable taxation, tenurial, and marketing systems. As a result, shifting agriculture has become increasingly widespread in some regions, and appears to be making deeper inroads into forested areas.

The Forestry Sector. Logging plays a direct role in reducing the existing carbon inventory when the amount of carbon in the sawn wood is not replaced by new growth. Secondary effects arise from the logging practices themselves: nearby trees are damaged in the process of harvesting those with commercial value, and soil degradation often follows intensive or poorly executed logging. Logging's most important indirect effect is through the construction of roads and trails into the forest which provide additional access for small-scale farmers, bushmeat hunters, and artisanal miners. Substantial attention is given in this report to the direct and indirect effects of logging activities on the net carbon release in central Africa.

The Infrastructure Sector. Infrastructure is both a direct source of landscape change, and an indirect factor which influences the pace of activities in other sectors. Significant areas of land are cleared in the course of infrastructure projects such as new roads, rail lines, and hydroelectric dams.

Infrastructure's more pervasive effect, however, comes from the dynamic change in the scale and range of economic activities it makes possible. Roads into forested areas facilitate capital-intensive logging, mining, and agricultural expansion. A new road or rail line reduces transportation costs and permits investments which were previously uneconomical; all-weather roads can stabilize access to areas which were impassable during the rainy season - a significant factor in large areas of central Africa. Market linkages develop as resources flow toward those areas best served by existing infrastructure. Population distribution maps of central Africa graphically illustrate the extent to which human settlements are concentrated along road and rail lines.

The Mining Sector. Mining plays a significant role in several of the national economies: Zaire is a major producer of cobalt, copper, and diamonds, while Gabon is one of the world's largest producers of manganese. The CAR's output of diamonds, although modest on a world scale, represents its primary source of foreign exchange. Most of the region's mining activities require clearing substantial areas

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of forest, thus contributing directly to greenhouse gas emissions. Even small-scale mining is reported to destroy forested riverbanks and contaminate the water with mercury and other chemicals.

Gabon, the Congo, and Cameroon are all net exporters of petroleum. The current importance of the region's off-shore petroleum and natural gas deposits could eventually be overshadowed by large reserves believed to exist in the Central Basin of Zaire and the Congo. Gaining access to these reserves will require massive investments in transport and other infrastructure, thus fueling industrial development and potentially resulting in substantial forest loss and degradation.

The Energy Sector. Energy consumption contributes to emissions through several direct and indirect mechanisms, notably the combustion of fossil fuels and biomass, and the flooding of forested areas for hydropower reservoirs. The latter is particularly significant as a source of methane emissions. With the exception of Gabon and the Congo, fossil fuel consumption in central Africa is minimal in comparison with biomass fuel consumption. Much of the biomass conversion is assumed to be neutral with respect to the carbon cycle: new growth sequesters carbon, offsetting what is released during combustion. Changing settlement patterns and population densities, however, are affecting the sustainability of the biomass cycle. In urban areas, consumption is probably well above existing local regeneration levels.

Finally, this study has found that the base of existing information about central Africa, especially reliable statistical data, is seriously deficient. Critical to a better understanding of the problem of deforestation in the region are: basic demographic statistics and patterns, forest and biomass inventories and statistics, information on forest degradation and regeneration, documentation of land use patterns and smallholder encroachment, and detailed information on biomass fuel supply and demand.

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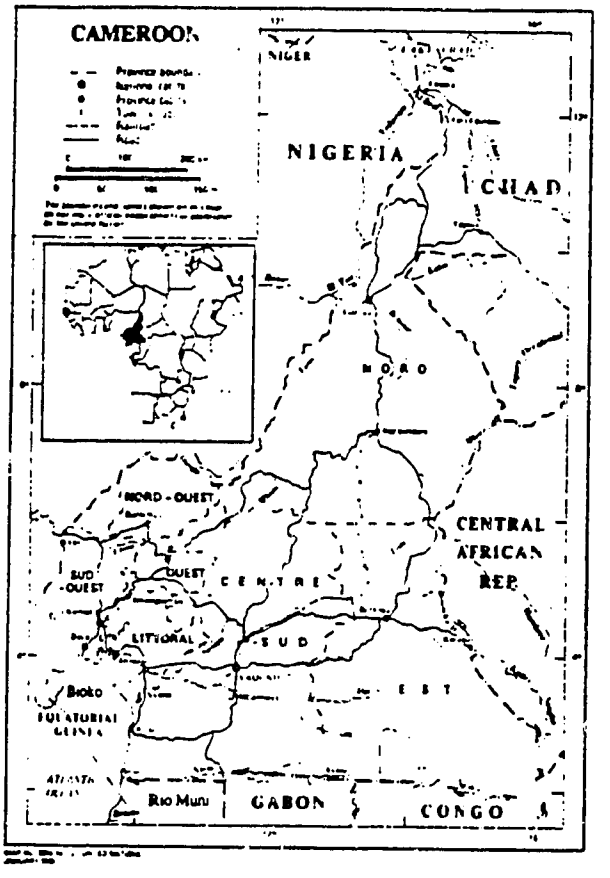
Country Profiles

Cameroon
Central African Republic
The Congo
Equatorial Guinea
Gabon
Zaire



Republic of Cameroon

Since independence Cameroon has had the most sustained economic growth in central Africa. Led by a strong agricultural sector, the country has also profited from a modest petroleum industry. Cameroon's timber production has grown at a rapid pace throughout the 1980s, and as a result the remaining forest areas are under more immediate pressure than elsewhere in central Africa. Rural population pressures accelerate the conversion of logged areas for agriculture.

Roughly 160,000 square kilometers of closed tropical forest are found in Cameroon, of a total forested area variously estimated between 200,000 and 260,000 square kilometers.

Area: 465,400 square kilometers
Population: 11.2 million, of which 50% is urban (1990 estimates)
Languages: English, French (both official), Bamiléké, Ewondo,
Fulfulde, and Arabic
Capital: Yaoundé (700,000)
Other large cities: Douala (852,705)
Primary Exports: petroleum, coffee, cocoa, timber, cotton
Per capita GNP: $ 990 (1989)
Currency: CFA franc
Foreign debt: 1980 - $ 2,513 million; 1990 - $ 5,358 million
Independence gained from France on January 1, 1960 and from Britain during 1961. Unification effective June 2, 1972
Head of State: President Paul Biya (since 1982)

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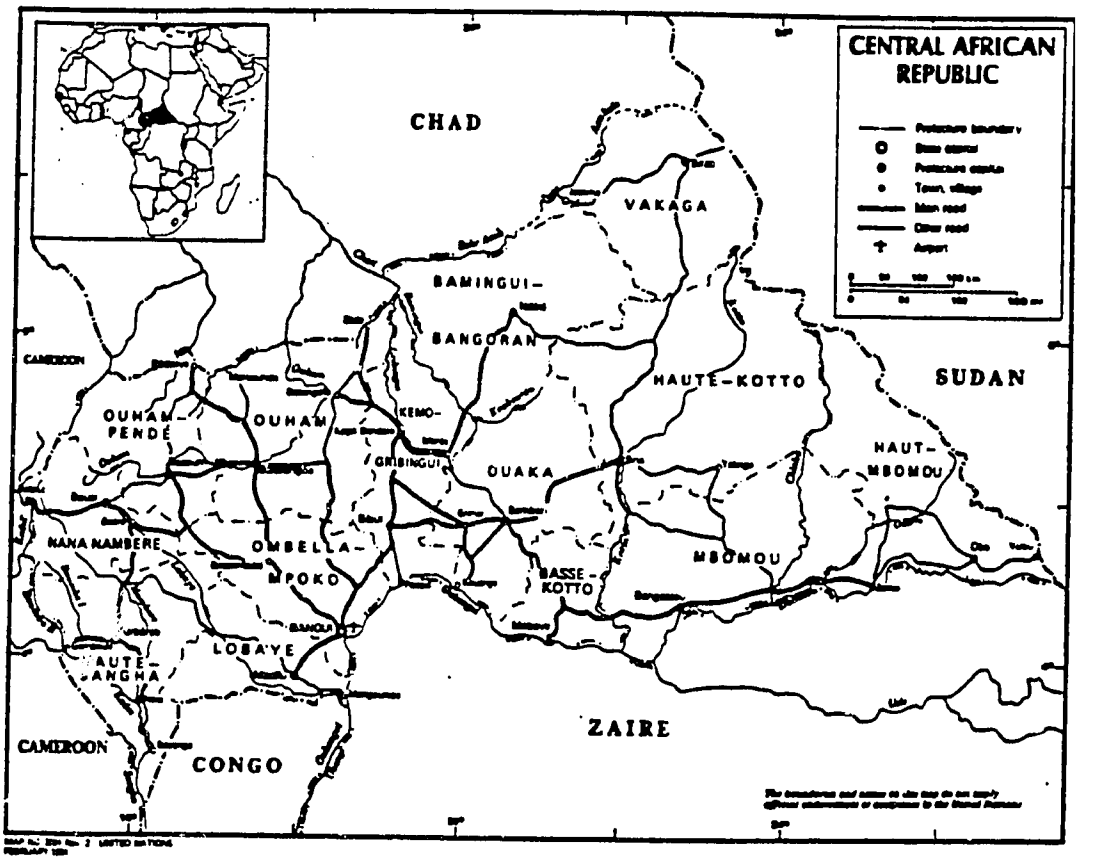


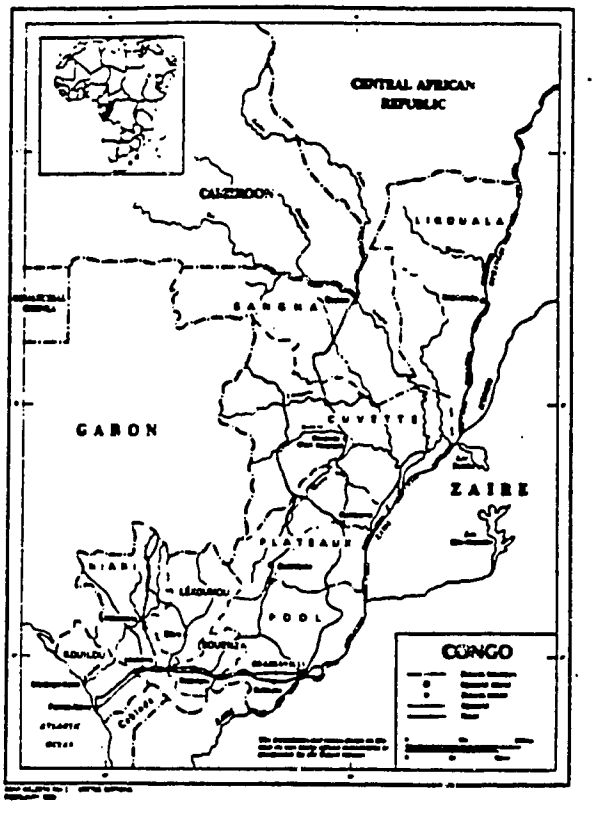
Central African Republic (CAR)

(République Centrafricaine)

The tropical moist forests of the Zaire River Basin reach their northern limit in landlocked CAR, changing in a gradual transition to woodland savanna and gallery forests in the interior, and then to the shrub and bush savanna of the north. Without its own ocean port, CAR depends on two transportation routes that pass through other countries. CAR is also the only country of the six without proven oil deposits. CAR's export earners - coffee, cotton, diamonds, timber, and tobacco - have been stagnant or in decline for several years. The government is trying to promote increased timber production and processing.

Estimates indicate about 30,000 square kilometers of closed forest in the southwest, and an additional 320,000 square kilometers of open forest over the rest of the country.

Area: 622,980 square kilometers
Population: 2.9 million, of which 47% is urban (1990 estimates)
Languages: French (official), Sango
Capital: Bangui (473,000)
Other Large Cities: Berbérati (100,000)
Primary Exports: diamonds, coffee, timber, cotton
Per capita GNP: $380 (1988)
Currency: CFA franc
Foreign debt: 1980 - $ 195 million; 1990 - $ 621 million
Independence gained from France on August 13, 1960
Head of State: General André Kolingba (since 1981)



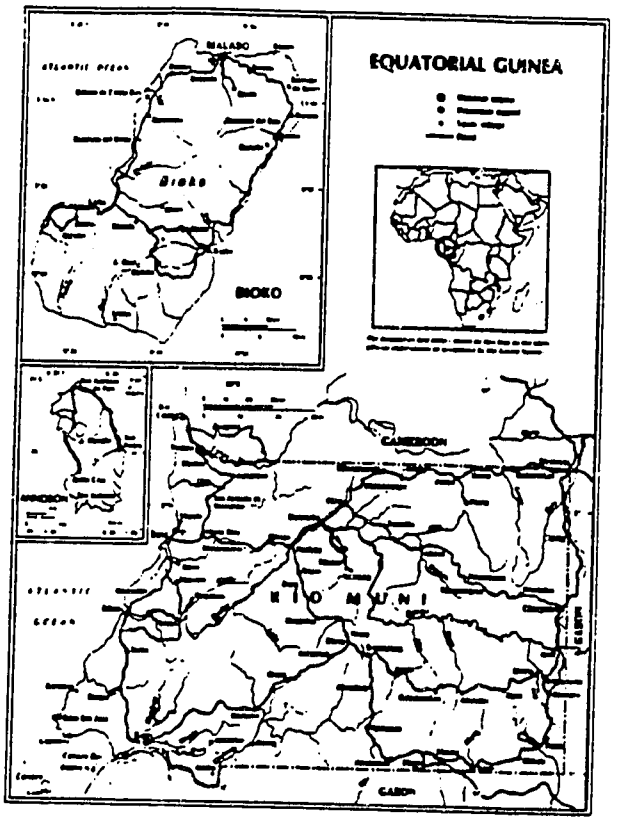
The Congo

(République du Congo)

The Congo has one of the highest per capita incomes in Sub-Saharan Africa, largely due to the success of its petroleum industry. Since the late 1980s, however, declining prices for crude oil have created severe revenue problems, and the Congolese timber industry, whose historic importance has been eclipsed by the growing petroleum industry, is now undergoing a revival. Increased logging is expected to help offset the revenue shortfalls from falling petroleum prices.

Figures for the total forested area in the Congo vary, usually within a range of 200,000 to 220,000 square kilometers; of this, some 50,000 square kilometers lie in the southern part of the country, and have already been subject to intensive logging. The balance of roughly 150,000 to 170,000 square kilometers is located in the less accessible northern and central regions. Infrastructure improvements are planned which would facilitate access for logging in these remote forest areas, but fiscal constraints have caused those plans to be deferred.

Area: 341,500 square kilometers
Population: 2 million, of which 42% is urban (1990 estimates)
Languages: French (official), Lingala, Munukutuba
Capital: Brazzaville (595,000)
Other Large Cities: Pointe-Noire (297,000)
Primary Exports: petroleum, timber
Per capita GNP: $ 940 (1989)
Currency: CFA franc
Foreign debt: 1980 - $ 1,496 million; 1990 - $4,116 million
Independence gained from France on August 15, 1960
Head of State: Colonel Denis Sassou-Nguesso (since 1979)



Equatorial Guinea

(República de Guinea Ecuatorial)

The smallest of the central African countries, Equatorial Guinea consists primarily of a mainland zone, Rio Muni, and the island of Bioko. During the colonial era, Bioko was a major exporter of cocoa, while Rio Muni sustained profitable timber exploitation. The rule of Macias Nguema (1968-1979) precipitated a steep economic decline. Since his overthrow in 1979 the country has been slowly recovering. Joining the CFA zone in 1985 has proven beneficial, and production from modest offshore gas reserves came on-line in 1991. Timber from Rio Muni has recently become the leading export revenue earner; logging concessions currently operate on 5,000 square kilometers of forest.

Estimates of the extent of Equatorial Guinea's forest cover vary from colonial-era figures of roughly 22,000 square kilometers, to more recent estimates of approximately 13,000 square kilometers. A forest inventory was completed by FAO at the time this report was being prepared, and more accurate data are expected to be available by early 1992.

Area: 28,050 square kilometers
Population: 0.4 million, of which 65% is urban (1990 estimates)
Languages: Spanish (official), Fang, English
Capital: Malabo (33,000)
Other Large Cities: Bata (40,000)
Primary Exports: timber, cocoa, coffee
Per capita GNP: $ 390 (1989)
Currency: CFA franc
Foreign debt: 1980 - $ 75 million; 1990 - $ 505 million
Independence gained from Spain on October 12, 1968
Head of State: Colonel Teodoro Obiang Nguema (since 1979)

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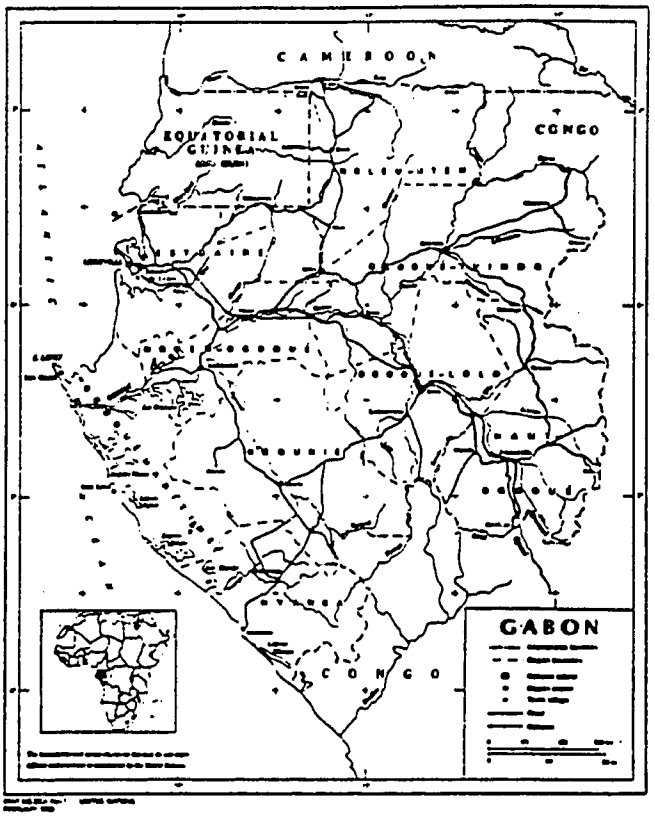

Gabon

(République Gabonaise)

A country rich in biodiversity, Gabon is one of Sub-Saharan Africa's major petroleum exporters. It also has the world's fourth largest reserves of manganese. Revenues from these resources combined with a relatively small population give Gabon the second highest per capita income in Africa. Crude oil prices have declined since the late 1980s, and Gabon's economy is now adjusting to a post-boom period of retrenchment. An expansion of the timber industry was facilitated by the completion of the Transgabonais railway, although the industry continues to face high production and transport costs, especially from the interior, and soft world timber prices. Even so, 75% of the closed forest is presently under timber concessions.

Original primary forest area has been estimated at about 210,000 square kilometers, but presently covers less than 80,000 square kilometers. By 1997, most of the forest will probably have been logged at least once.

Area: 257,670 square kilometers
Population: 1.2 million, of which 46% is urban (1990 estimates)
Languages: French (official), Fang, Eshira
Capital: Libreville (352,000)
Other Large Cities: Port-Gentil (100,000)
Primary Exports: petroleum, timber, manganese, uranium
Per capita GNP: $ 2,990 (1989)
Currency: CFA franc
Foreign debt: 1980 - $ 1,513 million; 1990 - $ 3,659 million
Independence gained from France on August 17, 1960
Head of State: President El Hadj Omar Bongo (since 1967)

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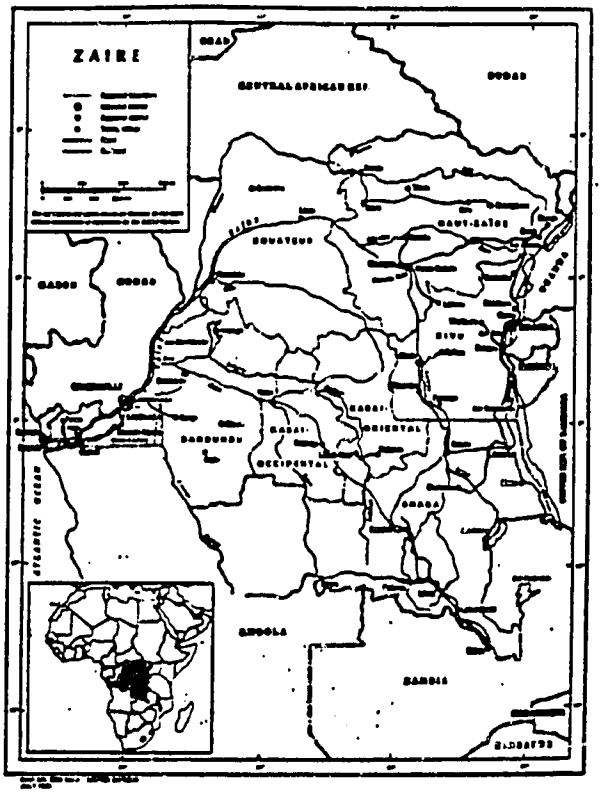

Zaire

(République du Zaïre)

As the third largest country in Africa, and the fourth most populous, Zaire dominates central Africa in terms of size and people. In addition, Zaire has the largest area of closed tropical forest on the continent. The country's great size and poor transportation network have hindered the extraction of its abundant natural resources, including the extensive mineral reserves in the southeast. Severe economic problems are slowing many planned infrastructure and development projects, but the same deteriorating economy is driving many Zairians into forested areas in search of timber, farm land, bushmeat, or minerals.

The area in Zaire presently under closed forest cover is often given as one million square kilometers, but many observers feel it is substantially less. The IUCN has suggested the true figure may be only half as large, while the IIED has estimated a closed forested area of 700,000 - 800,000 square kilometers. An additional 700,000 square kilometers of open forest are located outside the Central Basin.

Land area: 2,267,600 square kilometers
Population: 36 million, of which 40% is urban (1990 estimates)
Languages: French (official), Lingala, Kikongo, Kiswahili, Tshiluba
Capital: Kinshasa (3,000,000)
Other large cities: Kananga (704,000), Lubumbashi (451,000), Mbuji-Mayi (382,000), Kisangani (340,000), Bukavu (209,000)
Primary Exports: copper, petroleum, cobalt, diamonds, coffee, timber
Per capita GNP: $ 240 (1989)
Foreign debt: 1980 - $ 4,860 million; 1989 - $ 10,008 million Currency: the zaire
Independence gained from Belgium on June 30, 1960
Head of State: Marshal Mobutu Sese Seko (since 1965)

PART I. DEVELOPMENT AND CLIMATE CHANGE IN CENTRAL AFRICA

1. The Challenge of a Regional Assessment

A. Introduction: The Purpose of the Study

This World Resources Institute (WRI) report is part of a larger collaborative effort initiated by AID to assess conditions and trends relating to climate change in the six countries of central Africa: Zaire, Cameroon, Gabon, the Congo, Central African Republic (CAR), and Equatorial Guinea. The purpose of the WRI component of the project is to provide a desk study of the impacts of human activities on the region's landscape, with a particular focus on central Africa's extensive tropical forest ecosystem.

The region contains the world's second largest expanse of contiguous tropical moist forest. Estimates of the total area of the central African forests and woodlands vary widely, ranging from 2.2 to 3.2 million square kilometers (compiled from many sources).

While the tropical forests of the region comprise 40% or less of the combined land mass of the six countries, they account for most of the carbon stored in the region (see Chapter 3). The total clearing of this forest would result in the release of an estimated 14 million tons of carbon and 51 million tons of carbon dioxide (CO_2) into the atmosphere.

Of more pressing concern perhaps are the immediate environmental consequences of deforestation, forest degradation, and savanna burning. These consequences are already being felt whereas the effects of climate change are not likely to make themselves known for decades. Potentially more significant in the long run could be the possible adverse local impacts of global climate change. The immense volume of biomass contained within the tropical forest ecosystem gives the region the resilience to help mitigate local effects of climate change. However, this ability to cope with global climate change could be reduced by the acceleration of environmental degradation.

Central Africa's extensive tropical forest ecosystem and the plants, animals, soils, and products it encompasses also provide livelihoods for some 30 million rural people and are a major source of revenue for national governments. This resource could be endangered by the unintended consequences of environmental changes, both external and internal.

B. Developing an Analytic Framework for Assessing Climate Change Implications in Central Africa

This report examines the impact of a range of human activities on the tropical forests of central Africa. The analysis begins by identifying the most significant ways in which people use the forest, either by adapting its land for other purposes, such as growing crops, or by collecting the resources it contains - minerals, animals, timber. Past and present activities are described, and projections into the future, based upon current trends, are discussed.

The human activities examined here are divided into sectoral categories - forestry, agriculture, infrastructure, mining, and energy - primarily for ease of analysis. This should not obscure the fact that many activities transcend these arbitrary boundaries. For instance, a large share of charcoal production - one of the major forms of energy for central African cities - takes place on land being cleared for agricultural production, which in turn may have been made accessible by roads built for commercial forestry or mining operations. Nevertheless, dividing the analysis into sectoral categories helps to organize the available information into a more comprehensible format. In addition, this approach can be used as a checklist for specific situations or proposed interventions: by identifying a broad range of human activities with impacts on the forest, analysis can quickly be focused on relevant topics.

It is important to bear in mind that the larger purpose of this report is to examine the relationship between central Africa's tropical forest area and the processes believed to lead to global climate change. These forests represent one of the world's major stockpiles of biologically stored carbon. The human impacts on the region's forests are discussed here primarily as they relate to potential carbon emissions resulting from net loss of this vegetative cover.

The region's dense, closed forests of tropical hardwoods contain a large amount of biomass carbon. When burned, this material releases carbon dioxide, other gases, and particulate matter into the atmosphere. Through photosynthesis, new plant growth converts some of this carbon dioxide back into biologically fixed forms, effectively storing or "sequestering" the carbon. Eventually, through biomass decomposition or burning, a portion of this stored carbon is again released into the atmosphere through a continuous cycle of growth (sequestration) and harvest or decay (emission).

The equilibrium of this cycle can be disrupted by a variety of factors. Most important for the present analysis is the historic advance of human settlements into previously forested areas. As the area under forest cover shrinks, there is a corresponding decrease in the volume of carbon dioxide which is converted through photosynthesis and stored in the form of biomass. Changes in the type and distribution of vegetation may also affect this cycle.

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An important, though poorly understood, aspect of the carbon cycle concerns the volume of carbon which is normally concentrated in the region's topsoil. Loss of vegetative cover combined with harsh climatic conditions can apparently lead to the rapid loss of this topsoil, with unknown long-term effects on the ecosystem and with uncertain implications for climate change. This issue is discussed in greater detail in chapter three.

The analysis in this report is based upon a conceptual model which defines important inter-relationships between sectors such as agriculture, energy, logging, and mining, as well as underlying factors which influence them, such as demography, foreign debt, infrastructure development, etc. The model is intended to suggest several mechanisms or pathways by which it is believed that human activity in the region, directly or indirectly, leads to the release of carbon into the atmosphere.

The model of climate change described in this study can be summarized as follows:

1. Climate change is the result of a build-up of atmospheric greenhouse gases which trap heat in the atmosphere.

2. Some greenhouse gases are emitted through natural processes, such as the decomposition of living matter, or from fires caused by natural events such as lightning. Carbon dioxide, methane, and ozone can be released in this way.

3. The same gases can also be released through human actions: for example by burning fossil fuels or biomass. These activities also release nitrogen oxides and carbon monoxide into the atmosphere. Methane release is also associated with livestock and rice cultivation. (see Figure 2.)

4. Some man-made or synthetic gases, such as chloroflourocarbons (CFCs) used in refrigeration, are highly effective at trapping heat in the atmosphere, and are thought to be a significant factor in global climate change.

5. The burning of fossil fuels and release of CFCs are among the most important factors in the emission of greenhouse gases within industrialized societies.

6. In central Africa, the most important sources of atmospheric greenhouse gases are associated with landscape change. As the region's tropical forest area comes under increasing pressure from land clearing and other disturbances, carbon which had been stored naturally is released into the atmosphere. This also brings about a gradual reduction in the volume of ongoing photosynthesis and carbon sequestration, since a smaller area under forest cover contains less vegetation to carry out this process.

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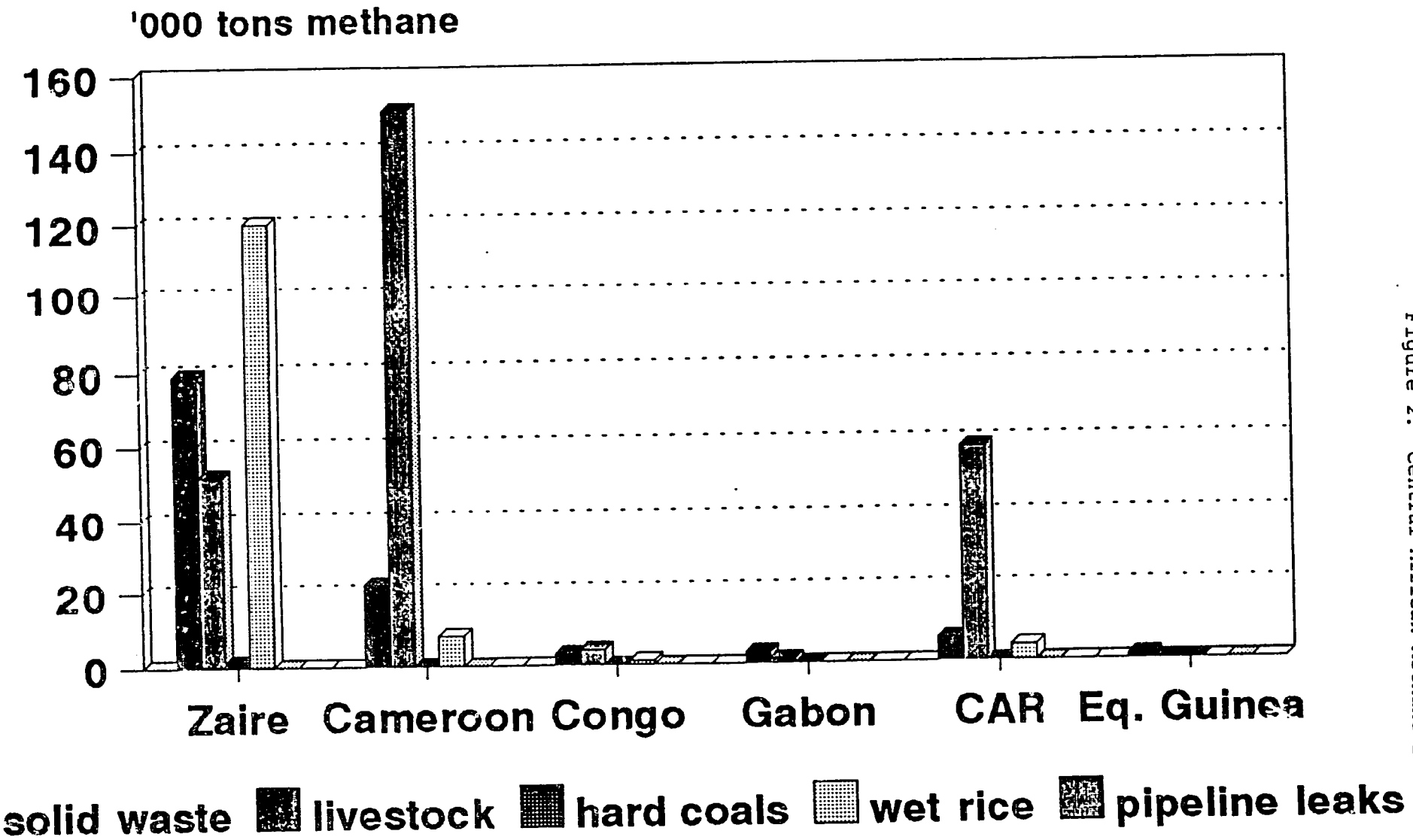
Central African Methane Emissions

'000 Tons of Methane, 1987



source: WRI, 1990

Figure 2. Central African Methane Emissions

7. Landscape change in central Africa results from many human interventions: clearing for farmland, mining, and road-building can permanently remove tree cover; over-logging and intensive fuelwood collection can degrade forested areas, damaging remaining trees and seedlings, and leaving areas vulnerable to soil erosion; 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. (see Figure 3.)

8. Clearing, burning, and over-exploitation of forest areas are associated with a number of factors. Among these are rapidly growing populations, which require resources to feed, house, clothe, and provide energy and livelihoods; macro-policies which foster short-term attitudes toward exploitation of natural resources instead of management for long-term sustainability of production; technical and management shortcomings which result in the waste of many of the region's resources; and economic pressures which exacerbate the other factors mentioned, and which undermine the willingness and ability of policymakers to give environmental conservation priority in national planning.

Figure 4, "Net Additions to Greenhouse Effect," illustrates the point that land use change is the predominant source of carbon emissions in central Africa. It also highlights another fact: Zaire and Cameroon together account for 88% of the estimated emissions attributable to land use changes in central Africa, as well as 87% of the region's population.

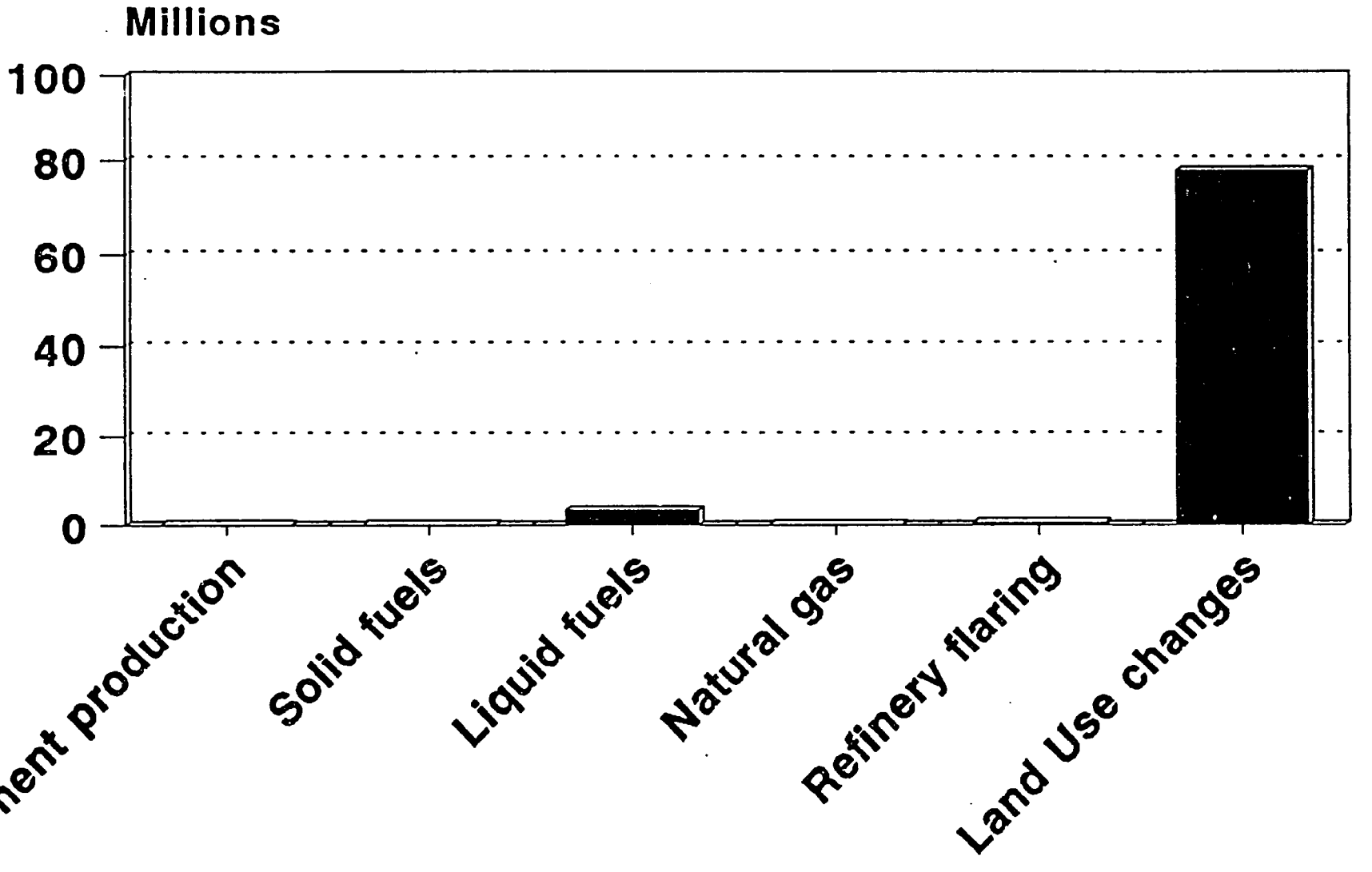
Figure 4 also reflects the fact that regional methane emissions are relatively low in comparison with the carbon dioxide emissions that result from land use changes. Sources of methane release include wetlands, livestock, rice cultivation, and deposits found under some of the region's volcanic lakes. In the region as a whole, methane emissions are estimated to be on a similar scale, or perhaps slightly greater, than those from combustion of fossil fuels and cement production.

In oil-rich Gabon and the Congo, fossil fuels represent a more important source of emissions than in the rest of the region. Over time, and given rising standards of living in the other countries, one would expect fossil fuel consumption to increase, and eventually to eclipse land use changes as a source of carbon emissions. Economic conditions in Zaire, the Central African Republic (CAR), and Equatorial Guinea do not suggest that this kind of change will take place anytime soon, although it could in Cameroon, which already has one of the highest levels of per capita income in Sub-Saharan Africa.

It should also be noted that savanna burning is widely practiced in Sub-Saharan Africa, and is thought to be a significant contributor to atmospheric greenhouse gases.

Regional Carbon Dioxide Emissions by Source

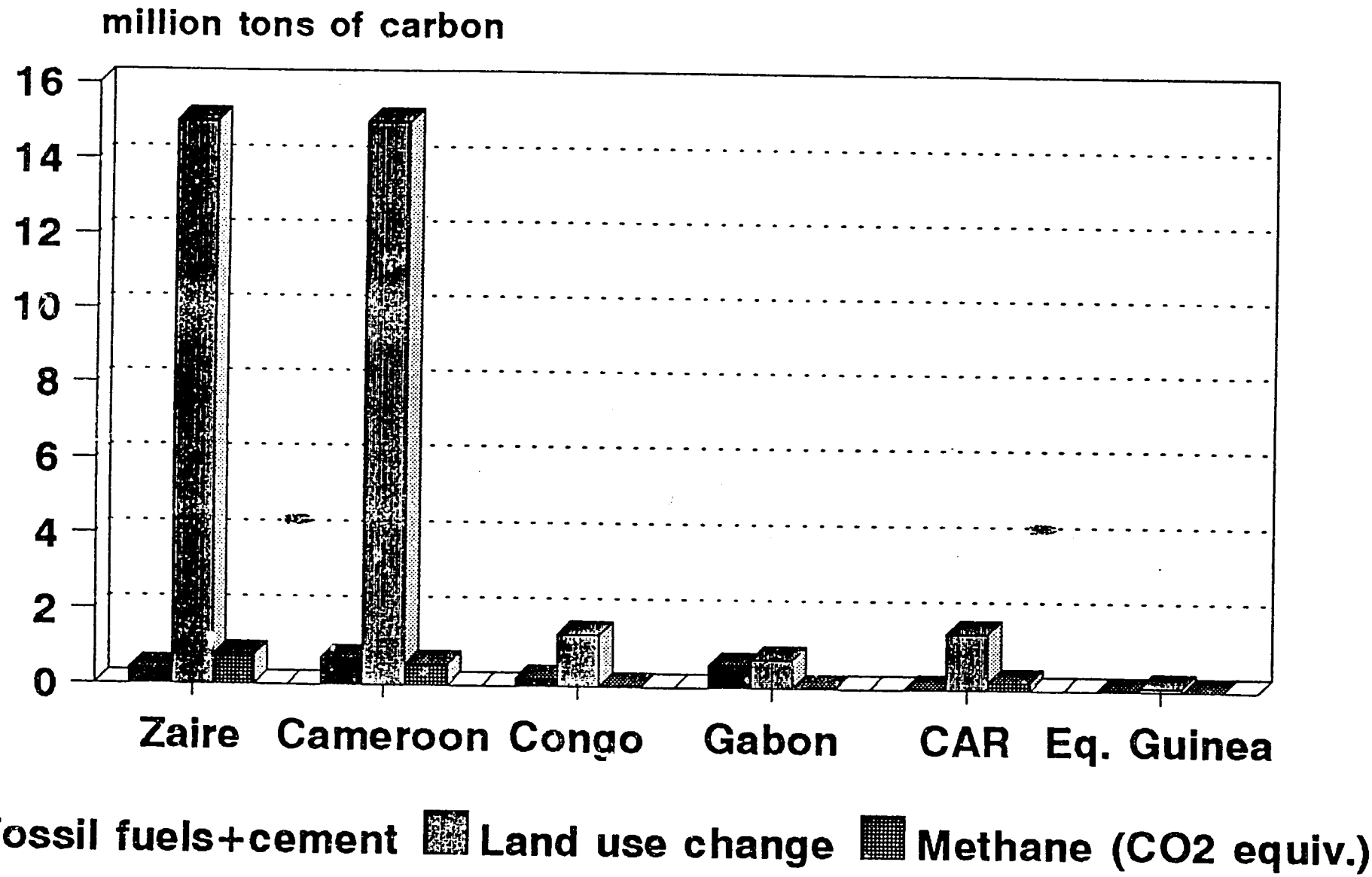
Tons of Carbon, 1987



source: WRI 1991

Figure 3. Regional Carbon Dioxide Emissions

Net Additions to Greenhouse Effect
Central Africa, 1987



source: WRI 1991

Figure 4. Net Additions to Greenhouse Effect

C. The Amazon Basin and the Forests of West Africa: Providing Historical Insights

Analyzing the human activities that have affected other tropical forests may offer insights for those concerned with central Africa's forests. Some analogies can be drawn from the cases of the Amazon Basin, with its extensive riverine forest ecosystem, and the coastal forests of West Africa. By studying the dynamics of change in these other two tropical forest regions, lessons can be learned about factors and trends likely to influence the fate of the forests of central Africa.

The Past as Prologue: Human Impacts in the Amazon Basin

The history of the Amazon Basin, like that of central Africa, has been one of cycles of exploration and discovery, followed by the extraction of natural resources for export to the colonial homeland and its more developed trading partners. Previously isolated territories and indigenous groups were exposed to the outside world, setting in motion a process of exploitation and arrogation of both people and land that continues to this day.

Colonial powers began appropriating the Amazon forests over four hundred years ago, nearly two centuries before similar activities were launched in central Africa. More than a hundred years before the first African countries were granted independence, the countries of South America won their independence. By the late 1800's, there was a rubber boom in the Amazon region during which settlements sprang up along the main tributaries of the Amazon River. Rubber remained one of the principal exports from the region until the 1920's, when a blight caused the world market to shift to production from Malayan plantations. Similar cycles of boom and bust have happened with other commodities. A similar pattern has occurred in central Africa. The region has experienced alternating cycles of economic investment and decline from colonial era plantations, and the timber and petroleum industries.

In more recent years, the Amazon has experienced colonization schemes, large-scale road-building projects, and industrial and agricultural development programs, all with the aim of opening previously inaccessible areas. One aspect of the strategy of opening the frontiers has been to establish an "escape valve" for the landless poor in other rural areas. A similar type of migration pattern occurs in central Africa where overcrowding forces agriculturalists to relocate in search of more land. One case in point is the Kivu region of Zaire.

The governments of the Amazon Basin countries, and those entrepreneurs interested in resource exploitation, realized that in order to gain access to the resources of the forest, they first had to develop a viable transportation infrastructure. All major programs in the region have been supported by the construction of roads. Once

they had finished building a road, however, the governments often found that they had little control over the process of migration. People seeking jobs, land, or other ways of earning a living, migrated into newly accessible areas much faster than had been expected, far outstripping the provision of services and amenities. This is currently the case in much of central Africa, especially along the new logging roads and railways.

A significant difference between the Amazon and central Africa is the fact that much of the forest clearing in the Amazon was done for the sake of large-scale cattle ranching. Cattle ranching has become the dominant land use throughout much of Amazonia in terms of area of rainforest transformation, and livestock populations have risen dramatically in the last two decades. Because of the prevalence of the tsetse fly, large-scale cattle ranching has been less feasible in central Africa. Instead, industrial timber exploitation and agricultural clearing have been the major economic factors responsible for forest degradation.

The Amazon Basin's forest system has also felt significant impacts from small-holder agriculture, following in the wake of ranching, logging, and burning. A cycle has evolved of abandoning old areas and clearing new forest sites as soil nutrients become exhausted and the costs of weeding increase. Farmers and ranchers often work the land in environmentally degrading ways with the net effect of creating an ever-expanding front of forest removal and land degradation (Hecht 1989, p.166). In central Africa, migration to areas recently opened through commercial logging represents a major source of deforestation.

Logging in the Amazon region has largely been a response to changes in world timber supply, notably the depletion of stocks of Southeast Asian tropical forests. Mining, particularly for gold, has also had direct and indirect impacts on the forest as well as the indigenous peoples who are dependent on them. Thousands of small-scale miners have pushed into isolated regions of the Amazon in recent years, and the environmental damage they have caused highlights the fragility of the tropical moist forest ecosystem. In similar fashion, small-scale mining operations are also on the rise in central Africa.

An Object Lesson: The Forests of West Africa

The recent deforestation along coastal West Africa offers an instructive perspective, for in many ways the relationship between the two regions is separated only by the dimension of time. Many of the same conditions that led to the extensive clearing of coastal West African forests in the 1980's can now be seen exerting similar pressures on central Africa's forests. These include, but are not limited to, economic crisis, particularly those related to debt and the need for foreign currency, inappropriate government policies, rapid population growth, internal migration, unsustainable shifting agriculture which encroaches on forests, and growing demand for fuel.

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West Africa formerly contained one of the world's largest and richest coastal tropical forest systems. Today, however, less than 25% of this forest cover remains. Since the mid-1970's, the rate of deforestation in West Africa has been one of the highest in the world, nearly four times greater than any other region in the world's tropical zone (Gillis 1988, p.299).

Logging has played a major role in the loss of West Africa's forest cover and is beginning to play a larger part in central Africa's forest degradation. Over the past decade, commercial logging in West Africa has declined as timber resources have become depleted. Some of the logging companies that have exhausted their concessions in West Africa are now moving into central Africa (Martin 1991, p.201).

Just as the West African governments did in the 1970's and early 1980's, the governments of central Africa are now looking toward forest-based industries to spur economic growth. Faced with economic crisis brought about by rapidly rising foreign debts and steel declines in export revenues, the region's governments have set ambitious goals for timber exports. Although governments are under increasing pressure from donors to take into account environmental issues in national development plans, external pressures are also being felt to balance budgets. In some cases, governments have been unable to meet their own civil service payrolls, deepening the sense of economic crisis which tends to take precedence over environmental issues.

As a result of diminishing supply in West Africa, roundwood production in central Africa is growing rapidly. Two and a half times more primary forest was logged in central Africa than in West Africa from 1981 to 1985 (Martin 1991, p.200). The French logging concern, Compagnie Industrielle de Bois reportedly plans to cut one of the last of Côte d'Ivoire's remaining valuable timber stands before relocating to areas such as Gabon (Horta 1990). Other French firms are expanding operations in Cameroon, Gabon, and in the Central African Republic, and the large German Danzer-Group has now shifted its African business from Côte d'Ivoire to Cameroon and Zaire.

Inappropriate policies and inefficient implementation throughout central and West Africa have prevented governments from receiving the full benefit of forest revenues through timber royalties, export taxes, and other official fees and charges, thus allowing timber companies to enjoy unusually high rates of return (Repetto 1988(b), p.20). This generated a timber boom in West Africa, and may lead to a similar effect in central Africa.

The coastal areas of central Africa, and those locations with relatively efficient transport networks, are attracting new logging ventures, as was earlier the case in West Africa. West Africa's timber industry centered upon the Côte d'Ivoire, a country which now retains perhaps 10,000 to 40,000 square kilometers of dense forest, from a previous total of 150,000 square kilometers (World Bank 1985, p.2; World Bank 1990c, p.6; Bourke 1987, p.1628; D. Reynolds, pers. comm.).

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Cameroon is now considered the gateway to timber in central Africa, a trend which resembles the earlier situation of the Côte d'Ivoire in many respects.

Yet large-scale logging has been only one factor in the depletion of West Africa's forests. Rapidly growing populations have also stimulated deforestation through the need for additional farmland. Between the years 1965 and 1985, when Côte d'Ivoire experienced a population growth rate of 4.6% (Repetto 1988a, p.13), rapid deforestation resulted from shifting cultivation and a growth in the size and number of farms. Population pressures are currently affecting certain areas of central Africa in much the same way. In the forests of eastern Zaire, for example, immigrants from the north and east are arriving in search of agricultural land. As the primary forest is converted, environmental degradation has become increasingly visible (Peterson 1990, p.1).

Another consequence of population growth is the increasing demand for woodfuels. In Ghana and Nigeria, for example, as population pressures mounted, particularly in urban areas, the demand for fuelwood and charcoal increased rapidly. In central Africa, where the urban population is already over 40%, the demand for fuelwood and charcoal is expanding steadily. Compounding this trend is the fact that poor economic growth has inhibited the transition to more modern fuels such as kerosene and LPG, especially in Zaire and CAR.

The undermining of customary tenure systems in West Africa has also affected the state of the forest and is beginning to play a similar role in central Africa. In Ghana for example, traditional community practices governed the use of natural resources until the government assumed control in the 1970's. As a result, local leaders and community level resource users had less responsibility for managing the forest and surrounding areas. Similar tenurial patterns exist throughout central Africa today. In Cameroon, for example, all land is owned by the state unless it is being actively cultivated and "improved". This has provided an incentive to clear forest areas in order to gain title to land.

D. Implications for the Central Africa Region

Many of the same trends which led to the clearing of the coastal forests of West Africa are now at work in central Africa. The present extent of the damage in central Africa is considerably less, but the pattern appears to be following much the same course as the case of West Africa.

Nonetheless, it should not be assumed that central Africa's forests are doomed to share the same fate. Instead, the experiences of the Amazon Basin and West Africa should be studied in order to devise policies and actions which can ensure more sustainable use of central Africa's forests for the future.

Many of the problems associated with infrastructure development in the Amazon Basin are also present in central Africa. Road building, particularly by logging companies in Cameroon and parts of Zaire, and the national railroads in Gabon and Cameroon, attract large numbers of itinerant farmers and other migrants who then begin the process of clearing pockets within previously isolated forests.

There is a serious shortage of reliable data about the six countries of central Africa. The region's tropical forests are among the least studied and documented of the world's major forest areas: little is known about central Africa's varied ecosystems; the size, characteristics, and distribution of forest; and the amount of biomass presently stored in the region's vegetation and soils (see Chapter Three).

This relative lack of information does not imply that little is happening in central Africa's forests. On the contrary, they face substantial threats from a variety of human activities. The cumulative effects of development factors such as accelerating logging, agricultural clearing and savanna burning, fuelwood harvesting, rapid urban growth, infrastructural development, and wildlife hunting, are beginning to become significant factors in localized deforestation. If these trends continue, one of the world's major remaining areas of primary forest could ultimately be endangered and central Africa's development potential and capacity to mitigate the effects of climate change could be undermined.

Because the area has been relatively isolated until now, comparatively less damage has been done to central Africa's forests than to other tropical forest areas. In parts of the world where extensive damage has already taken place, policy makers are facing serious environmental consequences, including the eventual necessity of costly remedial measures. In comparison, central African policy makers have a unique opportunity to implement preventive measures.

Yet the high degree of bureaucratic centralization that characterizes the governments of central Africa combines with the relative isolation of the forest areas to prevent the exercise of

effective control over most land uses. Certain activities in these isolated areas, including cross-border migration, trade, and smuggling, are neither officially sanctioned nor controlled, but may have a substantial impact on local economies and environments. The ability of the region's central governments to oversee activities, to regulate land use practices, and to monitor their impacts on the forests, is severely limited, and has perhaps been in decline since the colonial period.

Given the range and complexity of human impacts on central Africa's forests, the analytic framework used in this report focused on the most important factors, and highlights the relationships between them. The report also addresses the differences between the countries of the region. Zaire's size, history, ethnic makeup, economy, and politics are far removed from those of Equatorial Guinea, for example. Coastal Gabon, with its extensive petroleum resources and its high per capita income, is strikingly different from landlocked, relatively impoverished CAR.

Yet these countries have certain characteristics in common: extensive tropical forests, problems of internal communication and transportation, relatively high levels of urbanization combined with widespread rural and urban poverty, and a history of rigid political systems increasingly facing pressures for rapid change. The challenge is to recognize the important differences between countries while at the same time being able to examine the region as a coherent whole, and to extract from the analysis useful conclusions which can point the way forward to specific and practical interventions to mitigate the problems which have been identified.

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2. The Historical and Socio-Economic Context of Land Use in Central Africa

A. Early History: The People of the Forest

Some 5,000 years ago, Egyptian chroniclers reported the existence of forest peoples living south of the Sudan. More recent archeological discoveries show evidence of human habitation in central Africa dating back nearly 40,000 years. It is assumed that the present forest-dwelling hunters and gatherers, popularly known as "pygmies",[1] are the direct descendants of these earliest known inhabitants. The forest dwellers comprise three ethnic groupings, the Ba-Binga, Ba-Twa, and BaMbuti, inhabiting the western, central, and eastern regions of the Zaire River Basin respectively.

While their cultures have been undermined by a host of historical and political forces, these people continue to revere the forest. Their religion and culture revolves around the forest world as the ultimate provider for their society (Hart and Hart 1986). To ensure that local forest resources maintain their life-giving abundance, not only for the present generation, but for future generations as well, the hunter gatherers have developed an egalitarian social order based on limited agricultural intrusion, mobility, religious taboos, and sustainable hunting practices.

But the roughly 200,000 descendants of the original hunter gatherers are not the only historic residents of forest areas. Farming cultures began penetrating the basin's forests from the bordering savannas an estimated 2,000 to 4,000 years ago. Their descendants are the roughly 50 million Bantu people who today comprise the vast majority of central Africa's population.

Traditionally, the region's hunter gatherers lived in a symbiotic relationship with the sedentary Bantu agriculturalists. The hunter gatherers provided valued foods such as meat, honey, and mushrooms, as well as medicinal plants, fibers, and building materials. In exchange, they received starchy foods, pottery, and metal tools. The relationship between the hunter gatherers and the cultivators fostered an unusual complementary working arrangement that promoted sustainable use of the forest. In fact, the symbiosis of these two groups might well have increased ecological diversity and provided greater food resources for forest animals (Wilkie, 1988).

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[1] The term "pygmy" is considered inappropriate by most anthropologists and the forest people themselves because of demeaning connotations. For the remainder of this report, they will therefore be referred to as "hunter gatherers".

B. The Colonial Era: Extracting Forest Resources

The relationship between the hunter gatherers and the Bantu agriculturalists began to be disrupted by the slave trade and later by European colonialism. By the close of the nineteenth century, colonial rulers from France, Belgium, England, Spain, and Germany had staked out their territories and were well along in their campaigns to exploit the exotic natural abundance for the benefit of their European homelands. The vast majority of the area was claimed by France and Belgium and incorporated into French Equatorial Africa and King Leopold's Belgian Territories respectively. In all the colonies, large tracts of forests were assigned to concessionaires, for the most part trading firms in the business of extracting and exporting forest products such as hardwoods, ivory, valuable skins and furs, feathers, and so on.

Throughout the French and Belgian domains, tenure over forests was based on the colonial extension of the principles of Roman law which held that any "unoccupied" land for which ownership documents did not exist, belonged to the colonial state. The most extensive application of this was the Torrens Act which nullified any previous title arrangements and claimed all land for France, which could then freely grant concessions and leases. Virtually all forests were thereby opened up to colonial control, and any formal recognition of the land rights of indigenous people was lost.

With no legally defensible ties to the land, Bantu villagers became laborers for public work projects, such as the construction of roads and railroads, and for plantations cultivating export crops such as cotton, cocoa, and coffee. Though more difficult to control and discipline because of their ability to live deep within the forest, many of the region's hunter gatherers were also absorbed into the colonial enterprise by being forced to provide logistical support and field labor for the Bantus who no longer had the opportunity to tend their own fields.

Eventually this pattern was formalized, and colonial administrators in the Belgian Congo (modern day Zaire) instituted a system of indirect rule of the cultivators over the hunter gatherers in the period following World War I. Through an administrative system known as "Circonscription Indigène", local political control by sedentary farmers was ensured. In the 1930's, administrators in French Equatorial Africa introduced a "taming" policy intended to wean the hunter gatherers of their dependence on Bantu villagers. While the purported aim of this policy was to "emancipate" the hunter gatherer population, a more fundamental motivation was to bring them under the direct control of the colonial administration. This in turn would benefit the colonial economy by permitting more direct organization of the hunter gatherers available for the production of forest products.

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C. Post-Independence: Forests as State Domain

Many of the patterns of natural resource use established during the colonial era remain in force today. After gaining their independence in the early 1960's, some French-speaking African countries amended forest ownership laws in favor of indigenous inhabitants. Generally speaking, however, the legislative texts creating communal forests were not applied, and most traditional forest peoples were left effectively, if not legally, landless.

Other newly independent countries copied the acts of their colonial predecessors by means of decrees establishing forest lands, if not all national territory, as property of the nation state. In Gabon and the Congo, for example, governments continue the colonial French policy of denying the validity of customary titles to land, on the grounds that undeveloped primary forests are "vacant" and thus the sole property of the state. In Zaire, the General Property Law of 1973 abolished the category of "native lands" that had earlier been recognized under customary tenure.

Today the only legally secure titles to land in Zaire are those officially registered as private concessions granted by the national government. These account for only a small percentage of the national territory. Secure private titles or leases to land can be obtained only through written application to the state authorities. 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 agriculture (Salacuse 1985). This *a priori* ownership requirement is a common feature of land tenure in many countries and has been shown to have negative ecological consequences for primary forest lands.

The President of Zaire, Mobutu Sese Seko, at one time declared the nation's hunter gatherer groups "emancipated", but required them to live in "model" roadside villages. This experiment was soon abandoned as many of those resettled took ill and returned to the coolness of the forest. Meanwhile, the Mobutu regime became preoccupied with other issues. The end result of such practices has been the marginalization of people living within the forests. Disenfranchised, they remain uncounted and largely ignored by policy makers.

D. Present Day: Land Use Conflicts and Contradictions

Throughout central Africa, the operative reality of land use and ownership is far more complicated and contradictory than suggested by the legal principles codified in national law. In many cases, the state, despite its legal authority, has neither the ability nor the desire to exercise effective control over lands used by local people to supply their livelihoods. *De facto* authority over use and management of the region's forests is a complex mix of customary forest

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use practices and rules, modern statutes and laws, legal and business agreements with foreign entities in the form of timber and mineral concessions, and a wide variety of culturally and socially influenced local tenurial arrangements between different ethnic groups.

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 crises. Local forest dwellers, on the other hand, depend on the forest resources for their very survival. These conflicting interests often lead to a reluctance by local resource users and government authorities to work out equitable arrangements for managing primary forests for sustainable use and conservation.

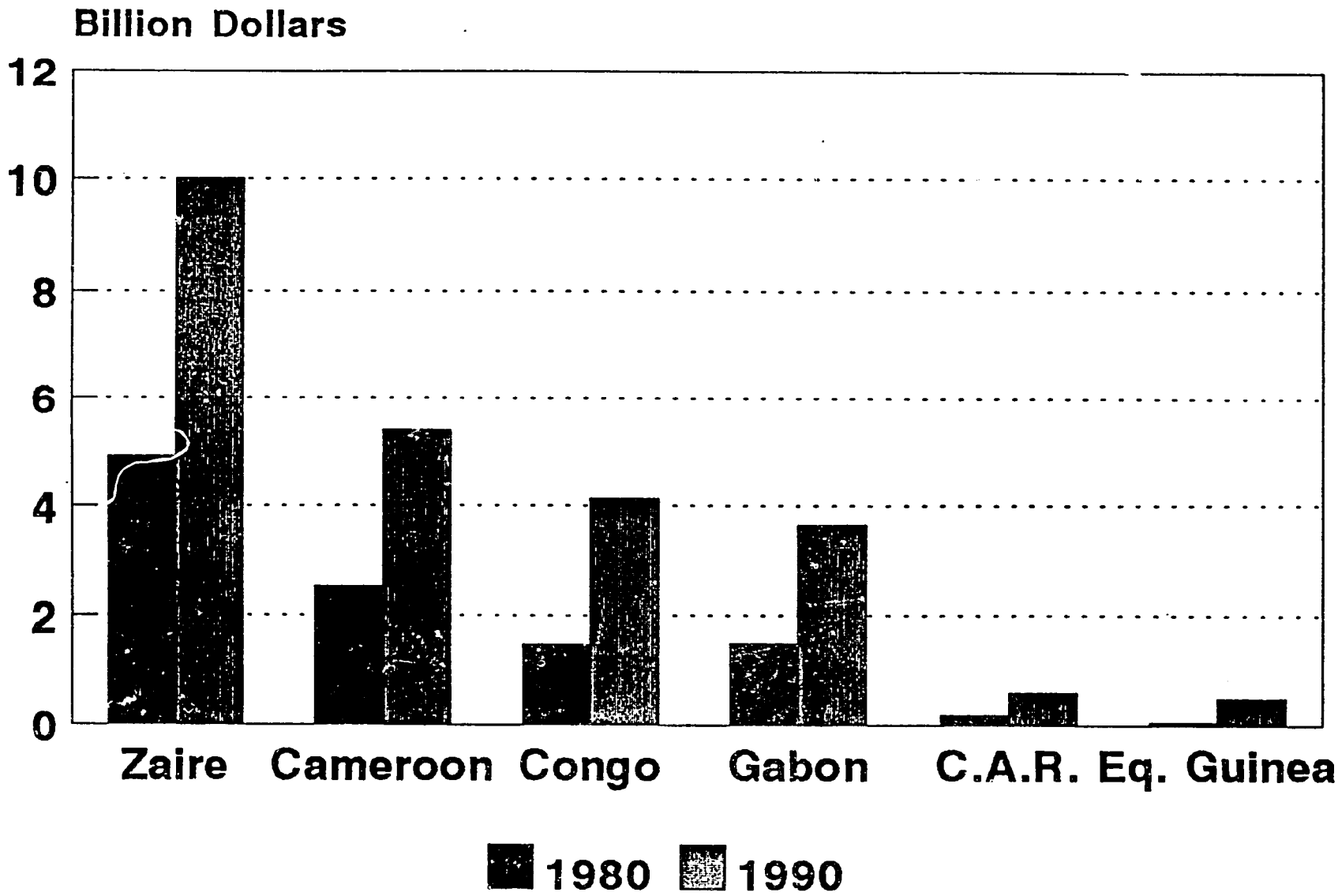
Compounding the problem is the dearth of information about the number, practices, and perspectives of the people living within, or dependent upon, the forests. Even well-intentioned development initiatives such as credit programs for small-scale investments, extension activities, and training in agroforestry, are often designed and implemented without local input or regard for customary laws and land use patterns. In the absence of participation by those who will be affected, such initiatives have little chance of long-term success.

In addition, most forest dwellers have little, if any, access to the official decision-making processes that affect the fate of their cultures. Instead, central governments unilaterally exercise legal control and regulatory oversight over vast forest areas. Commercial rights are often allocated to foreign business interests or political favorites who engage in extractive enterprises with little or no local input and with little regard for long-term, ecological consequences.

At the same time, national governments are largely unable or unwilling to effectively supervise activities within immense 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, 1991). At the same time, nation states in central Africa have been reluctant to involve the forest dwellers in the planning and management of their forest patrimony.

Multilateral, bilateral, and other development organizations have also largely failed to encourage the development of systematic, equitable, and environmentally sound strategies that address tenurial issues related to improved forest management. Large-scale, donor-initiated development projects are being planned in the region that could have major impacts on the forests. Mining projects, railroads, roads, and large-scale cash crop and forestry enterprises continue to be put forward with little concern for the importance of the local communities' vital role in promoting forest conservation and management.

Growth in External Debt
1980 - 1990



Source: Trends in Developing Economies 1991, World Bank 1991

Figure 5. Growth in External Debt

3. Political Economy and Development Trends

A. Economic Growth and Foreign Debt

The extraction of natural resources has long been the hallmark of central Africa's economies. In the colonial era, the region was a major world producer of timber, copper, palm oil, coffee, and cocoa. During the 1970's and '80's, petroleum became the most valuable regional export, often dwarfing the value of previous top export earners. In Cameroon, Gabon, and the Congo, crude oil exports fueled sharp rises in government expenditures; in Zaire, oil exports helped to compensate for a drop in revenues from other minerals, particularly copper.

The emphasis on petroleum has generally come at the expense of other economic sectors, particularly agriculture. Only in Cameroon has the agricultural sector avoided the deterioration experienced in the other five countries, but even there, soil erosion and declining productivity, especially in areas of 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 dwellers. In Zaire, the collapse of the once-extensive colonial plantation system has not yet led to a sustainable alternative. The growing reliance on export earners to underwrite the costs of basic food imports is another disturbing development: countries which were once net exporters of agricultural commodities are now turning increasingly to imports of even staple foods which must be financed by ever-tightening supplies of foreign exchange.

The commodity boom of the past has come to an abrupt end, with export revenues declining sharply as a result of increased competition from other regions of the world and a global slump in prices for agricultural and industrial raw materials. Prospects for their recovery remain bleak, especially in light of stiffening competition and worldwide economic constraints.

Faced with substantial revenue shortfalls and unrelenting debt payments on the one hand, and an ever-increasing population on the other, the countries of central Africa are counting on forest resources to alleviate debt and economic stagnation despite lackluster world prices for commercial hardwoods. The apparent abundance of forest assets makes them an obvious resource for government planners anxious to find solutions to the decline in prices for traditional agricultural commodities, or to the volatile markets for petroleum. Ironically, as central Africa strives to modernize itself, it continues to look primarily toward export-oriented extractive industries developed during the colonial era, over whose markets it has little or no control.

Economic Stabilization and Structural Adjustment

The economic recession of the past several years has been substantial. Oil-rich Gabon, which enjoyed a per capita income of around $4,000 in 1980, has seen this decline to $2,830 in 1988 (World Bank 1990(a), pp.207,212). All six central African countries have undertaken economic stabilization and structural adjustment programs since the mid-1980's. Some have been able to negotiate debt rescheduling, while others have entered into new borrowing mechanisms which alleviate short-term budgetary problems at the risk of long-term debt expansion.

In many ways, the economic downturn has helped to focus attention on deep-seated sectoral imbalances and other macro policy problems. Previously, resource mobilization and private sector initiative had been stifled by years of disproportionate investment in public enterprises. In some cases, recently introduced reforms have already resulted in tangible results. But more typically, the political costs of action have been perceived as being too high, and adjustment programs have been sidetracked. In addition, there is mounting documentation of the human costs of sectoral adjustment, which fall to a large extent on lower income and other vulnerable groups.

The ability of the six central African nations to successfully carry out the policy reforms they have launched, especially in the face of domestic political opposition, will depend to some extent on the willingness of multilateral and other sources of finance to provide effective support, and to mitigate some of the negative impacts of public sector retrenchment and elimination of subsidies.

Each of the countries has made policy statements on the need to protect social, educational, and health services during stabilization and adjustment programs, but harsh budgetary realities have forced reductions in these services as well. While the World Bank and others are now considering ways of targeting compensatory programs toward lower-income groups, the most vulnerable segments of central African societies are likely to continue to suffer - at least in the short to medium term - from the dislocations brought about by wide-ranging economic restructuring.

With the exception of Zaire, the central African countries are members of the Communauté Financière Africaine (CFA) franc zone. The declining US dollar relative to the CFA franc, which is tied to the French franc and guaranteed by the French treasury, has exacerbated revenue problems for Gabon, Cameroon, and the Congo, as world oil prices, which are set in dollars, have been yielding much lower CFA revenues. The CFA is widely perceived as overvalued, and there has been discussion for several years of a devaluation, though the currency continues to be fixed at the rate of 50 CFA to the French franc.

The strength of the CFA currency relative to neighboring currencies such as the zaire has handicapped regional exports by making

them more costly in terms of the weaker currencies. The unstable dollar to franc exchange rate has complicated the picture by causing massive swings in the region's debt statistics, which are denominated in dollars. On the other hand, access to a stable and convertible currency such as the CFA offers significant long-term advantages for governments as well as for investors, by facilitating international transactions as well as providing monetary security through the backing of the French Treasury for the CFA.

Based on World Bank data, Figure 5, "Growth in External Debt," depicts the growth of external debt in Zaire, Cameroon, the Congo, Gabon, CAR, and Equatorial Guinea from 1980 to 1990. On average, levels of foreign debt have doubled over this period. Specific information on the individual countries is encapsulated below.

Zaire. With an estimated per capita GNP in 1988 of $240, Zaire ranks as one of the world's poorest countries. Economic reforms in Zaire, which began with encouraging results in the mid-1980's, dissipated as the domestic political costs made themselves felt, especially with regard to reduction in public sector expenditure. Trade reform measures continued, but the economic stabilization and structural adjustment programs were largely discontinued. From 1984 to 1986, GDP growth averaged 3.3% annually; from 1987 to 1989, GDP growth fell to 0.6%.

In 1980, total external debt was $4,860 million; by 1989 the figure had soared to over $10,000 million. The government has again begun cautiously introducing reform packages, but with little visible success. The deterioration of infrastructure, the loss of public confidence, and the skepticism of foreign investors all pose significant constraints to development, a situation underscored by serious civil unrest in Kinshasa since late 1991 (World Bank 1991(d), pp.592-598).

Cameroon. With a per capita GNP of $990, Cameroon is considered a middle income country although it presently faces severe economic and political problems. The decline in oil prices in 1986 revealed serious structural weaknesses in the economy.

A stabilization program which featured deep cuts in public sector expenditure and a long-term effort to reduce the burden of parastatals began in 1987. A medium-term structural adjustment and sectoral reform program is now underway, with support from the World Bank, the African Development Bank, and other financial institutions. In 1980, total external debt was $2,513 million. By 1990, this figure had increased to $5,358 million (World Bank 1991(d), pp.78-84).

The Congo. The Congo's per capita GNP of $940 places it in the ranks of middle income countries, although the oil price decline brought with it a deep recession. Foreign debt has skyrocketed: in 1980 total debt stood at $1,496 million; by 1990, it had reached $4,116 million. Mirroring the debt rise has been unemployment which rose by 150%

between 1986 and 1989. Marxism was formally abandoned as the governing ideology in June 1991, and an extensive program of public sector reform and retrenchment is now underway. A stabilization program began in 1986, followed by a Paris Club (governmental) debt rescheduling (World Bank 1991(d), pp.129-135).

Gabon. Gabon's per capita GNP of $2,990 in 1989 makes it the most prosperous country in all of Sub-Saharan Africa, and places it on a par with Argentina and Chile. This oil-based wealth, however, tends to conceal a seriously imbalanced economy, and a large and costly public sector keeps wage levels significantly out of line with non-oil sector productivity.

The oil price collapse of 1986 sent Gabon into a financial crisis from which it has yet to emerge. Total external debt in 1980 was $1,513 million; ten years later, the debt level had reached $3,659 million. A stabilization program was launched in 1986-87, and deficits were reduced by massive cuts in government spending together with Paris and London Club (commercial loan) rescheduling agreements.

A major structural adjustment program was launched in 1988 with assistance from the World Bank, the French government, and the African Development Bank. Reductions in the public enterprise sector is a primary focus of this program, along with measures aimed at expanding the role of the private and non-oil sectors (World Bank 1991d, pp.210-216).

CAR. CAR's per capita GNP of $380 in 1989 places it among the least developed countries. Total debt in 1980 was $195 million; by 1990 this had reached $621 million, a 300% increase. Economic stabilization began in 1986, followed by Paris Club rescheduling in 1988, and the French government's cancellation of CAR's outstanding debt.

Structural adjustment is being intensified, and CAR qualifies for assistance under the Special Program of Assistance for debt-distressed lower income countries. Reforms in public enterprises, in the agricultural and transport sectors, and in overall management, are being pursued under this program. In addition, efforts are being made to stimulate expansion of the private sector (World Bank 1991d, pp.92-97).

Equatorial Guinea. Equatorial Guinea's per capita GNP is estimated at $390, a partial recovery from the chaotic years of the Macias Nguema regime, although well short of pre-independence levels.

In 1980, total external debt stood at $75 million; by 1990 debt levels reached $505 million, an increase of 670%. Government stabilization measures included joining the CFA franc zone in 1985, which in effect included a substantial devaluation. These measures brought only partial relief, but a Paris Club rescheduling in 1989 has eased the situation to some extent. International donor activity has also grown significantly in recent years.

Structural adjustment programs, including expansion of the role of the private sector, reduction in public enterprises, and reform of the banking sector, are moving more slowly than hoped, and further debt rescheduling is likely to be necessary (World Bank 1991d, pp.191-196).

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B. Demographics: Population Growth, Migration, and Urbanization

Pressures on forest resources come from a variety of factors, but population growth is perhaps the most important source of demands on the resource base in terms of demand for food production, fuelwood, and building materials. Although much of rural central Africa is able to meet its own needs, urban areas are increasingly hard-pressed to keep up with the demands of steadily rising numbers. Given the infrastructural incapacities of many sectors of central African life, population growth can widen the gap between sustainable production and resource depletion.

Tracking demographic effects on the rate of deforestation is difficult, in part because accurate and up-to-date statistics are lacking for each of the six countries. The specific reasons for this vary from country to country, but include a number of shared constraints, the most prominent of which is an administrative infrastructure incapable of accurately capturing basic data over time. Attempts to improve the situation are undermined by budgetary crises, transportation and communication bottlenecks, and the deteriorating state of governmental agencies in general. In Zaire, for example, the first national census in the country's history, which began in 1984, took three years to tabulate; some regions of the country reportedly never were tallied.

The situation is particularly acute in rural areas where administrative infrastructure has always been weak or nonexistent. Many births and deaths are simply never reported. In urban areas, there is a steady influx of job seekers from the countryside, many of whom live in overcrowded periurban slum settlements typically overlooked by national governments, not only in providing services, but also in the collection of vital statistics.

Table 1 lists estimates of basic demographic statistics of the six countries of central Africa. Overall population of the region is estimated at approximately 54 million. Of this, Zaire accounts for 70%, or roughly 36 million. Cameroon is second with over 11 million people. Together, the two contain 87% of the regional population.

Population growth rates - admittedly little more than guesses - range from 2.3% in Equatorial Guinea to 3.5% in Gabon. The population of central Africa is projected to top 140 million by the year 2025, a nearly threefold increase in thirty-five years (WRI 1990, p.254 (from UNDP sources)).

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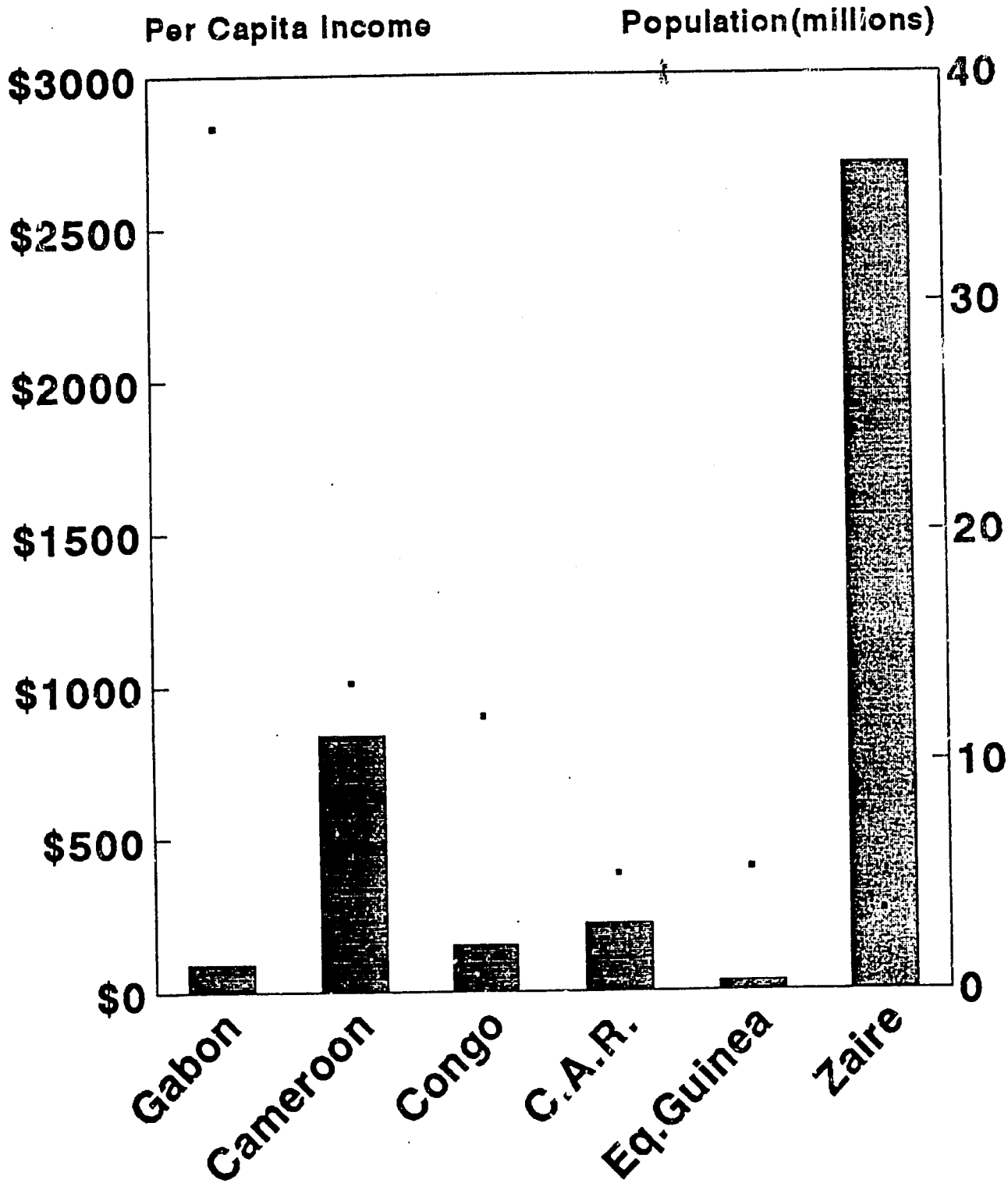
Figure 6. Population and Per Capita Income

Population and Per Capita Income



· Per Capita Income ■ Population

source: World Bank, UN data

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TABLE 1: Demographic Overview
(in millions as of 1990)

Country	Population 1990	Population 2025	Annual Growth Rate 1985-1990	Density per km2	% Urban	Annual Urban Growth Rate 1985-90
Zaire	36.0	99.5	3.2%	15.4	39.5	4.7%
Cameroon	11.2	26.2	2.6%	23.5	49.4	6.8%
Gabon	1.2	2.9	3.5%	4.4	45.7	6.3%
The Congo	2.0	5.0	2.7%	5.7	42.2	3.3%
CAR	2.9	6.8	2.5%	4.6	46.6	4.5%
Eq. Guinea	0.4	1.0	2.3%	15.3	64.5	5.1%
Regional	53.7	141.4	3.0%	15.9	42.2	5.1%

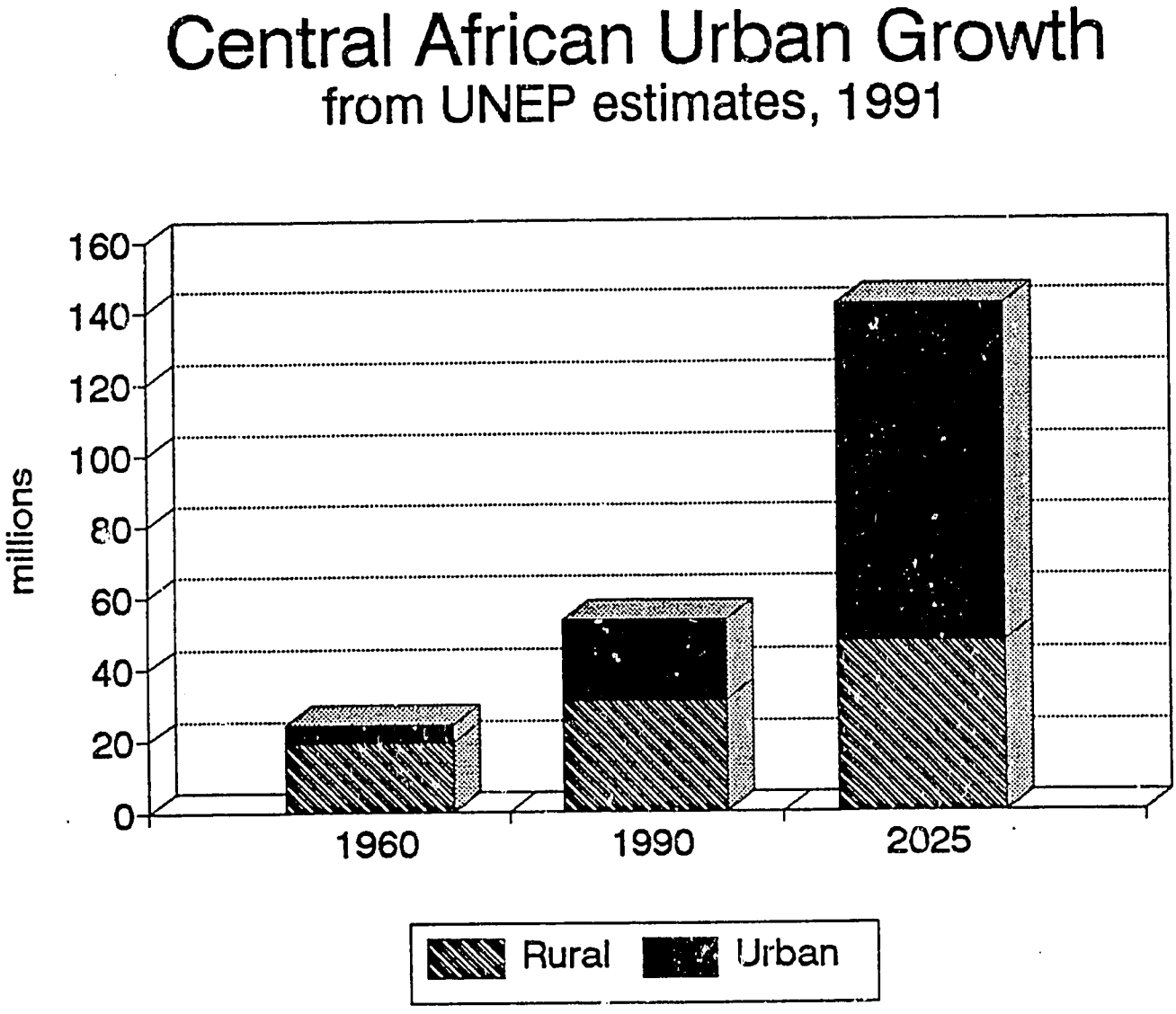
Source: 1990 WRI statistics

Overpopulation is not often considered a problem in central Africa in general as vast areas of virtually unoccupied territory extend across the breadth of the region. The most densely populated of the six countries, Cameroon, with 23.5 people per square kilometer, is slightly above the African average of 21.2. Gabon and CAR, with only 4.4 and 4.6 people per square kilometer respectively, are among the least densely settled nations on the continent.

Illustrative of the divergent governmental attitudes toward population growth is the fact that Gabon and the Congo consider their population growth rates to be too low, while CAR considers its rate to be unsatisfactorily high. The Gabonese government maintains pronatalist policies such as cash prizes and medals for mothers with large families. CAR, on the other hand, is concerned that food production and economic output are not keeping up with population growth. For this reason the government is encouraging quality of life programs rather than promoting larger families (United Nations 1989, pp.2-5,114-116).

Yet there is little doubt that many of central Africa's urban areas suffer from overcrowding. Urban dwellers presently number 23 million, but are expected to more than triple to 90 million within the next 35 years. In all of the countries, with the exception of Equatorial Guinea, the lure of jobs and social amenities has led to a long-term migration from rural areas, particularly to the capital cities and industrial centers. Most of these cities are now experiencing record levels of congestion, crime, unemployment, inflation, and disease, particularly AIDS with its potential to devastate the ranks of the most economically productive segment of the population, men and women between the ages of 18 and 40 (Chin 1991, p.208).

Figure 7. Central African Urban Growth



In addition to bringing social and economic problems, urban migration has strained the surrounding land's ability to provide food, fuelwood, and building materials. Strain on the resource base leads to localized deforestation and agricultural degradation as resources are utilized at unsustainable levels. Particularly hard hit are the forests near major urban areas: "urban halos" of deforestation now extend in a radius some 150 kilometers from Kinshasa and Brazzaville.

Despite these disadvantages, urban growth rates average between 3.3% and 6.8% annually, suggesting that prospects in the countryside are perceived to be very limited indeed (WRI 1990, p.270, from United Nations Statistical Office, International Labour Organization, and World Bank data). The resulting labor shortages in rural areas have significantly compromised agricultural productivity in some countries, prompting government policies geared toward keeping people in the countryside or inducing them to return. In addition, Zaire and CAR have had to deal with substantial numbers of refugees from civil wars in neighboring lands.

Figure 6, "Population and Per Capita Income," illustrates the correlation between population and income in the six central African countries. Figure 7, "Urbanization Trends," depicts projected regional population figures for the year 2025, divided into rural and urban components. As both charts clearly demonstrate, Zaire and Cameroon constitute the two most significant contributors to both present and future populations. Zaire alone has more people than the other five countries combined. Zairians are the poorest economically: per capita income is roughly US$ 240.

C. Industry and Investment

From a carbon emissions point of view, the industrial sector in central Africa is not presently a major contributing factor: the number of industrial firms is relatively low, and their energy consumption is limited and often derives from hydropower. Biomass is used by many firms, not only in the form of fuelwood or charcoal but through also waste materials such as sawdust and sugar cane bagasse. Most bakeries and brick kilns are fired by fuelwood; the sustainability of this supply for urban consumers is in doubt, however, due to the increasing distances from supply sources. Some coal is used for smelting in Shaba, but there is little prospect for a significant increase in the use of coal elsewhere in the region due to high extraction costs, low heating qualities, and transportation problems. A limited quantity of methane from Lake Kivu has reportedly been used by a local brewery on a more or less experimental basis.

One of the major obstacles to the expansion of industry in central Africa is the small size of national markets. Disposable income remains low, inhibiting the development of industries other than food processing and a limited range of basic consumer goods. Imported goods are widely available, although at high prices, and attempts at import substitution have not been particularly successful. Many

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central African plants operate below 30% of capacity due to a variety of factors such as poor management, shortages of skilled labor and spare parts, power failures, transportation and communication bottlenecks, and over-optimistic assumptions concerning markets, revenue, and profitability.

Apart from minerals processing and metallurgy, which are discussed separately in Part II, central African industry is largely dominated by the processing of agricultural products and the manufacturing of basic consumer products. Food processing is perhaps the major industrial activity; at the small-scale level, it is one of the most dynamic aspects of the region's industrial development, accounting for significant levels of local employment and domestic revenue. The milling of cereals and cassava, for example, has become a highly popular small business. The Kivu city of Bukavu, with an official population of 209,000[2], has as many as 300 privately operated grain mills serving local residents and rural producers (J.F. Swartzendruber, pers. comm., 1991).

Sugar and edible oil production are important industries, but have not always been able to keep up with demand. In Cameroon, where plantations have invested heavily in hybrid oil palm cultivation, the country has been able to remain competitive on the world market, while also meeting domestic demand. In Zaire, however, investment has lagged, and production has been declining for many years. As some of the oldest colonial era palm oil processing plants abandon production, some moves have been made to replace them with smaller and more efficient plants.

A few large firms, often state-controlled or foreign-owned, produce consumer goods such as beer, soft drinks, cigarettes, soap, simple textiles, and footwear. Demand for these products is traditionally strong, and this sector has performed well, even during periods of economic hardship.

Larger firms such as breweries often retain technical or managerial linkages with foreign companies, and while they generate local employment and produce tax revenues, their presence has not significantly stimulated local economies. In Asia, industrial development has often resulted in a proliferation of small enterprises with linkages to larger firms, supplying sub-assemblies and other services. This pattern of industrial diversification has yet to develop significantly in central Africa.

Processing export commodities such as timber, coffee, cocoa, and cotton is an important aspect of central African industry as national governments try to increase levels of local value added and employment. This strategy has been undermined by problems of quality control arising from lack of technical and managerial skills, shortages

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[2] the actual population is undoubtedly much higher

of investment capital for processing equipment, and uncertain commodity markets. In the long run, however, policies aimed at phasing out the export of unprocessed raw materials are likely to become both more prominent and more successful.

Despite incentive programs including tax holidays and guaranteed repatriation of profits, the long-standing problems of management, technical expertise, and basic manufacturing capabilities have consistently discouraged foreign investors. Furthermore, access to foreign exchange has been a chronic obstacle in Zaire with its non-convertible currency. It is not unusual for firms operating manufacturing plants in Zaire to also engage in a variety of trading activities - the export of coffee, for instance - in order to provide the foreign currency necessary for importation of spare parts, machine tools, or packaging materials, or to pay the salaries of expatriate managers. Construction firms and other private sector entities often base their budgets on Belgian francs or U.S. dollars, due to the instability of the zaire (J. F. Swartzendruber, pers. comm.).

Local entrepreneurs tend to prefer investing in high-return activities such as commerce and transport, and avoid more complex manufacturing ventures whose payback period would typically be much longer. An exception to the dominance of trading has been the rise of small firms, often in the informal sector, which produce furniture, bricks, and window and door frames, or the numerous small workshops providing welding and auto repair services, and so forth.

Cement production, an important industrial source of carbon dioxide emissions in developed countries, remains at relatively modest levels in the region. In 1986, for example, cement production was 779,000 tons in Cameroon, 445,000 tons in Zaire, 210,000 tons in Gabon, and 58,000 tons in Congo, for a regional total of roughly 1.5 million tons (Europa World Year Book 1990, pp.661,762,1081,2995).

D. Central African Political Systems in Transition

In many senses, the independence movements of the 1960's rearranged the political dynamics of central Africa more than they changed them. Colonial leaders representing the interests of Paris, Brussels, London, and Madrid were replaced by factional leaders representing primarily the interests of their particular ethnic groups. Not only were other ethnic groups ignored, they were frequently persecuted as internal opposition was suppressed.

Following independence, the new African nations were well positioned to profit from high levels of demand for the raw materials they produced. Revenues poured into the national treasuries, especially with the development of coastal petroleum deposits. Much of the newfound wealth, however, was spent on ill-conceived, large-scale capital improvement schemes as the new nations sought to "catch up" with the industrialized world. Foreign lenders encouraged high-profile projects without properly ascertaining need, feasibility, and maintenance requirements. Capital flight has been another drain on local economies, with significant volumes of funds being transferred to personal bank accounts abroad.

An essential part of the independence movement was the deliberate distancing from the colonial powers and the European way of doing things. Various forms of "Africanization" were introduced, industries were nationalized and sometimes handed over to friends and relatives with little technical or managerial expertise. Colonials received little encouragement to stay and lend their skills to the transition, and in some places, such as Equatorial Guinea, they were forcibly expelled. The result was frequently an increasing gap in productivity, first from shortfalls in technical and managerial knowledge, and then from deterioration of infrastructure.

Although the countries of central Africa have by now recognized many of these lessons, and have attempted to introduce reforms, the combined effects of economic deterioration and political repression continue to destabilize the region. Frustrated by their continued disenfranchisement from the system, rival groups have sought to overthrow incumbent leaders. Civil wars in Zaire, purges in Equatorial Guinea, and a series of military coups in CAR, exemplify the depth of the political instability which has undermined development in the region. To some extent, political instability and economic deterioration tend to reinforce each other, and have become a vicious cycle which is proving difficult for these countries to overcome.

Until recently, political power in central Africa seemed resistant to domestic pressures for change. The last major leadership transition took place in Cameroon in 1982 when Paul Biya succeeded his predecessor of twenty years, Ahmadou Ahidjo. Despite several challenges, General André Kolingba has remained in control in CAR for over a decade as have his counterparts in Equatorial Guinea and the Congo, General Theodore Obiang Nguema and Colonel Denis Sassou-Nguesso, respectively.

Two of the more senior rulers of post-independence Africa, El Hadj Omar Bongo of Gabon and Mobutu Sese Seko of Zaire, continue their twenty-five year reigns.

During the last two years, however, pressures for political and economic liberalization have begun to erode the once solid power bases. Much of the impetus has come from economic hardship that resulted from the depressed prices for export products, particularly petroleum, cocoa, and coffee. A more recent factor has been the worldwide movement toward democracy and the collapse of communism. One result of the end of the Cold War, for example, has been a decrease in international interest and involvement in the region, and a decline in bilateral assistance budgets.

Faced with mounting opposition, the Congo abandoned its Marxist orientation in June of 1991. Facing similar problems, Gabon, Cameroon, CAR, and Zaire have initiated national conferences in an attempt to address the widespread criticism which threatens to undermine the already weak base of governmental legitimacy. These national conferences are an encouraging development, yet it is not clear whether they will achieve solutions to deep-seated political and economic crises. With extensive foreign debts, scarce investment capital, and a worldwide slowdown in the demand for basic commodities, the region faces serious long-term economic difficulties.

Troubled economies and increasing political pressures have resulted in a general strike in Cameroon, and in serious civil unrest in Zaire since late 1991. It is difficult to be optimistic about the effects of economic and political instability on the region's natural resource base, and particularly the forests. In the absence of any short-term improvement in the basic economic picture, both worldwide and regionally, changes in leadership will not necessarily lead to more sustainable trends in use of the natural resource base.

PART II. SOURCES OF LANDSCAPE CHANGE IN CENTRAL AFRICA

1. The Forest Sector

Introduction

The moist forests of central Africa are the last remaining contiguous area in Africa which contain a substantial quantity of wood - some 42 billion tons - as well as a globally significant diversity of plants and animals. Because it is such a rich ecosystem and a large storehouse of carbon, there is concern that this area should not be allowed to deteriorate in the manner of other forest zones, such as those of West Africa. There are many pressures on some of the central African forests areas not only to locally over-exploit the plants and animals, but to convert them to other uses, particularly agricultural expansion.

Though some areas are overexploited, the majority of the central African forests are presently underutilized. The annual demand for wood and wood products is about 60 million cubic meters (40 million tons air dry). At present, an estimated 40,000 people are employed full-time in the commercial logging, sawmilling (including hand (pit) sawing), and the plywood industries. More importantly, there are over 100,000 people employed in commercial fuelwood and charcoal production and distribution. If the wholesalers and retailers of industrial wood and woodfuel are included, over 150,000 people are employed full-time. Thus, the forest sector is very important in the central African regional economy (Openshaw, 1980).

Consumption is about 60 million cubic meters, yet the annual production from the moist forest alone is on the order of 1800 million cubic meters (1200 million tons air dry), some 30 times the present level of demand. If not used, much of this wood will rot as many areas are in a state of botanical equilibrium, i.e., annual growth is offset by annual mortality. The potential exists for expanding the use of the forests, assuming the presence of proper management and exploitation, so that human use of the forest can be a positive influence for their preservation while at the same time being a vehicle for local economic development. Ensuring the presence of appropriate management, is, however, a significant problem in central Africa.

A. Parks and Protected Areas

The central Africa region is rich in plant and animal life, much of which is endemic. In Zaire alone, there are more than 11,000 species of plants, one third of which are found nowhere else; over 400 species of mammals, almost 100 more than any other African country; and more than 1,000 species of birds, again more than any other country on the continent (Wilks 1989, pp.15-16). Other countries of the region, particularly Gabon and Cameroon, are also endowed with large numbers and a great variety of wildlife, much of which helps to meet various human needs.

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Hunting of bushmeat is a major activity in central Africa, both for subsistence in the rural areas, and to supply the urban market where it can bring prices many times higher than those of domesticated livestock. Poaching in protected areas has become a major problem in the region. It is reportedly too dangerous for researchers to venture into Gabonese reserves at night as gunfire from poachers has become commonplace (Nicoll 1986, p.46). Since many trees depend on specific animal species as pollinators and seed dispersal agents, the relationships between the animals and the forest need to be further studied, as overhunting could adversely affect the potential for natural regeneration and eventually upset the species mix (Miller and Tangley 1991, p.95).

Setting aside protected areas for wildlife conservation began during the colonial era. Five percent of the territory of Cameroon and Gabon, for example, is currently incorporated in a variety of protected areas. The government of Cameroon has considered increasing this to 20%, but implementation has been delayed (World Bank(b) 1990, p.6).

Most of the region's parks have not been adequately managed since independence. Protected areas are encroached upon by agriculturalists, loggers, oil explorers, and bushmeat poachers. In the Congo, Gabon, and Cameroon, for example, where it is in principle illegal to carry out logging or other intrusive human activities in protected areas, logging concessions have been granted and oil exploration occurs in national parks and wildlife reserves.

A lack of field staff and equipment hampers adequate patrolling and protection: the Congo, for example, has 43 guards to patrol 15,000 square kilometers. Similar numbers exist for the other countries in the region (Johnson et al., in press). In addition, field staff must live under difficult rural conditions, are poorly and irregularly paid, and may face personal danger in confronting poachers who are often well-armed. In addition, local attitudes toward protected areas are often negative, and authorities may be reluctant to intervene when local residents make use of resources in protected areas.

As a result, governmental policies often have little practical application at the local level. Because there are large numbers of forest dwellers in these areas, it might be more effective to train them as resource managers, rather than trying to keep local residents out of protected areas through patrolling. Improving the management of existing parks is clearly a priority, and it is probably futile to reserve more land for parks until more appropriate management systems have been put in place.

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B. The Timber Industry

Historical Perspectives

Export logging has been carried out in central Africa since the end of the nineteenth century when African hardwoods became extremely popular in Europe. The region as a whole relied on exports of raw logs as its primary source of external revenue until well after independence. It wasn't until the 1960's and '70's that timber ceased to be the leading export earner, replaced by minerals such as petroleum in the Congo, Gabon, and Cameroon, cobalt and copper in Zaire, and diamonds in CAR.

Sharply decreasing prices for the region's agricultural, petroleum, and mineral export commodities in the 1980's, coupled with huge debt burdens, have severely compromised the economies of contemporary central Africa. As a result, government planners are turning to other natural resources, primarily timber, in an attempt to make up for falling export revenues. The recent revitalization of timber exploitation in the region represents the resumption of a historic activity rather than a new development in the economy.

With seemingly unending forests to exploit, an important factor in logging has always been proximity to ocean ports. Areas close to the coast or adjacent to the extensive riverine networks were the first to be logged. Later, roads and railroads extended the exploitation into the interior. A century later, the most accessible forests have been logged of commercial species several times, while the more remote forests have been logged in proportion to their accessibility.

With coastal forests now largely depleted of commercial species, the majority of logs today come from inland areas. Logs are either floated or loaded onto barges, and shipped downstream to inland ports, especially Brazzaville, where they are transferred to trucks or railroads for the overland journey to the nearest seaport. Because of the enormous distances involved, as well as the seasonal fluctuations in river levels, transport times can be as long as one year. This is particularly true for landlocked CAR and the more remote inland regions of Cameroon, the Congo, and Zaire (F. Weber, pers. comm. 1991). Additional constraints are now resulting from the fact that Brazzaville currently has a two-year backlog at its railroad loading facility (N. Seligman, pers. comm. 1992).

Inventories One of the primary problems in determining the state of central African forests is the shortage of specific data about the extent and composition of the forests themselves. Forest inventories were initiated during the colonial era, but the focus of interest then, as it remains today, was on a handful of commercially valuable species. Few of the colonial inventories have been updated, and there are of limited usefulness from an environmental perspective.

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Techniques such as remote sensing have limited potential for filling this gap. Satellite imagery can provide an approximate measure of the area of woodlands and forests, but reveals little about the condition of these forests, or about their contents in terms of species, remaining wood volume, habitat quality, and the direction and magnitude of trends. Biomass inventories for the region are scarce, making it difficult to estimate how much carbon is presently stored in central Africa's forests. Accurate analysis is likely to eventually require detailed and costly field surveys.

A minimum requirement for assessing the condition of the forests is some form of inventory of the dominant tree species, their geographic coverage, and their density. Satellite imagery, complemented by ground-truthing, may prove useful but must exclude anthropogenic vegetation such as banana or palm oil plantations. This differentiation may prove difficult to accomplish in practice. The conversion of the tropical forest to agricultural uses frequently begins with a few banana trees planted in the gaps that result from tree felling. Later, cassava or other root crops may be planted in or near the bananas, and intermittent oil palm shoots or slips begin to appear. As a result, the transition is often gradual and very difficult to detect or map, even from the ground (F. Weber, pers. comm., 1991).

Governments regard the lack of forest data as a major constraint to increasing timber production. Meanwhile, scientists, environmental groups, and policy makers would like to know more about the forests in order to make more informed decisions about future land uses. Improving forest inventories and developing more accurate logging statistics are now considered priorities. Donor agencies such as FAO, UNDP, the World Bank, and the governments of France and Canada are financing studies of the forest resource by combining satellite and aerial photography with plot samplings taken on the ground. In CAR, these programs are still in the start-up stage, while in Zaire, Cameroon, Gabon, and the Congo roughly 190,000; 100,000; 60,000; and 45,000 square kilometers respectively have been inventoried.

Area, Growing Stock, and Yield

Accurate data on the area, growing stock, and yield of the forests of central Africa are extremely scarce. Chapter 3 includes estimates of original and present forest cover, but inconsistencies between tables result from different definitions (particularly of what constitutes "cleared" land), interpretations, and dating of the "original" forest area. Satellite imagery, when analyzed properly, can provide a useful tool for monitoring changing land use patterns over time.

However, ground-truthing and measurement of the standing tree stock are needed to monitor the species mix and the stocking density within the various forest categories. In addition to the two broad "forest" categories used, open woodlands and closed forests, woody

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biomass is also found in the form of scrub, shrubs, and trees on all other land types - from grasslands to arable agricultural areas. Such "nonforest" trees may be an important source of wood products, particularly fuelwood and poles as well as nonwood products such as fruit, fibre, fodder, and medicines.

Bearing in mind these data problems, Table 4.1 gives an estimate of the land area, by ecosystems, of the six central African countries, together with approximate weights of growing stock, and annual yields of above-ground woody biomass.

Table 3 Estimated Land Type, Growing Stock, and Annual Yield of Above Ground Woody Biomass in Central Africa (1990)(1)

(all units in millions

Land Use Type(2)	Area (ha)	Woody Growing Stock(3) (in tons) (air dry)	(carbon)	Annual Yield(4) (in tons) (air dry)	(carbon)
grassland	1.73	4	2	0	0
low density wooded area	10.37	146	62	4	2
woodland	161.23	19,506	8,301	585	249
high woody mosaic(5)	64.36	1,210	515	36	15
forests	154.86	41,999	17,872	1,260	536
miscellaneous(6)	5.77	109	46	3	1
totals	398.32	62,974	26,798	1,888	803

Sources: Millington et al., 1992; (see Chapter 3)

Notes: (1) Cameroon, CAR, Congo, Eq. Guinea, Gabon, and Zaire. Total area equals 408.20 million hectares of which 9.88 million hectares are water. (2) The land use type has been modified from Millington et al, 1992: Estimating woody biomass in sub-Saharan Africa - Chapter 3, Table 8. (3) The above ground woody growing stock on the different land use types is given to the nearest million tons of carbon or wood to indicate the uncertainty of the estimation. It has been derived principally from Chapter 3, Table 10, by assuming that "undisturbed" and the "logged" areas refer to forests and the "unproductive" areas to woodlands. Nonforest or woodland area figures were taken from Chapter 3, Table 13. It is assumed that oven dry wood has 50% carbon by weight and air dry (a.d.) wood has 15% water by weight. Therefore, air dry wood contains 42.5% carbon. To convert tons of carbon to tons of wood, the multiplication factor is thus 2.35. In addition, there may be about 40% more woody biomass below ground in the form of roots and rootlets and up to 240 tons per hectare of carbon stored in the top five meters of soil. (4) The estimated annual yield has been derived by assuming that annual growth averages 3% of the growing stock. This depends on the tree formation, its density, and its age; it normally ranges from about 2 to 8% of the growing stock. (5) This includes most of the arable and permanent crop area as well as the permanent pasture. According to FAO's Agricultural Production Yearbook for 1990, there are 15.67 million hectares of arable agricultural land, 2.04 million hectares of permanent crop, and 41.1 million hectares of permanent pasture. The same publication estimates

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other land types. Its per hectare woody growing stock and annual yield is assumed to be the same as "High Woody Mosaic".

Table 4.1 suggests that there are approximately 27 billion tons of above-ground carbon in the 63 billion tons of biomass growing on 400 million hectares of land in central Africa. Each year, this woody biomass is producing some 800 million tons of carbon (1.9 billion tons of wood). Most of this, if not used, will eventually escape into the atmosphere as CO^2 through the various processes of decomposition and will later be reabsorbed. Two-thirds of the carbon is stored in the forests, which occupy about 39% of the land area, while another 30% is in the woodland formations which cover roughly 40% of the land area. The remaining 3% of carbon is stored in the other land use types. Any changes from forest to nonforest formations, therefore, lead to a direct reduction in the amount of stored carbon. In addition, reducing tree density could lead to a permanent or temporary reduction in stored woody carbon.

Besides being stored in the above ground woody biomass, carbon is also sequestered in roots and soils as well as in annual crops. About 30% of the total woody biomass in central Africa may be in the form of roots, a proportion that could represent as much as 11 billion tons. In addition, there could be up to 45 billion tons of carbon stored in the forest and woodland soils.[3]

For every hectare of forest cleared for arable or pastoral agriculture, about 115 tons of above ground carbon will be lost if all the cleared biomass is burnt. An additional 50 tons per hectare of the below-ground carbon contained in the soil and roots will also be lost in the transformation process. For each hectare of woodlands cleared for agriculture via traditional slash-and-burn techniques, there will be an average of 57 tons of carbon from above-ground woody biomass and 25 tons of below-ground carbon lost as a result. In traditional farming systems, this will eventually reaccumulate via regrowth.

Estimates of the amount of woodlands and forests cleared each year vary considerably. Table 3.7 posits an annual deforestation rate for moist tropical forests of between 4.9 million and 10.9 million hectares. Other data in Chapter 3 give the annual clearing rate for moist tropical forests at 3.5 million hectares and 3.4 million hectares

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[3]Chapter 3, page 29 states that in the rainforests of Central America, there are an estimated 240 tons of soil carbon per hectare. This figure has been used for the forests of central Africa as well, with half of that total (120 tons per hectare) used for woodland formations. Thus the total quantity of soil carbon in forests and woodlands is estimated to be 56 billion tons of carbon with roots, and 45 billion tons without roots. It is estimated, however, that only about 21% of this below ground carbon is lost as a result of converting the forests to agricultural purposes. (Chapter 3, p. 29).

for woodlands, (based on incomplete data for woodlands and estimates made for CAR, Eq. Guinea, and Gabon.) Some of the figures cited in the previous paragraph may include land that is temporarily cleared, but will be left to revert to forests, or land presently in a shifting cultivation cycle. It is important to separate these categories and exclude them from the permanently cleared category.

Assuming that land expansion is required only to feed the increased population, 4.6 million hectares of existing forest would be needed each year given current farming practices. If only woodlands were to be cleared, that figure would be twice as high.

If the annual clearing figures of 3.5 million hectares of forests and 3.4 million hectares of woodlands are a good approximation, then roughly 600 million tons of above-ground carbon are lost each year if the wood is burnt. An additional 250 million tons of below-ground carbon in the form of roots and soil carbon are also lost in the transformation process. It must be stressed that these figures are very tentative, especially the ones for below-ground carbon, and are given here mainly for the purpose of illustration.

If unit agricultural production could be increased, then less forest land would be required for agricultural expansion. But with the region's population expected to double in 23 years, more forest land will be required for agricultural purposes. The conversion, however, could be done in a more controlled manner so as to ensure that the wood and other resources are used as effectively as possible. In general, as more intensive forms of agricultural production are adopted, less forest land is needed to supply the additional agricultural output needed to keep pace with population growth.

Commercial Forestry Practices

Although the forests of central Africa are remarkably diverse with over 500 species growing to timber size (IIED 1988a, p.27), commercial logging has traditionally concentrated on only a small fraction of that number. In each country, one to five species generate the vast majority of export revenues.[4]

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[4]The trees listed below are some of the primary commercial species logged in the region, followed by the countries in which they play a major role in exports:

sapelli	(*Entandrophragma cylindricum*)	Cameroon, CAR, Congo, Zaire
sipo	(*Entandrophragma utile*)	Cameroon, CAR, Congo, Zaire
ayous	(*Triplochiton scleroxylon*)	Cameroon, CAR, Congo, Eq. Guinea
okoumé	(*Aucoumea klaineana*)	Congo, Gabon, Eq. Guinea
limba	(*Terminalia superba*)	Congo, Eq. Guinea, Zaire
ilomba	(*Pycnanthus angolensis*)	Congo, Eq. Guinea
azobe	(*Lophira alata*)	Cameroon, Eq. Guinea

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The logging industry in central Africa is dominated by European enterprises, many of which were previously active in West Africa. High-grading, the practice of taking only the best specimens of the most valuable species, is common as commercially valuable species grow at very low densities. Loggers typically seek 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. Only the best wood from the top of the buttress to just below the first branches is taken for export, though some slightly crooked wood may be converted in local sawmills. The rest of the tree is left on the forest floor. Sawlogs with imperfections are rejected for export and may be left to rot or burned. If there is a local demand, they could be utilized for lower value end products.

Central Africa's forest resources are not efficiently utilized: much potentially useful timber is wasted during both logging and processing. Only a fraction of the potential commercial volume in a given area is extracted by commercial loggers. In Cameroon, for example, harvested volumes of five to six cubic meters per hectare out of a potential commercial volume of 35 cubic meters per hectare are common (IIED(a) 1988, p.27). In Gabon, harvested volumes are even lower: on average, four to five cubic meters per hectare (IIED(a) 1988, p.7). (These figures should be viewed with caution, however, as under-reporting of wood volume is allegedly a common practice to reduce tax liability. Actual timber production is probably significantly higher.[5])

The logging practices generally employed also result in residual damage to the forest that may hamper the regeneration of the most desirable commercial species (though this could be overcome through enrichment planting). Some estimates put the loss of forest canopy due to logging at up to 20%. Many of the environmental services provided by the forest, however, are probably not threatened as up to 80% or more of the canopy may remain in place.

Small-scale loggers have sometimes been accused of doing more damage to the forest than their industrial counterparts. Artisanal loggers frequently remove all specimens of the high-value species above 30 centimeters in diameter - the practical limit for sawing.

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iroko	(*Chlorophora excelsa*)	Congo, Zaire
tiama	(*Entandrophragma angolense*)	Congo, Zaire
dibetou	(*Lovoa trichilioides*)	Gabon, Zaire
ozigo	(*Dacryodes buttneri*)	Gabon
ebony	(*Diospyros crassiflora*)	Gabon

[5]A more detailed discussion on logging and forest degradation in the tropics is given in Johnson et al. "Natural Forest Management and the Future of Tropical Forests", pp23-38, World Resources Institute (in press).

Such practices remove the seed bearers of commercial species, thereby undermining the long-term commercial potential of the forest (IIEDa 1988, p.7). For this reason CAR does not grant small-scale logging permits. On the other hand, felled trees can sometimes regenerate from root or shoot suckers. In addition, dormant seeds or suppressed seedlings of the commercial species may repopulate the area. Even if this regeneration does not happen, the remaining forest remains important for the provision of environmental services and non-timber forest products.

Timber Production: Potentials and Realities

Table 4.1 estimated the annual increment from tree growth at about 1.9 billion tons of wood. In volume terms, this represents approximately 2.8 billion cubic meters, half of which should be stem wood. How much of this wood is of commercially valuable species, and is accessible, is not known. However, there should be considerable potential for increasing the useful offtake from the forests: current removals amount to less than five million cubic meters of sawlogs and veneer logs, while total removals amount to about 60 million cubic meters. All told, this represents 2% of annual yield and a very small fraction of total growing stock. Table 4.2 gives an estimate of production, net exports, and apparent consumption of wood products in roundwood equivalent terms.

Table 4: Central Africa 1989: Estimated Production, Exports, and Consumption of Wood Products (all in million m3)

Product	Production	Net Exports	Consumption
Fuelwood & Charcoalwood(1)	50.50 (85%)	0.00	50.50
Poles	3.65 (6%)	0.00	3.65
Pulpwood(2) (4)	0.47 (1%)	0.47	0.00
Sawlogs and Veneer logs(3)(4)	4.69 (8%)	2.54	2.15
Totals	59.31 (100%)	3.66	56.30

Notes: (1) This is equivalent to 33.67 million tons of wood (air dry) or 12.71 million Tons Oil Equivalent. (2) This pulpwood was exported from the Congo. Actual exports for 1989 were 0.52 million m^3, the remaining 0.05 million m3 come from the previous year's stock and/or sawmill plus board mill offcuts and residues. (3) Of the total production of 4.69 million m3 of sawlogs and veneer logs, 2.08 million m3 were exported in log form, leaving 2.61 million m3 for processing in local mills. 1.81 million m3 went to sawmills and 0.80 million m3 to plymills and veneer mills. The estimated output from these mills is given in Table 4.3. Of this output, 0.46 million m3 of sawnwood (roundwood equivalent) was exported. (4) The export value of pulpwood came to US$ 20.34 million, that of roundwood US$ 319.60 million, sawnwood US$ 37.18 million, and wood-based panels US$ 81.18 million giving a total for 1989 of US$ 458 million. A small quantity of sawnwood was imported by the Congo valued at US$ 2.60 million, while Zaire imported US$ 0.17 million of wood based panels. Thus the net exports of wood products, excluding paper and paper board, came to US$ 456 million. The average export prices per m3 were: pulpwood US$ 39 (round), sawlogs/veneer logs US$ 154 (round), sawnwood US$ 266(sawn), and plywood US$ 812 (solid).

Source: FAO 1989 Annual Yearbook of Forest Products

Table 4.3 gives the estimated production of sawnwood and plywood for central African mills in 1989. The amount of the finished products is divided between local consumption and export. Some of the waste wood is also exported for pulpwood and some is used for fuel.

Table 5: Saw Mill and Ply Mill Production in Central Africa 1989

	Input ($m.m^3rd$)	Output ($m.m^3sawn$)	Exported ($m.m^3sawn$)	Local Consumption ($m.m^3sawn$)	Waste Wood ($m.m^3$)
Sawmills	1.80	0.94	0.14	0.80	0.87
Plymills	0.80	0.40	0.10	0.32	0.38

	($m.m^3rd.$)	Roundwood Equivalent Terms ($m.m^3rd$)	($m.m^3rd$)
Sawmills	1.81	0.27	1.54
Plymills	0.80	0.19	0.61
Totals	2.61	0.46	2.15

Source: FAO 1989 Annual Yearbook of Forest Products

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Sawlogs and veneer logs, which both come from the stemwood of selected commercial species, account for 8% of annual production of wood products but only about 0.2 percent of the annual yield. Thus, if logging of commercial species were properly managed and harvested, and the infrastructure were improved, there should be considerable scope to expand industrial wood production and use it as the vehicle for economic development presently envisioned by several of the national governments.

Assuming a reasonably stable world market, the potential thus exists for substantially increased economic returns from the forest sector. Already, just over half of the sawlogs and veneer logs are exported either directly or in the form of finished products. Together with the exported pulpwood, the value of these exports amounted to US$ 458 million in 1989 with the unit value ranging from US$ 39 per cubic meter for pulpwood to US$ 812 per cubic meter for finished plywood.

Although timber production fluctuates from year to year, recent promotion efforts have brought about an increase in overall production in the region. At the same time, exports of raw logs have dropped in Zaire, CAR, and Gabon due to increased wood processing in-country. Perhaps the most ambitious of the national promotional programs is Cameroon's recent Tropical Forestry Action Plan (TFAP) which called for an increase from 1977 levels of 1.3 million cubic meters, to four million cubic meters by the year 2000, and then to 5.5 million by 2010. Production is now just under three million cubic meters per year.[6] In the Congo, export targets were set at one million cubic meters per year by 1991; by 1989, they had reached 0.96 million m^3 including 0.52 million m^3 of pulpwood.

CAR is the only country of the six in which timber production has declined. Production in both 1987 and 1988 was about half that of 1981. Some of that decline is due to problems encountered by logging companies in the Haute Sangha area when the bridge connecting CAR to the overland transportation route through Cameroon collapsed in 1987. This compelled loggers to use the more expensive transportation river and railroad routes through the Congo which also brought them into contact with the two-year railroad backlog in Brazzaville. Since then, however, production has increased due to the construction of a portion of the "Fourth Parallel Road" into the forest, and two of the logging companies that went out of business in Haute Sangha will soon be reopening with new owners (Pinder 1990, p.9).

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[6]An anticipated export ban on *sapelli* and *sipo* logs to promote domestic timber processing is reportedly causing a noticeable increase in the rate of logging in an attempt to maximize profits before the ban goes into effect (Helen Sutch 1990, pers. comm.).

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Concessions and Infrastructure

Commercial logging is carried out under a variety of concession systems that vary by country. These range from authorization for subsistence or theoretically limited, small-scale logging known as family-logging permits in Gabon, or "piétistes" in the Congo, to large industrial concessions of 2,000 - 2,500 square kilometers for terms of up to 50 years in Gabon (IIEDa 1988, p.20). The shortest concession terms, five years, are found in Equatorial Guinea and Cameroon.

The Congo, Gabon, and Cameroon each have about 80,000 square kilometers currently under concessions while Equatorial Guinea has 5,000 square kilometers, and Zaire about 115,000 square kilometers. Much of the forest area in these countries has already been logged at least once: 100,000 square kilometers in Cameroon, and over 40,000 square kilometers in the Congo, for example. Nor are concessions spread evenly across the countries; in areas close to transportation routes, the forests have been logged more than once, with decreasing yields of commercial species for each subsequent harvest. In Cameroon, yields have dropped to one tree of commercial value harvested per two to three hectares in areas that have been cut over three to four times in the last 60 years (IIEDa 1988, p.28).

To make up for the declining harvests in previously logged areas, and the fact that stands of timber accessible by river are becoming increasingly depleted of commercial species, new transportation routes have been opened up 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. The Congolese government would like to have timber traffic replace the manganese traffic it lost when Gabon completed its own national railroad in 1986. Prior to that, the majority of the manganese had been lifted out of Gabon via an aerial tramway that connected with the Congolese National Railway.

Road maintenance and upgrading to accommodate the size and weight of logging trucks are priority issues in discussions with donors and lenders. Governments have planned controversial new road systems through forested areas and are experiencing some difficulties in obtaining funding from international donors.

Forest Taxes and Fees

In general, fees for logging permits are very low, as governments view concessions as a boost to rural infrastructure, including roads, housing, schools, and clinics for the nearby villages, and offices for the forest ministry field staff. Concessionaires often provide transportation to the logging sites for forestry inspectors, and in some cases even pay their salaries. However, government dependency on commercial firms can undermine the objectivity of the harvest monitoring upon which forest taxes are assessed. Under-reporting of wood volume results in the loss of government revenues since most

export taxes, royalty fees, and other charges are based on reported harvest volumes.

The system of taxation in most of the countries is an intricate one. Taxes and fees are paid by logging companies to different authorities at each stage of operations, from logging to inland transport to export. In Zaire, for example, a total of 53 separate taxes are levied on exported timber products (IIEDb 1988, p.77). In addition, some concessionaires in Cameroon also pay villages for local logging rights as a result of overlaps between formal and customary tenure systems (Gartlan 1990, p.2).

Yet these complex tax systems provide surprisingly low levels of revenue to national treasuries, relative to the total value of timber exported. In Gabon, for example, revenues from timber taxes totalled less than 20% of the government's forest sector budget in 1984 (IIEDa 1988, p.21). This is due in part to funding arrangements by which the parastatal timber marketing board, Société National des Bois du Gabon (SNBG)[7], keeps all the taxes it collects on *okoumé* and *ozigo* logs, which together account for 85% of Gabon's timber production.

Smuggling of timber is reportedly common in certain areas, due to different tax policies in neighboring countries. Equatorial Guinea's timber taxes, for example, are very high by regional standards, especially compared to neighboring Gabon which has some of the lowest in the world (Repetto 1988(a), p.87). This tax differential provides an incentive to float logs, especially the popular *okoumé*, from Equatorial Guinea across the border into Gabon where they will be taxed at much lower rates upon export.

Refinements and simplification in forestry tax systems could enhance revenue generation. Forest taxes in the region are generally calculated as a percentage of FOB[8] prices to encourage the export of lesser-known species, yet the amount to be taxed is based on the volume of wood harvested. If the governments were to assess taxes on the total standing tree volume or potential commercial volume per hectare, they could increase revenues while also encouraging loggers to harvest more carefully, utilize more of the tree, and decrease waste. However, one critical issue is to insure that collected fees and taxes are remitted to the proper authorities. Until the pay and conditions of the people administering and collecting these fees are improved, there is a great temptation to divert them for private use.

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[7]National Timber Corporation of Gabon

[8]FOB: "Free On Board," the value of the goods only, as differentiated from CIF, "Cost, Insurance, and Freight"

Wood Processing

In an effort to capture more income from forest resources, some governments are promoting domestic wood processing to increase local value added and employment. These initiatives are also designed to discourage concessionaires unwilling to invest in the local economy, and to discourage informal entrepreneurs who are not serious about conserving the forest resources.

In both CAR and Cameroon, processing levels of 70% and 60% respectively are mandated as part of new concession agreements. The government of Equatorial Guinea would like to raise timber processing to a level of 60% and is trying to accomplish this with incentives such as preferential export tax rates for processed wood. However, they are far from reaching that level due to a general labor shortage, a lack of trained workers, and antiquated and inefficient equipment. Similar situations exist in the other countries. The governments of the Congo, CAR, and Equatorial Guinea have also hoped to increase timber production and processing by lowering import duties on forestry equipment and spare parts.

Though well-intended, such legislation can lead companies to perform at the minimum level necessary to meet the standards. In addition, Repetto (1988a) has shown that inefficient processing can be less profitable than exporting raw logs for processing in more efficient overseas plants. An increase in inefficient, subsidized domestic processing plants can result in less sustainable rates of harvest.

On the other hand, these arguments against emphasizing local processing may be offset by other factors. For example, high grade logs are typically selected for export whereas local sawmills take many grades of logs. The latter's conversion efficiency may be much lower, yet they may be using more logs from a given area and thus more fully utilizing the local resource base while providing extra employment.

Institutional Capacity

The economic problems associated with the decline in export revenues have forced each of the countries to institute structural adjustment programs, including a downsizing of the public sector. Retrenchment has reduced staffing levels and budgets of already minimal forest sector agencies. Decreased monitoring and oversight by government foresters has meant that concessionaires are often at liberty to monitor themselves. In Gabon, this has resulted in over-logging of the coastal logging zone (IIEDa 1988, p.20).

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In theory, semi-autonomous agencies such as SNBG in Gabon and the Office National des Forêts (ONF)[9] and Centre National pour la Protection et Aménagement de la Faune (CNPAF)[10] in CAR could avoid some of the problems associated with bureaucratic and under-funded government agencies. They are able to pay higher salaries than the public sector and are not subject to civil service restrictions, such as staff reductions mandated in structural adjustment agreements.

Although these agencies were designed to be financially autonomous, some of their revenues have been appropriated by the national government to fund other projects deemed to be of higher priority. Revenues have gone to finance overstaffed headquarters offices in the capitals while some of the agencies have been used to employ job-seekers disgruntled by hiring freezes in the civil service. As a result, the performance of these agencies has been much lower than anticipated. After 16 years of reforestation, ONF has reportedly planted no more than 350 hectares (World Bank 1989, p.16). Due to a drop in its revenues from declining timber production and exports, ONF cut back its staff by 75% in 1989, and suspended field operations altogether shortly thereafter.

Despite the fact that the various agencies of the forest sector in central Africa have been unable to effectively manage, administer, and protect the forests in their charge, it must be said that they have been given an overwhelming task to perform, without being given the financial, institutional or human resources necessary (Gow 1991, p.5). International pressure to expand their scope of work beyond the traditional forestry arenas and to incorporate new philosophical concepts into their programs is increasing. These new directions include: community liaison, resource control, and extension activities; sustainable forest use practices; and habitat and ecosystem protection issues among others. Adding these new tasks to their present overwhelming workload may be unrealistic in the short-term.

Marketing Constraints

A common problem for suppliers of raw materials is that global political events and markets are factors beyond their control. Soft worldwide timber prices and a global economic slowdown have adversely affected commercial logging in central Africa. In the Congo, for example, the primary market for log exports from the northern forests rich in *sapelli* and *sipo*, relatives of mahogany, was eastern Europe, but demand from those countries has shifted significantly as a result of the sudden political realignment during 1989-90. Clients in other parts of the world, such as Scandinavia and western Europe, are less interested in reddish mahogany-type woods, preferring instead lighter-colored wood from other timber species (Pagni 1991, p.35).

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[9]National Forestry Office

[10]National Center for the Protection and Management of Wildlife

Compounding shifts in demand are the high costs for transportation, labor, fuel, and imported equipment and spare parts incurred by central African exporters. In addition, they face strong competition on the world timber market, especially from Southeast Asia. Although Gabon, for example, has 80% of the world's supply of *okoumé*, the world market for this plywood timber is presently saturated. Part of Gabon's problem stems from the fact that the dipterocarps of Southeast Asia are also used for plywood. Asian producers, with more experience in processing and marketing wood, can produce a higher quality product at a lower price than central African exporters.

C. Deforestation and Reforestation

Estimates of deforestation rates for the region vary considerably. Agricultural expansion to meet the demands of a population which is expected to double in 23 years is the principal cause, but infrastructure development and certain logging practices are also important, particularly where areas are partially cleared for commercial fuelwood and charcoal production. Such areas often then attract cultivators who finish the job of clearing begun by others. How to slow down this agricultural expansion will be discussed in more detail in the agricultural section of this report, but from a forestry viewpoint, it is assumed that trees will be preserved in direct proportion to the financial attractiveness of doing so.

Not surprisingly, the highest rate of deforestation occurs in the largest country, Zaire: some 4,000 square kilometers per year (Myers 1989, p.7). Cameroon, however, is losing the highest proportion of present forest cover: at 1.2% per year, this level is half again as high as the Congo, and three times the level of Zaire.

Infrastructure development, which normally affects the forest along fairly narrow strips alongside roads and railroads, also opens up new areas for logging. While this temporarily reduces the forest stock, it may also allow other areas to renew themselves. It bears remembering that some of the wood products from the forest are stores of carbon because they are used in construction, joinery, and furniture. Thus, removing forest products may increase the store of carbon if the areas are managed as a renewable resource. This should be the overall goal of human impact on these areas: rather than treating them as a wasting asset as has occurred in West Africa in particular, they should be managed as a perpetual asset.

Vegetation loss by fire is due to a variety of causes including burning to clear fields for planting, burning of grasslands by herders to encourage new growth at the end of the dry season for grazing, and burning to hunt game. In Gabon, for example, fires are set in the savanna areas adjacent to the railroad tracks, presumably to aid in bushmeat hunting.

Figure 8, "Deforestation in Central Africa," illustrates two different measures of deforestation: the percent of present cover lost per year, and the surface area lost per year. The bars to the left of the chart illustrate the three categories of cover discussed earlier in this chapter; the line graph, read against the scale on the right side of the charts, indicates annual loss rates.

One way of fostering forest preservation lies in convincing local people that they have a vested interest in doing so. Schemes have to be designed or expanded which not only involve the local people, but reward them sufficiently for their effort. Such schemes include vesting the responsibility for forest areas in local groups and helping them to manage these areas through training, extension, and marketing efforts. Instead of forest service people trying to exclude the population from forest areas, they should be working with them to develop the forests for their mutual benefit.

Where concessions are awarded, the forest service should ensure that concessionaires abide by the established management principles. But instead of being seen as a punitive enforcing agency, the forest service should experiment with strategies for maintaining or improving the stocking of commercial species. As suggested previously, they should also assess taxes on the basis of trees felled rather than export volume, to promote fuller utilization of the roundwood.

Of course, if the forest service personnel are not sufficiently compensated, they may have little incentive to pursue such initiatives. One possible solution is to allocate a percentage of the sale of logs and other forest products to all staff of the forest service, making it in the interest of all employees to ensure that money is collected and remitted. A similar scheme could work where local people are involved in forest management, yet until there is a sufficient reward from managing forests, the trees will continue to be treated as a wasting asset and mined for short-term gain rather than being managed for sustainable benefit over the long-term.

Reforestation and Regeneration

Fire, especially in the savanna areas, is the major cause of preventing many open woodlands from reverting back to dense woodlands or forests. The economic and management policies which motivate the annual burning of savanna grasses suggest that this traditional practice will continue until there are sufficient financial incentives not to burn. Governments should therefore investigate various management systems to whether it could be made worthwhile for farmers not to burn these areas, but instead to manage them for the forest products they could yield.

Because central Africa still has a large forest resource, there is little economic rationale for large-scale afforestation schemes. Only when the wood products become too distant will establishing plantations closer to the market prove worthwhile. Many periurban

fuelwood plantations have failed simply because they cannot compete on the open market with wood collected from the natural forest or woodlands. Where they have been able to compete, wood originally intended for fuel has frequently been diverted to more lucrative markets such as building poles and fencing posts. This is not to say that tree planting should be discouraged, but it should be targeted in the form of farm tree planting, enrichment planting, and plantations of economically attractive fine hardwood species.

A reforestation tax is presently collected from concessionaires in each of the six countries. This revenue should be used for the targeted forestry activities listed above rather than on large-scale plantation efforts. In principle, these revenues should be transferred directly to the relevant forestry agency, but at present most are deposited into the national treasury as general revenues, where they may be spent for other purposes. This is usually the case even where there is a special reforestation fund already established. In the Congo, however, the government is reportedly subsidizing the eucalyptus plantations around Pointe-Noire, possibly from reforestation tax revenues.

Use of the term "reforestation" can be misleading, however, as existing programs are not associated with commercial logging, for example reforesting or restoring logged-over areas. Instead, they consist primarily of plantation activities in separate areas of the country, generally involving exotic species. Where native commercial species have been established, planting is carried out only after the natural forest has been destroyed specifically for the purpose of planting commercial trees. This waste of natural forest resources is unnecessary and undesirable from the perspective of carbon emissions, sequestration, and biodiversity; there is plenty of degraded and deforested land that could be more productively utilized to grow trees, especially in periurban areas near good transportation infrastructure. The primary concern should be to better manage the existing tree and forest resources before embarking on new planting schemes. These planting efforts, if undertaken, should be aimed at the farmer with agroforestry initiatives rather than by means of large-scale plantations.

2. Agriculture

Introduction

Land clearing for agricultural purposes constitutes the single largest source of reduction of forest cover in central Africa. The largest portion of agricultural land use comes from the traditional sector in which rising populations of small-holder, subsistence farmers are competing for less accessible and often less productive land as a result of shortening fallows. The net result is that centuries-old practices of shifting cultivation are generating encroachment ever deeper into forested areas, while on the savannas, the burning associated with shifting cultivation is preventing forest regeneration.

A. Trends and Conditions

As estimated in Chapter 3, Tables 7 and 8, the extent of moist tropical forests in central Africa has decreased from some 300 million hectares around the turn of the 18th century to between 140 million and 155 million hectares today. It must be remembered, however, that the population has increased about twenty times over the same period: there were probably only between 2 and 3 million people in central Africa around the year 1800. Therefore, it is not surprising that substantial quantities of land have been converted to arable agriculture, especially with the influx of sedentary people from surrounding areas.

The FAO estimates, however, that there are 18 million hectares of cultivated land and 41 million hectares of permanent pasture for a total of 59 million hectares of agricultural land in the six-country region (FAO 1989 Agricultural Yearbook). The other former areas of moist tropical forests have been converted into woodlands, many of which are kept in that state through the practice of annual burning.

The current annual population increase for central Africa is between 1.6 and 1.7 million people. This is creating increased demands for food, fuel, and shelter. These demands largely account for the estimated deforestation rate of between one-half and one million hectares per year. Most central African governments give agriculture a low priority, and have tended to keep producer prices low through a policy of subsidizing imported food. This has led to a decline in fertilizer imports of about 7% per year between 1985 and 1989 and an 8% decline in tractor imports between 1987-89 (FAO 1989 Agricultural Yearbook). Not surprising given the low level of inputs, production increases have come primarily by expanding the amount of land under agriculture rather than through intensification of practices.

Table 4.4, "Agricultural Overview", highlights some of the more prominent aspects of contemporary agriculture in central Africa. Agricultural statistics should be treated with caution, primarily because they depend on estimates based upon a weak statistical foundation. In addition, much of the agricultural production is at the subsistence level where written records are not kept.

Table 4.4: Agricultural Overview

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

crop key: cf=coffee, co=cocoa, ct=cotton, po=palm oil, sc=sugarcane, t=tobacco

Sources: FAO 1991, pp.201-204; World Bank 1991d, p.82,95,133,194, 214,596. FAO 1990 Agricultural Yearbook, pp.3-5.

Despite their imprecision, the data reveal some significant general attributes of agriculture in central Africa. First, the overwhelming majority of production is performed by small-holders farming family plots for subsistence or local markets. In Zaire, for example, there are an estimated 3-4 million small farms averaging about 1.5 hectares in size (IIED 1988b, pp.10-15). Yet less than 3% of the national territory is devoted to cropland, a figure approximated in CAR, Gabon, and the Congo. Only in Cameroon does the percentage of land devoted to crops reach double digits.

Despite agriculture's dominance within the national labor force, its contribution to GDP is remarkably low. This could be because much of subsistence agriculture (and forestry) is under-represented or unrecorded in GDP statistics. Nowhere does agricultural activity account for more than half of national output, while in oil-rich Gabon and the Congo, it accounts for only 10% and 14% respectively. The modest role of agriculture in national economies is reciprocated by minimal support from the national governments. In Zaire, for example, agriculture received only 1% of government spending in 1985. Since then, its share has risen to more than 10%, but that still represents only one-third of its contribution to GDP.

Declining Productivity Figures showing that total agricultural production is increasing on an annual basis (from .53% in the Congo to 2.05% in CAR according to the most recent FAO statistics), are misleading as they fail to take into account populations that are

increasing at even faster rates. Per capita production of food crops declined in each of the six countries from 1988 to 1989 over a range of 1% in Cameroon to 6.8% in the Congo (FAO 1991, p.166). In general, rural populations are meeting their own food demands, but producing less for the expanding urban markets.

Compounding this supply shortfall is the fact that urban dwellers have come to prefer items that domestic agriculture does not produce, e.g, wheat for bread, or can produce only at a higher cost than the international market price, e.g. rice. In addition, agricultural subsidy programs within industrialized countries have also contributed to the fact that central African food imports have rise significantly in recent years. With the exception of CAR's relatively modest 8%, each of the other five central African countries import substantial quantities of basic foods, ranging from 15% in Equatorial Guinea and the Congo to 26% in Zaire. During the 1970's and early 1980's, when export revenues in general, and especially those from petroleum, were high, this reliance on imports was not particularly detrimental. This is no longer the case, however, as slumping export revenues have made food imports a substantial strain on national balance sheets.

Also contributing to the overall decline in agricultural productivity in central Africa are seasonal rural labor shortages. Though still the largest component of domestic employment, the decreasing returns to labor-intensive farming, taken in conjunction with the lure of high-paying jobs, have encouraged many young men to flock to the cities. This is especially true in Gabon and the Congo where the petroleum industry has created an important wage discrepancy between the public and private sectors. As a result, an even heavier burden falls on women farmers.

With greater pressure on the land in the closed forest areas and less labor to clear new plots, fallows are decreasing from traditional periods of 20-25 years to periods of 6-10 years and less (World Bank 1990b, p.9). Agricultural returns can eventually become non-viable as soils no longer have time to recover through revegetation, and pest cycles transcend the short fallow periods. It appears that many farmers choose simply to relocate to new areas as a response to these problems. This is especially true where land is available, having already been opened up to some degree by logging or road-building. The result is an agricultural frontier that advances at the expense of a receding forest, a trends which is especially pronounced in those localized areas in which land pressure coincides with ready access.

Three other factors also contribute to the agricultural dynamic that is reducing 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 food supply. Insecure land tenure can also represent a disincentive for managing land with a long-term outlook.

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And finally, agricultural extension services are poor or nonexistent in most areas. With the exception of some foreign-funded projects, research capacity is also minimal. The lack of knowledge about shifting cultivation as an agricultural system and the associated technical knowledge tends to preclude effective assistance in improving agricultural productivity. The international agricultural research centers have also overlooked the practical realities of central African farming. Not only is local knowledge about agricultural land use not being utilized, it is rapidly being lost as people migrate from their customary lands into new areas. These trends must be reversed if unit agricultural productivity is to increase.

Possibilities for Improvement The average production of crops in central Africa is below the African average, which is very low by international standards. For example, according to the 1990 FAO Yearbook, the average yield per hectare for cereals in central Africa was 1066 kgs whereas that for the whole of Africa was 1173 kgs. (The world average was 2763 kgs. per hectare.) There is a considerable range within and between countries, with the lowest average yield in Zaire at 761 kgs. per hectare and the highest in Gabon at 1444 kgs. per hectare. There is an even more pronounced discrepancy with root crops: central Africa's production is only 60% of the African average and 40% of the world figure. Obviously, there is considerable scope for improving unit output given proper incentives, improved infrastructure, and better storage facilities.

It is not necessary to have a massive input of capital to bring about an increase in agricultural production. Indeed, some fertilizer application has been wasted in the past because many soils suffer from high phosphorous fixation and are associated with aluminum toxicity. The addition of lime, to raise pH (hydrogen ion content) may do more to release plant nutrients than the application of nitrogen, phosphorous, and potassium (NPK). Indeed, liming with the planting of nitrogen-fixing trees in agroforestry formations may be a relatively cheap and sustainable way to improve unit agricultural output. At the same time, it would allow the harvesting of tree products such as fuel, poles, fodder, and fertilizer.

In order to bring such improvements about, it is necessary to have an effective training and extension service operating demonstration plots scattered throughout each country. It is equally important to get inputs to farmers when they require them, to ensure that grain and other crops are dried and stored properly, and most importantly, that farmers receive an adequate price for their product. Failing this, they will continue present subsistence practices, increasing production by expanding the area of land under crop.

Projects that address agricultural production, especially in the context of rapid urbanization, may learn much from one pilot project presently underway in the Congo. The Agricongo greenbelt model integrates small farming and processing businesses around urban areas, producing a variety of products for sale in town: vegetables

and fruit, small livestock, high value products such as mushrooms, and medicinal and ornamental plants. The use of agroforestry techniques allows the production of fuelwood and charcoal, fodder, and building materials while helping to control soil erosion. Integrating improved varieties of commodities such as oil palm on a small scale for domestic consumption could also be practical.

Such programs can provide self-employment and income for urban entrepreneurs, supply urban markets, save some of the foreign exchange now spent on imported foods, and replant deforested areas around the cities. They can also act to slow or eliminate the need to deforest ever-expanding areas around the cities to meet the urban demand for fuelwood and charcoal.

B. Plantation Agriculture

A plantation subsector founded in the colonial era continues to be an important though diminishing feature in all six countries. Relative to the traditional agriculture sector, however, only a small area of land is devoted to agro-industrial crops. In Cameroon, the only country in the region considered agriculturally self-sufficient, only 5% of the cultivated land is in plantations. Here there are a number of large parastatal plantations, but the bulk of cocoa and coffee production comes from small-holders who cultivate less than three hectares (Hazelwood and Stotz 1981, p.17).

In general, plantation production has declined in the years since independence, although some crops, such as coffee and sugar cane, have done better than the average. Decreasing world prices for the major cash crops of coffee, cocoa, cotton, and tobacco have led to disinvestment in the sector.

But the decline in export crops also results from factors other than low prices. Infrastructure deterioration, especially roads, has prevented large numbers of once productive plantations from getting their crop to market. It is not unusual for crops in remote areas to rot because they cannot be economically brought to market. Half of the 1990 coffee crop in CAR, for example, was never even picked (Economist Intelligence Unit 1991, p.33). Problems with spoilage caused by inefficient loading and shipping practices also eat into potential profits and thus reduce incentives to plant in subsequent years.

After independence, plantation management positions were sometimes awarded to political favorites or relatives of office-holders. With little practical experience in agribusiness, these novices set in motion a chain of poor management decisions that contributed significantly to the deterioration of plantation activities.

The cumulative result has been the decimation of colonial era agricultural industries. In Equatorial Guinea, for example, only one-third of the land that was in cocoa production at the time of

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independence is in production today. Most of the trees have not been replaced and are well past their productive prime, with yields down by 60% or more. Cocoa production, which averaged 31,000 tons during the three-year period 1968-70, had dropped to an average of just over 7,000 tons during the period 1986-88 (Economist Intelligence Unit 1990b, p.39-40). In 1958, Zaire was the second largest producer of palm oil in the world. Today, Southeast Asia supplies 90% of the world's demand, and Zairian production has fallen by two-thirds (IIED 1988b, p.14).

In response to this decline, some policymakers have called for the revival of the large-scale export crop plantation system for products such as palm oil, rubber, and cocoa. This could prove counterproductive, however, for a variety of reasons, including the fact that world markets for such commodities are presently saturated and prices are low. In addition, stiff competition from Southeast Asia, and the preference of the rural population to pursue activities other than farming, pose significant constraints to a revitalized plantation subsector.

C. Threats to the Forest

In central Africa, 39% of the area is classified as forests and another 40% as woodlands, thus accounting for a massive area under tree cover. With the population doubling about every 23 years, there will be an inevitable loss of some forest cover as a result of the demands for food, fuel, and living space. But if present trends continue, an additional 17 million hectares of forest land will have to be cleared by the year 2015 to provide sufficient food for the additional population.

If such an area were cleared and most of the wood burnt on site, nearly two billion tons of carbon would be released. An additional 900 million tons of carbon will come from the forest soil through cultivation practices and the rotting of roots. In addition to this release of carbon, there would be a substantial loss of flora and fauna, and a decrease in the annual biomass increment of over 200 million m3 of wood. The volume of wood disposed of in this way would probably exceed the wood product needs of the increased population.

The key to slowing down the rate of deforestation is increasing unit agricultural production. If the average unit cereal production for the region could be increased to that of Gabon's, cereal output overall would be increased by 35%. Similarly, if the region achieved the world average, unit productivity would more than double, requiring no extra land to meet the cereal requirements of the population in the year 2015.

The technologies exist to increase productivity, but in the past, they were geared to large-scale farming; little effort was placed on small-scale multicrop production strategies. Now, however, USAID and other donor organizations, through their work on farming systems

in various parts of Africa, have demonstrated that it is possible to stabilize production on areas once subjected to shifting cultivation cycles. This can be accomplished through agroforestry technologies plus modest inputs of artificial and natural fertilizers that increase soil fertility and improve soil structure.

Such increases are technically feasible. Whether they can be achieved in practice is a more difficult question. One avenue toward increased productivity is to set adequate producer prices, while ensuring that inputs are in place at the right time, and that the infrastructure is adequate to get the product to market. Production of maize increased dramatically in Zimbabwe shortly after independence when the farm-gate price was increased; as a result, Zimbabwe was able to export surplus maize to surrounding countries.

On the other hand, if maize is subsidized as it was recently in Zambia, the government not only provides "cheap" maize meal to its own population, but through smuggling, feeds people in neighboring countries and drains its foreign exchange reserves on imported maize. The imports became necessary because product prices for farmers were too low to stimulate sufficient supply to meet demand.

The governments of the region should devise strategies to increase unit agricultural output through the various initiatives mentioned above. Far more emphasis should be placed on rural development in general and increased unit agricultural production in particular.

3. Infrastructure

A. The Transportation System

In general, the transportation system in central Africa is among the least efficient in the world. The region's roads and railroads serve limited portions of the population, and have 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 of each remain isolated from the mainstream of commercial life. In many cases, these interior zones constitute a frontier whose long-term economic potential is only now beginning to be exploited.

The climate of the region, particularly the abundant rainfall, poses a serious obstacles to transportation. Seasonal damage to roadbeds can be severe, especially where dirt or other natural surface roads serve as drainage channels for rainfall run-off. Overloaded trucks represent another source of damage, stressing the surfaces beyond their limits to retain shape and structure. Railroads and river vessel services have suffered due to a lack of spare parts. The unwitting beneficiary of neglect in the other sectors has been the air transport sector. Though expensive, air service has grown rapidly in the region due primarily to the long distances between cities and the difficulty of maintaining surface routes in passable condition year round.

Expanding and improving transportation infrastructure has become a high priority for national governments. Several large-scale projects, most notably the Transgabonais railway and the Bukavu-Kisangani road in Zaire, have been carried out during the 1980's. Rehabilitation of existing transportation infrastructure has been a major component of bilateral and multilateral donor activities. Many new projects have been delayed, however, by budgetary crises. In a few cases, donor financing has been withheld due to environmental considerations. In Equatorial Guinea, for example, funding for a road between Evinayong and Kogo has been rejected by the European Community due to the potential damage it would have on remaining areas of primary forest.

B. Infrastructure Development and Landscape Change

Infrastructure's most significant effect is probably the indirect role it plays in opening up the forest to a wide range of economic activities. Until recently, plans for infrastructure development projects paid little attention to either the direct or indirect effects of road or railway construction upon forest resources. Yet secondary effects can be extremely significant. By some estimates, for every tree cut for timber in Zaire, 25 are cleared in building the roads to get to it (Goodland 1990, p.3). On the other hand, it must be remembered that such losses are one-time assessments: subsequent

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trips made by logging ventures into the same forest area avail themselves of the new roads and thus result in substantially less additional deforestation.

High unemployment and flat 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 deforested for each kilometer of railway (Nicoll 1986, p.53).

Secondary deforestation followed as land-seeking peasants settled along the rail corridor and cleared farther into the forest, taking advantage of the relatively easy access to urban markets. Their homesteading triggered even more economic activity as artisans and tradesmen set up shop, selling their products to merchants, local inhabitants, and railroad passengers. The gradual, but persistent establishment of human settlements has led to detrimental environmental effects other than deforestation. Bushmeat poaching, for example, in the vicinity of the Transgabonais railroad has reportedly decimated the populations of certain wildlife species (Nicoll 1986, p.53).

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 rapidly expanding populations in tropical forest areas. Infrastructure projects are often the catalysts that set this pattern in motion.

C. The Paradox of Infrastructure Development

In many cases, weak infrastructure has often been the most effective safeguard against large-scale deforestation in central Africa. Without the access that infrastructure provides, many activities are either not possible, or are only possible on a substantially reduced scale. Major road building projects are well beyond the capabilities of local communities. Construction projects must be supported by the state or by donor agencies, and at present, the states are extremely hard-pressed for capital.

It is unrealistic, however, to expect that significant areas containing valuable natural resources will remain isolated for long. Since infrastructure development is an essential prerequisite for further economic development in the region, national governments are interested in making improvements both in the geographic coverage and the efficiency of their current systems.

Plans currently exist for opening up some of the major resource areas of central Africa. The government of Cameroon, for example, has proposed the construction of a road from Kribi to Yokadouma, which

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would grant access to the last remaining primary forest region in the country (Economist Intelligence Unit 1989, p.20). There is also a proposal to connect Bangui with the Transcameroon railroad in order to provide landlocked CAR with a direct route to the sea, and provide Cameroon with improved access to its southern forests. Plans to build a northeastern spur of the Transgabonais Railroad to facilitate development of iron ore deposits near Belinga, would also open up previously inaccessible forest areas (U.S. Dept of Commerce 1987, p.8), but plans have been deferred for budgetary reasons.

Nor is it only large-scale projects that are being envisioned. In the Congo and Gabon, for example, development strategies are giving high priority to small-scale interventions aimed at reviving rural areas. Most of these will require significant investments in transportation infrastructure so as to reach remote areas and to link regions which presently are outside the mainstream of national economic life. Similar policies have been articulated in other parts of the region, though implementation, especially in Zaire and in CAR, remains a more distant prospect.

How such improvements can be implemented without stimulating patterns of exploitation and deforestation is one of the fundamental problems facing planners in central Africa, and the international donors who finance their projects.

4. Mining

Like infrastructure, mining has had both direct and indirect effects on forest resources in central Africa. The open pit method of mining manganese, copper, cobalt and uranium traditionally employed in Gabon and Zaire requires clearing large areas of land. Major mining operations also require the building of rail or roadways to bring in heavy machinery and to transport the 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, a process which often outstrips the capacity of authorities to provide services or to introduce effective land use controls. Even at the small-scale level, mining can have serious environmental effects: artisanal gold and diamond miners often clear vegetation along riverbanks and release mercury and other chemicals into rivers.

Although basically similar in their forest resources, the countries of central Africa differ markedly in the extent and nature of their nonpetroleum mineral resources. Roughly speaking, the region is divided into two groups: those with substantial mineral resources and a history of production and those without. There is surprisingly little middle ground.

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In CAR, for example, diamonds continue to be the number one export revenue earner, while in Zaire, copper continues to dominate the export economy despite declining prices. The Gécamines conglomerate, formerly Belgian owned and now state controlled, is the largest source of foreign earnings in Zaire, as well as the largest employer, and the greatest consumer of electricity. Gabon is a major world producer of manganese and uranium. In contrast, mining (other than petroleum) has not been a major factor in the national economies of the Congo, Cameroon, or Equatorial Guinea.

Most mining operations in central Africa began during the colonial period. Few new operations have been launched since independence as chronic transportation bottlenecks, high levels of investment, uncertain demand, and in some cases, a lack of investor confidence in the stability of the political and economic environment, have all impeded development.

The long-term outlook could be quite different, however. Much of central Africa has not yet been thoroughly surveyed, and the possibility exists that major mineral deposits remain undetected, especially in the Central Basin area of Zaire and the Congo. This region is already believed to contain substantial petroleum deposits, the exploitation of which will require the construction of new roads or railroads. Development of new transportation infrastructure would, in turn, facilitate exploration for, and exploitation of, additional mineral resources, as well as logging and agriculture into areas which are presently inaccessible.

The mining sector has been the beneficiary of a large proportion of the region's investment capital. For example, the massive Inga II hydro-electric project and the thousand-mile-long Inga-Shaba transmission line, the largest capital investments in Zaire's history, were constructed primarily for the benefit of the mining operations in the southeastern province of Shaba. The economic justification for the Transgabonais Railroad, described as one of the world's largest construction projects, had much to do with expanding production and export capacity for the national manganese industry which previously had to rely upon an aerial tramway that connected the mines, located in southeastern Gabon, with the Congolese railroad.

Given the prevailing economic situation in central Africa today, it is likely that the constraints to new investment that have existed in the past will continue to inhibit the development of major mining projects. The long-term potential for degradation of forest resources by the mining sector, however, is significant. Development of the Belinga iron ore deposits in northeastern Gabon, for example, would require the construction of a rail line through presently intact primary forest. Based upon past experience in the region, this development would probably entail a considerable degree of deforestation along the right-of-way, followed by the long-term expansion of forest encroachment by shifting agriculturalists, loggers, and others following the opening of a new transportation corridor.

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Large-scale mining operations are also heavy consumers of energy, particularly electricity. In some cases, mineral deposits are located near existing transmission lines; new mineral developments in certain areas of Zaire, for example, may be able to take advantage of current oversupply of hydropower. In most cases, however, minerals are not located close to existing services, and significant investments in new transmission and distribution facilities may be required. Occasionally, new generating capacity is also needed.

5. Energy

A. Energy Resources and Consumption

As a region, central Africa is well endowed with energy resources. The Zaire River system constitutes one of the world's major hydropower resources, most of which has yet to be developed. The coastal sedimentary basins of the Gulf of Guinea contain significant petroleum reserves. As a result, Gabon, the Congo, Cameroon, and Zaire are oil exporters, and Equatorial Guinea has recently begun production of natural gas. Untapped petroleum deposits are also thought to lie beneath sedimentary formations located in the interiors of Zaire and the Congo and perhaps beneath Lake Tanganyika as well. None of these areas has been extensively surveyed to date. Deposits of methane are found in the depths of volcanic lakes in Cameroon and eastern Zaire. Uranium ore and coal are mined in Gabon and Zaire respectively. Finally, solar and geothermal energy may also offer long-term potential, though presently these sources are not being exploited to any significant extent.

The most important energy resource in central Africa, however, is biomass. The tropical forest system which covers up to 40% of the total land area of the six countries represents a massive source of renewable energy. Even when seasonally flooded or inaccessible areas are taken into account, central Africa's fuelwood resources exceed its considerable hydropower potential. For this reason and also because of the generally low level of economic development in the region, biomass accounts for the largest share (77%) of energy consumption in central Africa. Most of this fuel, in turn, is consumed by the household sector.

When biomass is burned <u>and</u> replaced by new growth in a sustainable cycle, the result is no net addition of carbon dioxide to the atmosphere. The carbon released through combustion is offset by carbon sequestered by new plant growth. Traditional patterns of fuel use in central Africa follow this model. Reliance upon fuelwood as the primary source of energy would thus probably not contribute to a build-up of atmospheric carbon, and in most <u>rural</u> areas this conclusion is probably still valid. Other combustion products, however, such as carbon monoxide, methane, and nitrous oxide, are emitted by biomass fuel combustion, but less is known about their impact.

Population growth in many of the region's major urban areas, however, has already reached levels of demand at which fuel consumption exceeds local biomass regeneration. In such cases, more carbon is added to the atmosphere through combustion than is sequestered through new growth. Where rapid population growth coincides with increasing deforestation, the gap can widen quickly. It is important, therefore, to know where the fuel is coming from which is being burned in a given urban area. At present there is little information available for most of central Africa.

Analysis of the contribution of the energy sector to global climate change is further complicated by the fact that not all fuels contribute equally to greenhouse gas emissions. Charcoal is particularly problematic because of high conversion losses: up to seven kilos of wood may be consumed per kilo of charcoal produced. Charcoal, however, has twice the energy value of wood on a weight-for-weight basis. Figures for emissions from burning charcoal need to be adjusted to reflect emissions from the conversion process from fuelwood.

On the other hand, improvements in conversion and end-use technologies can have multiplier effects. Also, charcoal is often produced in areas already cleared for agricultural purposes, with little or no cutting of trees specifically for charcoal production. Thus the net effect of charcoal as a fuel must be considered on a case-by-case basis, rather than assuming that it is always detrimental (or that it is never a problem).

Another problematic fuel is natural gas or liquefied petroleum gas (LPG). Although LPG is usually associated with high end-use efficiency levels, some gas will always be lost to the atmosphere, while substantial volumes are also flared or vented at pumping sites and refineries, releasing both carbon dioxide and methane. Methane is many times more efficient than carbon dioxide in capturing heat in the atmosphere. Thus the LPG lost in processing, transportation, and through inefficient end-uses may represent a potentially significant source of greenhouse gases. From a climate change perspective, this needs further analysis in light of current recommendations that natural gas be promoted, even subsidized, as an urban fuel to replace biomass. For example, in several West African countries the European Community is promoting the use of bottled gas in urban areas, with substantial price subsidies to encourage consumers to switch to this fuel source (pers. comm., J. F. Swartzendruber).

Table 6 shows current regional energy supply, excluding crude oil exports and conversion losses.

Table 6. Available Gross Energy Supply
'000 Tons Oil Equivalent

	Biomass	Hydro	Petroleum[11]	Total
Zaire	9,120	1,129	703	10,952
Cameroon	2,502	525	808	3,835
The Congo	283	71	621	975
Gabon	101	167	702	970
CAR	588	18	82	688
Eq. Guinea	115	1	39	155
Total	12,709 (72%)	1,911 (11%)	2,955 (17%)	17,575 (100%)

Source: most recent ESMAP and UN data for each country: Zaire - 1983; the Congo - 1985; Gabon - 1985; CAR - 1990; Cameroon - 1988; UN data for Equatorial Guinea - 1987/88)

It should be noted that final energy consumption, which is shown in Tables 7 and 8, and in Figure 9, is a somewhat different measure: hydropower, for example, is consumed in the form of electricity, after losses in generation, transmission, and distribution. Conversion losses, bunker sales, and other adjustments to supplies are reflected in the final consumption levels but not in the supply data shown in Table 6.

Table 6 clearly illustrates the predominance of biomass in the regional energy balance. Biomass fuels constitute 72% of total available supply, while hydropower - one of the most significant regional energy resources - represents 11% of total supply. Even where hydropower is a key resource, limitations in geographic coverage of the electric grid restrict access for large portions of the population. In Zaire, for example, only an estimated 3% of the population have access to electricity (ESMAP 1986).

Petroleum is a significant fuel source, especially in oil-exporting Gabon and the Congo. In these two countries, modern sector energy (including electricity) plays a much more important role than elsewhere in the region. (Note that oil exports are excluded from this table, which only shows energy which is available on the domestic market.)

[11] includes natural gas

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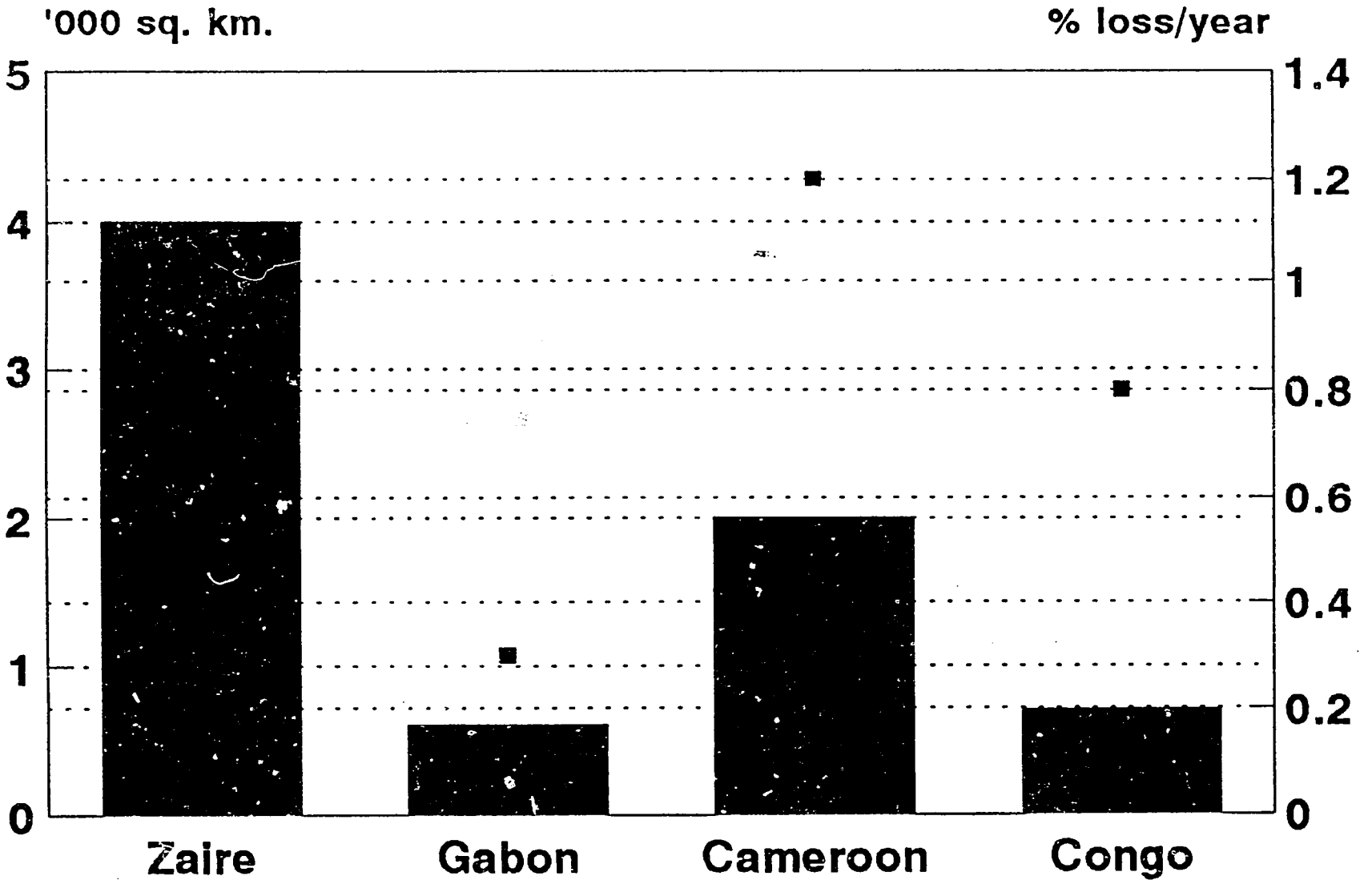
Deforestation in Central Africa



annual loss in sq. km. ▪ loss as % of cover

from data in Myers, 1989

Figure 8. Deforestation in Central Africa

Consumption data do not precisely mirror supply data, as each country has its own particular circumstances which affect consumption: transportation losses, conversion efficiency, etc. Table 7 shows the proportion of total energy consumption for each major fuel type after supply is adjusted for these factors.

Table 7. Final Energy Consumption by Fuel Type*
'000 T.O.E. (percentage)

	Biomass**	Petroleum	Electricity	Total
Zaire	7,487 (88%)	634 (7%)	337 (4%)	8,458
Cameroon	2,435 (65%)	808 (21%)	525 (14%)	3,768
CAR	577 (88%)	72 (11%)	9 (1%)	658
Gabon	101 (16%)	453 (73%)	65 (11%)	619
The Congo	266 (46%)	259 (45%)	27 (5%)	552
Eq. Guinea	115 (75%)	35 (23%)	4 (3%)	154
Totals	10,981 (77%)	2,261 (16%)	967 (7%)	14,209 (100%)

Source: most recent ESMAP and UN data for each country
*after conversion and other losses
**fuelwood, charcoal, and residues

Table 7 confirms that biomass is the primary source of energy in the region as a whole. Gabon represents a special case, as petroleum plays the dominant role ordinarily filled by biomass in most of the other countries. The Congo represents an intermediate case, using a much larger proportion of petroleum than Zaire, Cameroon, CAR, or Equatorial Guinea, while at the same time using a much higher proportion of biomass than Gabon.

Table 8 focuses on the role of biomass in the regional energy balance, and illustrates the extent to which traditional fuels such as fuelwood, charcoal, and agricultural residues still provide most of the region's energy.

Table 8. Biomass Consumption
'000 Tons Oil Equivalent

	Total Energy Consumption	Total Biomass Consumption	Household Biomass Cons.	H/H Biomass as % Total Energy Cons.
Zaire	8,458	7,487 (88%)	6,853 (92%)	80%
Cameroon	3,768	2,435 (65%	2,337 (96%)	62%
CAR	658	577 (88%,	555 (96%)	84%
Gabon	619	101 (16%)	77 (76%)	12%
The Congo	552	265 (46%)	251 (95%)	44%
Eq. Guinea	154	115 (77%)	?	?

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Totals	14,209	10,980 (77%)	10,073 (92%)	70%

Source: Most recent ESMAP data for each country: Zaire - 1983; the Congo - 1985; Gabon - 1985; CAR - 1990; Cameroon - 1988; UN data for Equatorial Guinea - 1987/88)
Note: "?" indicates data unavailable

B. Biomass Fuels and Landscape Change

These tables show that, with the exception of Gabon, and to a lesser extent the Congo, central Africa still retains a distinctly traditional pattern of energy consumption, with biomass fuels representing the major source of energy.

Fuelwood makes up the largest share of biomass fuels, and is traditionally collected from public or communal lands rather than purchased in markets. In rural areas, fuelwood is typically collected by children and women, and seldom involves cutting down trees. Instead, fallen branches or dead trees are sought, as less effort is required, and dry wood burns more readily and with less smoke. Trees cleared from land prepared for planting crops represent another ready source of fuelwood.

In contrast, urban areas are supplied by organized fuelwood and charcoal markets. Fuelwood is not only used by households, but also by small businesses such as bakeries, restaurants, and brick kilns. Charcoal is seldom used in rural areas; instead, this compact and lightweight fuel is produced in the countryside for urban markets. The growing urban demand for charcoal poses significant problems because of its high processing losses, as discussed earlier.

With economic growth, one would eventually expect to see a shift to more modern fuels such as kerosene, electricity, and liquified petroleum gas (LPG). Movement up this fuel substitution "ladder" is commonly observed with rising incomes: the cleaner, more convenient and efficient forms are preferred by people with the discretionary incomes to afford them. Given the present economic stagnation in much of central Africa, however, it is likely that biomass will continue to supply much of the region's energy for the foreseeable future. From a carbon emissions perspective, of course, slowness to adopt use of "modern" (i.e., fossil) fuels may be beneficial, assuming that biomass consumption is on a sustainable basis in which new growth offsets that which is burned.

The consumption of kerosene, charcoal, and fuelwood can be important indicators of urban demand growth and fuel-switching trends. Kerosene imports and refinery production figures are available for most countries, but analysis is complicated by the fact that statistics do not distinguish between kerosene used for lighting and kerosene used for cooking. In some cases, kerosene and jet fuel data are combined. In most cases, charcoal and fuelwood data are based on limited surveys, and even limited surveys have often not been done.

While promotion of electricity as a substitute for biomass fuels is a common policy recommendation, almost no information is available as to the specific uses of electric power within households: how much electricity is used for cooking as opposed to lighting, for example, or for other appliances. Nor is much known about how willing households might be to switch to electricity for cooking.

The perceived trade-offs between these fuels in terms of cost, reliability of supply, and investment required in cooking devices, are crucial in assessing how consumers will respond to fuel-switching or other demand management programs. Without better information on current patterns, it is very difficult to plan effective demand management programs. It is important to know more about the sources of biomass fuels now being used: where they are coming from, how far they are transported, the structure of supply and demand, the elasticity of supply and demand, and whether natural regeneration can to sustain consumption now and in the future. To be relevant, this information must be able to identify areas of relative abundance or scarcity and the direction and rate of underlying trends such as population growth rates, migration patterns, and deforestation.

Central Africa contains great hydropower potential, and in the long term this energy source could have a significant impact on the demand for both fossil fuels and biomass. On the demand side, constraints include the high cost of electric appliances, and the difficulty of changing tastes and habits. On the supply side, high costs for building new generation, transmission, and distribution infrastructure, hold hydropower well below its potential importance as an energy source.

Finally, carefully planned and implemented agroforestry interventions also hold promise for the sustainable production of biomass fuel. Small-scale producers near urban centers can retain the long-term objective of producing commercial timber, but also meet short-term needs by selling pruned or thinned wood as fuelwood or charcoal.

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PART III. TOWARDS SUSTAINABLE DEVELOPMENT IN THE REGION

1. Conclusions from the Sectoral Analysis

The above study of the impacts of human factors on the forests of central Africa begins by reviewing the region's history and summarizing important aspects of the political, economic, and demographic contexts. In somewhat greater detail, the framework then examines the effects of logging, agriculture, infrastructure, mining, and energy, identifying those factors which are most significant in contributing to deforestation and carbon release, or which have the greatest potential to do so in the future.

Forestry, agriculture, mining, and woodfuel harvesting promote carbon release throughout the region primarily through their direct impacts on the forests. Infrastructure development such as the construction of roads and railways also plays a direct role in contributing to the release of carbon in central Africa. Its more influential role, however, is as an indirect agent, facilitating or inhibiting the efficiency and growth of other sectors.

A variety of additional factors contributes indirectly to deforestation and carbon release, by the way they affect activities in the five sectors. These include: demographic pressures, political developments, economic policies, and land tenure systems. Population growth in central Africa contributes to deforestation pressures through increasing demands for fuelwood, building materials, and especially land for food production. Political and economic instability in the region exacerbate deforestation through weakened administrative capacity, economic pressures to extract natural resources as quickly and cheaply as possible, and inability to develop and implement long-term management plans for natural resources. In areas of high population density, land tenure policies undermine sustainable forest use through pressures to clear and settle forest areas.

The commercial timber industry in central Africa is the most visible source of deforestation, though not necessarily the most significant. European logging companies maintain extensive operations in the region. Having depleted their concessions in West African countries such as Ghana, Côte d'Ivoire, and Nigeria, some companies are now shifting their attention to central Africa. Unsustainable timber extraction practices previously widespread in West Africa are becoming increasingly characteristic of logging in central Africa. Reports of widespread damage to forest areas throughout the region are on the rise.

Logging in central Africa is dominated by large, foreign operators with a short-term attitude toward extraction of the region's timber resources. Their operations often result in unnecessary damage to non-commercial tree species and soils. In some cases, this damage threatens the regeneration of valuable commercial species as well. Inefficient processing techniques waste significant quantities of

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the region's timber resources. Inappropriate taxation and regulatory mechanisms contribute to this pattern, as well as such factors as low levels of funding, staffing, and technical expertise found in national forestry services charged with overseeing logging operations.

In addition to the direct effects of mismanaged logging and processing, this report identifies a number of other factors whose cumulative impact may be more serious over the long term. These include: encroachment by shifting cultivators and small-scale miners taking advantage of new roads into the forest, fuelwood collection and charcoal production for rapidly growing urban areas, and manmade fires which prevent natural regeneration along forest edges.

There is little evidence that reforestation is taking place on a significant scale in central Africa. Efforts to mitigate carbon release will probably need to focus on controlling the rate and pattern of loss of the natural forest rather than establishing plantations to substitute for the original forest cover.

Agricultural patterns vary considerably throughout the region. In Zaire and Equatorial Guinea, large-scale plantation agriculture during the colonial era significantly shaped the economy and the course of national development. Zaire was once a major supplier of palm oil and rubber, while Equatorial Guinea was a significant producer of cocoa. Since independence the plantation subsector in both countries has undergone a dramatic decline, one reflected in far lower levels of employment and production than in the past. The Central African Republic has also experienced a long-term decline in the value of its major agricultural exports: cotton, coffee, and tobacco.

Population pressure and other factors such as insecure land tenure, scarcity of agricultural inputs and land, and soil depletion are driving shifting cultivators to encroach into forests, especially along new roads and in areas with logging activity. Poor soils and shortened fallow periods are thought to be accelerating this trend.

In Gabon and the Congo in particular, the petroleum boom of the 1970's and 1980's resulted in significant depopulation of agricultural areas as young men migrated in large numbers to industrial centers. Food imports financed by oil revenues initially compensated for much of the decline in domestic agricultural production, but since 1986 depressed petroleum prices have resulted in serious economic hardship. Government plans to invest heavily in the development of rural areas could potentially lead to greater deforestation, but most of these investments have been deferred due to budgetary pressures.

In general, Cameroon's agricultural sector has fared better than in the other countries through a combination of physical advantages (rich soils and good rainfall), superior access to inputs and transport, and a more supportive agricultural policy environment. Even so, in the country's forested south, the region most relevant to this study, shifting cultivators are following new logging roads

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and establishing subsistence plots in areas which have not previously supported agriculture.

Savanna burning, which is widely practiced in areas adjacent to the contiguous forest of central Africa, emits trace gases into the atmosphere, and prevents the natural regeneration of secondary forest. Hunters also set fires along the edges of the forest in order to flush game, with the same effect on regeneration.

Wood fuels supply the bulk of the region's energy needs, and estimates of total annual consumption are much higher than the output from commercial logging. Some of the fuelwood supply is harvested on a sustainable basis, with no net impact on the carbon cycle. This traditional rural pattern breaks down in many urban areas, where proximity to remaining forested areas leads to localized overharvesting.

Fossil fuel consumption has reached significant levels in Gabon, the Congo, and to a lesser degree, Cameroon. In the other countries, biomass consumption is likely to remain the primary source of energy in the foreseeable future, and net carbon emissions will largely be dependent on the sustainability of the local forest resources from which wood fuels are harvested.

Mining is a significant economic activity in the region, especially in Zaire (copper, cobalt, diamonds) and Gabon (manganese). Petroleum production is mostly from off-shore sites as well as on-shore fields of the same Coastal Basin deposits. Plans to develop major petroleum deposits in the Central Basin of Zaire and the Congo raise the possibility of large-scale forest clearing, though these are presently being delayed by budgetary constraints.

With a few exceptions, transport infrastructure in the region is limited in geographic coverage and in an advanced state of disrepair. Improvements to the infrastructure are high priorities for all of the national governments, and would significantly facilitate the operations of logging companies, mining concessions, and agricultural producers. In the past, the opening of new transportation routes and the rehabilitation of existing ones has resulted in an escalation of deforestation pressures. Plans to significantly improve central African infrastructure constitute one of the most important long-term factors in the potential for major carbon release in the region.

This report has drawn attention to a number of human activities which presently appear to pose some threat to the viability of central Africa's closed tropical forest zone. Actions to mitigate these trends will need to be based upon a much more comprehensive and in-depth analysis of the situation in specific locations. The benefit of the present analytic framework lies in identifying patterns likely to be relevant across a wide range of cases, and in suggesting the kinds of interventions which would be necessary in order to address each

of the sources of landscape change. It is these anthropogenic transformations of the landscape that affect the region's carbon inventory and potentially contribute to climate change.

2. Institutional Cooperation in Environmental Planning and Management

While central Africa has yet to experience environmental degradation of the magnitude found in coastal West Africa, the Sahel, and the Horn of Africa, the trends described in this report suggest that the region's ecological challenges are growing rapidly. Given the extensive regional nature of the challenges and the diminished financial and institutional capacity of the six countries to adequately address the problems, interventions will probably require substantial external support, preferably from the agencies and donors which have been working in the region the longest.

Multilateral and bilateral donor agencies, government ministries and extension agencies, and a wide variety of local-level development organizations are working on environmental issues in each country. Bilateral aid agencies from Europe and North America have begun to focus in earnest on the ecological aspects of development. In total they have spent significant sums over the past decade on institutional development related to the environment.

The Canadian International Development Agency (CIDA), for example, has been active for many years in forest management projects and in supporting government forestry departments and parastatal institutions. The French and German governments are committed to large-scale, environmentally focused development projects and information gathering programs in the region. The European Community has budgeted more than US$ 30 million for conservation activities for the forests of central Africa.

In the late 1980's major multilateral initiatives were launched, including the Tropical Forestry Action Plans (TFAPs) and the National Environmental Action Plans (NEAPs), led by the FAO and the World Bank, respectively. These have already became a significant feature of the institutional framework for environmental planning in central Africa. Other United Nations bodies such as the United Nations Environment Program (UNEP) and the United Nations Development Program (UNDP) have become increasingly active in promoting environmental projects throughout Africa.

At the same time, national governments are struggling to develop and sustain the institutional capacities of their forest, agriculture, and environmental ministries. International donor initiatives such as the TFAPs and NEAPs have emphasized strengthening the capacities of government institutions responsible for key sectors such as forestry and water management. The extension services of central governments operate to some degree with local government administrative bodies, which are in many cases the *de facto* legal authorities in isolated regions.

In central Africa as in the other developing regions of the world, non-governmental organizations (NGOs) are often the key institutions for supporting local-level development and natural

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resource management. International conservation and development NGOs are active in several parts of Central Africa. For example, the World Wildlife Fund is implementing a long-term integrated conservation and development project in the Dzanga-Sangha Forest Reserve and the Dzanga-Ndoki National Park in CAR. Wildlife Conservation International, of the New York Zoological Society, has begun a research and conservation project in the Nouabali area of northern Congo.

An important regional trend has been the growth of locally-based development institutions. Important roles in resource management are played by local development organizations, informal marketing cooperatives, and other community groups, including religious organizations. A 1988 UNDP study in Cameroon, "NGOs and their Contribution to Socio-economic Development in Cameroon", identified over one hundred local development organizations in operation in that country (UNDP 1988). Hundreds of religious organizations work on development and natural resources management activities in Zaire.

Finally, traditional corporate structures such as family and clan lineages and village political authority systems can provide unique local mechanisms for planning development and managing local resources. Building upon these local resources and institutions is increasingly being viewed as essential to the success of environmental initiatives.

In terms of financial support and technical assistance to environmental activities in the region, the cumulative contribution of donor agencies has been great. In practical terms, however, the impact of these activities to date has been disappointing.

Particularly disappointing have been the Tropical Forestry Action Plans (TFAPs) initiated in Cameroon, the Congo, and Zaire in 1987. Recent assessments of these and other TFAPs have concluded that they have been largely ineffective in meeting their goals (Colchester and Lohmann 1990; Winterbottom 1990). One reviewer has observed that most of the Plans "simply justify increased investment in the industrial forestry sector - a focus too narrow to adequately assess the root causes of deforestation, much less to affect them significantly" (Winterbottom 1990, p.21). While Zaire's TFAP made particular efforts to include NGOs and local communities in the planning process, Cameroon and the Congo have done less in this regard.

National Environmental Action Plans (NEAPs) have only recently been launched in the Congo and Gabon, and Cameroon is considering initiating one. A NEAP is defined as "a national government, demand driven, participatory process which provides a comprehensive, institutional framework for integrating environmental considerations into a nation's economic and social development" (Falloux et. al 1990). As might be expected, however, NEAPs are encountering many difficulties in achieving their objectives (Talbott and Furst 1991). While they offer considerable potential for strengthening institutional capacities and coordination, progress has generally been slow at best. Much

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work needs to be done to improve implementation of NEAPs through monitoring and evaluation, so that responsible individuals and institutions can be held accountable for results, and so that the integrative approach central to the NEAP concept can be realized.

The primary challenge for policy makers is to carefully assess and strengthen institutional capacities for environmental planning and management in the central African region. Success hinges on more effectively linking the many levels at which institutions presently operate. It is also necessary to better understand how institutions involved in large-scale environmental initiatives, especially at the international level, have struggled in trying to achieve their original objectives.

Linking institutional environmental planning and management initiatives from the international to local levels holds promise in mitigating deforestation and its concomitant potential for climate change. While the constraints to institutional cooperation are considerable, recent institutional and policy-related developments offer significant opportunities.

NEAPs and TFAPs offer international donors, NGOs, and national governments useful mechanisms for coordinating activities and avoiding the overlapping mandates and duplication of effort that often characterize development activities. Just as the European Community is now defining a regional focus for its conservation activities in central Africa, other donors and NGOs should also consider coordinating their activities regionally. In fact, the situation may warrant institutionalizing such regional cooperation, perhaps under the leadership of the African Development Bank or the United Nations Development Fund. A regional authority on forest management that maintains detailed information on projects and activities, offers technical assistance on forestry practices and institutional reform, and conducts policy analysis related to lessons learned in the region, is an idea well worth exploring.

Government line ministries, sector departments, and parastatals charged with environmental management responsibilities in central Africa are plagued by institutional problems. These include inadequate staffing and financial constraints, lack of political influence or will to address environmental issues, and a weak legal basis for affecting desirable changes. Poor coordination between ministries, excessive centralization, and competition for limited resources also undermine much of the public sector. Governmental capabilities for policy analysis and program implementation are also undermined by outdated or counterproductive laws and administrative practices, and by the absence of consistent and realistic regulatory standards and enforcement.

Many of these institutional problems can be addressed through the comprehensive NEAP or a substantially revised TFAP structure. As donor organizations better coordinate and target their activities,

they can contribute more effectively to national policies and institutional reforms. Cultivating governmental commitment to environmental reform requires a long-term, concerted approach by all.

Perhaps the greatest challenge is to link the institutions that operate most effectively at the community level with national and international resources. Much has been written but little actually accomplished in this regard in central Africa. This is largely a result of the political constraints discussed in the previous section, as well as a long-standing bias on the part of central authorities against grassroots organizations. Recent political trends in Cameroon, Zaire and the Congo, however, hold some promise for improved cooperation between these levels. Governments in central Africa are recognizing their limitations and, in some cases, are beginning to grant more political and economic authority, tenurial rights, and access, to local communities and organizations.

Experiences from a number of developing countries are showing policy makers that popular participation in planning and implementing development projects enhances the prospects for success of those initiatives. This trend is especially evident in natural resource management activities, which are often dependent on the active participation of local communities of resource users. Developing the institutional climate for this kind of sharing of responsibilities and duties between national and local institutions is becoming a priority of international organizations. Far more research and project activity is needed in this direction.

3. Information Gaps and Data Collection

Most of the information presented in this study has been drawn from a rather limited range of sources which are currently available in the United States. The most important of these are listed below, for each of the sectors featured in the report. In some cases, figures cited in the report have been drawn from the latest World Resources Report, published annually by the World Resources Institute in Washington. In most cases, these numbers have been drawn from the standard references mentioned below and this is indicated in the text. Where data have been adjusted by WRI analysts, for example in the discussion of greenhouse gas emissions, World Resources Report is cited as the reference and those seeking technical information on the basis of adjustments should refer to that document.

For none of the countries included in this regional study are there readily available and satisfactory data bases for assessing greenhouse gas emissions. Information on many topics is missing, and some important data are either contradictory or known to be based upon faulty sources.

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A brief discussion of the most significant of these data shortages, from a climate change perspective, is presented below.

Demographics

Standard references on population include:

World Population Prospects 1988. United Nations, New York, 1989.

Demographic Yearbook 1987. United Nations, New York, 1989.

In addition, projections of population growth have been drawn from publications of the Population Reference Bureau in Washington D.C.

a) Basic population statistics

In each of the countries, accurate and reliable population information is lacking. Even the most basic of demographic statistics, the registration of births and deaths, are not consistently kept. The limited body of census information is, in many cases, known to be incomplete or inaccurate. As a consequence, many of the statistics available are based on projections and "educated guesses", and there are few if any sets of time series data with which to establish rates of change. Particularly significant is the lack of accurate population growth data, since so much resource planning depends upon accurate assessment of the user base. Such deficiencies are only compounded in attempts to generate per capita statistics: extrapolation from an uncertain base yields ever more uncertain results.

b) Urbanization and migration statistics

The lack of available basic population statistics is magnified in the shortage of "secondary" statistics, those that show what the people are doing, how they are living, where they are moving, etc. In terms of climate change, such information is particularly important in identifying urbanization and migration trends. The general rule is that the further the people are away from the resources they need, the greater the strain on the system since more effort and energy must be used in their acquisition. This is particularly true for fuelwood, agricultural produce, and bushmeat.

With many central African cities already straining to provide basic human needs, the continued trend of rapid urbanization is alarming. Particularly important yet frequently overlooked by overextended national authorities are the periurban slum settlements that surround many of the region's largest cities.

Forestry

a) Forest inventories

In five of the six countries, comprehensive forest inventories are lacking, and some of the existing inventories are out of date, or incomplete. Most existing inventories have focused upon a limited number of commercially valuable species, and do not include information on the majority of species found in the region's forest areas. The condition of forests as a whole, and how they are responding to the pressures of deforestation, are important questions for which there are very few answers at present.

Satellite imagery is being used in several cases to update forest inventories, but it is unlikely that remote sensing alone will be able to provide the necessary level of detail for applications such as land use planning, or even for assessing deforestation and carbon release. It is not even clear whether forest inventories based upon satellite imagery will contribute significantly to improvements in forest management - the purpose for which many of the remote sensing studies are being undertaken - given the institutional weaknesses in forestry administrations in the region.

b) Biomass/carbon inventories

From a climate change perspective, biomass densities, and soil carbon estimates are as important as forest inventories; in the countries of central Africa, there is a near total absence of data on how much biomass is contained in the vegetation per hectare and how much carbon is stored in the soils. Most of the work in this area has been based on data sets of very doubtful accuracy, and that there can be little confidence in present estimates of carbon storage. Well planned and thorough field research will be required before analysts are able to begin answering the question of how much carbon is currently stored within the region's vegetation and soils.

c) Spontaneous regeneration of secondary forests

At present there is conflicting information concerning the potential for spontaneous regeneration within central Africa's secondary forests. Some references cite evidence that, where burning has been controlled, natural regeneration has been noticeable, and even impressive, but the hope for spontaneous regeneration of high densities of desirable commercial species has been described as disappointing. Circumstances vary widely, of course, thus there is little basis for drawing conclusions given the wide range of conditions which apply in the region. Factors affecting regeneration include levels of rainfall, distance to seed sources, and the availability of particular animals for seed dispersal. What is needed is a systematic study of this topic, focusing particularly on conditions typically found within the most threatened areas. This could help in the design of strategies to mitigate the release of carbon from

the most seriously threatened secondary forests.

d) Forest degradation

Forestry statistics in the region fail to document the extent of damage and degradation caused by logging; this is particularly the case in areas in which commercial high-grading has been practiced, followed by the arrival of large numbers of artisanal loggers and farmers whose operations are rarely monitored or regulated by government forestry departments.

Forests logged by companies practicing high-grading are sometimes assumed to retain high volumes of standing timber due to the low per-hectare harvest practices; however, the subsequent classification of high-graded forests as commercially depleted, followed by the arrival of small-scale farmers and loggers, can lead to the extraction of very high proportions of timber, including seed stock necessary for future regeneration. The significance of this pattern has not been fully tested by field research, a major gap in the information available on central African forests.

In Gabon, for example, the common perception is that most of the country remains forested, yet numerous sources report that large proportions of the forest have already been logged, some as many as three times. The condition of these logged areas is essentially unknown: they may be relatively healthy, or they may be seriously degraded. If mitigation of potential carbon release is to be achieved, it is important to have a clearer understanding of the condition of logged areas, and of the trends which affect their long-term viability.

Agriculture

a) Land use patterns

Land use changes are believed to be the major contributor to the emission of greenhouse gases from central Africa, and agricultural clearing is probably chief among these sources. The statistics on land use are very poor, however, and in some cases are little more than guesses. For example, in Equatorial Guinea the estimated area under cultivation by small-holders has been calculated by multiplying the total length of roads by the typical width of cleared strips alongside major roads. In the absence of any other information, this method can at least give some sense of orders of magnitude. But where much of the analysis is based upon similar projections, it is difficult to have much confidence in any conclusions which may be drawn.

Also, clearing of vegetative cover for agriculture or infrastructure development may be offset to some degree by other factors, for example the abandonment of former rubber or palm oil plantations in Zaire, some of which have reportedly begun returning to a forested state. The net effect of these trends has not been determined, nor has their significance been assessed from the basis

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of carbon release and sequestration. However, some observers claim that certain areas of the interior of the region have returned to canopy cover during the past 15 to 20 years.

As important as this topic is, collecting reliable data is among the most difficult challenges one could attempt in the central African context. Planning authorities are severely overtaxed, and many of the most important changes are taking place in remote locations, well beyond the reach of land use planners or even extension services.

It is hoped that time series analysis of remote sensing imagery will allow the identification of areas which are presently in transition. Even if the precise causes of loss of forest cover cannot be determined by remote sensing, identifying specific locations could permit selective ground level observation. If this technique proves effective, it could become invaluable given the logistical and institutional constraints noted above.

b) Smallholder encroachment on forests

This is another critical aspect of the carbon release issue, but detailed analysis is complicated by the absence of reliable demographic data, average plot sizes, and duration. Some observers believe that most descriptions of smallholder encroachment are based upon a faulty understanding of the forces driving the process, of its environmental impacts as presently practiced, and of its potential sustainability under different land tenure regimes. This being so, policies aimed at protecting forests from encroachment will need to be based on better information than is generally available now. This is especially true given that the pattern of causes and effects is likely to vary from place to place, and sometimes in fairly subtle ways.

Energy

Energy data for the region have been compiled from basic references
which are widely available, but do not always provide information for each country in this study. In addition, country-specific studies, published by the Energy Sector Management Assistance Program (ESMAP) of the World Bank and UNDP, have been used as available. ESMAP studies are available for: Zaire (1986), the Congo (1988), Gabon (1988), the Central African Republic (draft - 1991), and Cameroon (draft -1991). No ESMAP study has been done for Equatorial Guinea.

In addition to the ESMAP energy sector studies mentioned above, a more detailed analysis of the power sector has been done for the Congo (Congo: Power Sector Development Study. World Bank, Washington, 1990).

Standard references for the energy sector include:

1989 Energy Statistics Yearbook. United Nations, New York, 1991.

Energy Balances and Electricity Profiles 1988. United Nations, New York, 1990.

World Energy Statistics and Balances 1971-1987. OECD, Paris, 1989.

1989 Survey of Energy Resources. World Energy Conference, London, 1989.

a) Household and non-commercial energy

In most of central Africa, energy use is dominated by non-commercial sources of supply, and by household consumption. Most of the available documentation of energy supply and demand, in contrast, focuses on commercial energy such as petroleum and electricity, with little information available on the non-commercial sector, which is believed to be larger by far.

In general, rural households rely upon fuelwood while urban dwellers are more likely to use charcoal, but volumes consumed and prices paid are little understood. Most rural fuel use occurs outside the monetary economy, and little is known about how households allocate time or other resources to fuel collection, or how changing circumstances might induce them to switch to commercial fuels. Even in urban areas, very little is known about the way in which households acquire and use energy, or how they might respond to changes in prices and availability of commercial fuels. Household energy studies have been proposed for most of the countries in the region, but have yet to be implemented.

In Zaire, for example, it has been shown that prices for charcoal, the primary urban fuel, are unrealistically low because producers are not required to pay for the raw material - fuelwood - or to cover the cost of replacing it. According to the World Bank, the long-run marginal cost of producing electricity in Zaire, despite the country's enormous generating capacity, is significantly higher than the present price of charcoal, a fact which complicates plans to ease pressure on fuelwood supplies by encouraging greater use of electricity (World Bank 1986).

One solution, of course, is to charge stumpage fees for fuelwood which would price charcoal at economic levels; but doing so requires a detailed understanding of the network of production and marketing which presently does not exist. Also, it is not clear that most households would be willing to substitute electricity for charcoal even if the former were significantly cheaper; again, without a better understanding of the household energy sector, it remains extremely difficult to formulate effective policy changes. The World Bank in 1986 called for immediate implementation of a household energy study,

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but nothing more has been done on the subject. Meanwhile Kinshasa's annual consumption of charcoal is projected to reach 400,000 tons by the year 2000.

b) Sustainability of biomass fuel supply

It is generally assumed that traditional patterns of fuelwood collection in rural areas pose no threat to the long-term sustainability of supply: the biomass consumed is later replaced by new growth in a continuous natural cycle. Yet in some parts of central Africa, particularly near urban settlements, local biomass supplies are visibly being depleted. Attempts to promote periurban fuelwood plantations to augment fuelwood supplies, and reduce pressure on remaining forest areas, have been largely unsuccessful. Why this is so, and how interventions can be made more effective, are controversial topics, but there is very little hard evidence on which to base the analysis at present. More information is needed on where and how biomass supplies are collected, with practical criteria for assessing the degree to which sustainability is jeopardized in given locations and under given conditions.

c) The "Energy Ladder"

In most societies there is a strong correlation between income levels and the forms of energy consumed. Generally, higher incomes are associated with greater use of modern forms of energy such as fossil fuels and electricity. Lower incomes are associated with traditional energy such as fuelwood and charcoal, agricultural residues and wastes, or dried animal droppings. Transitional stages often include use of kerosene for lighting or cooking. In much of Africa, urban households often use multiple sources, primarily because of frequent supply interruptions and price fluctuations.

Of the six countries studied in this report, Gabon has by far the most modern profile of energy use, with fossil fuels accounting for a large share of the total. This is due to Gabon's relatively high (by developing country standards) per capita income and level of urbanization. It is doubtful whether the rest of central Africa will be able to adopt modern energy sources on the same scale as Gabon except in the very long term. Yet there is a visible trend toward greater use of fossil fuels, and a gradual shift away from biomass as the primary energy source. With growing populations, however, this does not mean that biomass consumption will decline in absolute terms; it could, in fact, increase significantly.

It is difficult to predict trends along the energy substitution "ladder" without a sound base of information on present energy consumption, which also examines the factors which influence changes in consumption. For this it is important to have better information on demographic trends, as described above.

General regional information

This study, and the six country studies on which it is based, reflects a "desk study" review of information available locally. No field research was carried out, and no visits were made to European agencies which certainly possess significant information relevant to the subject of deforestation in central Africa. French and Belgian archives reportedly contain large bodies of survey and forest inventory information, including maps, but access to such sources was not possible during the present study. Significant activity in this sector has also been financed by the European Community and by the German government's technical assistance agency, GTZ. These could be valuable sources of information.

Any future work on this topic should make specific efforts to gather the widest possible range of information from international sources, and to document what is available within each of the six countries of central Africa. Such a bibliography could prove a vital tool for future research, improving the quality of both analysis and conclusions.

4. A Preliminary Set of Options for Action on Climate Change

The following is an outline of options for policy makers and those who implement them for and in the central African region. The outline is structured from "top to down" in that it begins at the international level and follows the path of actors to the local level.

A. International Level

Recommended Action #1: Improve the institutional setting for managing information and finding out what needs to be known about the central African landscape and its potential for mitigating global and regional effects of climate change.

International donor institutions (both multilateral and bilateral) have between them a great quantity of trip reports, project appraisals, sector analyses, and other highly relevant sources of information. The challenge is to improve the sharing of information and experience between the donor institutions. Perhaps UNDP or another appropriate organization could take the lead in putting together a data base of accessible information sources relevant to central Africa's economic development. One important initiative is to track land use changes through satellite imagery and train local people to interpret this highly useful information.

Individual donor organizations can improve their own information gathering and sharing between sectors and divisions such that infrastructure development projects interface more directly with forest conservation programs. One donor initiative might support a road building project while another part of the same organization is working in isolation to study biological diversity within the area where the road is planned. Too often, donor projects work at cross purposes.

Recommended Action #2: Improve coordination of forest and environmental assistance programs at the international level.

There is growing interest and activity among donor and international organizations in protecting and exploiting central Africa's forests. The United Nations (UNDP, UNEP, and FAO in particular), the European Economic Commission, and bilateral assistance agencies (especially the French, Belgium, German, British, and U.S.) are all increasingly active in supporting large scale national-level action plans and forestry initiatives. The Global Environmental Facility (GEF), the Tropical Forest Action Plan (TFAP), and National Environmental Action Plans are all examples of such efforts.

The problem is that many of these initiatives have been poorly planned and unsuccessful to date at meeting their stated goals and objectives. The relevant donor organizations need to better communicate and cooperate in supporting these efforts so that the effectiveness of their collective efforts can be improved.

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Structural adjustment programs and other donor initiatives linking policy reforms to financial assistance need to better incorporate environmental considerations into their programs. Analytic work needs to be carried out on the effectiveness of conditionality and environmental policy reform in the region.

International donor and environmental organizations need to work together more with the international timber and mining firms who are playing an increasingly important role in central Africa to work out a sensible and balanced approach to sustaining the region's resource base.

International organizations working in the region should consider adopting a standard environmental impact assessment procedure for all large-scale development/infrastructural projects in the region. Such a process (which is already institutionalized in the World Bank) needs to be developed for the Africa Development Bank and the bilateral funding agencies in the region. If these procedures could be standardized and taken seriously, much environmental degradation could be avoided and the development projects themselves made more sustainable.

The Global Environmental Facility is a multilateral fund of over one billion U.S. dollars which has among its four objectives the protection of biological diversity and mitigation of global warming. This mandate clearly allows for the consideration of a number of projects that could deal with the problems of forest and land use planning and management in the region. If successfully planned and monitored, the Fund could provide substantial financial resources relevant to the project at hand.

B. Regional Level

Recommended Action #3: Develop a regional authority for coordinating policy analysis and large scale project activity relating to the region's natural resources and forests in particular.

The six nations of central Africa and the donor organizations that work in those countries should consider establishing a regional environmental information coordination body that would be based in the region. Perhaps such a body could be connected to the Communauté Economique des Etats de l'Afrique Centrale. The challenge would be to widen this existing trade and monetary union to deal with the scientific and socio-economic development issues germane to this and other regional development initiatives.

Such a regional body could have among its specific mandates the responsibility to monitor what is happening to the regional forest system. This is a new idea which builds on the concept of regional bodies that support regional cooperation for international waters (such as the Akagera River System authority in East Africa) and, in a few cases, ecosystems. Certainly the globally significant central

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African forest system warrants a similar initiative.

The organization would collect and disseminate information concerning forestry conditions and trends, especially information concerning growing stocks and trends, provide training in forest management, and promote sustainable forest use throughout the region. It might eventually be given the authority to act as a "watch dog" and enforcement body for projects with potentially large-scale ecologically damaging effects. Such authority might best be allocated under the aegis of the United Nations system.

A particularly important function of this regional authority would be to work with the national governments and international donors to improve and standardize international trade and fiscal policies relating to forest products so that smuggling and other environmentally damaging practices can be discouraged throughout the region.

C. National Level

Recommended Action #4: Improve the coordination of information management and project activity relating to forestry in the region.

Much of the information relating to each of the six nations' natural resources and their development is spread out among a number of government ministries and parastatal organizations. AID and other donors working in these countries could help financially support and provide technical assistance for the improved coordination of relevant data and information in each of the countries. At present, very little inventory work is being undertaken; what is, is usually confined to "economic" species. Inventory work must be expanded in terms of area and scope to cover the whole region and all species.

Recommended Action #5: Strengthen the institutional capacities of national government ministries in forest production and conservation.

As is widely known, the region's national government ministries and agencies responsible for forest production and protection need significant support in administration, technical effectiveness, extension and research. These are all areas for improved and better coordinated assistance. Much empirical work has been done to date in Africa and other developing regions in this area of institution building at the national level. Lessons learned from these studies could be applied in the six countries of the region. A study should be undertaken to see if and how forestry departments can be made self-financing.

As stated above, environmental impact assessment procedures should be standard practice for all government ministries overseeing large development projects in the region.

Recommended Action #6: Promote improved agricultural practices which increase economic opportunities and relieve pressure on forest resources.

Agricultural and especially agroforestry research and extension capacity needs to be strengthened dramatically in the region. There is a good opportunity for introducing a comprehensive system of documenting and adapting indigenous agricultural technologies in conjunction with the best knowledge available from international (and national) agricultural research facilities. Technological interventions which should be explored within each of the countries of the region include: agroforestry efforts focussing on soil fertility, fuelwood, or food; provision of improved seeds, inputs, and implements, and improving agricultural transport to markets and processing facilities.

Work should be carried out on agricultural pricing policy to see how important prices are in determining agricultural output. At the same time, the supply of agricultural inputs, the marketing system, storage facilities, and infrastructure should be investigated.

Perhaps most important to the improvement of national agriculture (and forest) sectors is the reformation of land tenure systems throughout the six countries. Tenurial security over agricultural and forest lands needs to be strengthened considerably if local resource users can be expected to manage small holder plots in a sustainable fashion. Indigenous corporate structures (villages, lineages, and clans) could serve as a viable basis for the granting of tenurial control and access rights in the promotion of agricultural development.

Recommended Action #7: Develop energy demand management strategies.

Preliminary assessments have shown the importance of biomass fuels in central Africa's energy balance, but not enough is known about specific consumption patterns and trends to design effective strategies for managing energy demand. In each country, household fuel surveys are needed, along with surveys of other sectors which consume biomass fuels, for example bakeries, restaurants, and brick kilns. Fuel pricing and substitutions policies, and improved stove programs, can be implemented once the information gathered by the surveys has been assessed.

On the supply side, costs paid for fuelwood resources need to better reflect the cost of replacing trees harvested. Stumpage policies on government controlled lands must be enforceable, and should include incentives for enforcement by local officials. At the same time, private sellers of wood products, especially fuelwood and charcoalwood growers, must be provided with better market intelligence so that they can obtain a fairer price for their products. Supply substitution efforts may need foreign exchange support in order to ensure consistency of supply and price stability.

D. Local Level

Recommended Action #8: Improving local level information sharing.

Regional organizations (connected to Universities, Church groups, government extension agencies, etc.) that deal with natural resource issues in each of the countries can be strengthened to provide improved information management and sharing. Workshops, newsletters, technical assistance in improving data management, library services and computer systems are very much in demand throughout the region. Radio is a particularly important medium that can reach local levels and provide a critical educational tool for areas populated by isolated ethnic groups.

Recommended Action #9: Better understanding of local forest use practices.

A great deal of research is needed on local forest use practices. This is a key area in terms of the long term sustainability of the regional forest system as in many areas throughout central Africa, little is known about local variations in forest use. Different ethnic groups within individual countries use the forests in very different ways and these variations need to be better understood for policies to be improved. Minor forest production for households, small scale agriculture, artisan materials etc. provides an important economic basis for sustainable forest management. Such activities need to be supported.

Recommended Action #10: Improved analysis of demographic conditions and trends in both rural and urban areas.

While present population levels are relatively low in central Africa compared with much of the developing world, growth rate trends and demographic patterns suggest problems in the future. Therefore a priority intervention for all concerned actors in the region is to better understand this set of issues throughout the region. Local level demographic trends are critical in such an endeavor. Studies need to be conducted on migration patterns, concentrating on which areas are receiving the highest numbers of migrants from both within and outside the region. For example, the forests of eastern Zaire are beginning to feel the stress of increasing migration from Rwanda, Burundi and Kivu in Zaire. To be able to address this problem, the trends need to be better understood. The local level is the best place to target demographic analyses so that regional patterns can be disaggregated.

Another focus of this general activity centers around the growing urbanization phenomenon. Much analyses needs to be conducted concerning the trends of urban growth and sprawl. This will allow policy makers to devise appropriate strategies for meeting the consumption demands for fuelwood and other forest and agricultural products for the growing urban populations. Urban planning and land

use strategies for periurban areas will also be more feasible and effective given this line of inquiry.

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REMOTE SENSING AND GIS CONTRIBUTIONS TO A CLIMATE CHANGE PROGRAM FOR CENTRAL AFRICA

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Figure A2.4 - Typical example of the NDVI data showing vegetation activity for Africa

REMOTE SENSING AND GIS CONTRIBUTIONS TO A CLIMATE CHANGE PROGRAM FOR CENTRAL AFRICA

An important component of this design phase activity 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 geographic information systems (GIS's). These relatively new techniques for primary data acquisition, management and analysis offer considerable potential for improving the 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 land conversion in understanding the carbon cycle, the regional applicability of the data and the need for up-to-date information.

Current vegetation maps of central Africa are generally old and not representative of the last 10 years of anthropogenic pressure. The current distribution of plantations and shifting cultivation is poorly known and the precise location and extent of logging is largely undocumented. There is substantial disagreement as to the areal extent of the moist tropical forests of central Africa (Myers, 1989). By all accounts central Africa contains the second largest area of moist tropical forest in the world, the largest portion being in Zaire. The importance of the moist tropical forest biome in terms of species biodiversity and its role in global climate change is discussed in the volume "Central Africa: Biogeophysical Setting and Global Climate Change". Quantifying the spatial distribution of tropical forest at regional and continental scales and the rates of land cover conversion are necessary steps towards 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. This is particularly true for central Africa, where the existing maps are for the most part inaccurate. The most recent estimate of CO_2 release for Africa is based on the 1980 FAO Tropical Forest Assessment and was prepared using a 500 by 500 km grid cell. For each cell, carbon emissions were estimated for forest and savanna land cover (Hao et al., 1991).

The first section of the volume (1) describes five remote sensing feasibility case studies which were undertaken as part of the design phase activity. The first two studies (1.1 and 1.2) examine the utility of coarse spatial, high temporal resolution satellite data for regional forest mapping and fire monitoring. The third feasibility study (1.3) examines the application of multitemporal high resolution data for monitoring land cover change. The forth feasibility study (1.4) examines the use of high spatial resolution satellite data for generating an improved map base for the region. Section 1.5 examines the use of satellite global positioning systems for improving the utility of ground data. Section 2 examines the need for improved data management and the application of GIS within the region, providing examples of information management systems at different spatial scales. The final section of this volume (3) summaries the findings from the above surveys and case studies and gives the recommendations for how to improve data acquisition and data management.

Appendix 1 outlines a database created to allow easy access to cartographic, photographic and research information on the forested region of Zaire. The database is a bibliography of historical data for Zaire relevant to climate change studies which currently resides in Belgium. Appendix 2 provides an overview of satellite data availability and the status of remote sensing within the central African region. As a product of this review we have also been able to provide a preliminary assessment of current gaps in remote sensing data availability for the region and an indication of what could be done to fill these gaps.

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1 REMOTE SENSING CONTRIBUTION TO CLIMATE CHANGE: CASE STUDIES

Satellite remote sensing can make a unique contribution to climate change studies by providing an opportunity for up-to-date regional mapping and monitoring. This unique capability led us to give special attention to satellite remote sensing in this design phase program. We have included the preliminary results of five 'proof-of-concept' case studies undertaken during the design phase of the study.

1.1 Application of AVHRR to tropical forest mapping

The National Oceanographic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite sensing system provides data which can be used to perform small scale environmental monitoring. These data provide daily global coverage at a resolution of c. 4 km, with local coverage of 1km available on request (Justice et al., 1985). For this project, the visible and near-infrared spectral channels have been used for mapping within the forest domain. The middle infrared and thermal channels have been used to map the forest savanna transition zone. Mapping of the current land cover for all the tropical belt at 1km resolution is seen as a unique contribution to global scale studies by the scientific community (IGBP-DIS, 1991). The global wall to wall mapping of the tropical dense humid forest using 1km data is an international effort involving CEC, NASA/GSFC, UN/FAO, UNEP/GRID (Geneva). The CEC TREES project of the Joint Research Center, Ispra has recently taken the lead in coordinating this wall-to-wall mapping of the tropical belt (TREES, 1991). Assessment of global climate change implies the need for long term monitoring. A standard 1km product of vegetation maps from the early 1990's for the entire tropical belt, will provide a useful long-term monitoring tool.

An up-to-date inventory of the forest resources of the region is clearly one of the first steps in developing an effective management plan and should be given high priority by the national governments and international development community.

1.1.1 Methodology for AVHRR forest / non forest mapping

The vegetation classes derived from remote sensing data do not correspond directly to classical vegetation categories defined by floristic, ecological or physiognomic criteria. The categories available from remote sensing are determined by the ability of the sensing system and the analysis techniques to discriminate between vegetation types spectrally or temporally. AVHRR data have a coarse spatial and spectral resolution permitting in the case of this study the discrimination of dense humid forest, degraded forest, mixed forest/savanna and savanna categories. Table 1 (page 34) shows the correspondence between these AVHRR derived vegetation classes and the Yangambi vegetation classification (Trochain, 1957).

Multi-date analysis of daily AVHRR data permits the discrimination of additional vegetation types based on their phenological characteristics (Tucker et al., 1985), however this analysis approach was not part of this design phase activity. Persistent cloudiness in humid tropical rainforest areas makes multitemporal analysis problematic. Several methodologies have been developed to map dense humid forest using 1km NOAA AVHRR Large Area Coverage (LAC) data (Cross, 1990, Laporte, 1990, Päivinen et al., 1992). The AVHRR is poorly suited for direct parameterisation of the land surface and more attention should be given to converting satellite radiance to biophysical parameters. Data correction for atmospheric effects is important for tropical regions but is hampered by the limited availability of quantitative data on the state of atmosphere.

For the central African study interactive thresholding on visible, middle and thermal infrared channels was applied to dry season data for 1988-89 and 1989-90 to delineate the

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above categories. The thresholding method is illustrated in figure 1. Thresholds for discrimination were established empirically using Landsat data and field knowledge. The first step of the analysis involved thresholding middle infrared multi-date composite images to delineate the forest-savanna boundary (see (1) on figure 1). 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 (see (2) in figure 1). Finally thresholds in the near-infrared band were used to differentiate closed forest from degraded forest in the Congolian Zone (see (3) in figure 1). The greatest spectral contrast between forest and the degraded forest formation is found in the near-infrared channel for the Congolian Zone. A similar finding was reported for West Africa (Laporte, 1990, Malingreau et al., 1989).

1.1.2 Map products

The map products were generated from classified LAC imagery. These maps are provisional and are currently being further refined and evaluated at NASA/GSFC and by national forest services. On a country basis, they give the extent and the spatial distribution of 5 vegetation units. The correspondence between these units and conventional vegetation formation typology is given in table 1 (page 34). These maps were generated in a digital format and can be easily integrated into a GIS. The most practical mapping scale using 1km resolution data is approximately 1:1,000,000, which corresponds well to the requirements for a regional data base for meso-scale biophysical studies (e.g. Hao et al., 1990). Maps at this scale will provide a preliminary estimate of total forest area in anticipation of the results from proposed comprehensive high spatial resolution mapping and monitoring programs (Appendix 2). Details present in the original maps are missing in the map products when presented at 1:5,000,000 for Cameroon and 1:10,000,000 for Zaire (figure 2 and 3) due to the small scale of the illustration.

The vegetation maps of Zaire and Cameroon illustrate the potential of NOAA AVHRR imagery for first order mapping of dense humid forest vegetation at a small scale. NOAA AVHRR data are currently the only global and consistent high temporal frequency data set available to derive land surface parameters at a regional scale.

1.1.2.1 The AVHRR vegetation map of Cameroon

The AVHRR Cameroon vegetation map product covers southern Cameroon, south of 7 degrees north latitude (see figure 2). 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.

With the exception of the northern part of the Central Province, the pattern of degradation is clearly associated with the road network where shifting cultivation is taking place. The determining factor of degradation in general appears to be population density. This is well 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 part of the Central Province, the degradation is mainly located at the fringes of the remnant forest blocks. This pattern of degradation is common throughout West Africa. The degradation associated with timber exploitation can not be quantified with 1km spatial resolution data.

It is difficult to compare directly the areal extent of these vegetation units with existing estimates, as the different estimates use different class definitions. Even the

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physiognomic classification adopted by FAO for Cameroon shows some difficulties for comparison to LAC vegetation units (see table 1, page 34). Nevertheless, we have grouped the FAO, 1980 classes (table 2) according to our typology to permit a preliminary comparison.

Table 2
Areal extent of vegetation types from FAO, 1980 and the AVHRR LAC classification for Cameroon, 1989

Vegetation classes	FAO, 1980 (sq km)	AVHRR LAC, 1989 (sq km)
Forest	191,600	168,087
Degraded forest	45,350	64,218
Mixed forest /savanna	68,550	63,691
Savanna	22,550	24,709

The areal extent of forest reported by FAO for Cameroon in 1980, was 180,000 sq. km of dense humid forest. 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 sample aerial photographic interpretation. From the NOAA-AVHRR analysis, the total extent of dense humid forest estimates is 168,087 sq. km. Using these two estimates to derive an estimate of forest loss is problematic and inadvisable. Firstly, the errors associated with the AVHRR estimate resulting from the coarse spatial resolution of the sensor have yet to be fully quantified (Section 1.1.3). Secondly the errors resulting from the class groupings for the comparison between different classification schemes need to be considered. Thirdly, the errors implicit in the FAO estimate have not been quantified.

1.1.2.2 The AVHRR vegetation map of Zaire

The AVHRR map of Zaire (figure 3) shows the large block of forest covering the Cuvette Centrale. The forest to the north shows a continuous and distinct boundary. The boundary between the closed forest and the open formation is more broken for the southern margin, where forest spatial distribution shows a more complicated "interface" with the dry forest.

The largest pattern of degradation inside the closed forest is located in the Equatorial region centered on Djolu (Mongala Province), in the Haut Zaire region between Niangara and Ango in the Haut Uele Province. Linear patterns of deforestation are well represented in the Cuvette Centrale, these linear structures follow the main communication network of rivers and roads. The linear patterns are exemplified by the triangular structure between Kindu-Kasongo-Shabunda and North West/ Southeast linear structures near Ilebo, Mweka, Lusambo, in the Bandundu region and in the South Kivu province. A centrifugal pattern of deforestation can be seen around Kisangani, similar to those found around cities in Cameroon. The preliminary area estimates for the AVHRR derived classes are presented for comparison with the 1980 FAO classes.

The most comprehensive areal estimate that is currently available for Zaire was produced by FAO (1980) and is based largely on figures and maps which were produced in the 1950's. In particular the work of Devred (1958) provides the basis for the current estimate. Recent estimates of the areal extent of the tropical moist forest of Zaire are summarized in table 3. The authors believe that the map produced by Devred (1958) at 1:5 million is currently the most comprehensive map of vegetation published for Zaire, although more recent and detailed vegetation maps exist for parts of the country e.g.

Compére (1970). The Devred (1958) map has 37 classes of vegetation and was based on a series of publications from the 1930's to the 1950's (e.g. LeBrun, 1936, LeBrun and Gilbert, 1954, Duvigneaud, 1952) A comparison of the satellite derived boundaries with this map shows the core area of moist forest in the Cuvette Central to be the same but with considerably more detail for the satellite derived boundaries 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 lead us to believe that the Devred classification is inaccurate for the current vegetation cover of this area which is predominately 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.

Table 3
Areal extent of vegetation types from FAO, 1980 and the AVHRR LAC classification for Zaire, 1989

Vegetation classes	FAO, 1980 (sqkm)	AVHRR, 1989 (sqkm)
Forest	1,056,500	1,117,963
Degraded forest	78,000	102,821
Mixed forest /savanna	824,400	437,565
Savanna	30,700	34,299

A more recent map which covers the entire country is the UNESCO Vegetation Map of Africa (White 1983) which is also at a scale of 1:5 million and in several areas the boundaries appear similar to those depicted by Devred (1958). There is a good correspondence between the boundaries of the Guinea-Congolian lowland and drier types of rain forest and the satellite derived forest boundary for the northern margin of the forest. For the southern boundary of the forest the registration of the UNESCO map and the satellite derived boundaries is poorer.

The general correspondence between previous maps and the satellite derived maps gives an indication of the success in interpreting broad vegetation classes from the AVHRR data. The accuracy of the existing maps is however insufficient to allow the interpretation of differences between the existing maps and the AVHRR map as changes in land cover.

1.1.3 Validation procedures

The 1km resolution of the AVHRR results in an inherent error in the estimate of vegetation class areal extent. Similarly the classification schemes are obliged to include combinations of single vegetation types. Validation of the accuracy of NOAA AVHRR classifications are generally based on higher resolution data from Landsat, SPOT, or from recent reliable vegetation maps. The TREES project of the CEC is currently using Landsat Thematic Mapper (TM) data to validate AVHRR LAC forest classifications.

Validation of the map accuracy for this study was undertaken using three approaches. The first approach was to compare the map derived from the AVHRR with the available maps for the country. Secondly the AVHRR derived map was compared visually with a number of high resolution Landsat and SPOT images distributed throughout the country (figure 4). Thirdly, vegetation maps from three classified Landsat MSS scenes were compared quantitatively with the AVHRR derived map (table 4).

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Table 4
MSS data used for the validation of the AVHRR LAC forest classification

Date	MSS (path/row)
06/20/86	178/60
06/20/86	180/62
01/15/86	174/58

In the last two approaches the Landsat data, at more than ten times the spatial resolution of the AVHRR, were considered to be an adequate representation of the actual vegetation distribution. Similarly, the classes obtainable from the Landsat data can be combined to permit direct comparison with those derived from the AVHRR. The Landsat images were chosen according to a south-north stratification corresponding to the 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 access to local knowledge to assist in the interpretation.

From the preliminary results obtained from the Landsat comparison we have determined that the LAC classification underestimates the areal extent of forest from 19 to 21% in the Transition Zone. The error is smaller where the dominant land cover is forest (8% overestimate). Underestimation is clearly linked to the discrepancy between the 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 (21%), occurs where mixed formations are present. In the area of savanna/forest transition, most of the forested areas such as riparian forest have an areal extent smaller than the sensor instantaneous field of view, thereby introducing a large underestimate of forest area. Inversely, in the forested region known as the "Cuvette Centrale" the disturbances have a very small size and an overestimate can be expected (8%).

From this study we conclude that a preliminary estimate of the areal extent of broad vegetation classes is possible using AVHRR 1km 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 our current estimate of forest area with respect to the inherent error 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 the other countries in the region and the above maps are being refined as a contribution to the CEC TREES Project. The 1km data from the Niamey receiving station which covers the western part of the region have not been used 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 forest and savanna type. This study should include use of the ten year record of AVHRR GAC (4km) data in conjunction with the 1km data base acquired through this study.

1.2 Application of remote sensing to biomass burning

One of the largest uncertainties in estimating the amount of biomass burned or trace gases emitted in Africa is a lack of knowledge about the spatial extent of savanna burning, or the interannual variability (Hao et al., 1990, Fredericksen et al., 1990) observed that about 80% of savanna areas in the Sahelian and Sudanian zones of Senegal were burned during the 1987 and 1988 dry seasons. This observation was made using Channels 1 and 2 and the normalized difference vegetation index data from the NOAA AVHRR. There is currently no such satellite derived estimate for the central African region

Recent development of remote sensing techniques have shown the feasibility of using the NOAA/AVHRR 3.75um and the 11um channels to detect fires (Pereira et al., 1992; Setzer and Pereira, 1992). Matson and Dozier (1981) demonstrated a method to determine sub-pixel fire size and temperature under controlled conditions from the AVHRR 1km data, however the method has limitations for operational implementation at a regional scale. In particular the method requires an accurate estimate of the background surface temperature of the fire pixel. Kaufman et al., (1990) showed that it is possible to detect fires as small as 10m x 10m using the AVHRR sensors. Due to the low saturation of the 3.75um channel (318-320°K) some land areas are hot enough to saturate the afternoon images. Multispectral analysis incorporating the thermal channels is required to distinguish between active fires and warm soil saturation effects (Robinson, 1991). A combination of day and night AVHRR data can be used to detect the occurrence of fires on a daily basis. The presence of dense clouds may obscure the 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 the total number of fires in a given area can be obtained. Factors such as the timing, duration and size of fires and the 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. Figure 5 shows a preliminary map of the distribution of active fires in central Africa detected using the AVHRR sensors during the month of January, 1989. The sharp boundary to the south corresponds to the forest savanna margin. At this time of year very few fires are seen within the forest domain. Estimates of the number of fires occurring in this time period can be easily calculated.

In addition to the detection of fires, it is also possible to identify burn scars particularly in savanna regions where the contrast of burned areas with surrounding unburned areas is high in the visible channels of the AVHRR (Pereira et al., 1992, Setzer and Pereira, 1992). Burn scars can in theory provide a regional estimate of area burned but further analysis is needed to determine the spectral, temporal and spatial characteristics of burns scars as observed by the AVHRR. Figure 6 shows an AVHRR image of burn scars. One approach to such analysis is a comparison of contemporaneous data from the AVHRR and high spatial resolution satellite images, such as the 30-80 m resolution Landsat Thematic Mapper (TM) or Multispectral Scanner (MSS) imagery, or the 10-20 m resolution SPOT. The approach has been used successfully for the savanna region of Ivory Coast, West Africa. Quantifying burn scars needs to be evaluated for a range of vegetation types, particularly for vegetation types with variable tree and shrub density. Burn scar area estimates may be used synergistically with fire counts to give improved estimates of burned area over the use of fire counts alone. The AVHRR 1km data needed for operational fire detection are available for central and southern Africa on a daily basis by programmed Large Area Coverage (LAC) obtained by the on-board tape recorders and HRPT data received by the regional ground reception stations in Pretoria, Nairobi and Niamey.

The objective of current research at NASA/Goddard Space Flight Center (GSFC) is to establish whether fire counts and burn scars can be used to improve current estimates of emissions for central and southern Africa. This research builds on a study to provide a demonstration of the satellite contribution to the estimation of regional trace gas emissions for Brazil by Kaufman et al., (1990). Two techniques are described for estimating trace gas emissions, both rely on operational monitoring using AVHRR data. One method determines the emission of particulates per fire using

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the satellite imagery which is then converted to trace gas emissions. The total emissions are then calculated by multiplying the average per fire emission by the total number of fires observed. The other method computes the total burned biomass by multiplying the biomass burned in an 'average fire' by the number of fires and then calculating the emitted trace gases using emission factors from the literature. The total number of fires was obtained from the NOAA AVHRR. The approach currently adopted at Goddard Space Flight Center (GSFC) is to derive an estimate of area burned either by estimating the average area burned per fire for a given landscape or by direct measurement of burn scar area. Average fire size will vary as a function of vegetation, terrain and land-use practice. The low saturation level of the AVHRR thermal sensors makes any direct calculation of fire size problematic. Research is needed to determine fire size distributions using sample high resolution data. As these techniques are developed it will be important to estimate the associated errors. To translate the detected total burned area to emissions it is necessary to know the fuel loading, the fraction of burned material, the efficiency of the fire and the emission ratios. This information can be acquired mainly by field measurements (e.g. Greenberg et al., 1984, Crutzen et al., 1985, Ward, 1986, Andreae et al., 1988, Ward et al., 1990). Such data are largely absent for the savannas of central Africa and need to be collected.

The visible and near-infrared channels of the AVHRR permit the identification of burn scars, the monitoring of vegetation state (Fredericksen et al., 1990, Lopez et al., 1991, Paltridge and Barber, 1988, Malingreau, 1990) and estimation of above ground biomass for savanna vegetation (Prince, 1991). In addition it is possible to monitor the products of biomass burning with the visible and near-infrared channel of the AVHRR through determination of the single scattering albedo of smoke (Kaufman et al., 1990). In summary, the limitations of the AVHRR system for fire monitoring include the low saturation level of the sensors, the sensor noise in the 3.75um channel and the overpass time of 2:30 am and pm for even numbered NOAA satellites and 7:30 am and pm for odd numbered satellites, which provide only a sample of the diurnal cycle of fire activity. In addition dense clouds will prevent detection of the surface by the visible and infrared sensors and will obscure active fires. In these respects the AVHRR is poorly suited to quantitative fire monitoring but it does however provide us with an immediate tool to start addressing the topic of regional fire distribution and timing.

The recent launch of the European Resource Satellite (ERS-1) provides two sensors that may contribute to the study of fire. The Synthetic Aperture Radar (SAR) will give additional information concerning changes in vegetation structure as a result of burning (Kaschiske, in press). The Along Track Scanning Radiometer (ATSR) will provide coarse resolution sensing in the middle and thermal infrared parts of the Electromagnetic Spectrum.

The Defense Meteorological Satellite Program (DMSP) has a broad band panchromatic low-light sensor which has been used to detect visible light sources at night, including fires. This sensing system has been operational since 1974, however the intensities measured by the system are not well calibrated (Sullivan, 1988).

The Geostationary Operational Environmental Satellite (GOES) Visible Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) system provides high temporal frequency coverage every 30 minutes but its coarse spatial resolution of 16 km, permits only the largest of fires to be detected (Menzel et al., 1991). Application of the sub-pixel fire technique described by Matson and Dozier (1981) provides a means to estimate fire size and temperature, however as with the AVHRR, there are serious limitations to applying the method on a regional scale. The unique contribution from geostationary sensing systems is their ability to monitor the diurnal cycle of fire activity. Knowledge of the diurnal distribution of fire activity will help quantify the error associated with fire detection by the diurnal sampling provided by the polar orbiting systems. The decrease in fire activity late in the day and during the night in the tropics, indicates that night-time sensing alone may result in a significant underestimate of fire occurrence. This diurnal cycle of fire activity is corroborated by field observations of controlled agricultural burning (Malingreau, 1990). Preliminary results of analyses of Meteosat data of West Africa have shown the thermal dynamics of a savanna landscape as it relates to biomass burning (Citeau et al., 1988). In addition to fire monitoring, the visible channels from the existing network of operational geostationary offer considerable potential for regional monitoring of smoke plumes.

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The needs of the fire research community will be better served by sensors currently planned for service later this decade (Robinson, 1991). The Moderate Resolution Imaging Spectrometer (MODIS) planned for launch in 1998 as part of NASA's Earth Observing System (EOS) will have 32 spectral channels at resolutions of 250 m, 500 m and 1 km and will include a 3.75um channel specifically designed for measuring fire temperature and size. In addition there are plans to operate both morning (10:30 am) and afternoon (1:30 pm) copies of the MODIS instrument. The imager currently being designed for the geostationary Second Generation Meteosat will provide 13 spectral channels with a 3km resolution, including a 3.7um channel and a panchromatic channel with a 1 km resolution every 15 minutes.

The conclusion from this case study is that the NOAA-AVHRR 1km 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 the satellite based techniques and to give representative emission factors for the vegetation/ fire types found within the region. Focus at the initial stage for central Africa should be to contribute to a broad continental scale program which will identify the priority regions for future focus for biomass burning studies. From our preliminary evaluations it would appear that the humid forest areas of central Africa contribute very little in terms of burning emissions and immediate focus should be given to the humid savannas.

1.3 Application of high resolution satellite data to land cover change detection

Change detection, as referred to in this report, is simply the detection of a spatial change in land cover over a period of time. This time period can be on the order of days or weeks but more commonly refers to changes on the order of years. Examples of Landsat change detection studies in the region have been provided by Wilmet and Vennetier, (1986), Berta et al., (1990), Malingreau, (1991), and Castiaux et al., (1991). The objective of these studies is to provide an accurate estimate of the distribution and rate of change of land cover. These estimates are important for a number of reasons, but their significance for global change studies is that, when combined with biomass estimates associated with the land-cover in question, they can be used to produce improved trace gas flux estimates. Also, change detection can be used to locate 'hot spots' where mitigation activities might be implemented. Once a mitigation activity affecting land-use commences, these techniques can then be used to monitor the effectiveness of slowing rates of deforestation and increasing reforestation.

Change detection studies can be conducted at different scales. At the regional scale, change detection can provide an overview of forest extent, forest fragmentation, and rates of change. At the national level, change detection activities can provide an accurate accounting of land-use and land-cover change for a particular country. This information can be used to monitor government land-use policies and to provide information on resource use. At the local level, change detection techniques can be used to monitor land-use related mitigation efforts, monitor the impacts of climate change on the region and to better understand the land-use dynamics of an area. Change detection studies at the local level can also be used to better understand the dynamics affecting land-cover change. For example, using a relatively high frequency of coverage, one can study the regrowth of vegetation after clearing. These data can also be used as input to modeling land-use and land-cover change (see section 2.3.2). At finer scales, satellite imagery may not be appropriate and higher resolution imagery such as aerial photography or videography may have to be used (Gilruth et al., 1990).

1.3.1 Overall methodology

Change detection analysis approaches can be categorized as: visual, digital, or integrated digital/visual. The majority of satellite data are currently provided in a digital format, from which photographic products can be produced for visual analysis. Alternatively, thematic maps can be generated directly as the output from digital analysis. Digital thematic maps can be directly entered into digital information systems.

Visual satellite image interpretation builds upon techniques developed for aerial photographic interpretation (Chuvieco and Vega, 1990). The results of visual interpretation can be digitized for entry into digital data bases, such as a GIS, for more quantitative analysis. Digital techniques use automated procedures to classify areas based on their radiance values (Hoffer, 1986). This approach requires the appropriate computer hardware, software, and trained personnel. The advantage is that these procedures can apply spectral class statistics to an entire image, thereby decreasing the subjectivity associated with visual interpretation. The disadvantages are that poor data quality caused by problems such as data transmission errors, atmospheric and terrain effects can result in classification errors.

Combining visual and digital techniques allows one to maximize the advantages of both approaches. For example, by performing scene-specific digital enhancement prior to visual interpretation, one is better able to delineate the classes of interest (Beaubien, 1986). Another, more computer-intensive, technique is to perform a digital classification and refine the classification by visual analysis (Ahac et al., 1992).

It should be noted that the cost of personal computer-based image analysis systems is not as prohibitive as it once was (Prince et al., 1991). However, other factors such as physical environment, lack of persons trained in computer applications, and political and administrative conditions create limitations for using computer-based image analysis in the region (Hedberg, 1991).

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

1.3.2 Approaches to change detection

Change detection methodologies can be developed to survey an area in its entirety (wall to wall) or on a sample basis, which provides representative statistics on clearing rates for the entire area.

1.3.2.1 The sampling approach

An example of the sampling approach to quantifying rates of deforestation is the UN/FAO Tropical Forest Assessment 1990 Project, which has the objective of establishing global estimates of the rate of deforestation over the last decade (Singh, 1990). As part of this global study, central and southern Africa have been stratified into ecofloristic zones and a stratified random sample of 40 Landsat image pairs have been selected. The analysis method involves using two Landsat MSS color photographs, enlarged to a scale of 1:250,000, and acquired approximately 10 years apart. The interpreter starts with the most

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recent image and delineates the land cover classes on a transparent overlay. Next, the interpreter superimposes the map from the most recent image on the historical image and delineates areas of change. A dot grid is used to assemble a change matrix for the scene.

The FAO approach is a simple and cost effective visual technique. The interpretation is done by foresters from the region. In most cases, they are familiar with the range of conditions found within their country. The accuracy of the results will depend largely on the ability of the photo-interpreters to identify the land cover transformation from the multi-date imagery. One problem with this technique is that it does not provide a regional map of the land cover change and therefore is not adequate to support spatial analysis for regional carbon modeling, planning, or forest management. Also, the representability of the statistics will depend largely on the appropriateness of the preliminary stratification and the availability of multi-temporal data.

1.3.2.2 The wall-to-wall mapping approach

Another visual technique is being used at the Complex Systems Research Center (CSRC) at the University of New Hampshire and the Goddard Space Flight Center (Skole, in press). CSRC has been mapping deforestation in the Amazon Basin using Landsat TM black and white (channel 5) image photos at a scale of 1:250,000. This technique delineates clearings on single date images and then manually digitizes the delineation into a GIS package (see section 2.3.5). Once the data are digitized, the results are compared with TM data sets created for other years or digitized map data. The advantage of this technique is that it provides a map of the clearings for the entire region and the results can be easily compared, point for point, to other data sets. one drawback of wall-to-wall mapping of the region is that the large volume of images required results in a higher cost that the sampling approach. Nearly 200 Landsat scenes are needed to cover the forested portions of the central Africa region (Park et al., 1983).

1.3.3 Change detection example for central Africa

Very few studies have quantified deforestation in the central African region. The following change detection examples provide insight into the possibilities and problems associated with establishing a satellite based change detection methodology for the region.

1.3.3.1 Site locations

Four Landsat MSS scene pairs were selected to demonstrate a change detection methodology and illustrate some of the methodological problems that can be expected with quantifying deforestation within the region. The four areas were selected to provide a variety of land cover types. The sites were selected to include dense forest, the forest margins and gallery forest. The location of the scenes is shown in figure 7 and the date and path row information is presented in table 5.

The first site, hereafter referred to as the Kananga site, is located in south central Zaire. The Kananga region is at the boundary between the Guineo-Congolian regional center of endemism and the Guinea-Congolian/Zambezian regional transition zone (White, 1983). This region receives approximately 150cm of rainfall annually, but experiences a more pronounced dry season than in the equatorial rain forest to the north. The climatic and edaphic conditions produce a mosaic of peripheral rain forest, dry evergreen forest, and secondary wooded grassland (savanna). Extensive blocks of closed forest occur, mostly at higher elevations in the region. The area is characterized by an extremely intricate pattern of gallery forests in the small river valleys, surrounded by savanna. The most obvious pattern of change is found in the woodland/savanna. This area is altered by cultural practices which involve burning, and can range from virtually no woody cover shortly after a hot fire, to 30-40 percent woody canopy closure, in approximately a 5-year cycle (D. Harder, personal communications, 1991). Rural population density, in 1970,

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was 15-25 persons per square kilometer, which is above the average of 9 persons per square kilometer for the entire country of Zaire (Roth, 1979).

Table 5.5
Date, path/row, and area information of images used in the change detection case studies:

Region	Date	Path/Row	Area (km^2)
Kananga	July 6, 1981	190/64	10080
Kananga	June 5, 1989	177/64	10080
Nyunzu	June 29, 1973	186/64	13300
Nyunzu	July 29, 1984	173/64	13000
N. Ituri	January 13, 1976	187/58	3400
N. Ituri	January 16, 1986	174/58	3400
S. Ituri	January 13, 1976	187/58	3400
S. Ituri	January 16, 1986	174/58	3400
Kutu	July 6, 1973	193/62	3400
Kutu	June 2, 1986	180/62	3400

The second study site, hereafter referred to as the Nyunzu region, is in southeastern Zaire, including the village of Nyunzu just west of central Lake Tanganyika. This region also straddles the border between two vegetation regions - the Guinea-Congolia/Zambezian regional transition zone to the north, and the Zambezian regional center of endemism to the south (White, 1983). Rainfall averages 120cm per year. The vegetation of the area has a considerable amount of diversity and spatial heterogeneity of land cover types and is experiencing modification by fire and cultivation (White 1983). Land cover types in the Nyunzu region include closed evergreen forests, modified or degraded forests, and woodland/grassland. These latter areas have a wide variation in the extent of woody cover and their degree of integration with forested areas. Population density was 2-5 persons per square kilometer in 1970 (Roth, 1979).

The third site, hereafter referred to as the Ituri site, is located in the north eastern part of Zaire. The region is divided into a northern section consisting mostly of a mosaic of Guinian Congolian lowland rain forest and secondary grassland, and a southern region comprised of lowland rain forest - wetter types (White, 1983). The region receives approximately 190cm of rain per year (Buxtehude, 1981). This site is in the Haut-Zaire region which has a population density of 7 persons per square kilometer (Europa,, 1975). Visual inspection of the early and late date images in the northern region showed that the forest along roads was heavily disturbed and that the disturbance decreased as distance from the road increased. Much of the clearing in the southern part of the site is done to establish coffee plantations. These spatial patterns of disturbance is very different from the large, blocky clearing patterns associated with clearings in the Brazilian Amazon (Tucker et al., 1984).

The fourth site, hereafter referred to as the Kuto site is located in western Zaire just south of lake Mai Ndombe, approximately 200 km north east of Kinshasa. Due to excessive cloud cover, only the area south of the lake was analyzed. This area is in the is in the Guinia-Congolia rain forest - dryer types (White, 1983). This site is at the margin of the humid forest at the western edge of the Cuvette Central. Most of the forests south of the lake are found in gallery formations. The region receives approximately 170cm of rain per year (Buxtehude, 1981). This site is in the Bandundu province which has a population density of 9.6 persons per square kilometer (Europa, 1975). Visual inspection of the multi-date imagery for this region does not show any large areas of change.

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1.3.3.2 Methodology

In this section we: 1) describe digital 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. For explanation of the terminology associated with data processing and analysis, the reader may wish to consult standard remote sensing text books e.g. Lillesand and Kiefer, (1987), Cracknell and Hayes, (1991), Lintz and Simonett, (1976), and Richards, (1986).

The Kananga and Nyunzu images were processed at the Illinois Natural History Survey (INHS) and the Ituri and Kutu images were processed and analyzed at the NASA Goddard Space Flight Center (GSFC).

Each image pair was co-registered using ground control points that could be accurately located in both dates. Using the selected points, a linear transformation algorithm was applied to the data to geometrically fit the older date image to the newer date image. The image pairs were registered to sub-pixel accuracy.

The co-registered image pairs were then subset to their common area. The images processed at the INHS made use of the entire common area, whereas those processed at GSFC were subset to a standard size square (1024 lines by 1024 columns). The sizes of each data subset are listed in table 5. The INHS used a larger subset in order to capture data more representative of the region that would not have been possible with a smaller, square data set. The Ituri image was subset in order to independently classify the southern dense forest from the northern transition forest. The Kutu image was subset because clouds obscured the northern portion of the image. MSS channel four (0.5 - 0.6 um) was eliminated from all of the images because of the poor image data quality due to haze and very low dynamic range. Different classification techniques were explored by GSFC and INHS.

The multi-date images processed at the INHS were classified independently and the two classified images were then compared to compute a change matrix. Because of a lack of ground data, the images were clustered using an unsupervised classification. An algorithm using sequential clustering and minimum distance classification was then applied to each image. A large number of clusters were generated (between 66 and 125). Each of these clusters was then identified using the available descriptions of the area which, included comments from persons who were familiar with the areas, an operational navigational chart (ONC), a treatise on the vegetation of a small portion of the Kananga region (Focan and Mullenders, 1955), a map generated from a visual interpretation of Landsat MSS for the Kananga region (Lejeune and Dautrebande, 1981), a report on change in land cover in the Nyunzu region from visual MSS assessment and field work (Stancioff and Pessutti, 1981), and the regional vegetation map for Africa (White, 1983).

Based on these evaluations, the clusters were aggregated into a simple classification of land cover, which varied by study area. For the Kananga region, the image classes were closed forest, savanna/woodland complex, agricultural land, and water. The Nyunzu image classification consisted of closed forest, degraded or open forest, savanna with varying degrees of woodiness, and water. Clouds, haze or smoke, shadows, and bad data lines were not included in the classifications.

The images processed at the GSFC were classified by using an isodata algorithm (Tou and Gonzalez, 1974) on a six channel image containing bands 5-7 (0.6um-0.7um, 0.7um-0.8um, and 0.8um-1.1um respectively) from both the early and late date image (Nelson et al., 1987). Fifty clusters were generated for each six channel image. The clusters were grouped using information gained from people familiar with the areas of interest, along with the use of Landsat image photos of the area. The clusters were identified as either a no-change class e.g. primary forest, secondary forest, non-forest, or a change class e.g. forest to non-forest, and non-forest to forest, non-forest to secondary forest.

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1.3.3.3 Results

The results of the study will be discussed region by region. For the Kananga region the results will be compared to a study done by Lejeune and Dautrebande (1981) and a change detection study done as part of the FAO 1990 assessment.

1.3.3.3.1 The Kananga region

The Kananga area (figures 8a and b), was classified into the four land cover classes shown in figures 9 a and b, and table 6a. In the classification of the Kananga region, attempts were made to separate two classes of forest, one that was closed, and a second that appeared on the imagery to be spectrally distinct, possibly related to differences in tree density and/or species composition. However, there was too much spectral overlap between the classes to produce consistently separate classes. Various techniques were tried, such as stratification and reclassification, to separate these forest classes, but without success. The forest class that was finally mapped represents mostly closed forests, with only a slight variation in density or canopy closure. The savanna/woodland complex class was essentially used to classify the non-forest areas and appeared from the imagery to vary from nearly all grass to considerable amounts of shrubs and trees. The rural development class included the village of Kananga and a road running north from Kananga, with small areas of occupation along the road. The water class was limited to the Lulua river. Many other smaller rivers were in the study area, but the overhanging tree canopy limited their spectral separation.

The change detection results are illustrated in figure 10 and itemized in table 6b. The land cover that did not change from 1981-1989 represented 82% of the total area, or a change of 18% of the area. In examining the change that is indicated, it is interesting to note that forest to savanna was 8.2% of the change, while savanna to forest was 8.0% of the change. Visual assessment of these two images suggest that there is no significant change between the two dates and that the change figure of 18% is much too high. This difference between apparent change and classified change may largely be accounted for by spectral overlap between classes and mixed pixel mis-classification. The savanna/woodland complex class had spectral overlap with forest, because of the variation in the woody component, resulting in some mis-classification within the forest class. Also, this area has an extremely intricate drainage pattern, with gallery forests. Linear features, such as gallery forest, when imaged at the resolution of MSS (79 m), causes a 'mixed pixel' spectral responses, resulting in 'fuzzy boarders' between cover types.

Table 6a
Kananga region land cover classes derived from Landsat MSS change detection analysis:

	1981	1989
Forest	75.0%	74.7%
Savanna/Woodland	24.1%	23.8%
Developed	0.6%	1.0%
Water 0.3%	0.4%	

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Table 6b
Kananga region change detection results derived from Landsat MSS change detection analysis:

	1989	Forest	Savanna	Developed	Water
1981	Forest	66.5%	8.2%	0.1%	0.1%
	Savanna	8.0%	15.2%	0.7%	0.2%
	Developed	0.1%	0.3%	0.2%	0.0%
	Water	0.1%	0.1%	0.0%	0.1%

1.3.3.3.2 The Nyunzu region

The Nyunzu region (figure 11a and b), was classified into the four land cover classes shown in figures 12 a and b, and table 7a. There is a distinct difference between the closed forests, where little disturbance is evident, and the degraded forests, where trees are being removed for various purposes including cultivation. Also, included in the class with these degraded areas are forested areas that are naturally less dense than the closed forests, for edaphic or climatic reasons. Based on a visual assessment of the satellite photos, the accuracy of the closed forest classification appeared to be high. The degraded forests overlapped spectrally with dense woody savanna and could not be separated. As with the Kananga region, the savanna class represents a wide variation in density of woody vegetation. The accuracy with which water could be detected was limited because of confusion with dark shadows in the mountainous areas.

The change detection results are illustrated in figure 13 and itemized in table 7b. The land cover did not change from 1973-1984 for 73% of the Nyunzu region and 26.1% change is documented. Loss of tree cover is indicated for 14.8% of the area, including closed forest to degraded forest, closed forest-savanna, and degraded forest to savanna. Conversely, tree cover increase is indicated for 11.0% of the area, including degraded forest to closed forest, savanna to closed forest, and savanna to degraded forest. Interpretation of these results is difficult and there is clearly some spectral confusion among the classes, especially between dense savanna and closed forest. The mixed pixel phenomenon discussed earlier, as well as cyclic change in the tree cover in the savanna caused by burning compound these errors. However, both from the statistical and visual assessment of the data, the area is clearly experiencing change, especially in the opening up of previously closed forest areas. More forest cover loss than increase was indicated.

Table 7a
Nyunzu region land cover classes derived from Landsat MSS change detection analysis:

	1973	1984
Closed Forest	17.2%	16.9%
Degraded Forest	9.4%	4.2%
Savanna	73.3%	78.7%
Water	0.1%	0.2%

Table 7b
Nyunzu change detection results derived from Landsat MSS change detection analysis:

	1984	Closed Forest	Degraded Forest	Savanna	Water
1973	Closed Forest	8.5%	1.0%	7.6%	0.0%
	Degraded Forest	2.4%	0.6%	6.3%	0.0%
	Savanna	6.0%	2.6%	64.8%	0.1%
	Water	0.0%	0.0%	0.1%	0.0%

1.3.3.3.3 The Ituri region

The northern Ituri region (figures 14a and b) was classified into the four classes shown in figure 15 and table 8. The non-forest class consists of natural savanna and areas of rural development including roads and villages and land cleared for agriculture. Two forest classes were classified: primary and secondary/disturbed. The primary forest is closed canopy dense forest and the secondary/disturbed class represents secondary and degraded forests. The only change class which could be identified is a forest to non-forest class which represents 2.4% of the image. It is likely that the mixed pixel effect discussed earlier is contributing to this change figure. These effects are enhanced because the forest disturbance is occurring along a gradient of heavy disturbance along the road tapering off to little or no disturbance well in the interior of the forest. Forest loss or regrowth occurring along a gradient is much more difficult to quantify compared to clear-cutting and regrowth occurring in blocks

Table 8
Northern Ituri change detection results:

No-Change Classes		Change Classes	
Primary Forest	41.0%	Forest to non-forest	0.5%
Disturbed forest	15.9%		
Non-forest	42.6%		

The southern Ituri region (figures 16a and b) was classified into the seven classes shown in figure 17 and table 9. As in the northern region, the non-forest class is predominantly natural savanna and rural development. The primary forest class is comprised of moist, dense forest. The secondary forest class includes secondary forest, palm forest and a small amount of seasonally flooded grass/sedge marshes. The shadow/water class was created because terrain in the region caused significant shadows which were spectrally similar to the river. The change classes included forest to non-forest, and a forest to disturbed class. The difference between these two classes is that the forest to disturbed class includes areas where the forest was cleared and vegetation is growing or the forest was heavily disturbed. In the forest to non-forest class, the forest was cleared in its entirety. It appears that most of the regrowth class is occurring on abandoned plantations. It is hypothesized that this is due to a drop in coffee prices since the first image acquisition (1976) which has made growing coffee economically less feasible. As coffee plantations were abandoned, the forest was allowed to reestablish itself (personal communication, D. Wilkie, 1992).

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Table 9
Southern Ituri change detection results derived from Landsat MSS change detection analysis:

No-Change Classes		Change Classes	
Primary Forest	75.8%	Non-forest to disturbed forest	2.3%
Disturbed forest	13.2%	Primary forest to disturbed forest	1.0%
Non-forest	4.0%		
rivers/shadows	3.7%		

In this region, the largest uncertainty with the change statistics is related to the actual composition of the secondary forest class. It is probable that there is a great deal of variation within the secondary forest, especially in the regrowth class. To improve this differentiation, additional ground information would have to be utilized.

1.3.3.3.4 The Kutu region

The Kutu region (figures 18a and b) was classified into the seven classes shown in figure 19 and table 10. As in the Ituri region, the non-forest class is predominantly natural savanna and rural development e.g. roads and villages and land cleared for agriculture and the primary forest class is comprised of moist, dense forest. The secondary forest class includes secondary forest, most likely established after agriculture fields were abandoned. A class was also created to account for missing data from the earlier date image. The change classes were similar to the classes identified in the southern Ituri region.

The biggest problem encountered in this region stems from the poor data quality of the early date image. Often when incorporating an image of poor data quality in a change detection exercise, visual interpretation techniques are better than digital techniques. This is primarily because a human interpreter can make logical decisions based on a number of visual cues.

Table 10
Kutu change detection results derived from Landsat MSS change detection analysis:

No-Change Classes		Change Classes	
Primary Forest	33.7%	Primary forest to disturbed forest	3.2%
Disturbed forest	3.7%	Forest to non-forest	0.9%
Non-forest	56.1%	non-forest to disturbed forest	1.1%
Bad data	1.5%		

1.3.3.4 Comparison to other studies

In this section we compare the findings of our preliminary case studies to some previous studies from the region, The results from the Kananga study are compared to two studies for the same area which used visual techniques. The purpose of these comparisons is not to determine which study is more accurate but to illustrate that there can be significant differences in the results when different techniques are used. The first comparison is with a land cover classification made by Lejeune and Dautrebande (1981) using a photographic copy of the Landsat MSS image in figure 8a. The second comparison is with a change detection classification produced as part of the FAO Forest Assessment 1990. The FAO classification used the same images as those classified by INHS (figure 8a and b). Unfortunately, the FAO change map was not available so only a comparison of the statistics can be made. The land cover classes used in each study are listed in table 11.

Table 11
Land-cover classes used in the FAO, INHS and Belgian study for Kananga:

FAO Classes:	INHS Classes:	Lejeune and Dautrebande:
Other land cover	Forest	Moist forest
Water	Savanna/Woodland	Degraded moist forest and gallery forest
Man-made woody veg. cover	Developed	Mixed gallery forest and tree savanna
Shrubs	Water	Tree Savanna
Fragmented forest		Rural/developed
Open canopy forest		Rural/ less developed
Closed canopy forest		Water
Short fallow		
Long fallow		
Other non-interpreted		

Comparing the, visually interpreted, classified map of Lejeune and Dautrebande (figure 20),with the, digitally classified map from INHS, one can see that the maps are locally different but that there is general agreement. The most obvious difference is that the visually interpreted map generalizes classes, whereas the digitally classified map does a more detailed pixel by pixel classification. The INHS's forest class includes the two forest classes used by Lejeune and Dautrebande. There is confusion between the Lejeune and Dautrebande mixed savanna class and the INHS forest and savanna woodland class. The developed class is in general agreement although the Lejeune and Dautrebande class is more generalized.

In an area that is very heterogeneous, such as the Kananga region, visual interpretation of an image is difficult. In this case there is a trade-off between the greater number of classes obtainable from a visual interpretation and the spatial accuracy obtainable using digital techniques.

The FAO technique was briefly described in section 1.3.2.1. The change matrix is shown in table 12 (page 35). When comparing the change matrix from the INHS study (table 6b) with the FAO change matrix one can see that the change figures for each class are quite different, however, the net change figure is similar. Using a technique such as the one FAO uses, the change statistics are not susceptible to the 'salt and pepper' type of change that the INHS encountered. This is because the FAO is only interested in change when it is delineated from the most recent image. The technique where two images are classified independently of one another and then overlaid to compute change will often result in change classes with a 'salt and pepper' appearance largly due to pixel-to-pixel registration errors. The per-class change statistics generated in the INHS example are inflated but the errors tend cancel out when computing net change.

In a region such as this, with a gradient of disturbance, it is very difficult to develop accurate change statistics. It is expected that a visual change detection approach would produce less reliable results due to the generalization and subjectivity inherent in visual interpretation.

1.3.3.5 Summary findings from the change detection analysis

Many of the problems and limitations encountered in this study can be associated with the data and techniques used, although some are specific to the types of land use and natural phenomenon occurring within the central Africa region. The purpose of the study was to evaluate procedures for change detection rather than provide representative deforestation statistics. However it is worth noting that at the sample of locations

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examined, it would appear that rates of deforestation are low, in comparison for those reported from other parts of the tropics.

In general, the data quality of many of the images was marginal. Many factors, including low dynamic range, line drop-out, and striping contributed to the low 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 greatest in the savanna/woodland and secondary forest classes. The line drop-out and striping did not adversely affect the classification, however, it did lead to gaps in usable data coverage.

Using MSS data limits one to a ground resolution of 80m by 80m. Classification limitations related to MSS resolution are highest in areas where land cover classes are very heterogeneous or fragmented. This was illustrated in the gallery forest areas in the case studies presented above.

The images used in this study were registered to one another using a linear transformation. Although this procedure produces good results, problems can still arise due to slight image mis-registration (Townshend et al., in press). This image to image mis-registration can be minimized if the images are precision-corrected prior to performing the change detection (see section 1.4.1).

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

It has been shown that classification accuracy can be increased using a variety of ancillary data (Evans and Hill, 1990; Bocco and Valenzuela, 1991). If suitable ancillary data such as digital soil maps, vegetation maps, digital terrain models were available for this study, it is likely that the classification accuracy would have been improved. Most of the digital datasets that are available for this region are at too small a scale and too generalized, to be useful for MSS classification.

Clearly, the greatest limitation for this study was the lack of ground information. Neither of the analysts doing the classification were familiar with the areas being classified and they did not have access to higher resolution products such as aerial photos or video overflights. For some of the sites, the analysts were able to consult with persons familiar with the area and gained some insight into the land cover and cultural practices which affect land cover change.

It should be pointed out that these are preliminary findings and the studies are being further refined. However, the following preliminary observations can be made from the previous change detection study:

- digital analysis techniques can be used for monitoring land transformations when used in concert with supporting field information
- general knowledge of the area in question and the associated land use practices is essential when generating land transformation statistics from satellite data for areas of complex land cover
- the success of the monitoring is a function of the number of transformation classes that are to be classified. Changes between forest and non-forest classes will provide the highest accuracy. Attempts to define more detailed transformation classes will lead to decreased classification accuracy

- detection of land transformation is difficult in areas where land cover change is occurring in small patches or as gradient as is the case in many areas in central Africa
- the temporal dynamics of certain land use practices e.g. burning and regrowth, can confuse the classification of land transformation
- ground information is necessary to determine the accuracy of satellite derived land transformation statistics
- there is a trade-off between the greater number of land cover classes obtainable using visual interpretation techniques and the higher spatial accuracy obtainable using digital techniques

1.4 A satellite derived cartographic map base

The poor state of the current baseline cartography for the region (Appendix 2) is an obstacle to improved regional management. Extensive cartographic mapping programs were undertaken during colonial times, the maps produced are, to a large part, out of date. Although satellite mapping does not produce the detail available from large scale aerial surveys, in many cases it is adequate for national mapping, and the cost is much less. 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 to effective resource management within the region. In addition, information derived from geo-corrected satellite data can be easily entered into spatially referenced data bases such as a GIS.

1.4.1 Introduction to ortho-photo image mapping

Ortho-photo images are precision-processed, map images which conform to a cartographic map projection. When the precision processing is applied to satellite data, the end result is imagery free from distortions related to the sensor, satellite, and earth. The bulk of ortho-photo processing is done automatically using algorithms that model sensor geometry and radiometric properties, and the satellite orbital characteristics (Emery et al., 1989). Using ancillary information, such as a digital terrain model (DTM) and ground control points (GCPs), it is possible to greatly improve the map accuracy over using only the automated technique (Irish, 1990). There are varying degrees of accuracy that can be achieved, depending on the information available. The highest accuracy is possible if a number of ground control points and a DTM are available.

Using a DTM it is possible to correct for distortions induced by topography for all points throughout the image. Unfortunately, in central Africa detailed DTMs do not exist; therefore, a mean elevation value can be used to partially correct the terrain-induced image distortions. In most parts of central Africa, using a mean elevation value is not a problem because of the lack of significant topographic relief.

GCPs are used to refine the satellite orbital model. The accuracy of the image map is directly related to the accuracy of the GCPs. For example, the accuracy attained using GCPs from a map at a scale of 1:200,000 would be less than if the GCPs were from large scale aerial photos showing the location of surveyed points. In most areas of central Africa, photos showing the location of surveyed points are available through the organization that originally surveyed the area. For Zaire, much of the aerial photography that was acquired during the 1950's is stored at the Institut Geographique National (IGN) in Belgium (see Appendix 1). For the other central Africa countries, many of the photos acquired during the 1950's are stored at the Institute Geographic National (IGN) in France. Where photos are not available, another potential source is small scale maps (often less than 1:200,000). Where maps are not available or where higher accuracy is desired, it is possible to use a Global Positioning System (GPS) to acquire highly accurate coordinates

of features which can be used as GCPs (see section 1.5). As part of the design phase we have provided an example of a satellite ortho-photo map of the region.

1.4.2 Trinational image map description

A geo-corrected Landsat Thematic Mapper (TM) image map has been produced to illustrate the type of cartographic product that can be made using state-of-the-art, precision processing techniques. The acquisition date for both images is November 26, 1990. The creation of this image map was closely monitored by personnel from the USGS (Reston, VA and the EROS Data Center, Sioux Falls, SD) and their suggestions were incorporated in the final map. The image was precision-processed by Hughes STX Satellite Mapping Technologies, Lanham, MD.

The area selected for this example is located around the borders of Cameroon, Congo and the Central African Republic (center: lat. 2.5 deg. N, long. 17 deg. E). Several national and international organizations are developing a program to provide an improved management plan for the area, which will be facilitated by an improved cartographic base (WWF, WCI, 1991). This region of relatively undisturbed, dense lowland forest is believed to contain the highest concentration of forest elephants on the African continent. The human population density is very low in this area, however, there is a significant pigmy population. In addition, the forest is recognized for its extremely important ecological and cultural value and significant economic potential. This image map will provide people working in this area an overview of the distribution of settlements and land use in the area. The resulting map was derived from digital data and can be used as a baseline map in a GIS for the area.

The output map is geometrically corrected to the Universal Transverse Mercator (UTM) projection at a scale of 1:125,000. The processing corrected for systematic distortions in the data related to sensor, satellite and earth movement. In addition to the systematic 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, France. An 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.

Some of the features that can be seen on this image include topography, roads, logging roads, villages, and a number of different land cover types. Different forest types can be differentiated including semi-deciduous, mixed forest (semi-decidiuos/evergreen), and mono-specific Macrolobium. Other land cover types that can be distinguished are savanna (including *Hymenocardia acida, Annona senegalensis, Bridellia*), plantations, subsistence agriculture, high salinity areas, and urban areas.

This example demonstrates that satellite data can be used to provide an up-to-date map base for the region. It is recommended that national mapping agencies be upgraded to a level where satellite ortho-photo maps can be generated in-country and the results can be integrated into national mapping programs. Copies of the sample map produced in this study are planned to be made available through WWF.

1.5 Satellite global positioning systems (GPS) and Landsat satellite imagery assisted field surveys

Information concerning ground conditions should be an integral part of any remote sensing mapping program. This is particularly the case when trying to produce or verify land cover classifications in landscapes unfamiliar to the interpreter. Obtaining ground information for these purposes in remote areas such as the primary forests of Zaire is problematic for two reasons. Firstly, the difficult logistical problem of accessing remote areas and secondly, the difficulty in obtaining accurate geographic location information

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associated with ground data. In many areas the existing topographic maps are inadequate for precise location.

The first objective of this case study was to assess the utility and practicality of using satellite GPS in conjunction with LANDSAT satellite imagery as tools to assist in forest assessments within central Africa. The approach taken was to use an existing network of Private Volunteer Organizations (PVO's) with on-going field projects in the region to provide a preliminary assessment of the utility of the instrumentation. 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.

A GPS is being developed by US Department of Defense to replace the 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 navigation and geographic location 24 hours a day anywhere on the globe. Each satellite transmits a coarse/acquisition navigation signal that provides users with location accuracy ranging from 15 m using one GPS receiver to a centimeter or less when 2 GPS receivers are "connected "in differential mode.

As recent large scale maps are not available for much of central Africa, GPS are a valuable source of locational information. These data are needed to a) transform the satellite imagery to a standard map projection (see section 1.4), and b) relate landscape features that characterize the region with their representative spectral features on the imagery.

The major constraint to the use of satellite imagery as a forest mapping tool is the quality of ground data collection (Wilkie, 1990). While ground studies are essential to associate accurately landscape features on the ground with spectral features in the imagery, they are generally costly to implement, and require field-workers with knowledge of the region. As extensive areas within central Africa will need to be inventoried if our estimates of the role of the region in global climate change are to be improved, both the costs of obtaining the necessary ground-truth data and our ability to find experienced field-workers could become a major constraint. To minimize the costs of conducting ground studies, it was proposed to examine whether field "experts" working on NGO or individual projects within the region could be encouraged to participate in ground-truth data collection studies. The case study described below outlines the strategy adopted for assessing the utility of satellite imagery as a forest survey reconnaissance tool, discusses the minimum requirements for the practical application of this technology, as well as some of it's limitations, and assesses the practicality of linking climate change related research activities with those of PVO's active in the region.

1.5.1 Kivu feasibility study

It was decided to provide to World Conservation International (WCI) with satellite imagery to guide field surveys for lowland Gorilla, in exchange for information that would help us to distinguish ambiguous spectral features on the Landsat images. Locations were selected to be representative of the main vegetation types of the region. From the digital tapes, false-color composite images were produced and printed at a scale of approximately c. 1:200,000. A set of spectral features within the imagery that were of particular interest for remote sensing feature verification were identified. A standardized method for gathering and recording landscape information using a GPS was devised with the assistance of Dr. Peter Alpert of USAID. In areas where high-quality, large-scale topographic maps are available, and where suitable features exist for accurate positioning by triangulation, groups of Landsat pixels can easily be visited and identified, or the geographic locations of landforms characteristic of a given area can be determined and subsequently related to pixels within an image. However, in many tropical forested regions of the world topographic maps greater than 1:1,000,000 in scale often do not exist, and suitable features for ground based navigation/positioning by triangulation are absent.

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Accurately locating and surveying unique land-cover types within inaccessible, and poorly mapped areas is thus extremely difficult. To overcome some of these difficulties in relating a specific field location to its representative site within the LANDSAT satellite imagery, a field person was provided with a battery powered, portable GPS receiver.

Landsat image prints were found for the large part, to be very useful in guiding selection of sites for gorilla surveys. However, rapid demographic and land-use changes within certain areas of Kivu highlighted the importance of providing field researchers with contemporary imagery. Even imagery from 1988 was, in some cases, not representative of the present, rapidly changing landscape of Kivu. As a result at least one field survey that was targeted within what appeared on the imagery to be undisturbed forest was, in actuality, located in an area heavily modified by subsistence and market agriculturists. Similarly, new roads through the forest were obviously not visible on imagery that predated their construction. Several landscape feature have been verified and geo-referenced with the GPS.

1.5.2 Case study conclusions

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, satellite obscuring topography and vegetation, and too little time for pre-field work training of the PVO research conspired to limit the effectiveness of this exercise. Never-the-less the principle of utilizing the skills and local knowledge of PVO field researchers is still sound, and the case study certainly provided much useful information concerning how best to implement future activities of this kind. The strategy for co-opting 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 study, and provides a very useful model for implementing future activities.

2 Improved Data Base Management for the Region

This section is concerned primarily with a form of spatially referenced data bases called geographic information systems (GIS's). The section begins with a brief introduction to GIS. An overview of the current state of the art of GIS and trends in hardware is then presented. This is followed by a summary of the state of geographic information in central Africa. The section concludes with six case studies that illustrate how GIS can be used to support climate change studies in central Africa.

2.1 General GIS principles and concepts

A geographic information system (GIS) is a specialized type of digital information system in which data are spatially referenced. Typically, a GIS will be referenced to a geographic reference system such as latitude and longitude or UTM. Using a system of hardware, software and procedures, a GIS allows one to acquire, store, analyze, and display geographically referenced data (Burrough, 1986).

Data acquisition - Data can be acquired in a number of different ways (Weir, 1991). Point, line and polygon information can be entered by hand digitizing or scanning existing maps or directly input from other digital media (e.g., satellite data). Some digital data bases can be acquired in a usable format from commercial vendors or as output from other GIS's. Point data and attribute information can also be input in a text format.

Data storage - Data can be stored on a variety of media such as hard disk, compact disk, magnetic tape which allow easy retrieval (U.S.G.S., 1988).

Data analysis - Because the data are geo-referenced, it is possible to perform various spatial analyses with relative ease. Types of analyses include map overlay, proximity analysis, statistical summary, and attribute crosstabulation to name a few (Tomlin, 1990). Also, having the data attributes organized in a relational database allows one to use a single attribute or a combination of attributes for analysis.

Data display - Perhaps the most important component of a GIS is its ability to present geographic data in a form that is easily interpreted by the general public. Presenting the results of spatial data analysis in graphic form such as a map is often the easiest way in which it can be understood. GIS data display is a powerful tool which can be used to illustrate a number of spatially represented attributes to people who would otherwise be unable to visualize them (U.S.G.S., 1988).

There are many different types of GIS's in use. GIS's are often grouped into two categories, vector and raster (Hedberg, 1991). A vector GIS uses a coordinate-based structure to represent point, line or polygon information. In a vector system, data is stored as a list of ordered x,y coordinates. A raster GIS, on the other hand, is a cellular-based structure which stores data in grid cells which are referenced by row and column coordinates. Both types have advantages for particular applications. For instance, a vector GIS is typically better suited for cartographic uses and network analysis (Lupien et al., 1987). Raster systems, because of their data structure, are better suited for overlay analysis, remotely sensed data analysis, and various types of modeling. No matter what the application, one must always keep in mind that a GIS is only a tool to aid in the management and analysis of spatial data. A common misconception about GIS is that it is a solution to a particular problem.

2.1.1 Current state of GIS

Currently, 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 a GIS are available to many organizations. It has been reported that the number of GIS installations is doubling every two to three years (Frank et al., 1991). Some examples of the use of advanced GIS techniques in the US include: tax assessment, water utility management, document management, land information/tenure, natural resource monitoring, and species distribution modeling.

2.1.2. Recent trends in GIS development

Although major advances are being made in both hardware and software, improvements in software lag behind advances in hardware. Advances in technology are happening so fast that it is difficult to predict beyond the near term (Faust et al., 1991). In general though, the cost of computing systems, relative to overall measures of performance, will decrease. Significant changes are also being made in the area of user/computer interface (Frank et al., 1991). The ability for users to develop computer programs to perform data analysis is becoming much easier through the development of interfaces such as object oriented programming. Object oriented programming uses icons (similar to the Macintosh system) to query the operating system and build programs (Mueller, 1991). Display technology will also continue to improve by developing higher dimensional display surfaces represented in a smaller area (Faust et al., 1991). Perhaps the most important advances are being made in the area of data entry. Currently, data entry is

the bottleneck for most GIS operations. Improvements in data entry, such as automation of map digitizing with the use of scanners (Ansoult et al., 1990), will facilitate entry of spatial and attribute information into a database thereby decreasing the manual effort required for data entry. The cost of scanners is dropping which is making it an appropriate addition to many GIS's (Carstensen, 1991). Studies are also being conducted to develop techniques to automate the process of database creation (Ahac et al., 1992). Compatibility between GIS systems is still a problem, however, in general, it is getting easier to transport data between systems.

2.2 State of geographic information in central Africa

Countries within central Africa have not made much progress in the development of regional or national geographic information systems, although, there are a limited number of local GIS's being established. However, a number of African countries outside the region are using GIS's effectively (Nkambwe, 1991, Bwanaali, 1991, Falloux, 1989)

The following section is intended to provide an overview of the state of geographic information in central Africa, it is not intended as a comprehensive survey. When planning a GIS project, it is critical that a thorough survey of existing geographic information, expertise, and institutional support be completed to learn from previous experience and avoid duplication of effort.

2.2.1 Current status

Throughout central Africa, thematic mapping is very heterogeneous and in most cases outdated. Maps that do exist 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 between various institutions. The standard topographic and thematic maps that do exist for most of the region can be difficult to access. Many of the available maps originally produced during colonial times can be purchased in France or Belgium although some must be purchased directly from the appropriate national mapping agency. A good overview of the mapping status for each of the central African countries can be found in "World Mapping Today" (Parry and Perkins, 1987).

Most of the digital maps for this region as a whole exist as a subset of a continental or global dataset. The UNEP Global Resource Information Database (GRID) and the National Oceanographic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) have compiled information which covers the central Africa region as a subset of large African datasets. The World Conservation Monitoring Center (WCMC) has produced a protected area map for the region which is also a subset of a continental mapping effort. 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, 1991).

On a national and local level, there are limited digitized map data available. These data are being produced by various projects within the region (section 2.3.6). An overview of the availability of digital satellite data is given in Appendix 2.

2.2.2 Planned projects

A Digital Chart of the World (DCW) is being compiled using the U.S. Defence Mapping Agency (DMA) Operational Navigation Charts (ONC) and is being distributed commercially by the USGS(Danko, 1992). The DCW contains 17 layers of information including; political boundaries, drainage, topography, and transportation structure. The DCW will provide a consistent map base for a regional GIS in areas, such as central Africa, where a consistent base does not exist.

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2.3 Case studies of information systems

To illustrate the variety of potential uses of GIS to support climate change projects in central Africa, a number of case studies are identified. With each case study, the benefits, drawbacks, and lessons learned for each example will be discussed in the context of a central Africa climate change program. The GIS case study applications are: program impact evaluation, land use modeling, land use planning, biodiversity inventory/monitoring, climate change modeling, and spatial database support

2.3.1 USAID program performance monitoring and evaluation; The Bandundu, Zaire example

Program performance monitoring and evaluation compares the efficiency of alternative development assistance portfolios by measuring and comparing the success of development assistance in achieving "people-level" impacts. The United States Agency for International Development (USAID) in Kinshasa, Zaire started using geographic information technology for program evaluation in 1990. The USAID Mission began by designing their GIS database to measure the contribution of development assistance to increasing nutritional status, one of the four goals identified by the AID Mission as part of its strategic plan (Green-Larson, 1991; Rogers, 1991; Barnes et al., 1992).

The GIS contained data for the Kwilu sub-region of the Bandundu Region in western Zaire where USAID had implemented various health, infrastructure, and agriculture projects. Initially, the researchers focused on assembling the information required for measuring the impact of assistance on nutritional status. They used the percentage of children under standard weight-for-age as an indicator of nutritional status. In order to graphically represent the weight-for-age statistics, they digitized the location of health clinics, and linked the weight-for-age information to these points.

The researchers organized other information crucial to the analysis of health clinic data. They coded each clinic as to whether or not their was an agricultural intervention within the health clinic service area and classified the clinic according to whether or not the clinic beneficiaries had access to forest resources. Information derived from Landsat imagery, population statistics, and agricultural survey data were also important elements in the database.

Creating a map showing the spatial distribution of the percentage of under-weight children across the sub-region was the first step in the evaluation analysis. The researchers overlaid this map with maps of roads, population density, and the location of agricultural interventions. The composite maps revealed that extremely high malnutrition rates tend to correlate with areas where the population has limited access to forest resources and where there are high population densities. They also revealed that, in some cases, where USAID had sponsored agriculture and infrastructure projects, the percentage of under-weight children was less than in neighboring areas suggesting the possibility of a positive impact from development assistance.

The project demonstrates the value of using a GIS for evaluating the impact of project assistance. The project helped to emphasize the value of spatially linking different types of information for a better understanding of the environmental conditions under which program assistance is implemented. This project also provides a baseline for additional research on understanding program impacts on nutritional status over time, analyzing success of the USAID program in achieving other program goals, and better understanding the assistance environment by incorporating other land resources information into the analysis. A similar approach could also be used to evaluate the effect climate change or mitigation policies are having on a region.

2.3.2 Land use modeling: central Africa (Boston University)

The objective of the project is to develop an ecological model to explain the land use practices of ethnic groups in active deforestation zones in central Africa. The study is currently in the planning stages.

At the regional scale, zones of active deforestation are being analyzed using satellite data to select sites to be studied on a local scale. Models in human ecology will be used to simulate the balance established between an agrarian community and its environment. This modeling scheme will only take into account the spatial patterns of deforestation related to the activity of traditional farming systems. Other factors such as logging activity or industrial agriculture will not be studied, in part, because these activities depend heavily on the international economy and national corporate policies.

The relationship between remotely sensed spatial patterns of land use and farming systems will be used to classify different areas undergoing deforestation in terms of land cover change processes. These processes are related to ecological, demographic and socio-economic variables that determine present and future rates of deforestation.

For a climate change action plan, this information could be used to better understand the causes of deforestation and to better predict future changes. Such an approach would also be helpful to plan for mitigation measures and to gain insight into the effect that different mitigation actions would have on an area.

2.3.3 Land use planning - Collaborative Study of Cassava in Africa (COSCA) (COSCA Resource and Crop Management Program, Nigeria)

For land use planning, it is important that one understands the various land use options from the socio-economic and the biophysical perspective. For example, how will it benefit the land owner and is it appropriate for a given location.

COSCA illustrates how a regional information system can be established to understand marketing systems, farming systems, and demand for a particular agricultural crop, in this case cassava. The central African countries involved in this study include; Cameroon, Congo, and Zaire.

COSCA is an inter-institutional effort aimed at providing baseline information on cassava over a wide area in Africa. The objective is to improve the relevance and impact of agricultural research on cassava by research centers in order to take full advantage of the potential of cassava in increasing food production and incomes in Africa. Information is being collected at the local level which will be used to characterize production, processing, marketing and consumption units (Nweke, 1988).

Initially, a GIS was used to locate the survey sites for the study using spatial information on such factors as distribution of cassava, climate, population density, and infrastructure. After the sites were selected, information from village surveys was input into the GIS. This included information such as; fertilization practices, farm ownership by gender, and cropping history of land. By having this information in a GIS, it is possible to view the spatial distributions and inter-relationships of various practices. For instance, it would be possible to produce a map showing the distribution of particular fertilization practices throughout a region of interest.

This type of approach can be used initially to collect and manage baseline data for a particular land use practice and then later to monitor the effect of altering these practices. In its monitoring role, a system similar to COSCA could be used to predict famine and long term monitoring may provide data which could be linked to climate change.

2.3.4 Biodiversity inventory/monitoring - Madagascar (World Wildlife Fund)

Although the GIS which is being discussed here is only in the planning stage it serves as a good example of the potential of GIS to inventory and monitor biodiversity. A GIS is being established to inventory and monitor biodiversity in Madagascar. The primary objective of this project is to establish the in-country ability for biodiversity and socioeconomic data base management and application, in support of the Malagasy government's National Environmental Action Plan (NEAP). The NEAP provides a strategy of environmental protection combined with natural resource conservation to provide sustainable economic and social development (Smith et al., 1990). This Biodiversity Planning Service (BPS) project involves conducting flora and fauna field surveys and coordinating these efforts with the GIS activities. The goals of the BPS are to:

1) establish readily accessible, permanent and continuously up-dated national biodiversity and related socio-economic data bases, which will be used for national conservation planning and management,
2) promote appreciation and use of good data management and GIS capacity as accessible and applied management tools for EAP coordinators, conservation planning units, conservation project managers, and research organizations,
3) provide training and support, promotion of data exchange, and assurance of nationwide system compatibility, and
4) test the effectiveness of different approaches within Integrated Conservation and Development (ICD) projects, and to provide analytical support for evaluating and fine tuning these approaches.

As pressure on the central Africa forests increases, an effort should be made to ensure that loss of biodiversity is kept to a minimum. This BPS project is a good example of how a GIS could be used to better address biodiversity questions related to a global climate change program.

2.3.5 Deforestation/Carbon modeling- Amazon Basin (The Complex Systems Research Center at the University of New Hampshire)

The general objective of this research project is to determine the net annual flux of carbon between terrestrial ecosystems and atmosphere (Skole and Chomintowski, in press). The approach couples remote sensing, GIS, in-situ measurements, and modeling. To date, this work has been focused on the Amazon Basin. The objectives will be reached through:

1) The quantification and mapping of the annual rate of deforestation in the tropics primarily through satellite remote sensing.
2) Determination of the fate of deforested lands. This will be accomplished through the acquisition of multi-date high resolution remote sensing data.
3) The development of geographically-referenced estimates of biomass and soil organic matter, as well as a detailed description of the changes in these carbon pools when affected by disturbance. This will take advantage of a GIS to link these estimates to the mapping of deforestation and the fate of deforested lands.
4) An estimation of the net flux of carbon associated with change of carbon stocks within intact forests from degradation, selective logging and regrowth.
5) A calculation and analysis of the net annual exchange of carbon between tropical ecosystems and the atmosphere from deforestation, reforestation, and degradation using a large-scale, geographically-referenced carbon model. The model which will be used has been in development for several years and has been the basis for most of the estimate of biogenic carbon flux described in the literature. It will be improved to

directly utilize remote sensing data and provide geographically-referenced results at spatial resolutions of 20-50 km.

This approach to climate change modeling focuses on improving predictive model results through better quantification of deforestation and its dynamics, and on improving the understanding of spatial and temporal ecosystems response to disturbances. It is appropriate for studying the effect of ecosystem changes on climate change and the effect of climate on the ecosystem.

2.3.6 Spatial database - Africa (UNEP/GRID)

The Global Resource Information Database (GRID) was established, in 1985, by the United Nations Environment Programme (UNEP). GRID's mission is to help bridge the gap between the scientific understanding of earth processes and sound management of the environment at national, regional, and global levels. It aims to do this by providing up-to-date and reliable geo-referenced information, coupled with access to various geographic information systems (Jaakola, 1990).
The objectives of GRID are:

1) to assemble, process and supply geo-referenced environmental information to its users,
2) to provide GIS expertise in support of environmental studies and applications, and
3) to help institutions and nations unfamiliar with GIS technology to acquire the know-how and hardware they need to put it to good use.

GRID has compiled a collection of global digital map information. These data are available to a broad range of governmental and non-governmental users at minimal costs. The GRID center in Nairobi is one of a network of nodes and has been operating since 1985. It has acquired continental datasets and national datasets for a few selected countries. Data for all of the countries in central Africa have been entered into the GRID system as continental datasets (table 13, page 36). Although most of these data exist at a scale of 1:500,000 or smaller they were used successfully for a study on elephant populations in central Africa (Michelmore et al., 1989).

2.4 GIS conclusions and recommendations

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, one must also consider the 'secondary' effects such as data sharing and data gathering. These 'secondary' effects can form linkages between groups who otherwise would not be collaborating.

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 related projects.

Before GIS projects are started in the region, it is important to conduct a more in-depth survey of existing information systems 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

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

3 Summary and Recommendations

3.1 General conclusions

The previous review and analyses lead us to some general conclusions. These conclusions are based on an assessment of the current status of environmental data within the region, however, it should be noted that some of the same recommendations would also apply to many developed countries.

The comment that is often made about environmental data from central Africa is that the data are of poor quality, out-of-date or unavailable. Our survey leads us to conclude that in general this is correct. However there are data which have been collected for various purposes at the local scale which are very good. Although, by no means optimal, satellite remote sensing has provided a significant amount of data from the region which is applicable to climate change studies (Appendix 2). Appendix 1 leads us to conclude that there is also a wealth of historical data of various types suitable for addressing various aspects of climate change research, which are poorly developed, underused and difficult to access. This is true both for data of located within the region and in the developed World.

Management of data within the region is generally poor. Assistance is needed to develop effective environmental data management strategies for countries of the region. Useful data sets generated by development projects are often unsupported once a specific project ends. Similarly data sets produced by international agencies are often the property of the country for which the study was performed and can be effectively unavailable to individuals not associated with the project. Some critical data sets which are continuously supported within the region, such as meteorological data could benefit from being converted to a digital, permanent, media. The recent policy of charging for meteorological records in Zaire is seen as counterproductive to developing climate change studies within the region.

The unique aspect of climate change research is that it embraces regional data issues and has regional data needs. These needs are not currently addressed by national development programs. Currently, there also appears to be no regional organization capable of coordinating between national data collection programs or developing a regional data collection strategy.

The national estimates of emissions are very poor and as a result countries of the region are currently poorly equipped to participate in the international arena which develops international policy on climate change For example, the region is currently not an active participant within the Intergovernmental Panel on Climate Change.

There are very few operational environmental monitoring programs within the region. Satellite remote sensing provides a number of pertinent data sets for this purpose. However, its potential utility to provide up-to-date environmental data for the region is not being realized.

The data needed for modeling studies is sparse. Lack of data is currently the biggest obstacle to developing and testing models to analyze and predict the contribution to and effects of climate change.

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3.2 Underlying issues associated with data for climate change studies

Climate change is currently not viewed as an important priority by the government agencies within the region. This is seen as a major obstacle to the development of national programs of data collection associated with climate change research. It is worth noting that this is also true for countries of the developed world. The current understanding as to the possible implications of climate change on the region and the data needs to improve this understanding needs to be made available to the 'decision makers' in the various government and international agencies.

Climate change data are often not specific to this topic but are often the same data that are needed for objective natural resource management.

Long term underpinning of the national institutions to be involved in climate change research is essential. Problems of staffing, salaries, and transport can undermine even the most well funded research program if they are not properly addressed.

The international implications and responsibilities of climate change and the limited scientific expertise in the study of climate change indicates that programs should be both national and international. Coordination between international donors concerned with resource and socio-economic data collection and management is essential. Similarly, there is a need to facilitate coordination between national agencies within and between countries to optimize the use of resources for data collection and analysis.

The temporal scale of climate change necessitates a long-term commitment by funding agencies to develop effective monitoring programs. Currently funding agencies are unable to make the long-term commitment to such programs. A new mechanism needs to be established for securing the commitment needed to address the questions in hand.

3.3 General recommendations from the above studies

1. There is a need to develop a series of in-country research programs associated with climate change. These could address some of the more critical aspects of the subject and be used to build a body of expertise within the region. It is recommended that such research projects be twinned with research institutes may be to give a long term commitment that is needed. The current policy of some international aid agencies of contracting institutional support to the private sector within the developed world is inappropriate in this case. A long term commitment might be easier to establish through universities or non-government organizations. Stronger links are also needed between national researchers and the international global change research community e.g. IGBP, WCRP.

2. New primary data acquisition strategies are needed in all of the sectors outlined in the volume "Central Africa: Biogeophysical Setting and Global Climate Change". Where possible these new data sets should be prioritized to help meet the objectives of specific climate change project needs. So as to benefit the national agencies in the largest way, these data should also be pertinent to other pressing issues of natural resource management

3. There is a need to establish regional or national archives to focus initially on meta-data and subsequently to develop a long-term regional strategy for data archiving (a GIS approach should be adopted)

4. Since independence, focus on science has taken a low priority with respect to environmental issues as compared to developing other sectors. There is a need to fully evaluate the historical data collected during colonial period. These data are often not available in country. It appears to be worth screening the existing data and developing data bases of these unique historical information.

5. A series of demonstration pilot projects applying GIS techniques need to be developed over the range of scales.

6. Long term monitoring sites need to be established over a range of natural and altered vegetation types to provide the data needed to monitor and model the effects of climate change on the region.
7. Remote sensing offers a unique potential for developing up-to-date regional data bases on land cover and land cover change.

3.4 Specific recommendations from the above studies

Recommendations are provided in the relevant sections of the above text and the appendices. We have identified the key recommendations from each of the above sections for emphasis here:

Satellite derived climate data - It is recommended that meta-data on the currently available satellite climate data sets be provided to national agencies within the region and the international donor community concerned with climate change. The IGBP-DIS and WCRP could 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 regional environmental monitoring by countries in the region. Currently these are the largest obstacles to effective use of the data in the region. Meta-data on the current and historical availability of high resolution data for the region should be made more easily accessible and available to the region. 'One-stop shopping' facilities providing information on data coverage and access 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, adequate staffing and a close contact with the international remote sensing community. This should be done with careful considerations of the successes and failures of regional remote sensing centers outside of the region. Similarly, potential problems of interagency rivalry between the remote sensing centers and the inventory and monitoring agencies need to addressed directly. There are several proposals currently being made by different donors to establish such centers, it is critical that the 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 operational use by the relevant national agencies. This may best be performed through a series of demonstration studies in collaboration with the 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 in the use of satellite data between the different agencies in the region would be most valuable. The AVHRR regional forest mapping study outlined in the case study above should be completed and then made available for evaluation and refinement by the national forest agencies. Further evaluation of change detection procedures over a wider range of conditions needs to be performed. The need for ground data necessitates a supporting field program. The use of PVO's in this process has shown considerable potential. A closer link should be encouraged between the national forest agencies of the different countries within the region and the international programs which are attempting to determine deforestation statistics.

Biomass Burning- It is recommended that a project be developed to provide improved emission estimates from the region. The AVHRR should be further evaluated as a means to derive improved estimates of the extent of biomass burning within the region. Specifically, emission factors should be developed which are representative of vegetation types and conditions that can be delineated 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 the results can be integrated into national mapping programs. Programs for satellite cartography should be supported within the region.

Geographic Information Systems- As a follow-up to the above 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 related projects. Specifically a regional GIS system which would include up-to-date information on climate change related spatial-data availability, such as maps and satellite data coverage would greatly improve the current management of data in this area.

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Table 12

FAO change matrix for Kananga region

LOCATION: Kasai Occidentale, ZAIRE, CENTRAL AFRICA SUB-REGION

State Assessment file: 1505F089 RECENT IMAGE : Path: 177 Row: 64 Date: 05/06/89
Matrix file : 1505CMMX HISTORICAL IMAGE : Path: 190 Row: 64 Date: 06/07/81
Results file : 1505RSLT

Years between images : 8

STATE ASSESSMENT based on RECENT image interpretation

MAIN CLASSES Codes		'000 Ha	%	ADDITIONAL CLASSES Codes		'000 Ha	%
0	Other land cover	360.8	10.9	77	Snowcaps, rocky areas		
1	Water						
2	Man-made woody veg. cover			22	Forest plantation		
				23	Agricultural plantation		
3	Shrubs			33	Sparse (c.c. 10-40%)		
				34	Dense (c.c.>40%)		
4	Fragmented forest	1255.2	37.8	44	Forest fraction 10-40%	698	21.0
				45	Forest fraction 40-70%	557.2	16.8
5	Open canopy forest	337.2	10.2				
6	Closed canopy forest	1298.8	39.2	66	C.c. 40-70%		
				67	C.c. >70%		
7	Short fallow	64.4	1.9				
8	Long fallow						
9	Other non interpreted (1)			97	Clouds and cloud shadows		
				98	Mountain shadow		
				99	Outside study area	683.6	
	TOTAL '000 Ha	3316.4	(1)		(1) = excluded 99 (Outside study area)		

CHANGE ASSESSMENT based on inter-dependent interpretation of the area common to the RECENT and OLD images

CHANGE MATRIX ('000 hectares)

OLD image	Classes of RECENT image 0	1	2	3	4	5	6	7	8	9	total Cloud free	OLD TOT
0	352.4										352.4	352.4
1												
2												
3												
4					1244						1244	1244
5	0.4				0.4	290.8	0.8				292.4	292.4
6	0.4				2	23.2	1239.6	8			1273.2	1273.2
7								52			52	52
8												
9										786		786
Cloudfree	353.2				1246.4	314.0	1240.4	60.0			3214.0	
Total RECENT	353.2				1246.4	314.0	1240.4	60.0		786.0		4000.0
Total Change	0.8				2.4	21.6	-32.8	8.0				
Annual simple rate '000 ha	0.1				0.3	2.7	-4.1	1.0				
Annual simple rate %	0.03	ERR	ERR	ERR	0.02	0.92	-0.32	1.92	ERR			

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Table 13

GRID Nairobi data holdings for Africa as of April 1991

AFRICA-CONTINENTAL

AGROECOLOGY
AQUIFERS
BOUNDARIES COASTLINE COUNTRY
BOUNDARIES COASTLINE LAKES
BOUNDARIES COASTLINE NATIONAL
BOUNDARIES DISTRICT PROVINCE
BUFFALO
BUFFALO CATTLE
CATTLE
CLIMATE TICKS SUITABILITY

COASTLINE
CROPS BOUNDARIES
DESERTIFICATION
DISTORTION SCALE DEPARTURE
EAST COAST FEVER
ECOCLIMATE TICKS SUITABILITY

ELEPHANTS
EVAPORATION ANNUAL CLIMATE
EVAPORATION ANNUAL?
EVAPORATION MONTHLY CLIMATE
GEOLOGY KLIMBERLITES

GEOLOGY TECTONICS ESCARPMENTS
INTEGRATED TERRAIN SOILS
LANDUSE
ISLANDS
LAKES
LANDUSE
MILITARY RELIABILITY
BOUNDARIES
PEDOLOGY SOILS
POPULATION

TICKS CATTLE BUFFALO
TICKS ECF
TOPOGRAPHY
TSETSE FLY
VEGETATION
VEGETATION NDVI ANNUAL
VEGETATION NDVI MONTHLY
WATER BALANCE
WATERSHEDS
WATERSHEDS TOPOGRAPHY
WILDERNESS
WINDSPEED MEAN ANNUAL
POPULATION BOUNDARIES
PROTECTED AREAS
RAINFALL
RAINFALL ANNUAL CLIMATE
RAINFALL MONTHLY MEAN
RAINFALL WETDAYS
RIVERS
RIVERS MAJOR
ROADS RAILROADS
SETTLEMENTS AIRPORTS
SLOPE
SOILS
SOILS IRRIGATION
SOILS TEXTURE SLOPE
TEMPERATURE
TEMPERATURE MAXIMUM MTHLY
TEMPERATURE MTHLY MINIMUM

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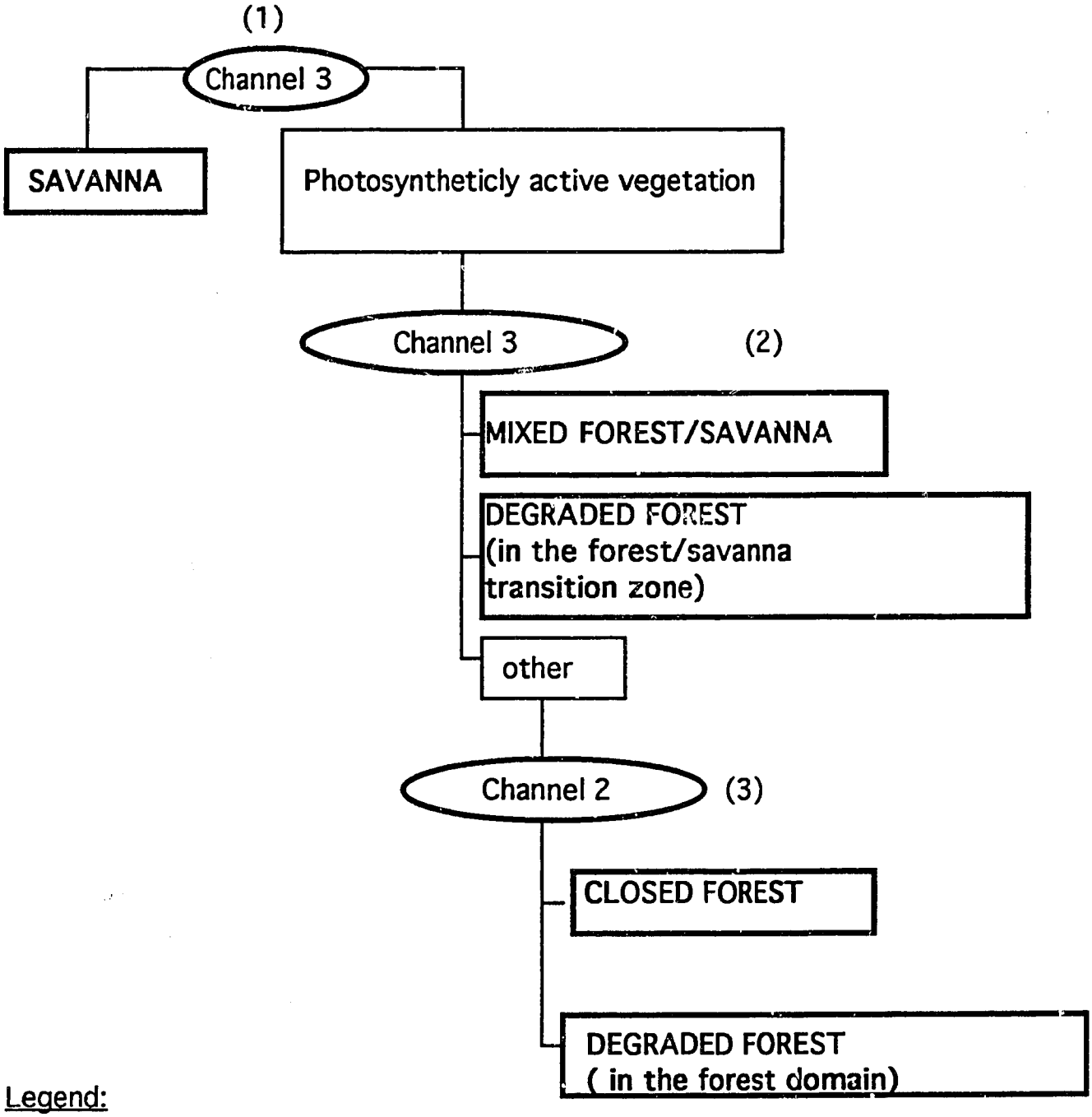
Figure 1

Thresholding method for LAC discrimination of broad vegetation types



Legend:

LAC vegetation types classes

LAC temporary classes

Thresholding steps using different LAC channels
(1) and (2) channel 3 maximised images in time (N variable)
(3) channel 2 images for different dates

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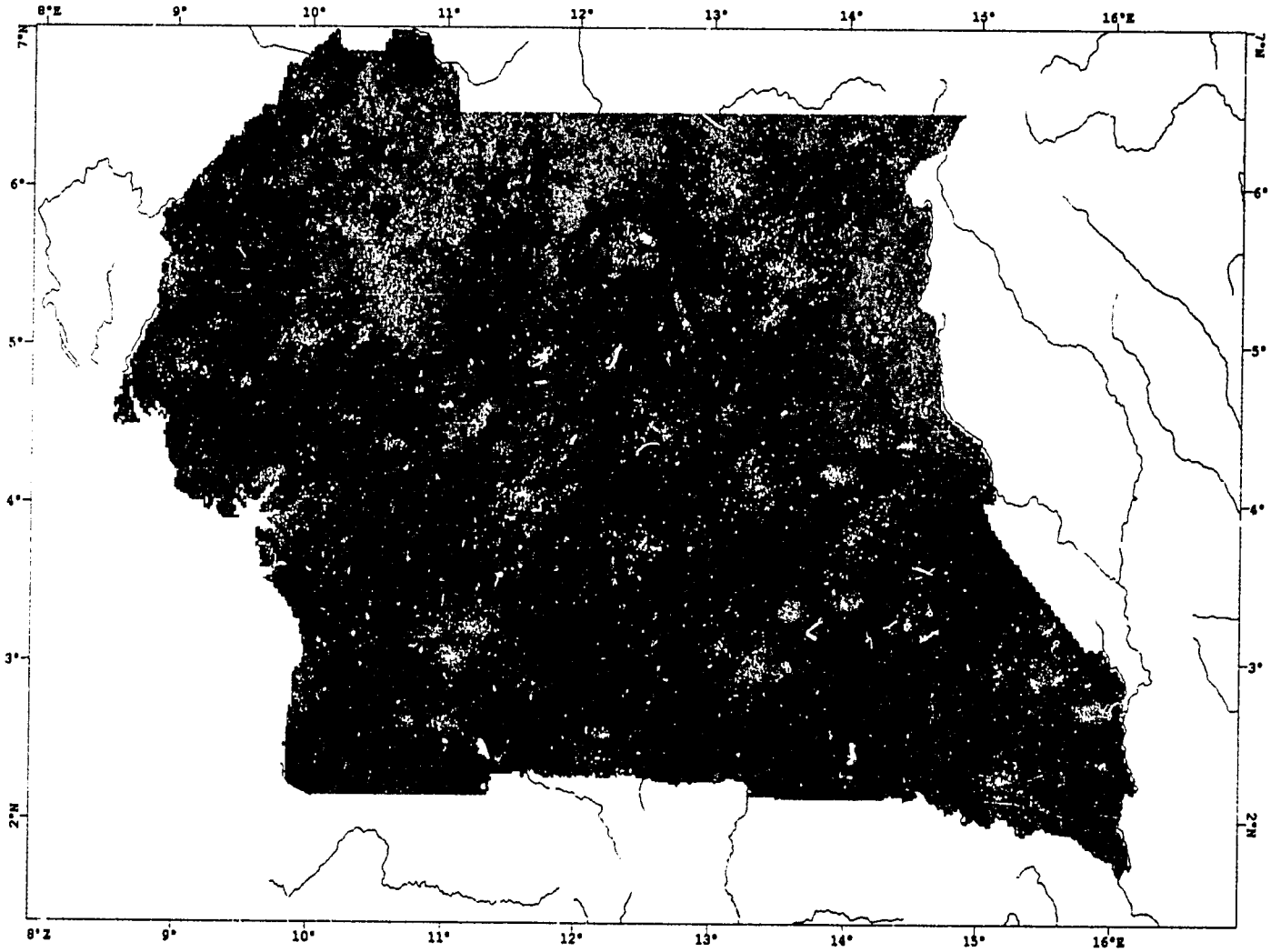
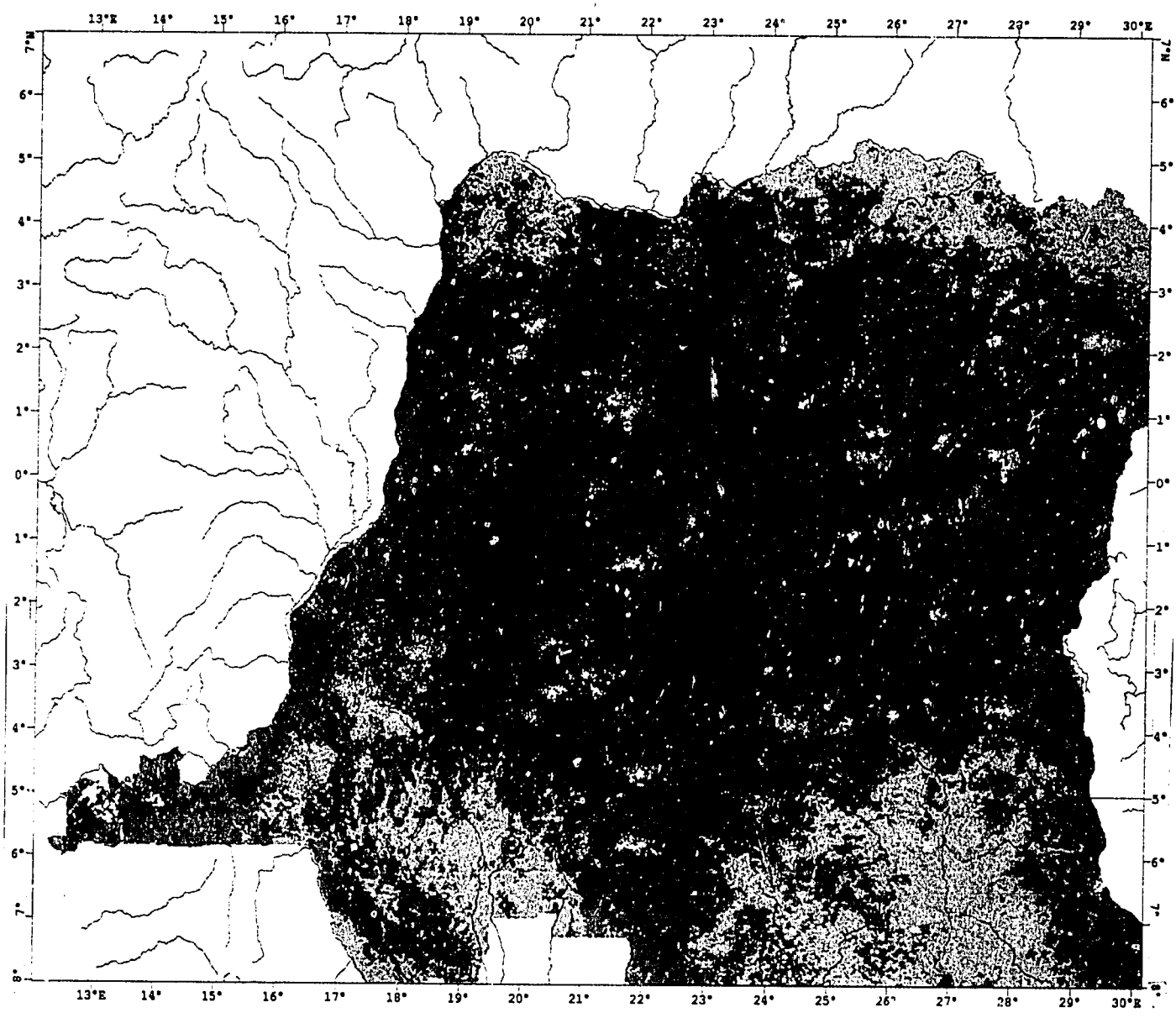
Figure 2—Vegetation map of southern Cameroon derived from 1989 NOAA-AVHRR data



Cameroon vegetation

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

Figure 3—Vegetation map of northern Zaire derived from 1989 NOAA-AVHRR data



Zaire vegetation

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

Figure 4—Landsat MSS holdings at NASA/GSFC available for validation of classified AVHRR LAC vegetation images.

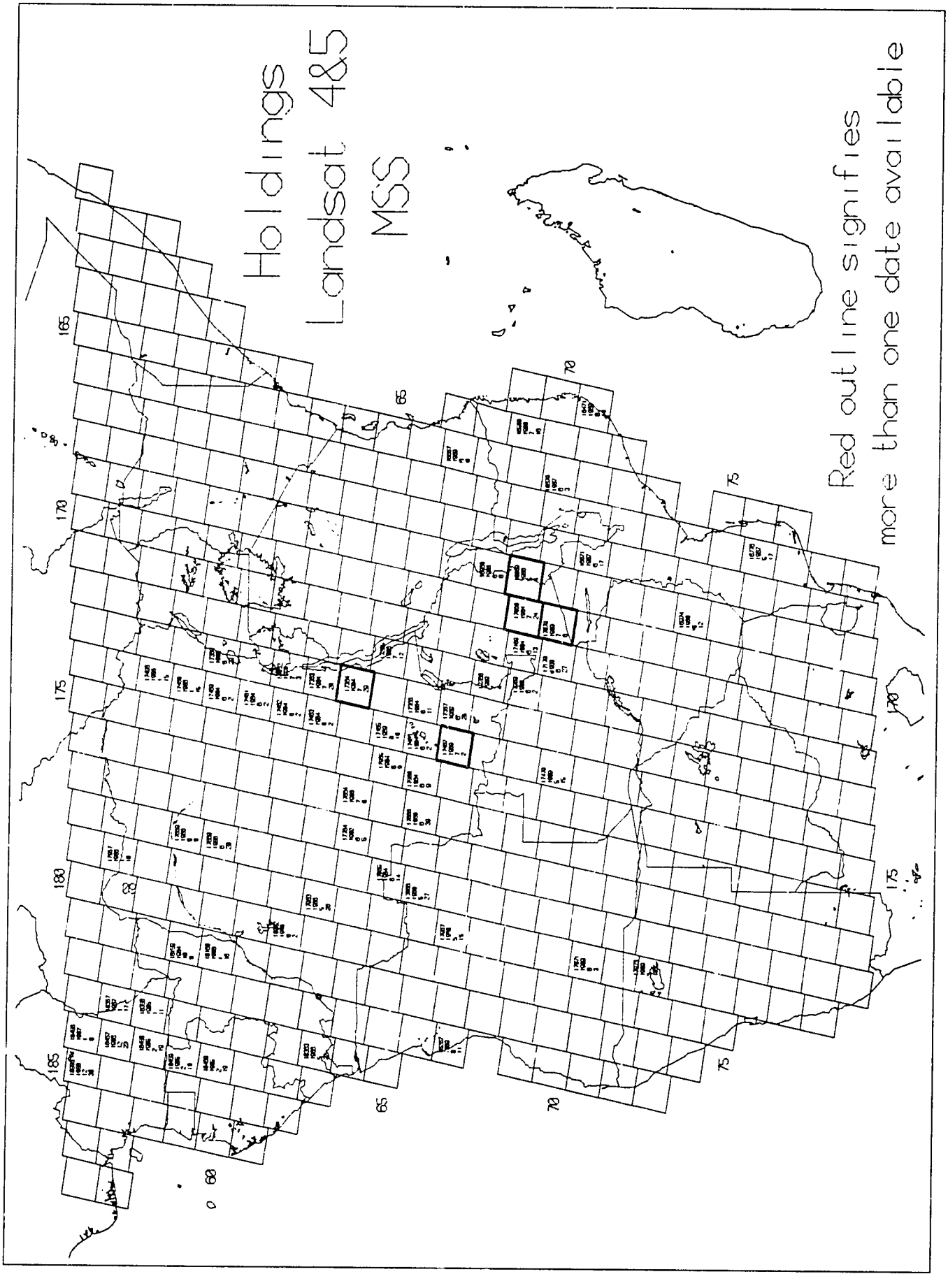
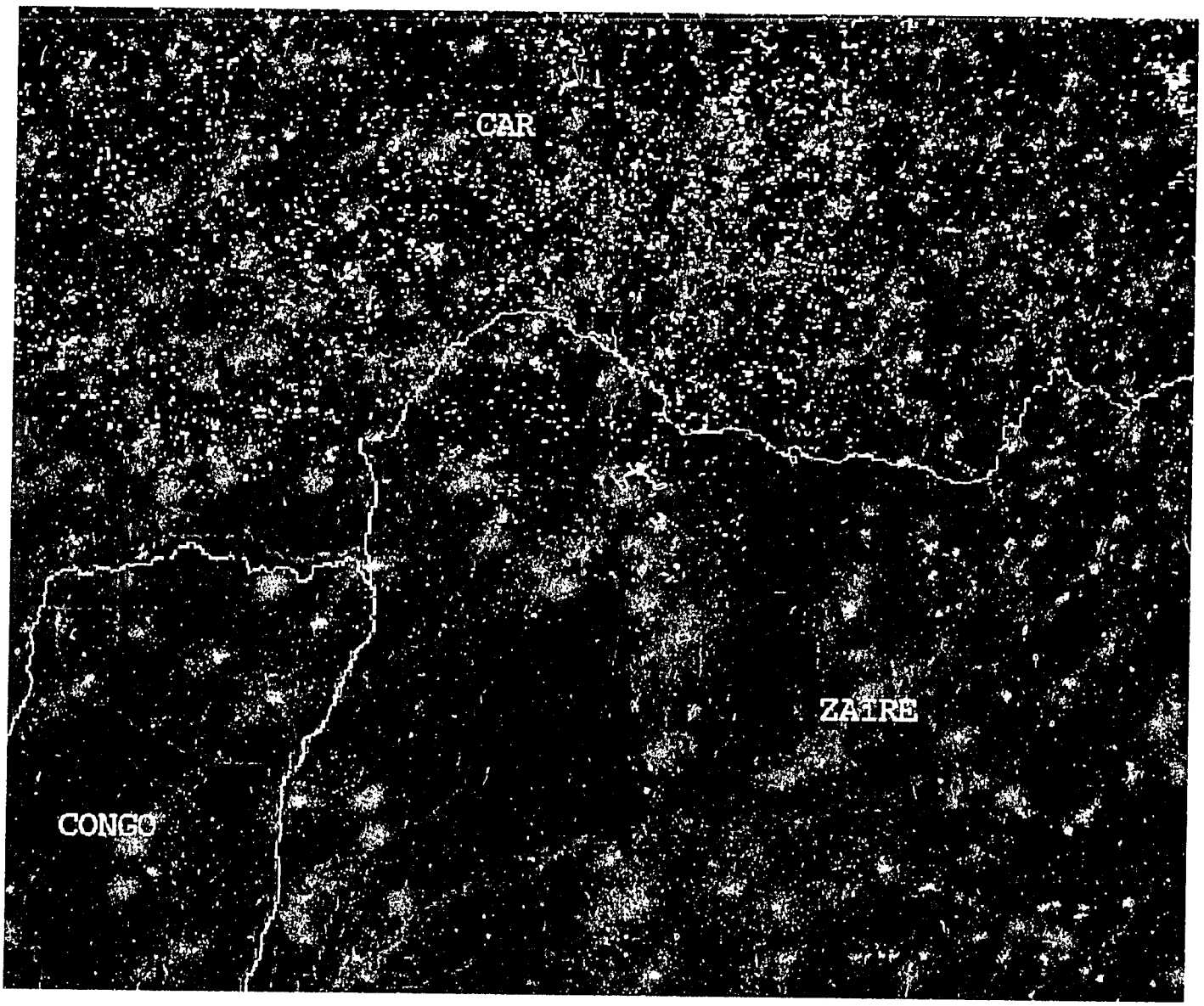
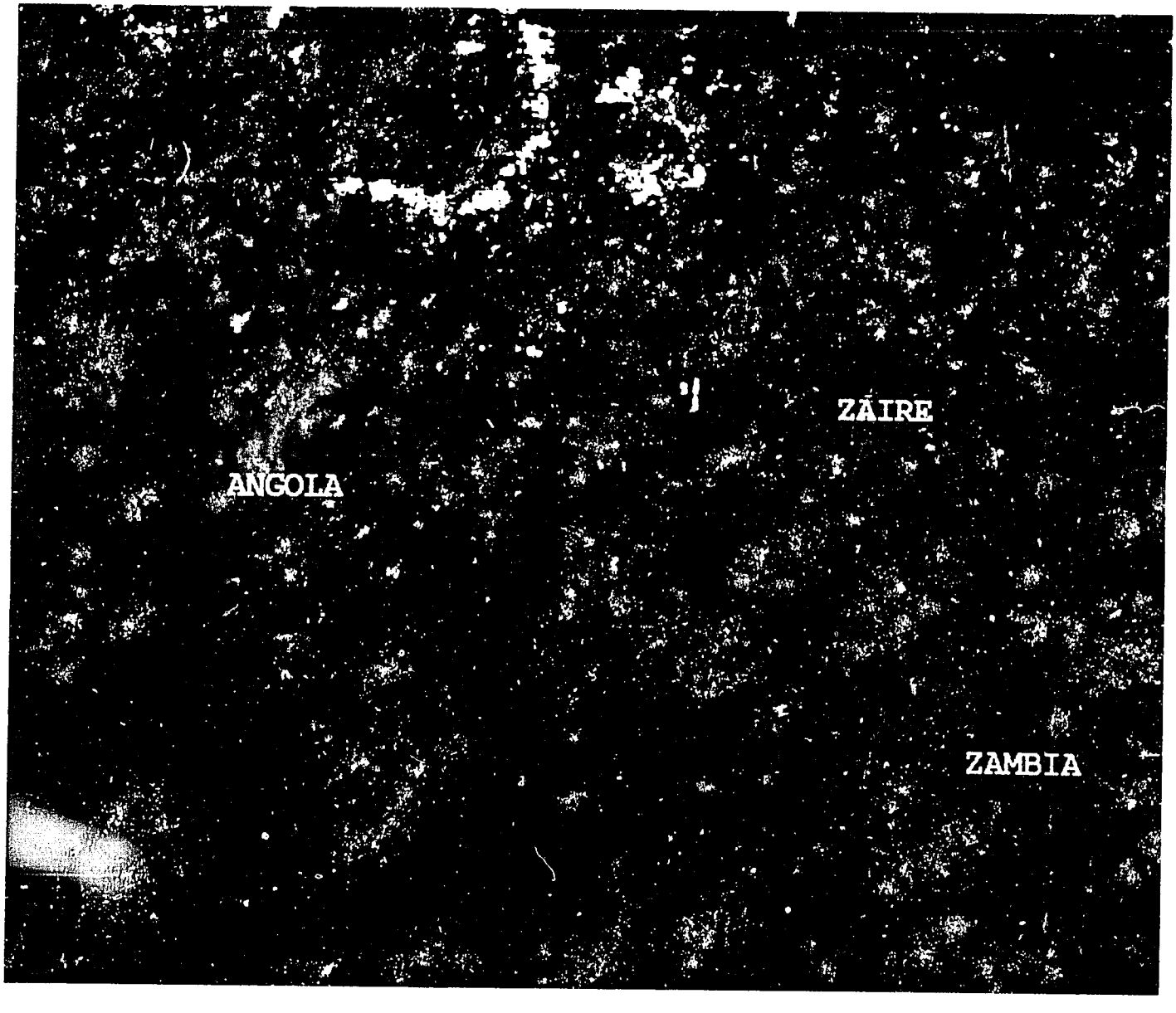


Figure 5—A preliminary map of the distribution of active fires detected using the AVHRR sensors during the month of January 1989



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

Figure 6—The areal distribution of fires and burn scars for southern Africa during the late dry season (August 7, 1988):



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

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

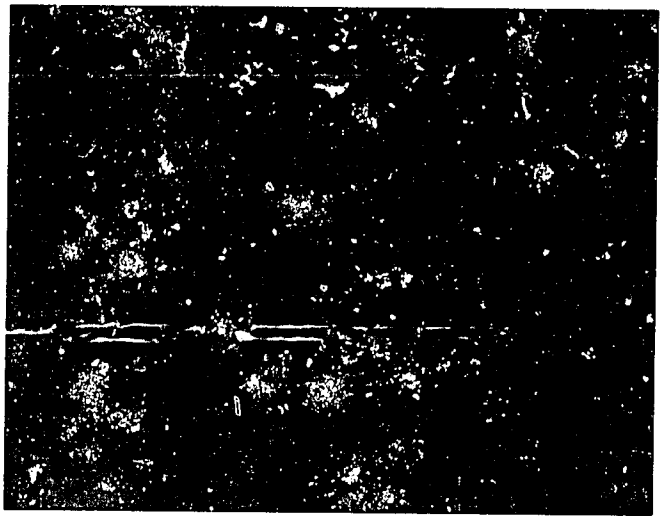
Classified Vegetation Types

No Change:

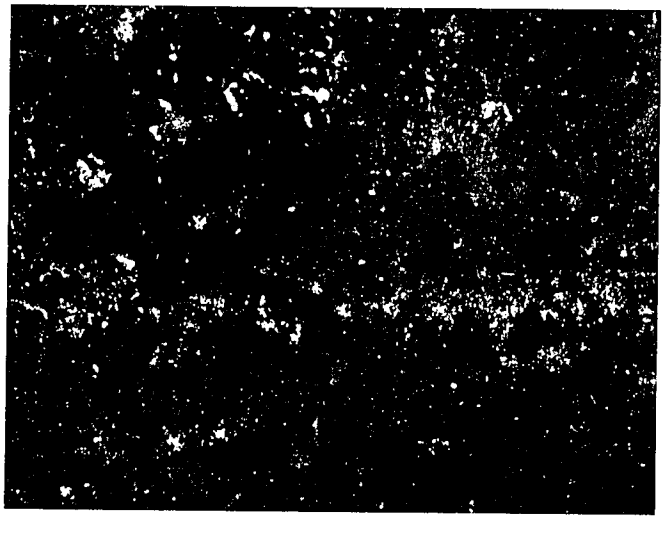
Green	=	Forest
Red	=	Disturbed/secondary forest
Black	=	Shadow/river
Tan	=	Bare soil/ savanna

Changed Vegetation:

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



Landsat MSS image, 13 January 1976

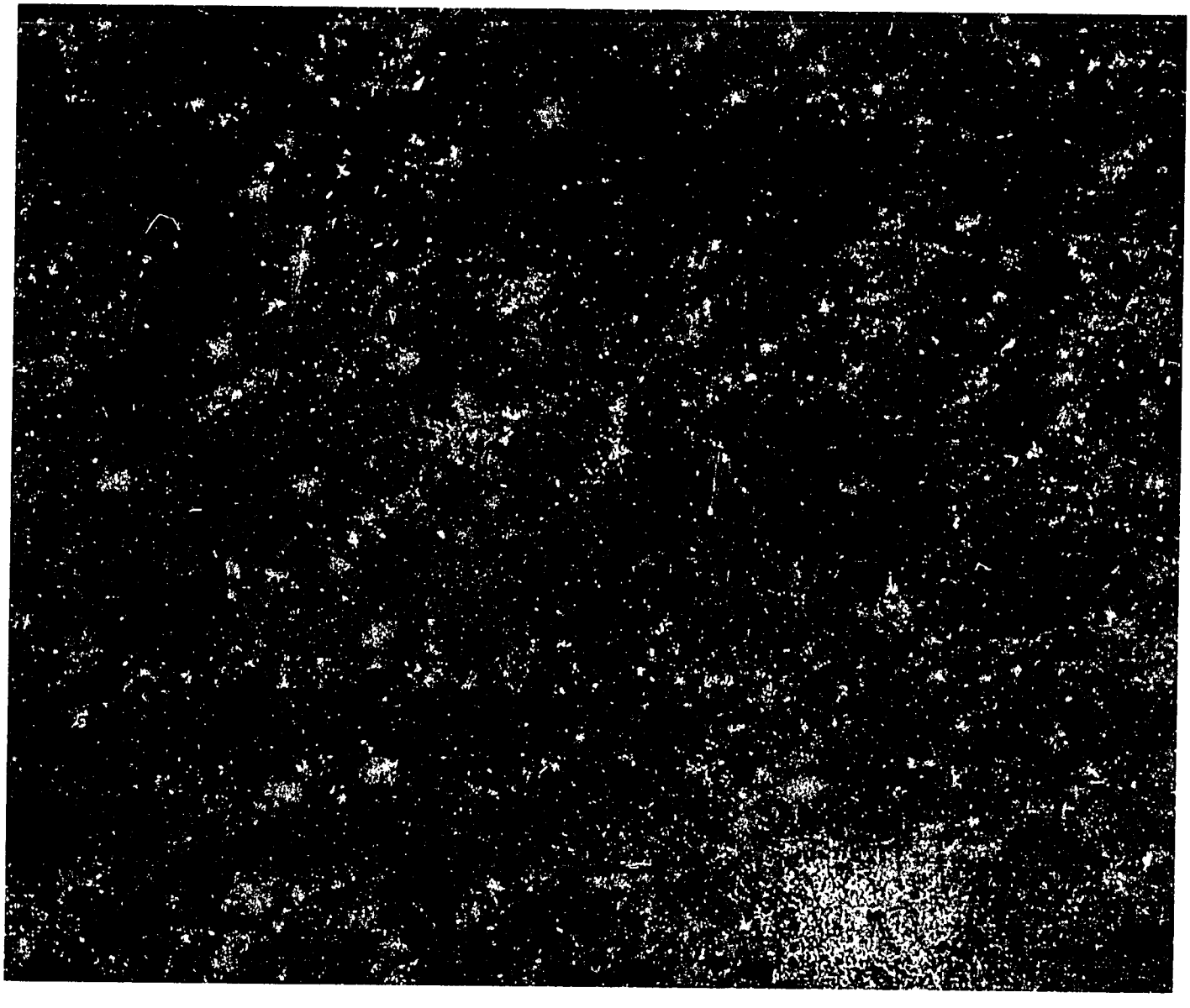


Landsat MSS image, 16 January 1986

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 8a—Kananga Region, MSS 1989, Bands 4,2,1



.23

Figure 8b—Kananga Region, MSS 1981, Bands 4,2,1

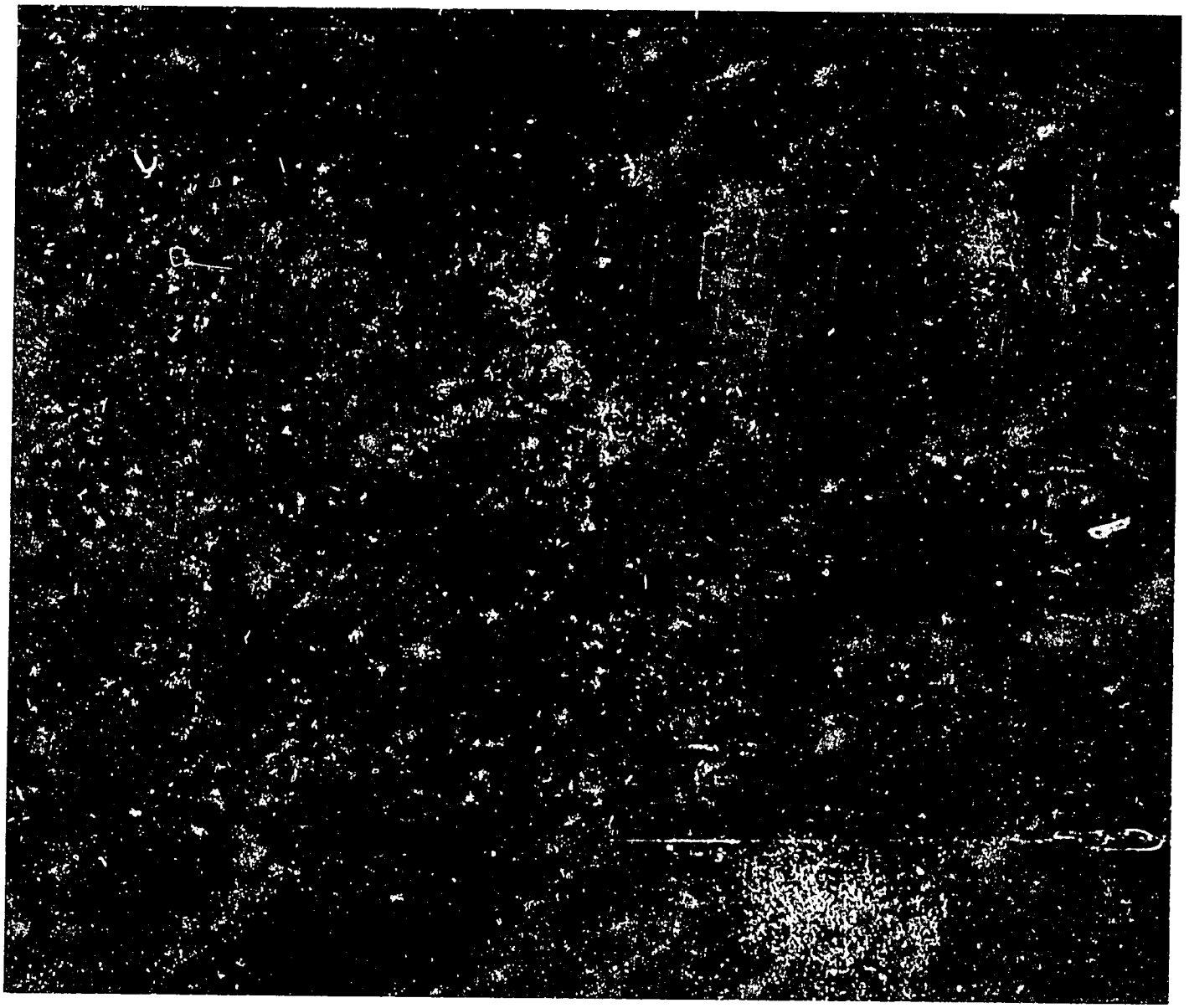
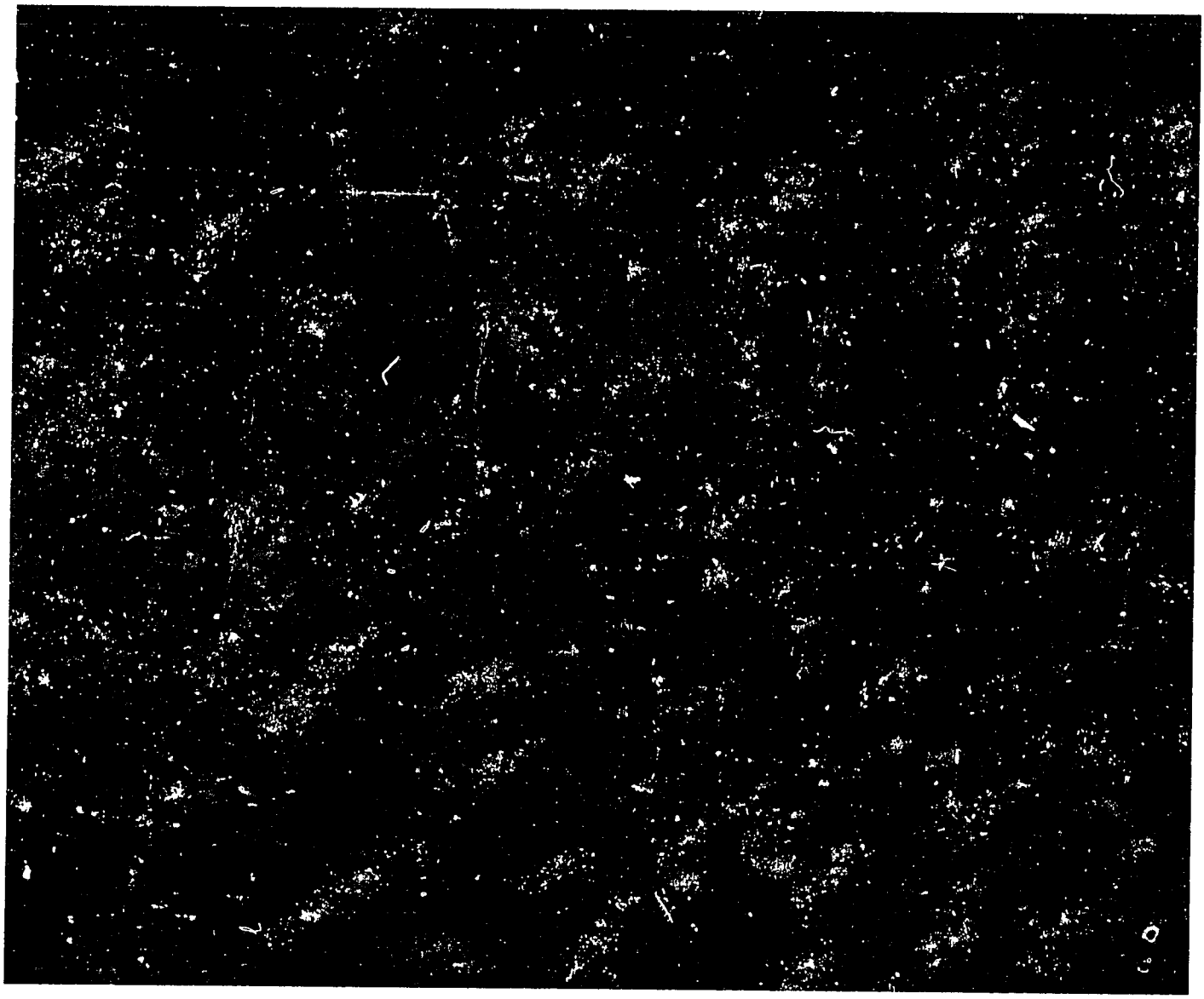
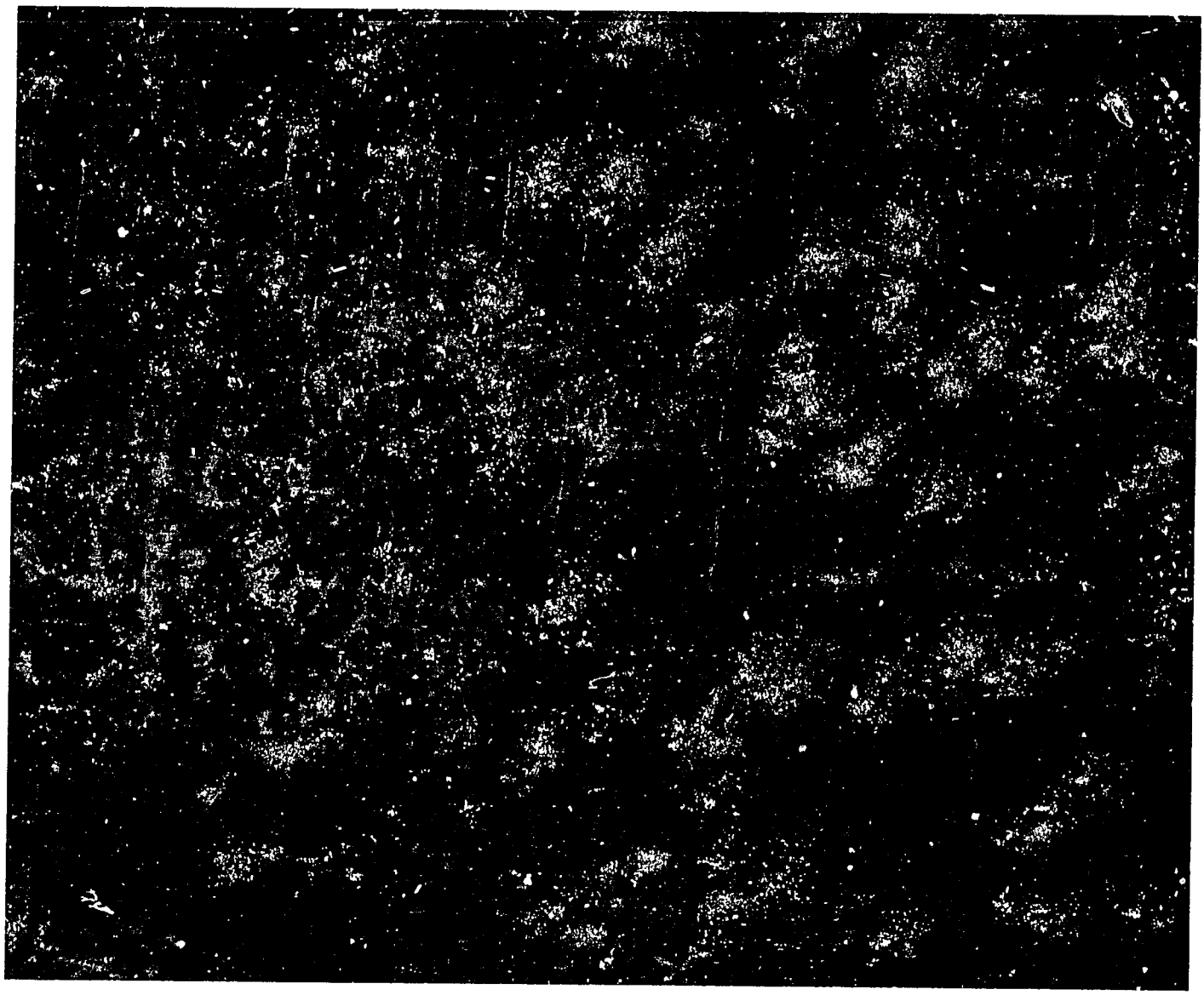


Figure 9a—Kananga Region, 1989 Classified



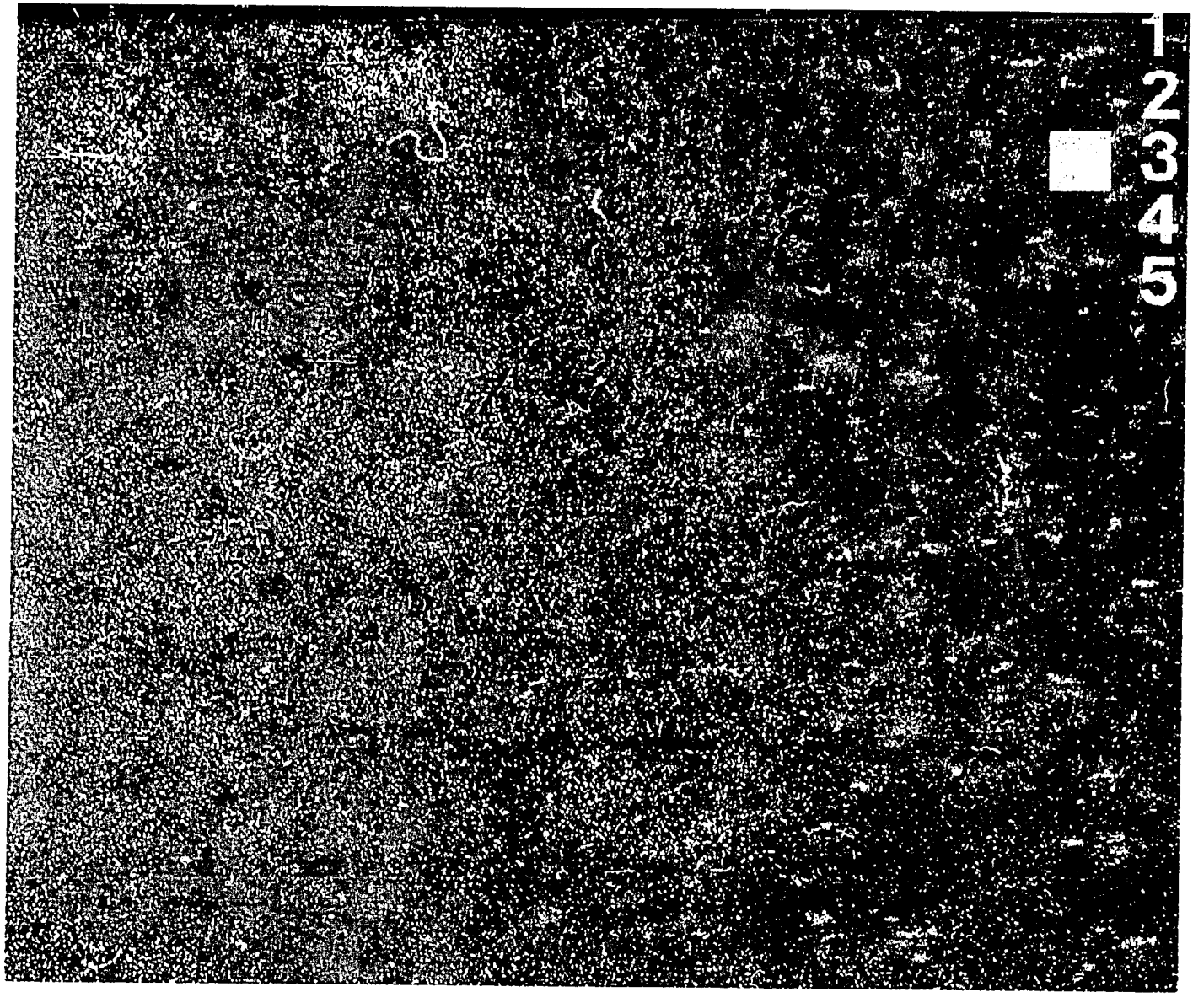
Green = Forest
Cyan = Savanna/Woodland
Red = Developed
Blue = Water
Black = Bad data

Figure 9b—Kananga Region, 1989 Classified



Green = Forest
Cyan = Savanna/Woodland
Red = Developed
Blue = Water

Figure 10—Kananga Region, 1981–1989, Land Cover Change

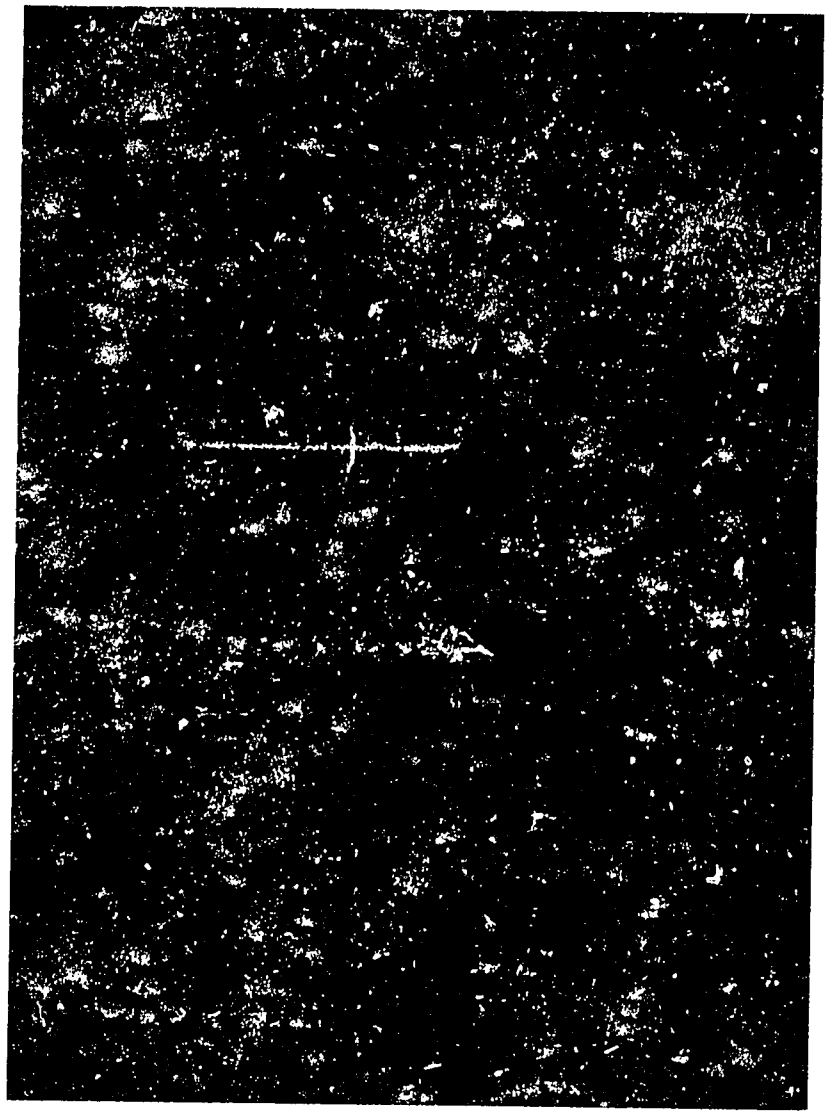


Cyan = No change
Green = Forest to Savanna
Yellow = Savanna to forest
Red = Forest to developed
Blue = Other change
Black = Bad data

Figure 11a—Nyunzu Region, MSS 1973, Bands 4,2,1

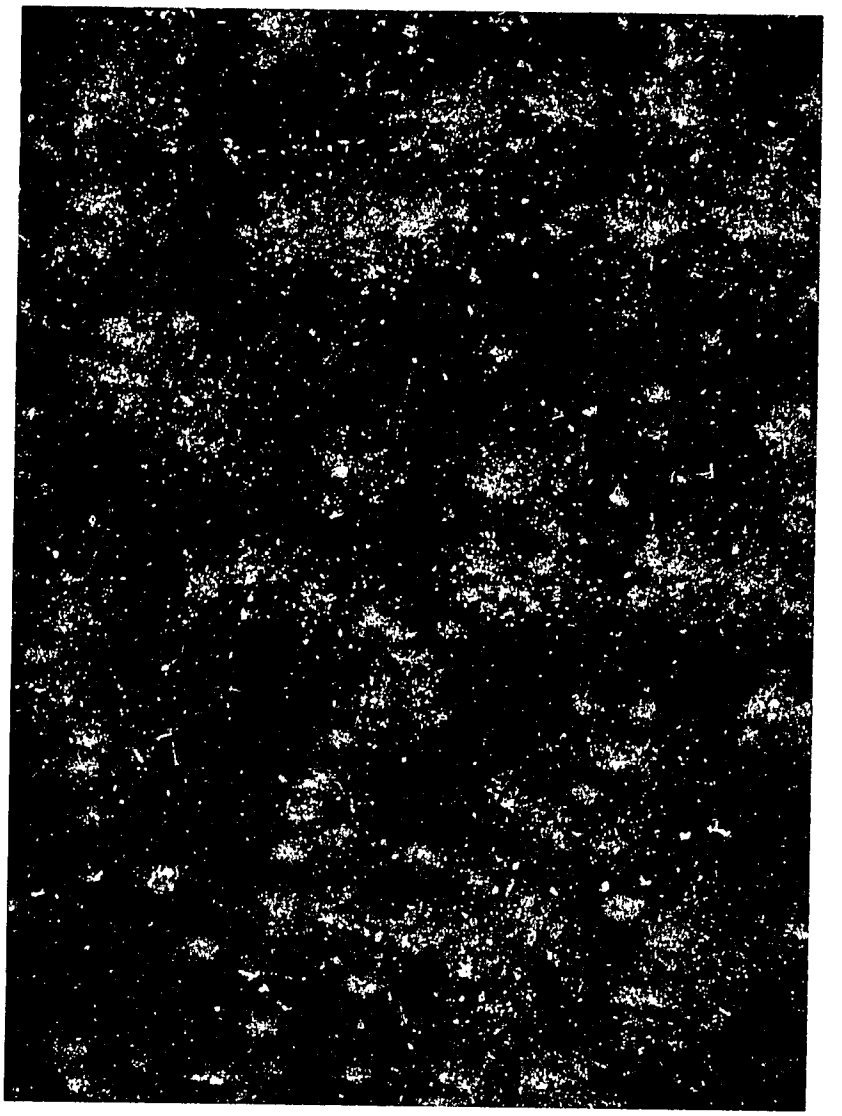
Figure 11b—Nyunzu Region, MSS 1984, Bands 4,2,1

Figure 12a—Nyunzu Region, 1973 Classified



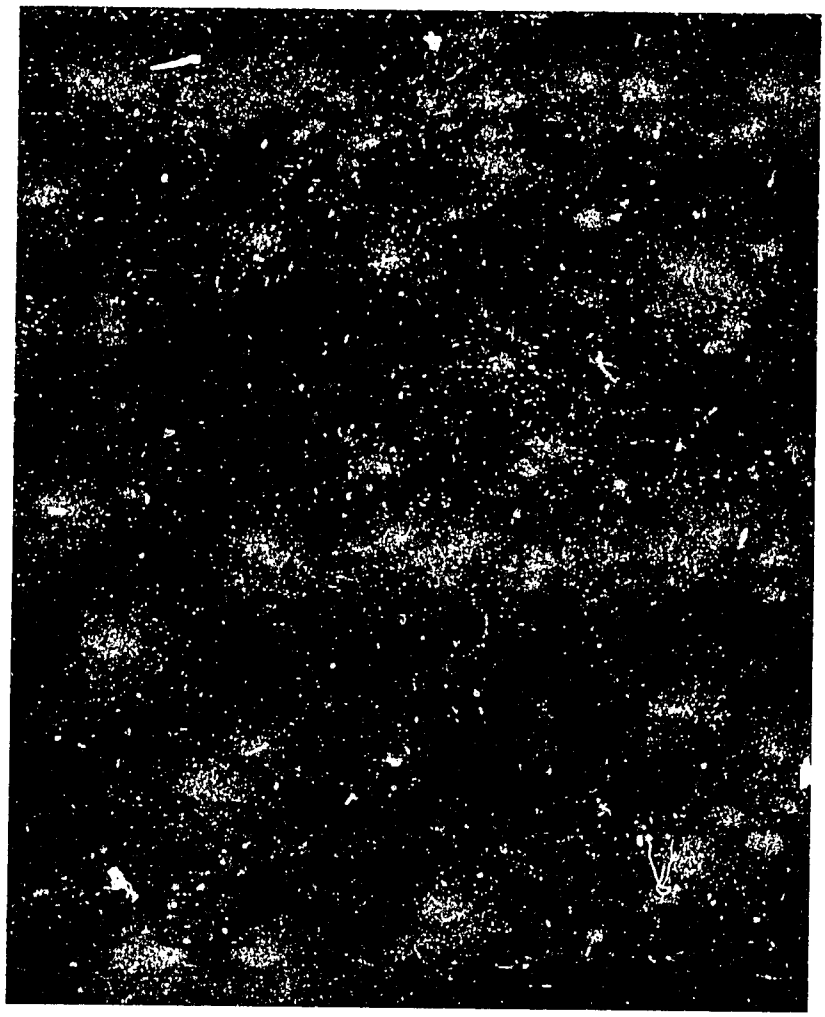
Green = Closed forest
Cyan = degraded forest
Red = Savanna
Blue = Water
Black = Clouds, bad data

Figure 12b—Nyunzu Region, 1984 Classified



Green = Closed forest
Cyan = degraded forest
Red = Savanna
Blue = Water
Black = Clouds, bad data

Figure 13—Nyunzu Region, 1973–1984 Change in Land Cover



Red = No change
Cyan = Tree loss
Green = Increase in trees
Black = Clouds, bad data

Figure 14a—Northern Ituri region Landsat MSS image = January 13, 1976
Bands 4,2,1 (R,G,B)

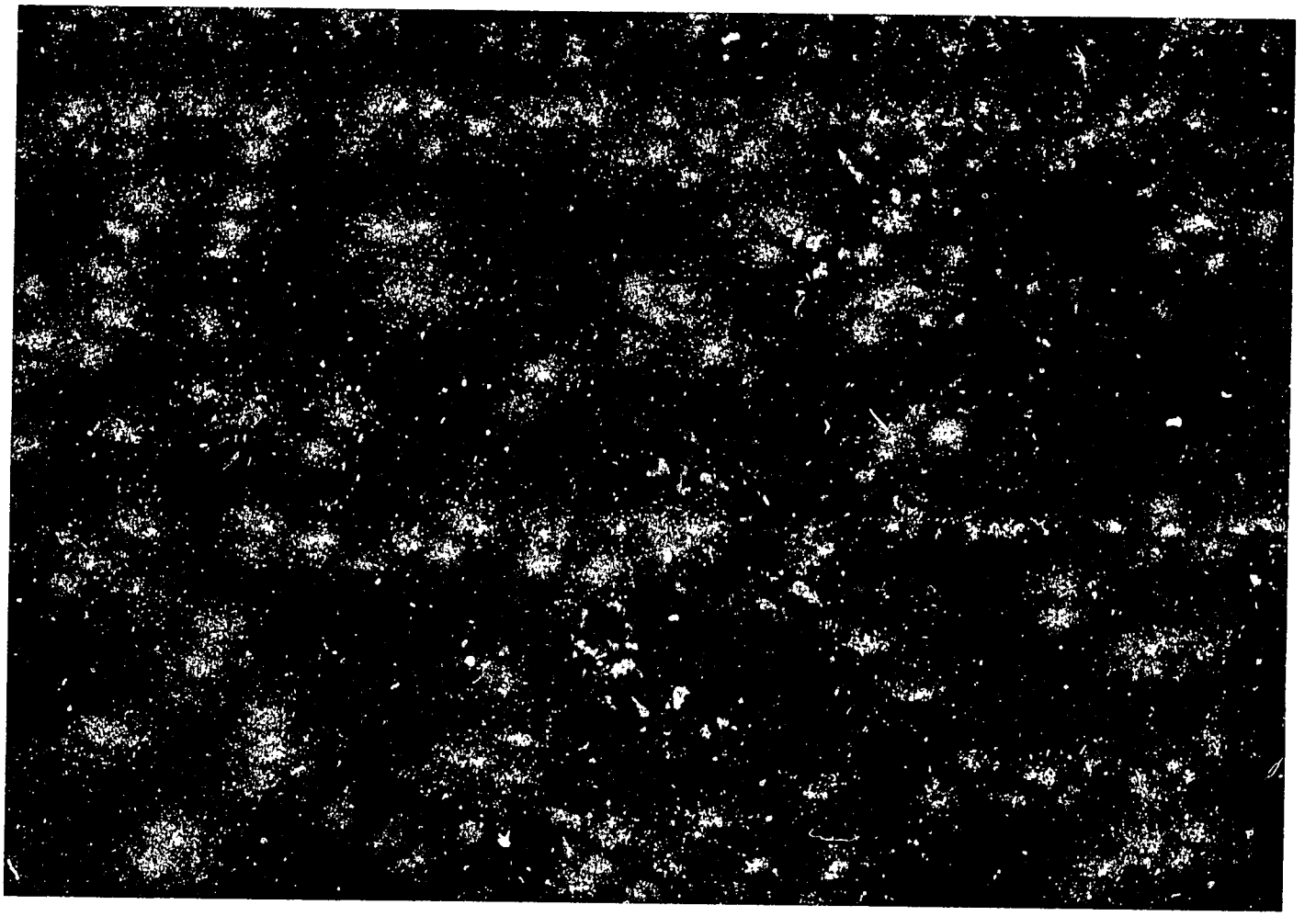
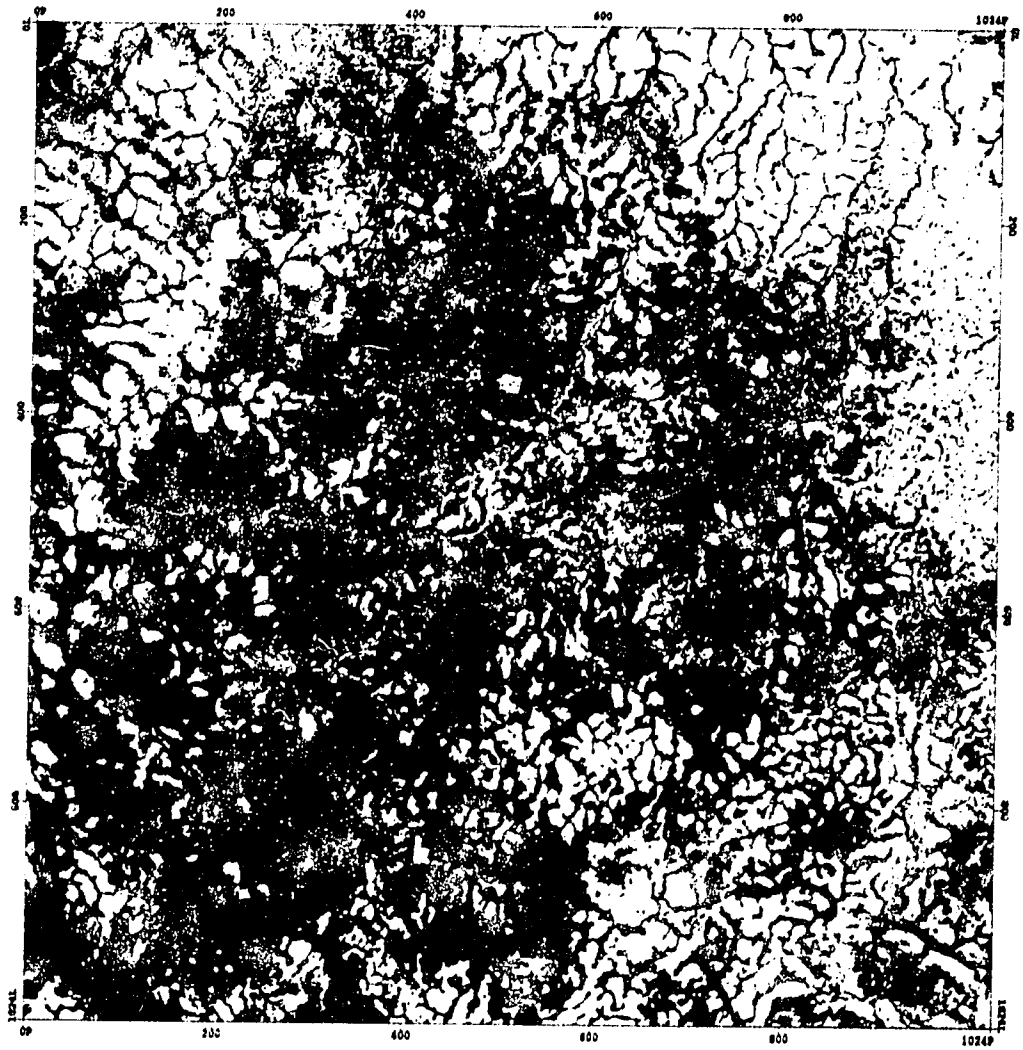


Figure 14b—Northern Ituri region Landsat MSS image = January 16, 1986
Bands 4,2,1 (R,G,B)

Figure 15



change image for northern Ituri

Green = Primary forest
Red = Disturbed//secondary forest
White = Bare soil/savanna
Cyan = Clearing (primary forest to cleared forest)

Figure 16a—Southern Ituri region Landsat MSS image = January 13, 1976
Bands 4,2,1 (R,G,B)

Figure 16b—Southern Ituri region Landsat MSS image = January 16, 1986
Bands 4,2,1 (R,G,B)

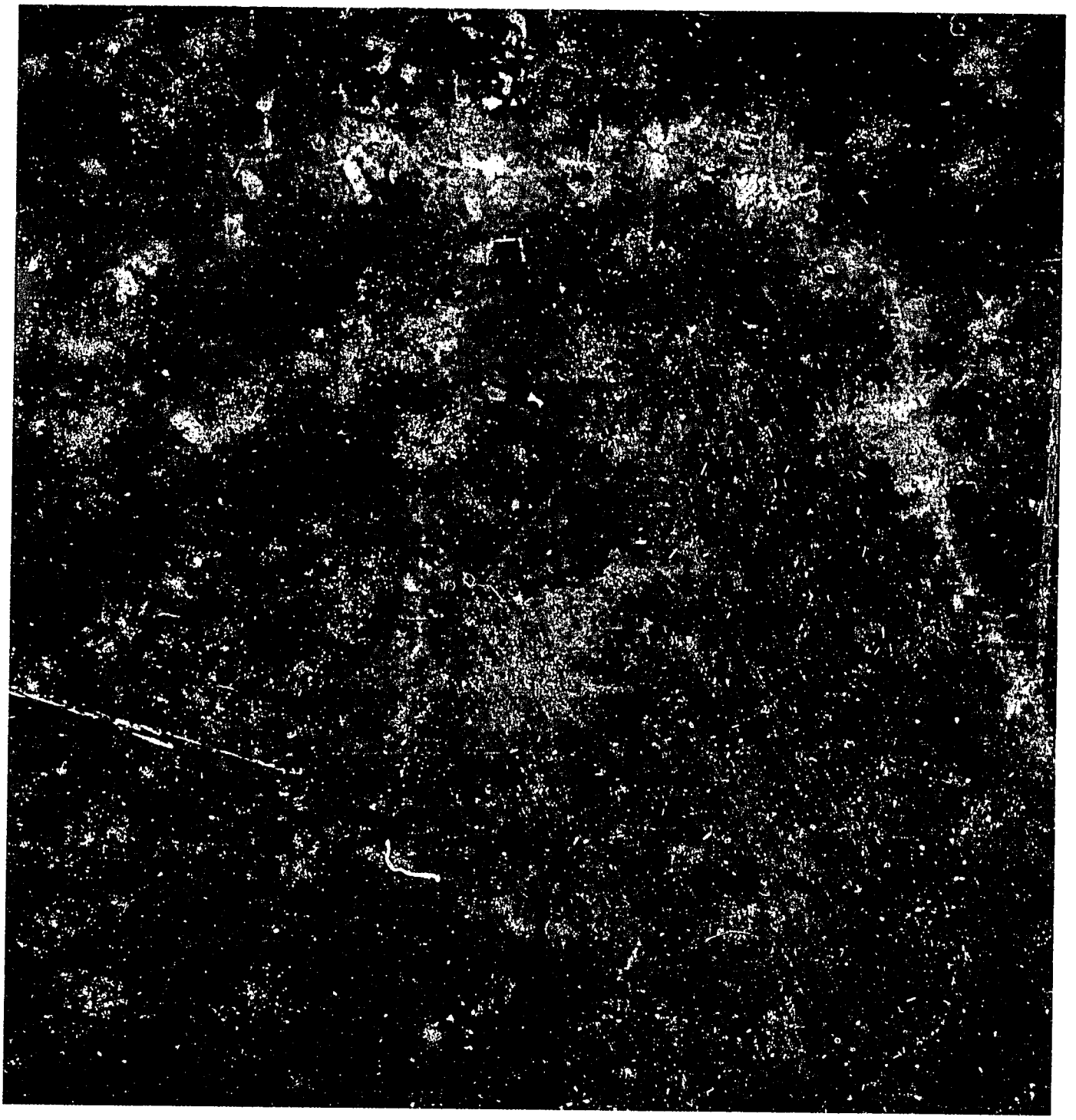
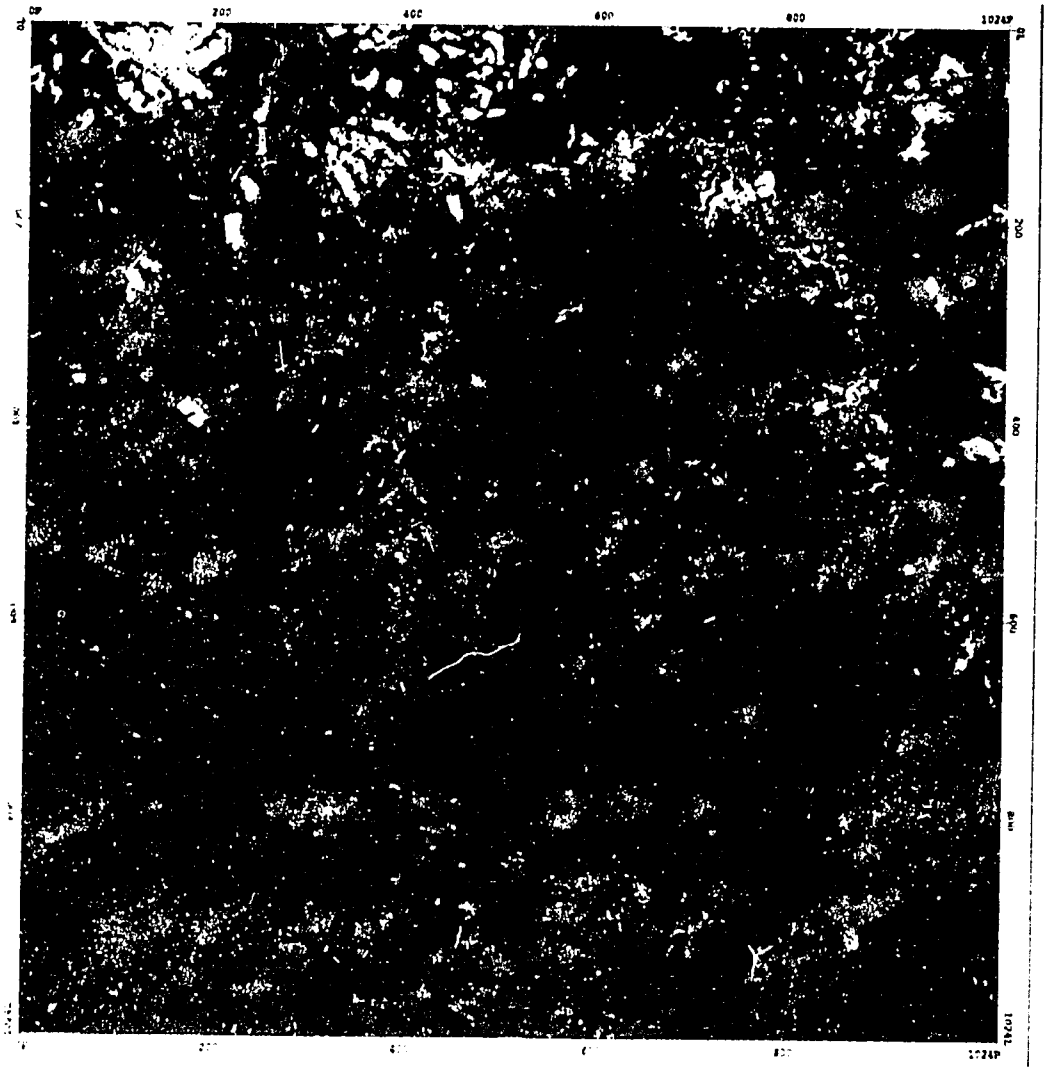


Figure 17



change image for southern Ituri

Green = Primary forest
Red = Disturbed/secondary forest
Black = Shadow/river
White = Bare soil/savanna
Yellow = Disturbance (primary forest to disturbed forest)
Blue = Regrowth (cleared to vegetated land)

Figure 18a—Kutu region Landsat MSS image—July 6, 1973
Bands 4,2,1 (R,G,B)

Figure 18b—Kutu region Landsat MSS image—June 2, 1986
Bands 4,2,1 (R,G,B)

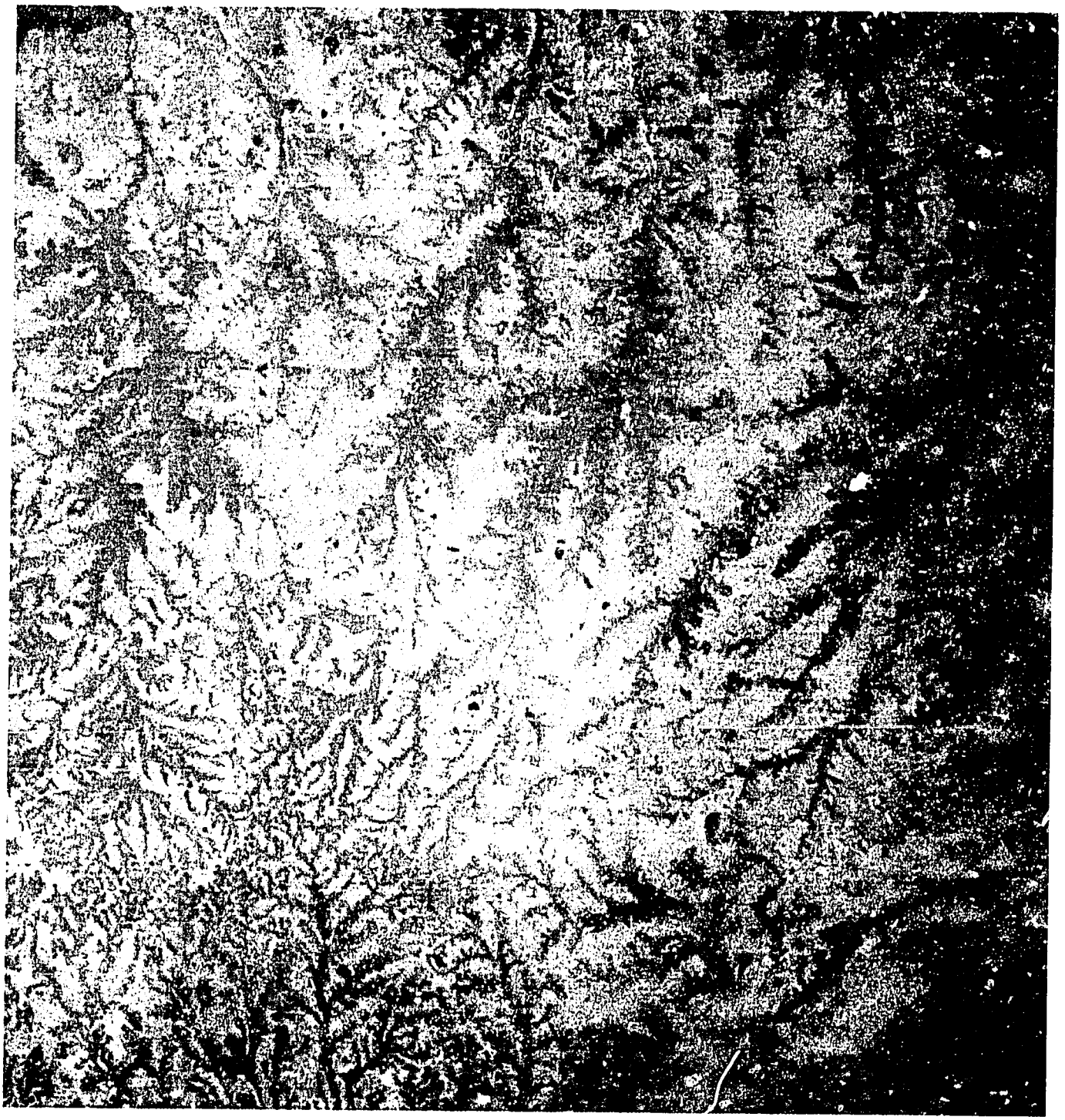


Figure 19

change image for Kutu

Green = Primary forest
Red = Disturbed/secondary forest
Black = Bad data
White = Bare soil/savanna

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

Figure 20—Photo-interpreted vegetation map using Landsat MSS data; 190/64 July 6, 1981 (Lejeune and Dautrebande, 1981)

Forêt ombrophile

Forêt ombrophile à faciès secondarisé

Complexe forêt ombrophile à faciès secondarisé savane arbustive

Savane arbustive

Localités et zones d'occupation rurale

APPENDIX 1

CARTOGRAPHIC, PHOTOGRAPHIC, BIBLIOGRAPHIC AND RESEARCHER DATA BANKS ON EQUATORIAL FOREST ENVIRONMENT OF ZAIRE

Laboratoire de Teledetection et d'Analyse Regional
Université Catholique de Louvain
Louvain-la-Neuve, Belgique

The data produced from this research are available from the Africa coordinator for the Biodiversity Support Program, World Wildlife Fund, 1250 Twenty-Fourth Street, NW, Washington, DC 20037, USA.

CARTOGRAPHIC, PHOTOGRAPHIC, BIBLIOGRAPHIC AND RESEARCHER DATA BANKS ON EQUATORIAL FOREST ENVIRONMENT OF ZAIRE

This report refers to the contract n°28 (09/12/1991) between Professor J. Wilmet, director at the "Laboratoire de Télédétection et d'Analyse Régionale", Université Catholique de Louvain and the World Wildlife Fund (Washington D.C.) in the context of the Biodiversity Support Program. This report has been carried out in collaboration with Professor J. Feyen, director at the Institute for Land and Water Management, Faculty of Agricultural Sciences, Katholiek Universiteit Leuven.

Under their direction the research has been realised and compiled by N. Sorel and M. Tshiunza, researchers, respectively for U.C.L. and for K.U.L.

Four data banks have been made :

1° the available maps on Zaire (floppy 2),

2° the available aerial photos and photomosaics on Zaire (floppy 2),

3° publications and reports on the equatorial forest environment of Zaire (floppy 1),

4° overview of the international and national (belgian) forestry operators working in zaire since 1945 (floppy 2).

The contents of these data banks cannot be considered as exhaustive. The work is huge and the data has been collected in more time than estimated initially in the contract.

All data have been registered on floppies and the files have been established according to six annexes presented at the end of this report.

1. DESCRIPTION OF THE CARTOGRAPHIC DATA FILE

For each map information has been registered according to the annexes 1a, 1b, 2, 3 and 4.

a. Geographic localization (LOC)

Registered with a numerical code (which represents a square degree: see annexe 1a) or an alphabetical code for the main zairian administrative divisions (Régions and Sous-Régions, 1982: see annexe 1b).

Sometimes the numerical code is preceded by N, S, E, W, referring respectively to north, south, east and west.

b. Scale of the map

c. Dates

The first one is related to the basic document and the second is the date of publication.

d. Theme

It is registered according to the annexe 2.

e. Author

Represents a name or the acronym of the institution which has established the map (see annexe 3).

f. Document

Sometimes a map can be followed by an explanatory notice.

g. Projection

UTM (U), Mercator (M), Polyconique (P), others (A), Gauss (G), Lambert (L).

h. Quality

Related to the physical state of the map: A for good, B for fair and C for bad quality.

i. Institution

The acronym of the place where the map is available (see also annexe 3).

j. Reproduction, borrowing

Describes the availability of the document.

j. Comment

This field includes various informations.

2. DESCRIPTION OF THE AERIAL PHOTO AND MOSAIC DATA FILE

The following data have been registered for mosaics and photos as below.

a. Localization (LOC)

The place where the photographs (or photomosaics) have been taken is registered according to annexes 1a and 1b.

b. Scale of the photographs or photomosaics

c. Date

The year when the flight was carried out.

d. Assembly

Photographs or photomosaics and among mosaics: simple mosaic, controlled mosaic or rectified mosaic.

e. Type

Black and white, false color infra-red or color.

e. Material

Physical support of the document: negative, positive on paper, or glasspaper.

f. Where

Institution where the photographs or photomosaics are available.

3. DESCRIPTION OF THE BIBLIOGRAPHIC DATA FILE

The main data registered for each publication are:

a. author 1

The name of the author in capital letters followed by the first letter of his first name. If there is no specific author, this field contains the term ANONYME meaning anonymous.

b. author 2

The name of the second author and " et AL " if there are more than two authors.

c. institut

The institution of the author or the institution which has published the reference.

d. title

e. editor

In this field, the country or the city, the name or the acronym of the publisher is mentioned with the date of the publication.

f. series

If it exists, the number of the series and if necessary, the number of the volume are given.

g. pages

Contains the number of pages of the reference or their interval in the volume.

h. categorie

The type of reference and the language used (see annexe 5).

i. code 1

Represents the code used in the library for the reference.

j. code 2

The code of the library where the reference is available.

k. isbn

Is the international standard book number

l. keyword

Sometimes keyword of the reference are given by the author or the library and they refer to the main characteristics of the reference.

4. DESCRIPTION OF THE DATA FILE OF THE OPERATORS.

This file contains the main entreprises which are working in the exploitation of the forest and some projects or NGO (Non Governmental Organisations) which have or are still working in zairian forest. Considering the time and the area of research, it was not possible to collect all information about all operators. The informationis labeled as below:

a. Name

The name (or the acronym) of the enterprise, the project or the non governmental organisation (NGO).

b. Adress

c. Dates

The year of the beginning and the year of the end of the activities in the case of a project or NGO .

d. Objectives of the project or "NGO "

e. Localization

Using the numerical code related to the square degree (annexe 1a). We have localized the region where the operator was working.

f. Realization

The work done by the operator until the date when our reference was established.

g. Area

Gives the size of the area covered by the realization of the operators (km^2).

h. Source(s):

Gives the source(s) of the information collected.

ANNEXES

1a . Map of Zaire subdivided and coded by square degrees.

1b . Map of Zaire with the main administrative regions alphabetically coded.

2 . Themes of maps

3 . List of acronyms

4a. Availability of document (map, photo, mosaic and bibliography).

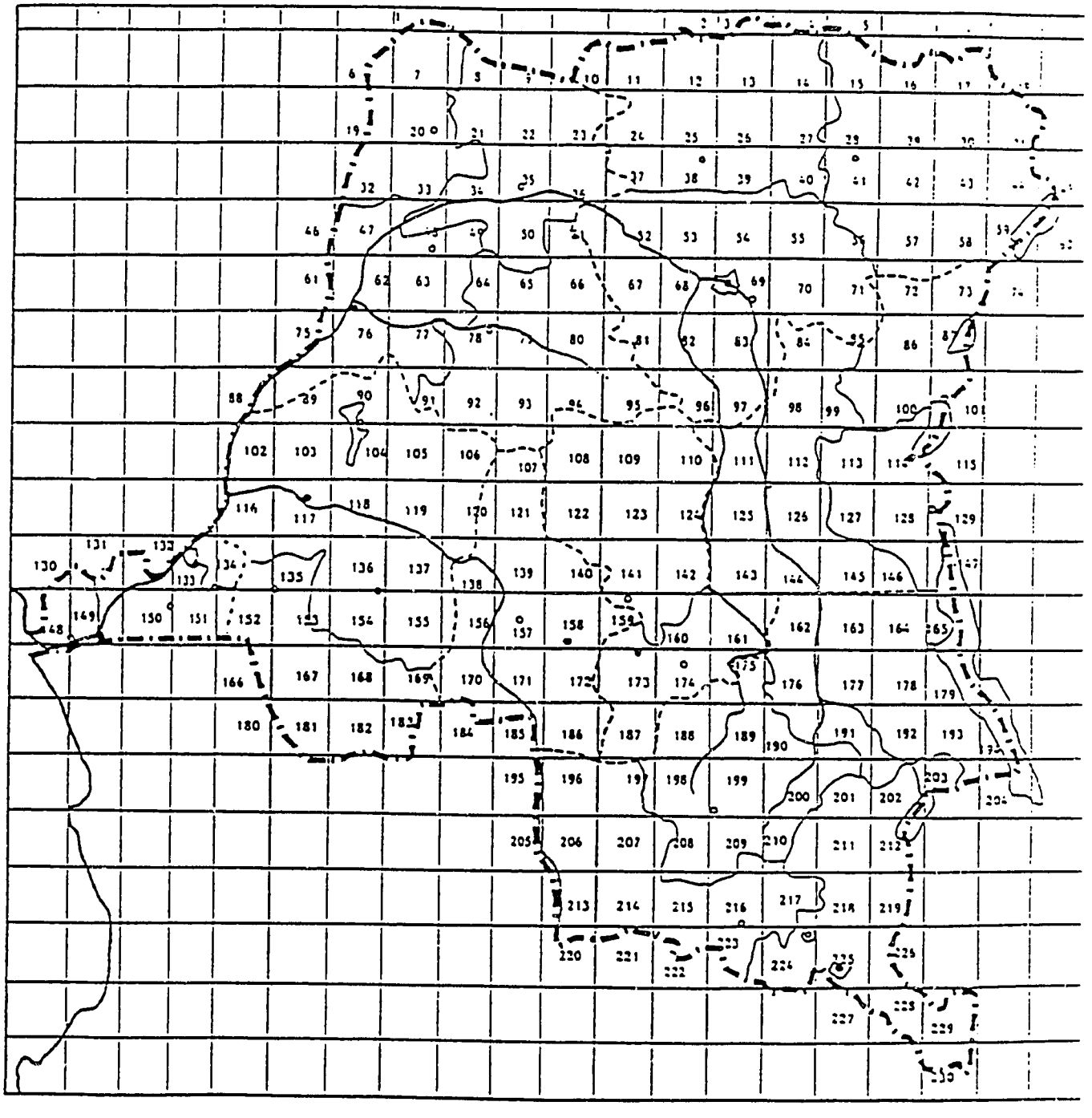
4b. Photographic and mosaic abbreviations.

5 . Bibliographic abbreviations.

6 . Adresses of the Institutions and Personalities visited.

ANNEXE 1 a

MAP OF ZAIRE SUBDIVIDED AND CODED BY SQUARE DEGREES



ANNEXE 1 b

MAP OF ZAIRE WITH THE MAIN ADMINISTRATIVE REGIONS ALPHABETICALLY CODED

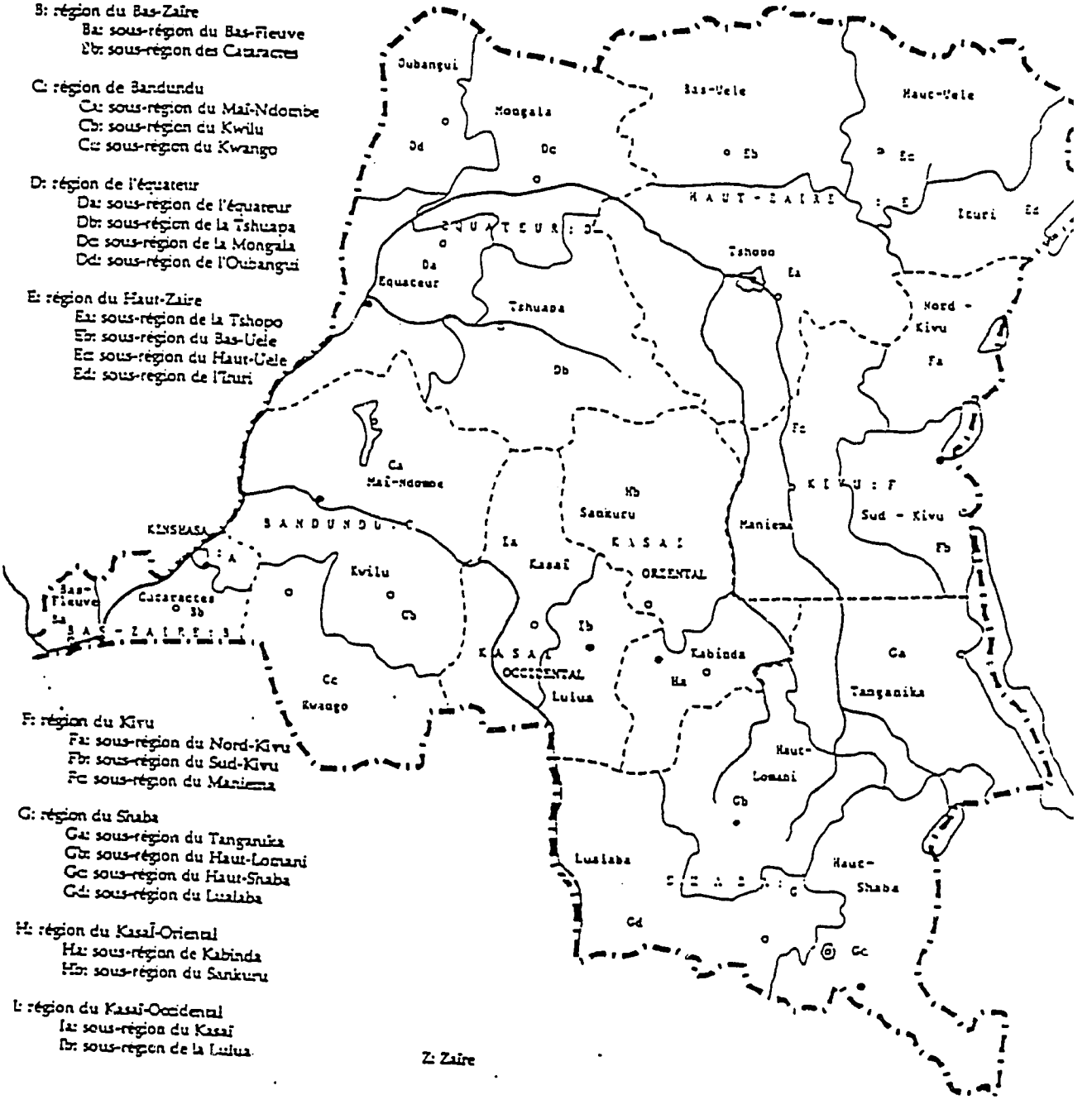
A: Ville de Kinshasa

B: région du Bas-Zaire
- Ba: sous-région du Bas-Fleuve
- Bb: sous-région des Cataractes

C: région de Bandundu
- Ca: sous-région du Maï-Ndombe
- Cb: sous-région du Kwilu
- Cc: sous-région du Kwango

D: région de l'équateur
- Da: sous-région de l'équateur
- Db: sous-région de la Tshuapa
- Dc: sous-région de la Mongala
- Dd: sous-région de l'Oubangui

E: région du Haut-Zaire
- Ea: sous-région de la Tshopo
- Eb: sous-région du Bas-Uele
- Ec: sous-région du Haut-Uele
- Ed: sous-région de l'Ituri



F: région du Kivu
- Fa: sous-région du Nord-Kivu
- Fb: sous-région du Sud-Kivu
- Fc sous-région du Maniema

G: région du Shaba
- Ga: sous-région du Tanganika
- Gb: sous-région du Haut-Lomani
- Gc sous-région du Haut-Shaba
- Gd: sous-région du Lualaba

H: région du Kasaï-Oriental
- Ha: sous-région de Kabinda
- Hb: sous-région du Sankuru

I: région du Kasaï-Occidental
- Ia: sous-région du Kasaï
- Ib: sous-région de la Lulua

Z: Zaire

Laboratoire de Télédétection et d'Analyse Régionale
Université Catholique de Louvain

February 1992

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ANNEXE 2

THEMES OF MAPS

1. topography (with contours and/or altitude)

2. maps without contours

3. maps of vegetation and soil occupation

4. geology, geomorphology, natural resources,...

5. climate

6. pedology

7. human geography (demography, ...)

8. administrative maps, communications,...

9. energy, animal and crop production,...

0. others types of data (health,...)

ANNEXE 3

LIST OF ACRONYMS

ACDI	Agence Canadienne de Développement International
AETFAT	Association pour l'Etude Taxonomique de la Flore d'Afrique Tropicale
KUL	Katholieke Universiteit Leuven
ARSC	Académie Royale des Sciences Coloniales
ARSOM	Académie Royale des Sciences d'Outre-Mer
BAC	Bulletin Agricole du Congo Belge et du Ruanda-Urundi
BAF	Bibliothèque Africaine
BRA1	Bibliothèque Royale Albert 1er
BXL	Bruxelles
CCE	Commission des Communautés Européennes
CCTA	Commission de Coopération Technique en Afrique
CCTA	Commission de Coopération Technique en Afrique
CDOU	Cartographic Department of Oxford University
ULB	Université Libre de Bruxelles
CEMUBAC	Centre Scientifique et Médicale de l'Université Libre de Bruxelles en Afrique Centrale
CIDAT	Centre Informatique Appliqué au Développement et à l'Agriculture Tropicale.
CNK	Comité National du Kivu
CSK	Comité Spécial du Katanga
DAFCN	Département des Affaires Foncières et Conservation de la Nature
DDRZ	Département de Développement Rural au Zaïre
DRA	Bibliothèque de M. Drachoussoff de la Fondation Roi Baudouin
EURO	Eurosense
FULREAC	Fondation de l'Université de Liège pour les Recherches en Afrique Centrale
GEO-ECO-TROP	Revue Internationale d'Ecologie et de GéographieTropicale
GOZ	Gouvernement zairois
ICRAF	International Council for Research in AgroForestry
IFOAM	International Federation of Organic Agricultural Movement
IGCB	Institut Géographique du Congo Belge
IGN	Institut Géographique National
IGM	Institut Géographique Militaire
IGZ	Institut Géographique du Zaïre
INEAC	Institut National pour l'étude Agronomique au Congo
IRCB	Instiut Royal Colonial Belge
IRAZ/CEPGL	Institut de Recherches Agronomique et Zootechnique de la Communauté Economique des Pays des Grands Lacs
ISEA	Institut Supérieures d'Etudes Agronomiques

IUCN	International Union for the Conservation of Nature and Natural Resources
IZCN	Institut Zairois pour la Conservation de la Nature
JB	Jardin Botanique National de Belgique
KUL-ABIB	Bibliothèque de la Faculté d'Agronomie (KUL)
KUL-ALEO	Département d'Economie Agricole (KUL)
KUL-ILWM	Institut of Land and Water Management (KUL)
KUL-WAAR	Instituut voor Aardwetenschappen (KUL)
KUL-WARD	Instituut voor Sociale en Economische Geografie (KUL)
MAECE	Ministère des Affaires Etrangère et du Commerce Extérieur
MC	Ministère des Colonies
MCBRU	Ministère du Congo Belge et du Ruanda-Urundi
MRAC	Musée Royal d'Afrique Centrale
N-Y	New-york
ORSTOM	Office de la Recherche Scientifique et Technique d'Outre-Mer
ONRD	Office National de Recherche et de Développement
RUGPED	Département de Pédologie Régionale (RUG)
RUG	Rijks Universiteit Gent
SGB	Société Géologique de Belgique
SGC	Service Géologique du Congo
SIFMC	Société Internationale Forestière et Minière du Congo
SNR	Service National de Reboisement
SPIAF	Service Permanent d'Inventaire et d'Aménagement Forestier
UCL	Université Catholique de Louvain
ULB-LBSP	Université Libre de Bruxelles, laboratoire deBotanique Systémathique et de Phytosociologie
ULg fac. Sc.	Université de Liège, Faculté des Sciences
UNAZA	Université Nationale du Zaire
UNIKIN	Université de Kinshasa
UNIKIS	Université de Kisangani
UPPBCB	Union Professionnelle des Producteurs de bois au Congo Belge
USAID	United States Agency for International Development
WWF-UK	World Wildlife Fund United-Kingdom

ANNEXE 4

4 a. AVAILABILITY OF THE DOCUMENT

The first field gives the institution where the document is available referring to the annexe number 3.

Borrowing: Y or N if the document can or cannot be borrowed.
Reproduction: Y or N if the document can or cannot be reproduced.

4 b. ABBREVIATIONS RELATED TO PHOTOGRAPHIC AND PHOTOMOSAIC PRODUCTS

PA	simple aerial photographic
MS	simple mosaic
MC	controlled mosaic
MR	rectified mosaic
BW	black and white
IRC	fasle color intra-red
PAPER	paper support
NE	negative support
PV	glasspaper support

ANNEXE 5

BIBLIOGRAPHIC ABBREVIATIONS

doc. techn.	technical document
j.a.c.	agricultural colonial days (journées agricoles coloniales)
comm.	communication
doct.	Ph.D.
fr.	french
néerl.	dutch (flemish)
art.	paper (article)

ANNEXE 6

ADRESSES OF INSTITUTIONS AND PERSONALITIES VISITED

1. UNIVERSITE CATHOLIQUE DE LOUVAIN (U.CL.)

- Prof. J. Wilmet	3, place L. Pasteur 1348 Louvain-La-Neuve Tel : 32-10/47 28 70
- Prof. C.Evrard	5, Place croix du sud 1348 Louvain-La-Neuve Tel : 32-10/47 34 42
- Prof. P.Louant	3, Place croix du sud Sc, 15D 1348 Louvain-La-Neuve Tel : 32-10/47 37 39
- Prof. P. Giot	2, Place croix du sud 1348 Louvain-La-Neuve Tel : 32-10/47.25.48

2. UNIVERSITE LIBRE DE BRUXELLES (U.L.B.)

- Prof. H. Nicolaï (CEMUBAC) - Prof. J. Lejoly	Tel : 32-2/650 50.76 28, av. P. Heger C.P.169 1050 Bruxelles Tel : 32-2/6502125
- Mr. Bebwa (via Prof. Lejoly J.)	

3. MUSEE ROYAL D'AFRIQUE CENTRALE (M.R.A.C.)

- Mr. Maes - Bibliothèque	Steenweg op Leuven, 13 1980 Tervuren Tel : 32-2/767 54 01

4. Service de Documentation en Agronomie Tropicale et en Développement Rural (SERDAT) et Académie Royale des Sciences d'Outre-Mer (ARSOM)

1, rue Defacqz
1050 Bruxelles
Tel : 32-2/538 29 15

- Mr. Simoens — Tel : 32-2/538 47 7269
- Bibliothèque

5. BIBLIOTHEQUE ALBERT 1ER

4, Bd de l'Empereur
1000 Bruxelles
Tel: 32-2/519 53 11

6. GROUPE SUCRIER

164, Ch. de La Hulpe
1170 Bruxelles
Tel: 32-2/672 03 45

- Mr A.. Gheysen
- Mr M. Litvine

7. BIBLIOTHEQUE AFRICAINE (B.A.F.)

65, rue Belliard
1040 Bruxelles

- Microfiches
- Fichier

8. FONDATION ROI BAUDOUIN

21, rue Brederode
1000 Bruxelles
Tel: 32-2/511.18.40

- Mr. Drachoussoff — Tel: 32-2/343 71 52 (privé)

9. JARDIN BOTANIQUE NATIONAL DE BELGIQUE (J.B.)

Domein van Bouchout
Nieuwelaan, 38
Tel: 32-2/269 39 05
1860 Meise

- Mr. Bambs
- Bibliothèque

10. FACULTE DES SCIENCES AGRONOMIQUES DE L'ETAT

2, Passage Déportés
5800 Gembloux
Tel: 32-81/62 22 24

- Prof. Malaisse

11. WORLD WILDLIFE FUND (W.W.F.)

608, chsée de Waterloo
1060 Bruxelles
Tel: 32-2/347 30 30

-Mr. Duhart
-Mr. Mertens

Tel: 32-2/374 26 58 (privé)

12. KATHOLIEKE UNIVERSITEIT LEUVEN (KUL)

a. DEPARTEMENT D'ECONOMIE AGRICOLE (KUL-ALEO)

Kardinaal Mercierlaan, 92
3001 Heverlee
Tel: 016/22 09 31

-Prof. E.Tollens

Tel: 32-16/22 09 31 ext.1616

-Bibliothèque

Tel: 32-16/22 09 31 ext.1642

b. BIBLIOTHEQUE DE LA FACULTE D'AGRONOMIE (KUL-ABIB)

Kardinaal Mercierlaan, 92
3001 Heverlee
Tel: 32-16/22 09 31 ext 1525

c. CAMPUSBIBLIOTHEEKDIENST EXACTE WETENSCHAPPEN

Dialog International Retrieve Service:
AGRIS (International data base coordinated by FAO, for agricultural sciences and technlogy, with references of non-US origine since 1975), PASCAL (data base produced by the "Institut de l'Information Scientifique et Technique of the French National Research Council since 1973) and CAB(data base comprising references of journals published by Commonwealth Agricultural Bureaux since 1972)

Celestijnenlaan 300 A
3001, Heverlee
Tel: 32-16/28 62 11
ext. 2494, 2560, 2557

d. INSTITUT FOR LAND AND WATER MANAGEMENT (KUL-ILWM)

- Prof. H. Eerens

Vital Decosterstraat 102
3000 Leuven
Tel: 32-16/23 13 81

e. INSTITUT VOOR AARDWETENSCHAPPEN (KUL-WAAR)

Redingenstraat, 16 bis
3000 Leuven
Tel: 32-16/ 22 69 20 ext.53

f. INSTITUUT VOOR SOCIALE EN ECONOMISCHE GEOGRAPHIE (KUL-WARD)

13. RIJKS UNIVERSITEIT GENT (R.U.G.)

DEPARTEMENT DE PEDOLOGIE REGIONALE (RUGPED).

- Mr. Baert (via Prof. Van Ranst)

Geologish Instituut
Krijslaan, 281
9000 Gent
Tel: 32-91/644631

14. AGENCE GENERALE DE LA COOPERATION AU DEVELOPPEMENT (A.G.C.D.)

- Mr. Risch

Place champ de Mars, 5157
Building AGCD, 12è étage
Tel: 32-2/519 06 75
1050 Bruxelles

15 INSTITUT GEOGRAPHIQUE NATIONAL (IGN)

13, Abbaye de la Cambre
1050 Bruxelles
Tel: 32-2/648 64 80

16. EUROSENSE (EURO)

- Mr Jadot

av. des Nerviens, 54
1780 Wemmel
Tel: 32-2/460 70 00

17. COMMISSION DES COMMUNAUTES EUROPEENNES(CCE)

- Mr. E. Pironio

CCE/ DG 8-bâtiment G12
12, rue de Genève,
Bruxelles
Tel: 32-2/299 25 76

APPENDIX 2

THE CURRENT STATE OF REMOTE SENSING DATA TO SUPPORT CLIMATE CHANGE RELATED STUDIES FOR CENTRAL AFRICA AND THE CRITICAL DATA GAPS.

1 Satellite derived climate data

Satellite derived data sets of geophysical parameters are starting to be developed as part of a new NASA focus titled Mission to Planet Earth (Wilson and Huntress, 1991). The data sets are at global and regional scales and include central Africa. The data sets are derived from the current suite of satellite sensing systems and are precursors to improved data sets planned from the next generation of sensors on board the Earth Observing System planned for launch in 1998. The objective of Mission to Planet Earth is to better understand global change and provide information to support policy making. These data sets include some important climatic variables and provide the means to improve parameterisation of both global and meso-scale climate models.

The International Satellite Cloud Climatology Program (ISCCP) has since the early 1980's generated a cloud climatology for the region using geostationary and orbital satellites (Rossow, 1991). Cloud and aerosol properties are also generated on an operational basis by NOAA (Stowe, 1991). Radiation budget data at regional and continental scales can be obtained using satellite data (Jacobowitz, 1991). Several studies have demonstrated a technique for deriving albedo data for Africa using visible reflectances (Arino, 1990, Dedieu et al., 1987) . The meteorological satellites NOAA-Advanced Very High Resolution Radiometer (AVHRR) and Meteosat are generally used for generating albedo maps (Wydick et al., 1987). Global albedo changes due to anthropogenic modification have been analyzed by Gornitz (1987). Estimation of albedo with an accuracy of 2% by vegetation type is required for global climate change models with a recommended grid cell size for the primary data of 10 X10 km cell (IGBP-DIS, 1991). Comparisons of the reflected solar radiation derived from AVHRR and the NASA Earth Radiation Budget Experiment (ERBE) datasets have been initiated and the best estimation of albedo will be computed (NOAA, 1991). Satellite derived land surface temperature data sets have been generated for Senegal from Meteosat data (Assad, 1986). Currently a working group of IGBP-DIS is defining the algorithms needed to generate a global surface temperature data from NOAA AVHRR data (IGBP-DIS, 1991).
A global dataset on temperature anomalies and albedo in a digital format can be obtained from GRID/UNEP in Nairobi.

Improvements to global climate models are currently being made by introducing biosphere/ atmosphere interactions (Sellers and Dorman, 1987, Dickinson, 1984). Improved global land cover data sets are being generated for this purpose using data sets of monthly vegetation indices derived from the NOAA-AVHRR (Townshend et al., 1985). These AVHRR vegetation index data which include central Africa provide a ten year data set from 1981 to the present and are being used to provide a measure of primary production and the associated water and energy fluxes.

Satellite derived estimates of rainfall for Africa are currently being used by UN/FAO as part of their food security early warning program. (Snijders, 1991). These

estimates are generated from high temporal resolution Meteosat data using a cloud top temperature correlation technique (Milford and Dugdale, 1986). Accuracy assessment of the technique is currently underway (Snijders, 1991). NASA is currently embarking on a Tropical Rainfall Mapping Mission (TRMM) which will provide improved measurement of tropical rainfall. This mission due for launch in 1995 will include two microwave radiometers, a precipitation radar and a coarse resolution imager (NASA, 1991a). Data from the mission will provide estimates of rainfall rates and data to better modeling of cloud and rainfall processes.

2 Satellite derived data on gases and particulates

Satellite measurement of trace gases is in an early stage of development although some new sensing systems are planned for the second NASA platform of the Earth Observing System (EOS) to be launched in 2001, which will improve current data availability significantly. At present there are a small number of global or regional data sets and a series of data analysis methods which are currently under development. For example, global data sets of ozone distribution are available from the Total Ozone Mapping System (TOMS) which provides an estimate 15-20 DU (Dobson unit) higher than ground measurement (Chesters, 1991). A technique to map tropospheric ozone to better than 10% in the tropics has been developed by Fishman et al., (1990), using data from two satellite systems.

A technique to estimate the distribution of water vapor using the thermal channels from the NOAA-AVHRR is presented by Justice et al., (1991), although comprehensive data sets for central Africa using this technique have yet to be generated. Similarly, methods for estimating aerosol loadings applicable to this region have been developed using visible and near infrared sensors by Kaufman et al., (1990).

In August and September of 1992 there was an international program aimed at measuring the emission products of savanna burning from central and southern Africa. As part of this study NASA conducted a boundary layer experiment similar to the ABLE mission collecting airborne gas measurements from Africa south of the equator (NASA, 1991b).

3 Satellite derived resource data

3.1 Satellite data availability for resource studies

3.1.1 Visible/Optical systems

In this section we review the current and historical availability of data from satellite remote sensing systems which are relevant for terrestrial remote sensing. Satellite data availability is a problem for the region. The longest record of data is from the Landsat system which was launched in 1972 (Freden and Gordon, 1983). In the early years of the program there was an effort by USGS who was running the Landsat program to provide complete cloud free global coverage of the region using on-board tape recorders. 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 capability. The South African receiving station is actively acquiring Landsat data of the region and has been since 1982. However, their reception is limited to the extreme southern extent of the

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central African region, below five degrees south. Although a Landsat receiving station was proposed for Nairobi this was never established and as a result data coverage for the region has been largely limited to data collected by the on-board tape-recorders on a by-request basis. The small amount of remote sensing studies performed within the region over the last twenty years has resulted in very few requested acquisitions and poor data availability. The multiyear Landsat MSS coverage is shown in figures A2.1a-q.

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 prohibited the use of the data, to a large part of the potential user community, owing to the low level of funding available to national resource monitoring agencies and university researchers. Although there were significant improvements in Landsat data quality and the addition of a higher resolution (30 m) sensing system known as the Thematic Mapper (TM), these data are effectively too costly and systematic regional coverage has not been acquired. We are now facing a possible new development in the pricing of Landsat data and the operation of future Landsat systems which may lead to an improvement of data policy, providing data at the cost of reproduction for non-profit organizations (Brown, 1991). This could lead to a major improvement in future Landsat data availability for the region.

The SPOT satellite has been acquiring high resolution (20 m multispectral and 10 m panchromatic) data since its launch in 1986 (Harris, 1987). SPOT data of the region (figure A2.2) were not acquired on a systematic basis. Hence, the historic database represents a patchwork of images acquired during different times (figures A2.3a-f). The SPOT panchromatic data seems to be the popular choice for conducting high resolution studies such as urban mapping, however, its high cost and relatively low areal coverage (60km by 60km) prohibit its widespread use for large area applications. Also, it is important to note that the cloud cover estimates, provided in the metadata by SPOT Image Corporation, often under-estimate the cloud cover. As a result, it is recommended that one visually inspect the data before purchasing it.

The Japanese Earth Resources Satellite (JERS-1), was launched in February 1992 (NASDA, 1992). The JERS-1 is acquiring multispectral (seven channel) high resolution (18 m). At the time of writing there are no JERS-1 receiving stations in Africa, however, the satellite does have an on-board tape recorder capable of recording data for transmission when the satellite passes over a receiving station. JERS-1 coverage of central Africa has been ranked as a second priority; however if there is a strong interest to acquire data for this area, it may be possible to increase the priority. ERS-1 provides a similar microwave capability, however, there is currently no means of collecting data over central Africa.

The NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite sensing system provides daily global coverage at a resolution of c. 4 km, with local coverage of 1km available on request (Justice et al., 1985), its high temporal resolution makes it attractive for regional to global scale environmental monitoring. These data are available from NOAA (See section 5.1.1) or from the European Space Agency (ESA) at Frascati (Italy) for the High Resolution Picture Transmission (HRPT) acquired at the receiving station of Niamey (Niger) and Nairobi (Kenya) (TREES, 1991). A global dataset of normalized difference vegetation index (NDVI) data derived from the visible and near-infrared channels has been created using the 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 is given in figure A2.4.

The Soviet Soyuz Carta satellite is the only commercial satellite system using

photographic cameras for its primary data collection. The two camera systems most frequently used are: the KFA-1000 (5 m) and MK-4 (4 m). These data are acquired primarily on a by-request basis (Minshew, 1992). The archive for central Africa is minimal although there is very good coverage for southern Africa (south of 7 degrees south latitude). Because of high acquisition costs and the unavailability of a digital products, these data have not been a popular choice among people working in the region.

3.1.2 Microwave sensors

Radar sensors provide the capability of cloud free coverage and will afford a considerable advantage for tropical remote sensing. Radar sensors which are currently operational include the European Remote Sensing Satellite (ERS-1), the Japanese Earth Resources Satellite (JERS-1), and the Soviet Almaz satellite. A number of 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 of this region will not be collected (Fea, 1991). The purpose of the JERS-1 satellite is primarily to obtain information related to non-renewable resource exploration, although the scope is being expanded into other disciplines such as environmental monitoring (Kodaira et al., 1987). The Soviet Almaz radar data are being distributed Hughes STX Satellite Mapping Technologies (Lanham, Maryland). The data has a resolution of 15 meters and will be recorded on a by-request basis (Space Commerce Corporation, 1991). Due to the high cost of this data ($0.90/km2) it is unlikely that this data will be used for regional studies.

3.1.3 Future remote sensing systems for climate change studies.

Several new sensing systems are currently being developed which will provide data continuity and in some cases lead to improvements to the current suite of land sensors. There are plans to improve the sensor compliment for SPOT 4 planned for launch in 1996. SPOT 4 will include a vegetation monitoring sensor with a spatial resolution of c. 1.6 km which will give global coverage every two days. This instrument will give improved calibration over the current AVHRR optical sensors.

Landsat 6 is planned for launch in late 1992 and will carry an Enhanced Thematic Mapper (ETM). The ETM will include a 15m panchromatic band. The sensor package for Landsat 7, which is planned for launch in 1998 is currently being reviewed by NASA. At the time of writing this report, major changes are taking place concerning the management of the Landsat program. These changes will lead to NASA and Department of Defense (DOD) taking joint responsibility for the Landsat program and will include an easier data policy for those using Landsat data for global change research.

Minor improvements are planned for the AVHRR's on the NOAA K,L,M series of platforms which will be launched starting in 1994. The AVHRR's will be upgraded to six channel instruments with an additional channel at 1.6um, plus a split gain in the optical channels to give higher radiometric resolution (Hussey et al., 1991). Current operating plans for discontinued daytime coverage for the 3.75um channel will result in a reduced capability fire monitoring.

A new microwave sensing system which is planned to be launched in 1994 is the Canadian Radarsat. Radarsat will be a commercial satellite and will have C band (5.3GHz) radar with a ground resolution range from 10 m to 100 m. In addition, Radarsat will have on-board tape recording capability which will enable complete coverage of the central Africa region to be acquired (Radarsat International, 1991).

The current focus by the international science community on global change has been matched by new initiatives from the space agencies to provide sensors capable of improving our understanding of climate change. The biggest program in this respect is NASA's Mission to Planet Earth (NASA, 1988), which will include new satellite sensing systems designed to monitor land surface, atmosphere and oceans. The Earth Observing System (EOS) is an international program which will provide a series of polar orbiting platforms with multiple sensing systems starting 1998. Perhaps the most relevant for central Africa climate change research will be the Moderate Resolution Imaging Spectrometer (MODIS) which will provide daily data at 250m, 500m and 1km. The MODIS is designed to monitor land transformations, aerosol properties and has a sensor designed specifically to monitor fires (Salomonson et al., 1989). Prior to the launch of EOS, NASA is planning some smaller satellite missions including the Tropical Rainfall Measuring Mission (TRMM) (NASA, 1991a).

4 Current use of remote sensing for resource studies for central Africa

This section addresses the general status of the use of remote sensing data within the central African region and includes a summary for each country on remote sensing projects and their status (table A2.1). The country reports are by no means comprehensive but are intended to give the reader an indication of the types of remote sensing studies currently being undertaken in the region. The information was collected during a number of brief visits to some of the pertinent agencies in the region. The authors welcome any additional information concerning oversights or misrepresentation.

As with most developing countries, central Africa has been exposed to satellite remote sensing technology over the twenty year history of the United States Landsat program and more recently with the development and promotion of the French SPOT system. Several government and university staff from the region have undergone training courses sponsored by international agencies such as UN/FAO, but the technology transfer to central Africa has been slow and largely ineffective at developing operational use of the data by government agencies. This speaks more to the inadequacy of the approaches to technology transfer, than to the potential utility of the satellite data for environmental monitoring (Prince et al., 1990). There is no regional remote sensing center for central Africa although some training for the region has been provided by the Sahelian Remote Sensing Center, CRTO at Ougadougou.

The national forest monitoring agencies have had exposure to remotely sensed data but are currently using high resolution data only to a very small degree. The primary task of these agencies is to provide conventional timber inventories of selected areas, usually in support of a proposed logging concession. The conventional tools of aerial photography and ground survey provide the basis for this work. In some cases historical aerial photography from the 1960's provides the only source of imagery used for these studies. The information currently required for conventional timber inventories cannot be readily obtained from the available remote sensing data and subsequently remote sensing is seen as being of secondary importance to the forest inventory agencies. In addition to local scale timber inventories the national forest agencies are tasked with providing national statistics on forest area and deforestation rates to the UN/FAO for their ten-year global Tropical Forest Assessment (TFA). This latter task of providing accurate global estimates has in general received little attention from the countries within the region due to very limited resources to improve upon the historical statistics. For the 1990

Assessment FAO is making an effort to include remote sensing methods. The " Service Permanent d'Inventaires et d'Aménagement Forestiers" (SPIAF) of Zaire is playing an active role in supporting FAO's sample approach to estimating deforestation rates from the region through visual interpretation of multitemporal Landsat data.

Perhaps the most important long-term contribution from remote sensing at this time would be to provide the basis for national and regional forest management, planning and monitoring. Landsat data could be used to provide a regional forest map base for the planning of timber concessions and preserved areas. Similarly logging companies could be required to provide yearly maps on the extent of their logging activities on ortho-photo satellite base maps (see Section 5.1.4). A geographic information system which would include national and regional maps of forest type derived from satellite data, past, current, planned timber concession, past inventories, national parks and reserves, road and navigable river networks would provide an important basis for improved forest resource management.

In central Africa, where there are still large forest resources, it is important to establish in a timely fashion, the best possible national inventory prior to logging and agricultural expansion rather than after the fact. It is interesting to note that, outside the region, in the Ivory Coast where extensive logging has seriously depleted the primary forests of the country, the National Remote Sensing Center is currently using high resolution satellite data to identify the remaining forested areas. A wall-to-wall map for the country at 1:100,000 has been produced using recent TM and SPOT data. In addition the National Remote Sensing Center is starting to use multi-date TM data to monitor agricultural encroachment into the protected reserve of Maraouhe, as a basis for improved management. Clearly there would be distinct advantages for the central African forest agencies to produce similar up-to-date inventories and monitoring, prior to extensive logging.

In central Africa Landsat data are available to all government agencies however the timeliness of the data and coverage are severely limited. Procedures for data interpretation rely primarily on visual interpretation techniques. Little of the recent developments in image analysis and processing are available to the potential user community within the region. It should be noted that it is these countries where inventory and monitoring of natural resources are at an early stage of development and implementation, that high spatial resolution satellite remote sensing has the most to offer. It is also appropriate to say that resource management in general is given a low priority within the region in terms of financial support and the agencies responsible for resource inventory and monitoring are unable to afford the costs associated with using the new technology. In particular the data costs associated with the commercialization of high resolution space data has effectively restricted the use of the data within the region and is currently one of the biggest obstacles to effective use of the technology.

There are several international activities within the region which are currently underway or in the planning stage which will result in increased availability and use of remote sensing data for the region in the near future.

In the United States an interagency collaboration between NASA, the United Sates Geological Survey EROS Data Center (EDC) and the Environmental Protection Agency (EPA) have initiated a project as part of the Earth Observing System Pathfinder Program to provide an estimate of deforestation rates for the dense humid forests of the Amazon, south-east Asia and central Africa. The project will provide deforestation rates for the entire region using data from three epochs (1973, 1985, 1993) using available Landsat MSS and TM data. An integral part of this project will be a major new Landsat data acquisition for the central African Region. A proposal which involves participation

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by NASA, USGS and USAID is currently under review by the World Bank Global Environmental Facility (GEF) to acquire complete Landsat Thematic Mapper data for central Africa during 1992 and 1993. The proposal includes provision for improved data availability within the region. The data will also be used by the national GEF projects in the region and their affiliated agencies and institutions. An additional US interagency collaboration between NASA and EPA is addressing research aspects of the carbon cycle which include a study of biomass burning emissions from west and central Africa.

The UN/FAO has proposed a program of Continuous Tropical Forest Assessment which will follow on from the 1990 Assessment using a sampling strategy and Landsat data (FAO, 1992). The details of the program have yet to be fully developed but the current proposal includes the development a regional center for central Africa to provide technical backstopping and coordination for the program.

The International Geosphere Biosphere Program (IGBP) provides an international focus for global change related science. The program consists of a number of Core Projects which address various aspects of climate change including hydrology, terrestrial ecology, atmospheric chemistry and global modeling (IGBP, 1990). An additional focus of the program is to provide support for the data requirements of these projects The IGBP Data and Information System (DIS) is currently performing this task. Of particular interest for the central African region is the IGBP-DIS data initiative to produce a global 1km AVHRR data set and to make this readily available to the research community (IGBP, 1992). The data set will be used to generate derived products for fire monitoring and land cover mapping. In addition IGBP-DIS has a working group tasked with producing a global land surface temperature data set

4.1 Country Status for Cameroon:

Remote sensing activities are in an early stage of development in Cameroon. The main organizations concerned with remote sensing are "Office National et de Développement des Forêts"(ONADEF), the "Organisme de Recherche Scientifique et Technique Outre-Mer"(ORSTOM), the Geography Department of the University of Yaoundé and Dshang University.

Several years ago ONADEF acquired an almost complete set of Landsat MSS imagery for the country (table A2.2). Current research at ONADEF (Mr. Temgoua: Director) is being undertaken in collaboration with the Canadian International Development Agency (CIDA) through a consulting firm Poulin Thériault Agency (table A2.3). They have undertaken mapping of the vegetation types of Cameroon using the Landsat data at a scale of 1/200.000. This map is currently unavailable and is being produced by the Canadian Company "PHOTOSUR". There are currently no plans to publish this map. ONADEF is also working on a land use map of Southern Cameroon at scales of 1:200,000 and 1:500,000. These maps will be available at the end of March 1992 from the Cameroon Ministry of Planning. The map was generated using several of the currently available thematic maps for the country. The resulting land use map may be digitized during the next phase of the Canadian assistance to ONADEF. This map will form the basis for the government forest management plan for the southern region of Cameroon. As part of the map generation, remotely sensed data were used to up-date the existing demographic data from the 1987 Census. ONADEF plans to organize a Laboratory of Remote Sensing which will be combined with their Laboratory of Cartography to support satellite image analysis for land cover change assessment. The exact details concerning this laboratory have yet to be decided. At the beginning of 1993 funds will be allocated to ONADEF for this purpose by CIDA.

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At the Geography Department of Yaoundé University (Mr. Tsalefac) is currently involved in a project entitled "A climatic survey of Cameroon by satellite". This is a collaborative project with ORSTOM and the Center for Space Meteorology (CSM) in Lanion, France. As part of this collaboration, a Meteosat receiving station is planned for installation at Yaoundé Airport and a remote sensing center will also be developed. This project will be funded by the French "Fond d'Aide à la Coopération" (FAC). ORSTOM also has a project on Forest Soil Cartography in the south of Cameroon, using airborne radar imagery (Director: Mr. Seyler). The flight campaign will be funded by FAC and is planned for 1992.

At the University of Dshang, (Mr. Chevalier, French Cooperation) is using SPOT imagery (SPOT reference: 081-339) to perform supervised classification of vegetation types. The vegetation classes used for this work are: high altitude forest, swamp forest, riparian forest, savanna and degraded formations.

In general, within Cameroon there are a few individuals who have been trained in remote sensing techniques and if the current and planned projects continue, there will be the necessary manpower resources in-country to sustain the developing programs.

4.2 Country status for Zaire

ERTS Zaire , the national remote sensing center (Director: M. Mukonki) was established with US/AID support in 1972 and remains active in satellite data analysis. UNDP is currently supporting this activity.

Remote sensing activities started at SPIAF (Director: Y. Ipalaka) in May 1985 with a national Landsat forest mapping project (Project de carte de synthèse du Zaire) in collaboration with CIDA. The project had a budget of $1,000.000 /year from 1976 to 1991. The objective of this map was to give a reference document to develop a national forest management plan. In this project 130 LANDSAT images at different scales and from different time periods were visually interpreted (88 images at 1/250.000-12 images at 1/200.000 and 30 images at 1:400.000) according to the SPIAF classification. The results of this project are given in table A2.4. The output of this project was to be regional maps at 1:1,000.000 scale for each province and one national map at 1:2,500,000 scale. Due to budget restrictions, the final product planned for 1992 has been delayed. The maps are being finalized in Canada but are unavailable to the public. In parallel, since 1985 several local forest maps have been produced using LANDSAT and SPOT images. There is a lack of recent aerial photography which was compounded by the loss of the historical national air-photo archive during a fire in 1984 at IGN, Zaire. Copies of the first comprehensive aerial photographic survey (1954 - 1959) can be found in Belgium .

SPIAF is actively participating in the UN/FAO global Tropical Forest Assessment producing the deforestation estimate for central Africa (SPIAF, 1992). This project started in 1991 is nearing completion. Sample MSS data from two dates were visually interpreted and a dot matrix approach was used to extract estimates of deforestation. The methodology used by FAO to obtain their deforestation estimate is discussed in section 5.1.3.2.1

A restructuring of SPIAF is currently being planned using World Bank funding (budget $1,000,000). The proposed structure will create two new divisions : Ecologic & Biologic studies and a Remote Sensing and Mapping division, in addition to the existing Inventory division.

4.3 Country status for Congo

Remote sensing activities are currently non-existent in the public domain. Private logging companies have used remote sensing imagery but at present, there are no facilities for remote sensing in Congo. The "Centre de Recherche Geographique et de Production Cartographique" (CERGEC-Director: Mr. Engolt) plans to install a remote sensing laboratory in the framework of a proposed project named CARTIS (Cartographie par Traitement des Images Satellitaires) which is being undertaken in collaboration with IGN France. The laboratory will be financed through FAC. Panchromatic SPOT imagery will be used to produce new topographic maps at 1:50,000 scale. The French counterpart for this project is Mr G. Marcel (IGN). In the framework of national GEF (Conservation and management of protected areas) support will be given to the progressive instalation of a GIS for managing the protected areas. In addition, a project concerning problems of erosion in the coastal zone will be financed by Canada (CRDI -International Center for Development and Research). Currently CERGEC has five personnel who have undertaken remote sensing courses at CRTO in Ouagadougou and GDTA in France.

In the framework of the Natural Resources Management Project (PRGN), CIDA financed a Canadian consultancy firm Poulin Thériault to make a survey of existing data for resource management and study the potential utility of radar imagery for vegetation studies.

The UN/FAO Tropical Forest Action Plan is currently reviewing a proposal to develop a landuse map for Congo at 1:250,000 using remotely sensed data. The LANDSAT coverage for this project may be obtained through the World Bank Global Environmental Fund (GEF) where a project for acquiring complete Landsat Thematic Mapper data for central Africa during 1992 and 1993 has been proposed by NASA, USGS and USAID.

4.4 Country status for Gabon

Until recently remote sensing activities in Gabon were undertaken only by private companies such as British Gas, which has produced a Land-use map of Abanga (South of Kango-North Lambaréné) at 1:100,000 based on a radar survey. This study has involved the participation of the Herbier National. Recently at OPT (Office Poste and Telecommunication) a remote sensing laboratory has been installed under the initiative of Mr. A. Hussard with a FAC budget. The OPT project has three objectives: training and outreach, integration of remote sensing in national research and development programs and remote sensing information management. The priority projects are: forest mapping and continuous survey of natural resources. They also intend to integrate remote sensing into the National Environmental Action Plan (NEAP).

The Institut Cartographique National is planning to use SPOT imagery and aerial photography at 1:5,000 to make an urban development plan for Libreville.

5 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. From the twenty year archive of the Landsat data it is possible to piece together almost complete coverage of the region

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but the landuse change which has occurred during this period makes the early data inappropriate for assessing the current conditions. The lack of comprehensive data coverage stems in a large part from the lack of an effective data acquisition policy for the region over the past several years. The persistent cloud cover for the region compounds the problem and is one that cannot be overcome by optical sensing systems. Such comprehensive coverage would satisfy many of the current needs for example for cartography and land cover mapping and would provide the basis for long term monitoring of land cover change. There is nothing that can be done to improve the historical record for the region, but 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 acquisition policy by the organizations acquiring data for the region are currently dictated by data orders. We therefore need a comprehensive data order for central Africa to improve the current lamentable 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 GEF Landsat proposal mentioned above may provide a partial solution to this current problem and would lead to a comprehensive acquisition policy for 1992/3 and 1997/8. Similarly the NASA Landsat Pathfinder initiative described above (section 4) will sort and 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. Just because data exist does not mean that those who need the data can afford to obtain them. This brings to the fore the questions of data pricing and copyright which account for some of the current obstacles to the use of satellite data. The recent reduction in price of historical Landsat data of more than two years old to the cost of reproduction, has resulted in some improvement to the cost problem. It is also difficult for researchers to obtain a clear understanding of the current data availability. Information concerning the historical coverage of Landsat and SPOT data is available from EOSAT, EDC, SPOTIMAGE and the South African Council for Scientific and Industrial Research (CSIR), however 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 a partial listings of the regional AVHRR data availability residing with NOAA, CSIR and ESA. A regional information center providing an up-to-date inventory of data availability would be a most 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 and facilitate access to foreign data centers and collaboration between national agencies.

When planning remote sensing projects it is important to obtain information on previous remote sensing projects undertaken in the region and on other projects currently underway. The experience gained by current and previous studies can be 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, naming a point contact would be a useful addition to the current dearth of information.

The cloud cover problem for optical sensors would indicate the potential utility of microwave data. ERS-1 is currently unavailable for the region. However, it will be sometime before the applications research and development will enable the operational

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use of this data for regional mapping. The ERS-1 applications research currently planned for other tropical forest regions will provide the basis for use of these data when they be made available for central Africa. There are plans to develop a portable ERS-1 ground station which could in principle collect data 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 carbon budget for the region it is necessary to combine remote sensing derived deforestation rates with a map of forest type and representative biomass estimates for each forest type. It is therefore important when developing a strategy to fill current data gaps, to examine remote sensing data needs in the context of achieving specific research or management objectives. Remotely sensed data alone will provide the answer to very few of the pressing climate change related questions which are inherently interdisciplinary.

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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.
	2-University of Dshang	Land use maps (R-P)	SPOT(scene ID:081-339) (F)(L)	(D+A+G)	-people are in training
	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	-ONADEF wants to initiate RS activities linked to forest survey
	5-ONADEF	Population density maps for South Cameroon	MSS (P)	D	
ZAIRE	6a- SPIAF	Synthetic maps of Zaire "Routine "forest map production	MSS from1974 unitl 1989 (N)	A	-Complete coverage of historical MSS imagery
	6b-SPIAF	Deforestation rate in Central Africa	MSS & SPOT (L)	A	-problems of budget due to political instability
	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
	7b-CERGEC	potentially SPOT/MSS images for erosion process detection	SPOT/MSS -Coastal Zone	?	-will to start RS activities - training planned
	7c-CERGEC	CARTIS & RS laboratory installation	SPOT+ aerial photos	?	-people are active in RS with the NEAP and GEF
	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 Environemmtal 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.

Table A2.2

Landsat MSS data available at ONADEF for the forest domain and transition zone
(Transparencies at 1/1,000,000 scale)

Landsat row and path	dates
183-57	14 Nov. 86
183-58	11 Jan. 85
184-56	26 Dec. 86
184-57	23 Dec. 86
184-58	13 Feb. 85
185-56	30 Dec. 86
185-57	15 Jan. 87
186-56	22 Jan. 87
187-56	29 Jan. 87
187-57	13 Jan. 87

Table A2.3

TECHNICAL AND MATERIAL SUPPORT TO THE "CENTRE NATIONAL DE DÉVELOPMENT DES FORÊTS (CENADEFOR)" AND "THE DIRECTION DES FORÊTS", REPUBLIC OF CAMEROON

CLIENT

- Canadian International Development Agency (CIDA) and the Government of Cameroon

YEAR

- 1985 - 1992

TYPE OF SERVICES

- Design and execution of a forest inventory program in order to expand the forest resource biophysical data bank and to work out a forest management plan.
- Setting of means to technically support small and medium size forestry firms as prescribed by the national policy on that matter.

DESCRIPTION OF PROJECT

- Fully operationalize the "Direction des Inventaires et Aménagement" by carrying out :
  - reconnaissance surveys ;
  - management-volume and pre-investment inventories ;
  - logging inventories supervision and control ;
  - classified forests management plans.
- Ensure a firm back-up to the "Direction des Forêts" full range of responsibilities : planning, management and control of forest resource uses.
- Ensure a constant back-up to the CENADEFOR's "Direction de la Promotion et des Industries du Bois" fields of activities :
  - marketing of wood and wood products ;
  - specialized training of forestry personnel ;
  - forest industry development with special reference to small and medium size Cameroon firms.
- Carry out technical specifications for the sawmilling training centre, a pilot forest logging operation, a yard of tree logging equipment for rental, inclusive of an equipment maintenance and repair shop.

- Establish a training Centre specialized in logging and in sawmilling to support one of CENADEFOR's objectives : the development of a sawmilling training school and of a pilot logging site.

- Ensure the complete servicing of :

  - the training Centre equipment ;

  - the forest engineering yard equipment ;

  - the CENADEFOR's vehicles.

- The equipment provided to the small and medium size forestry enterprises according to the Canadian support program on that matter, along with on-duty training of their heavy equipment mechanics.

- Provide direct technical support to small and average size forestry firms :

  - assistance to the establishment of an average size sawmill and to its wood supply delivery schedule ;

  - expansion of on-going sawmills ;

  - overall upgrading of forest logging practices.

- Ensure purchasing agent services for the entire project : radio-communication system, various technical material, repair shop equipment, office supplies and equipment to enhance the forest industry performance.

- Plan a period of instruction chronogram for the CENADEFOR's and Forest Direction executive personnel coming to Canada to upgrade their on-duty training : logistics, supervision, control, follow-up.

- Coordinate from Canada the project execution chronogram as well as the administrative and technical activities.

- Ensure in Cameroon, the complete management and control of the project : detailed planning, adequate administration, close coordination and follow-up, public relations responsibilities.

Table A2.4

Preliminary results of the SPIAF satellite image interpretation of forest classes (SPIAF, 1992):

FORMATION VEGETALE	SUPERFICIE (KM2)	% FORET	% TERRITOIRE
FORET DENSE HUMIDE	872.251,16	68,14	37,20
FORET DENSE DE MONTAGNE	38.612,39	3,01	1,65
FORET DENSE TROPOPHILE	51.946,17	4,06	2,22
FORET DE GALERIE	2.500,08	0,19	0,11
FORET DE MANGROVE	555,57	0,04	0,02
FORET CLAIRE (MIOMBO)	102.225,61	7,99	4,36
FORET SECONDAIRE	121.670,70	9,50	5,19
FORET DE BAMBOU	1.666,72	0,13	0,07
FORETS MARECAGEUSES	88.614,05	6,92	3,78
TOTAL FORET	1.280.042,46	100,00	54,59
MOSAIQUE FORET-SAVANE	165.838,83		7,07
NON INTERPRETE	67.502,24		2,88
PLANTATIONS	555,57		0,02
SAVANES	768.358,82		32,77
EAU	62.502,07		2,67
TOTAL	2.344.800,00		100,00

Figure A2.1a

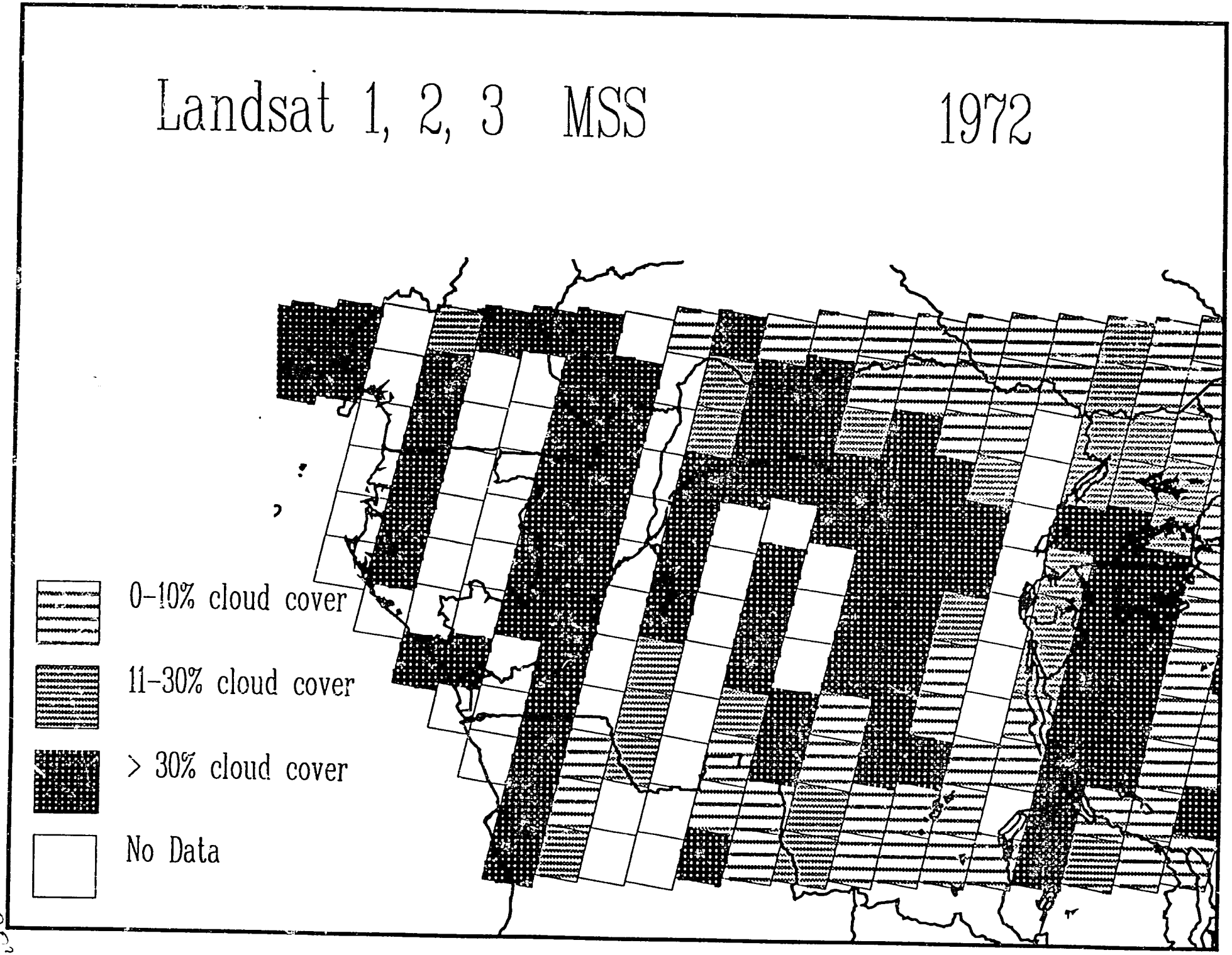

Landsat 1, 2, 3 MSS
1972
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1b

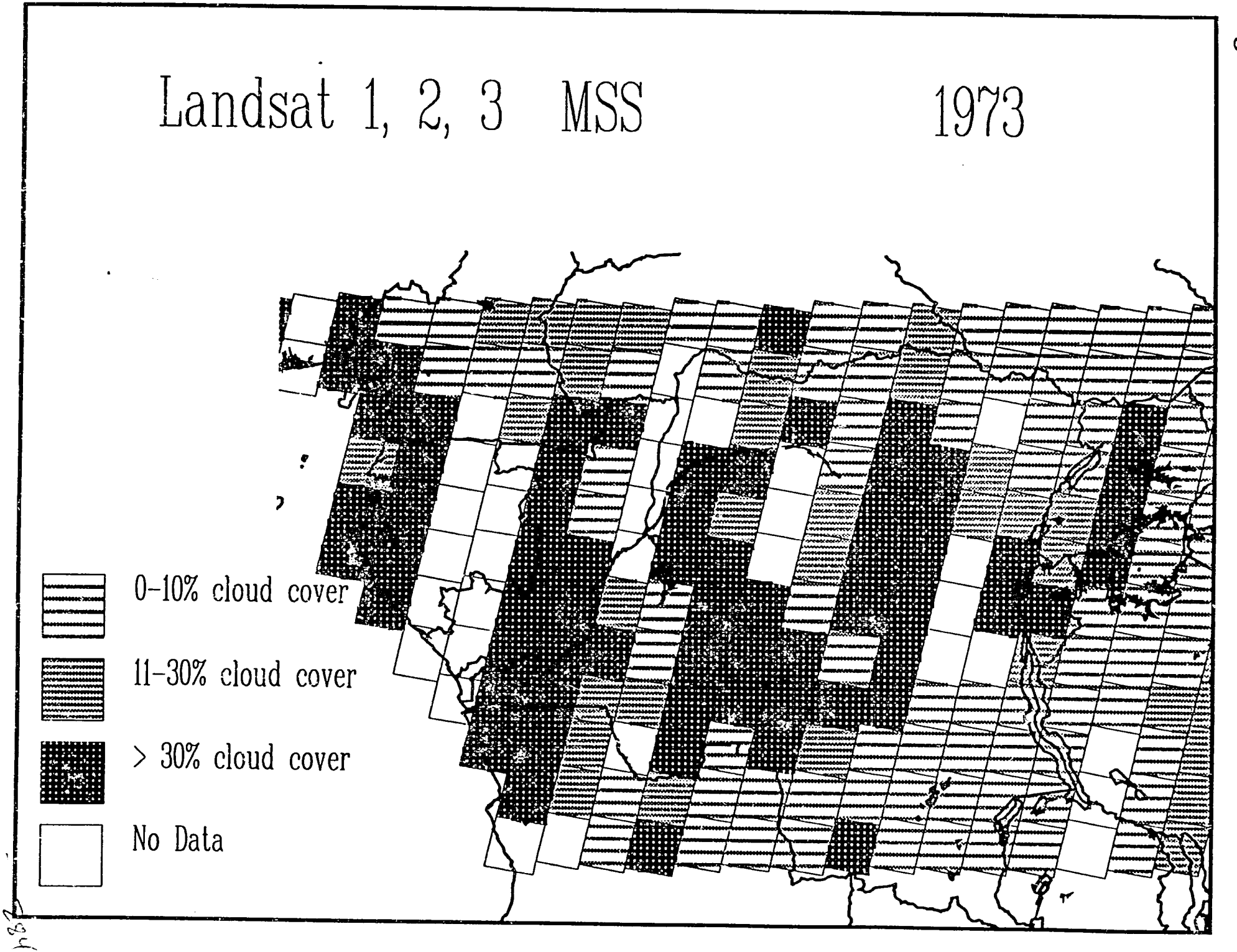

Landsat 1, 2, 3 MSS 1973
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1c

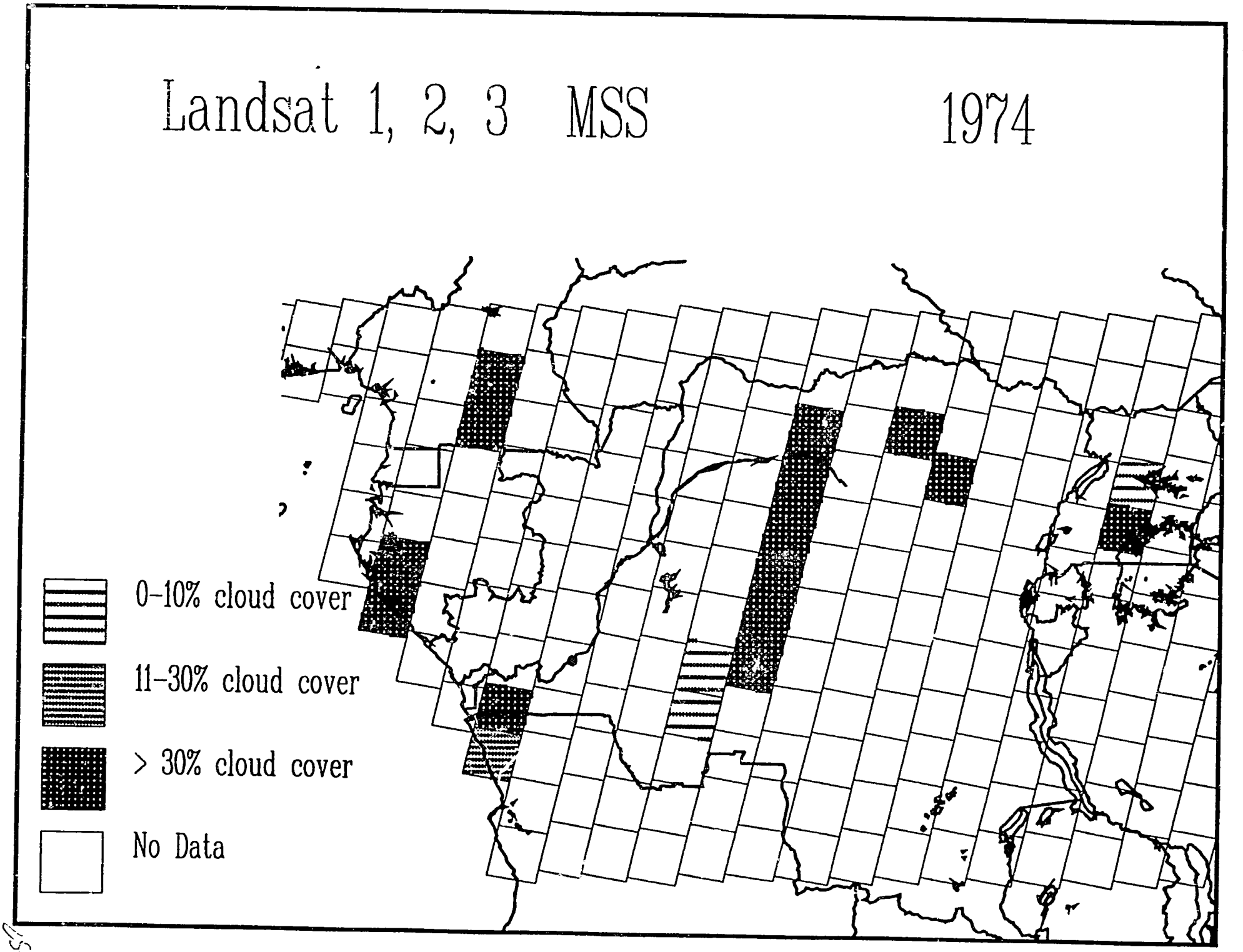

Landsat 1, 2, 3 MSS 1974
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1d

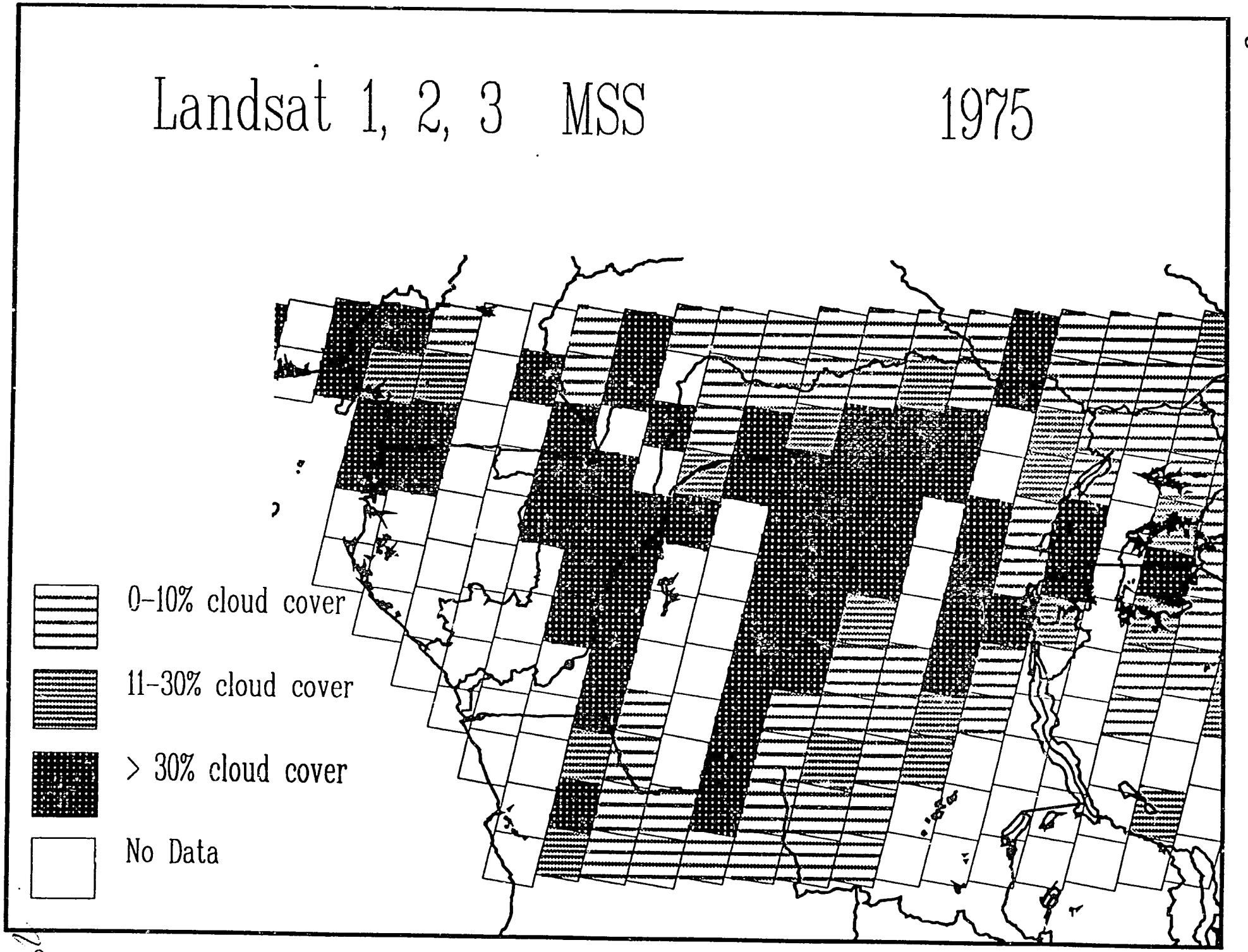

Landsat 1, 2, 3 MSS 1975
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1e

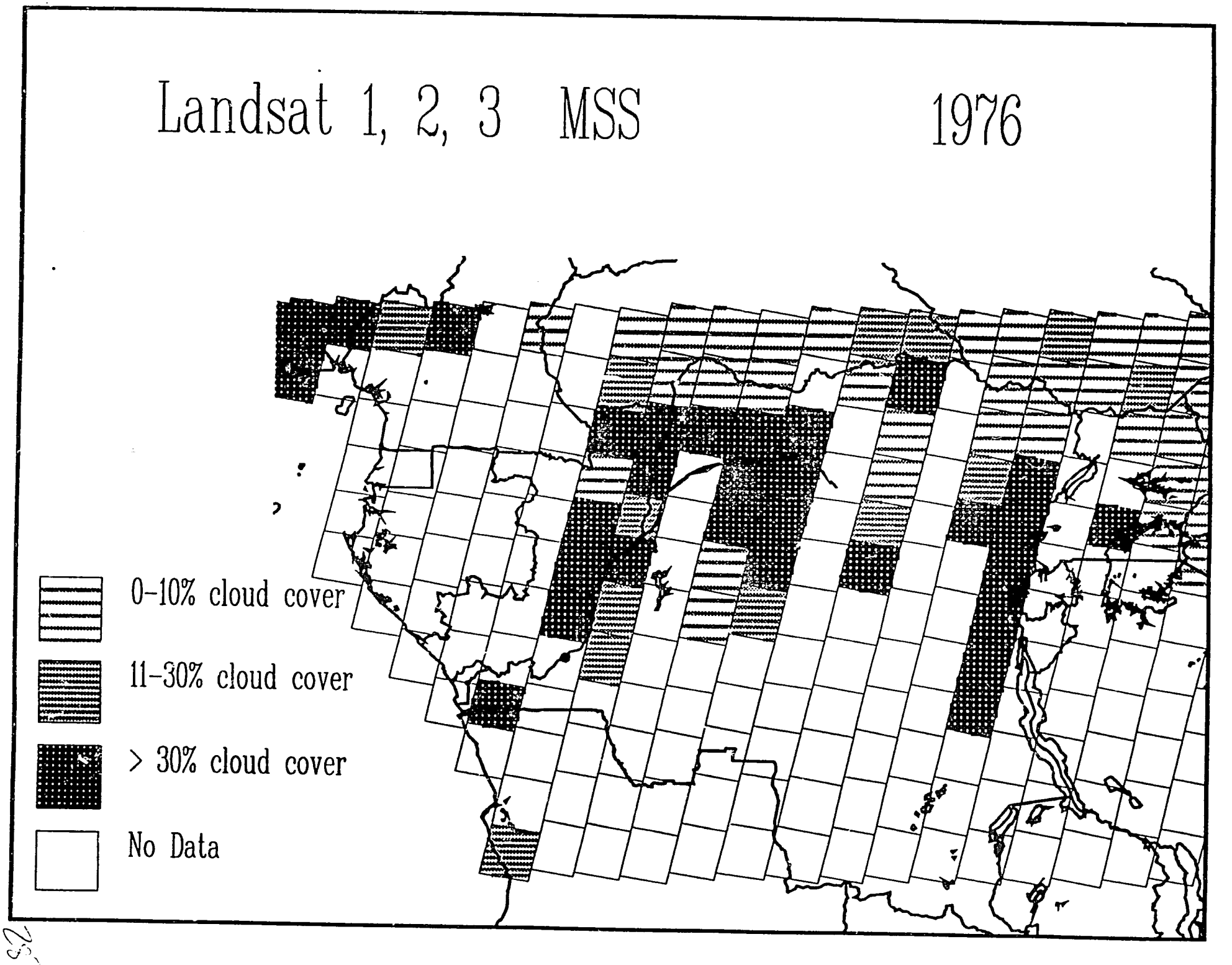

Landsat 1, 2, 3 MSS 1976
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1f

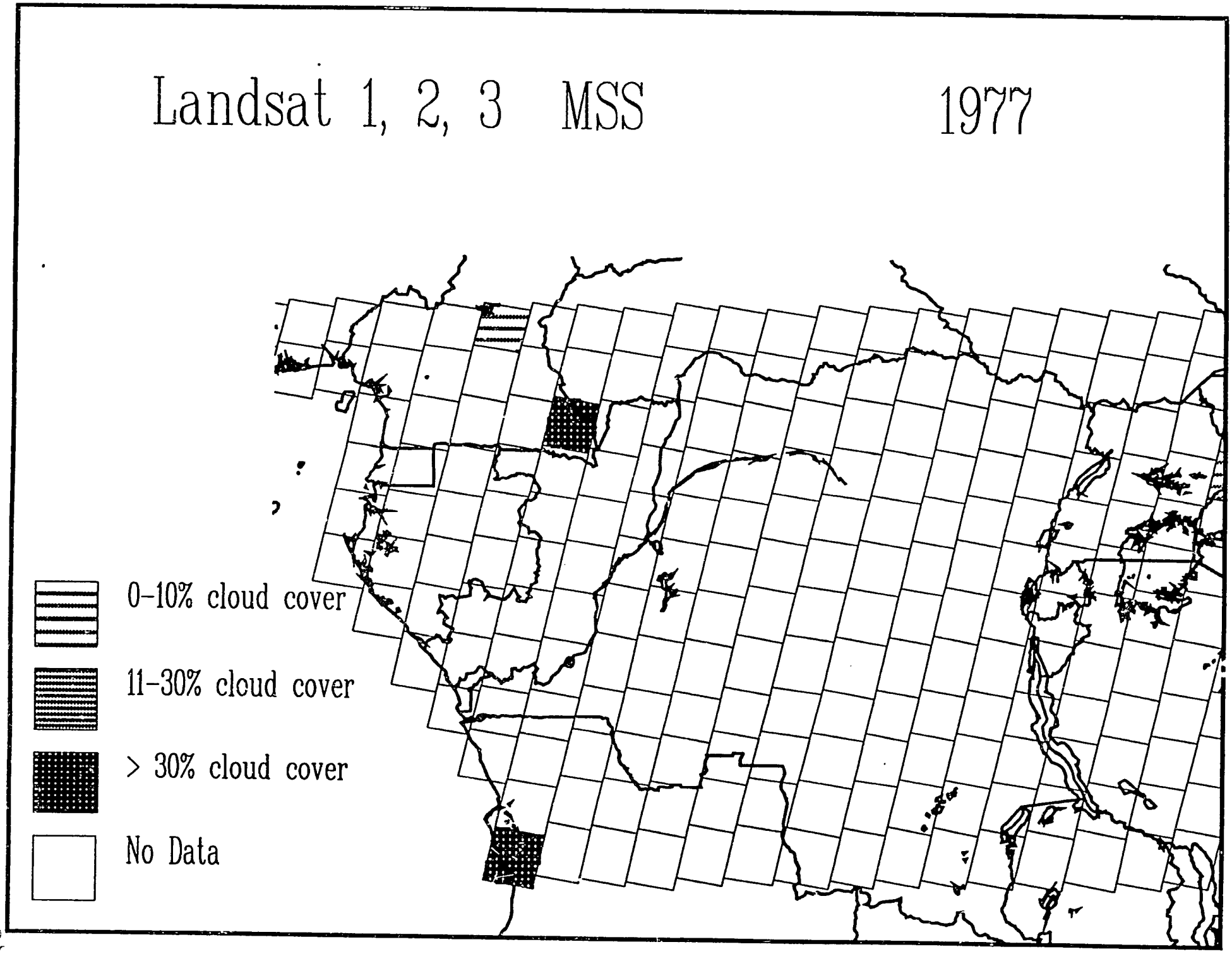

Landsat 1, 2, 3 MSS
1977
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1g

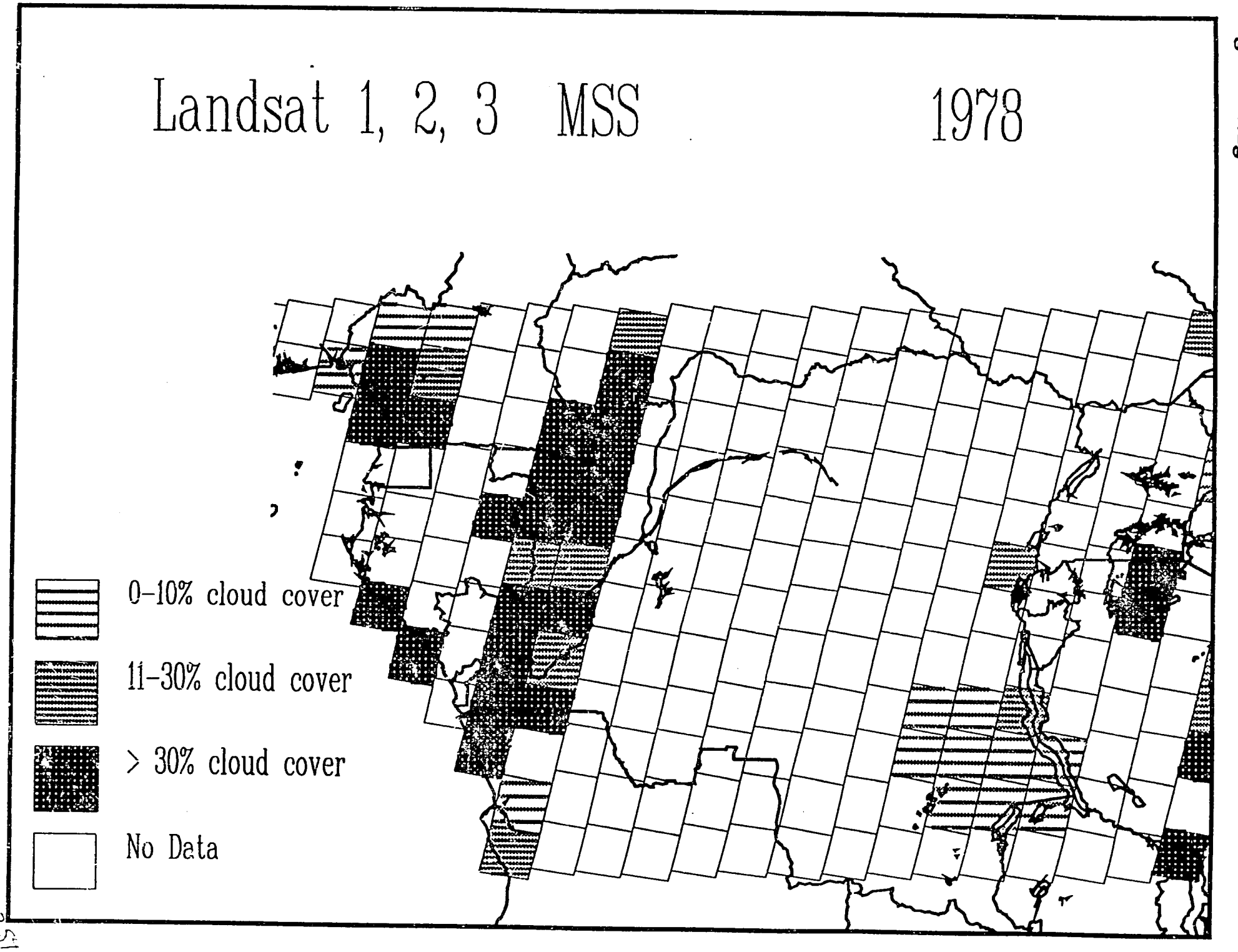

Landsat 1, 2, 3 MSS
1978
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1b

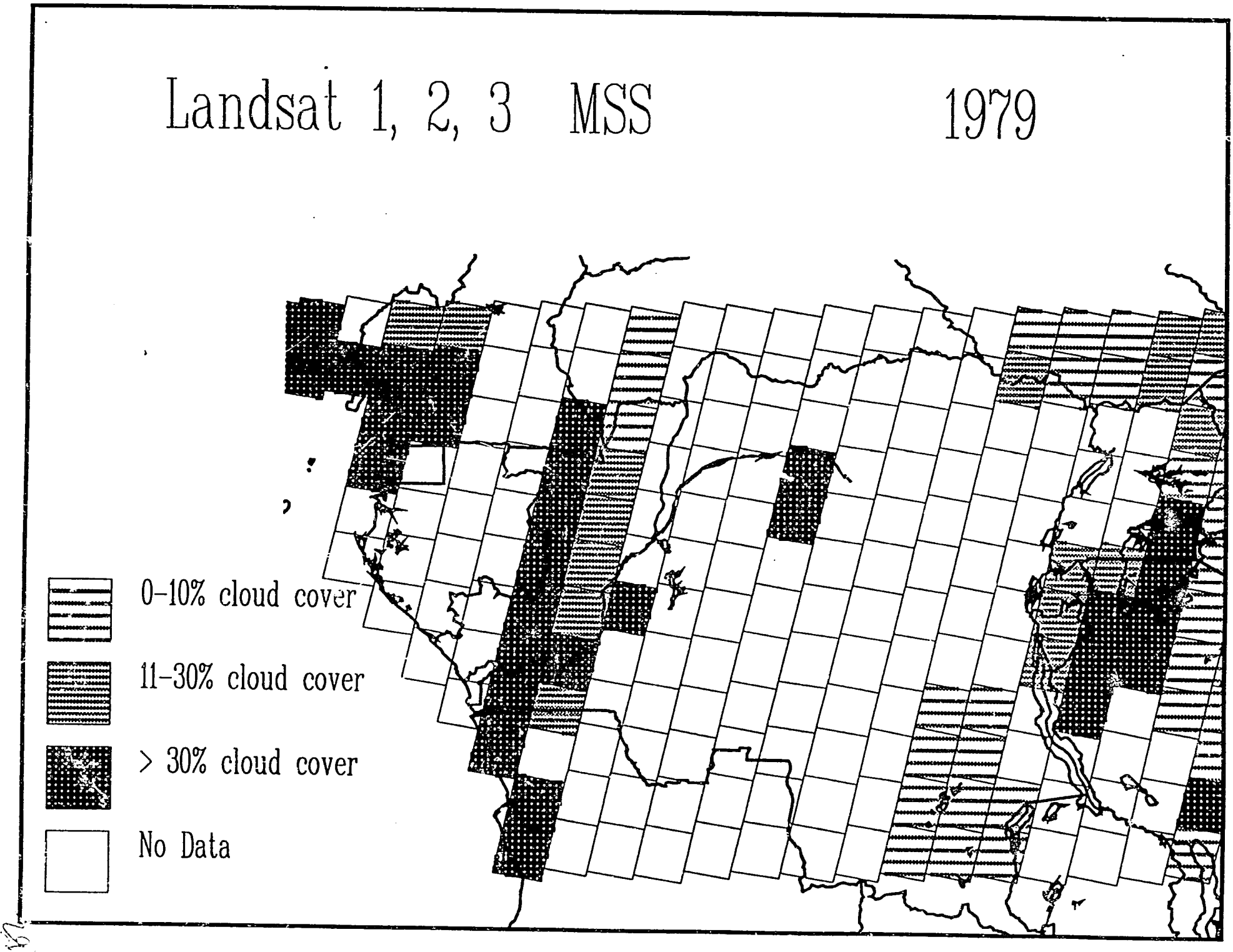

Landsat 1, 2, 3 MSS
1979
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1i

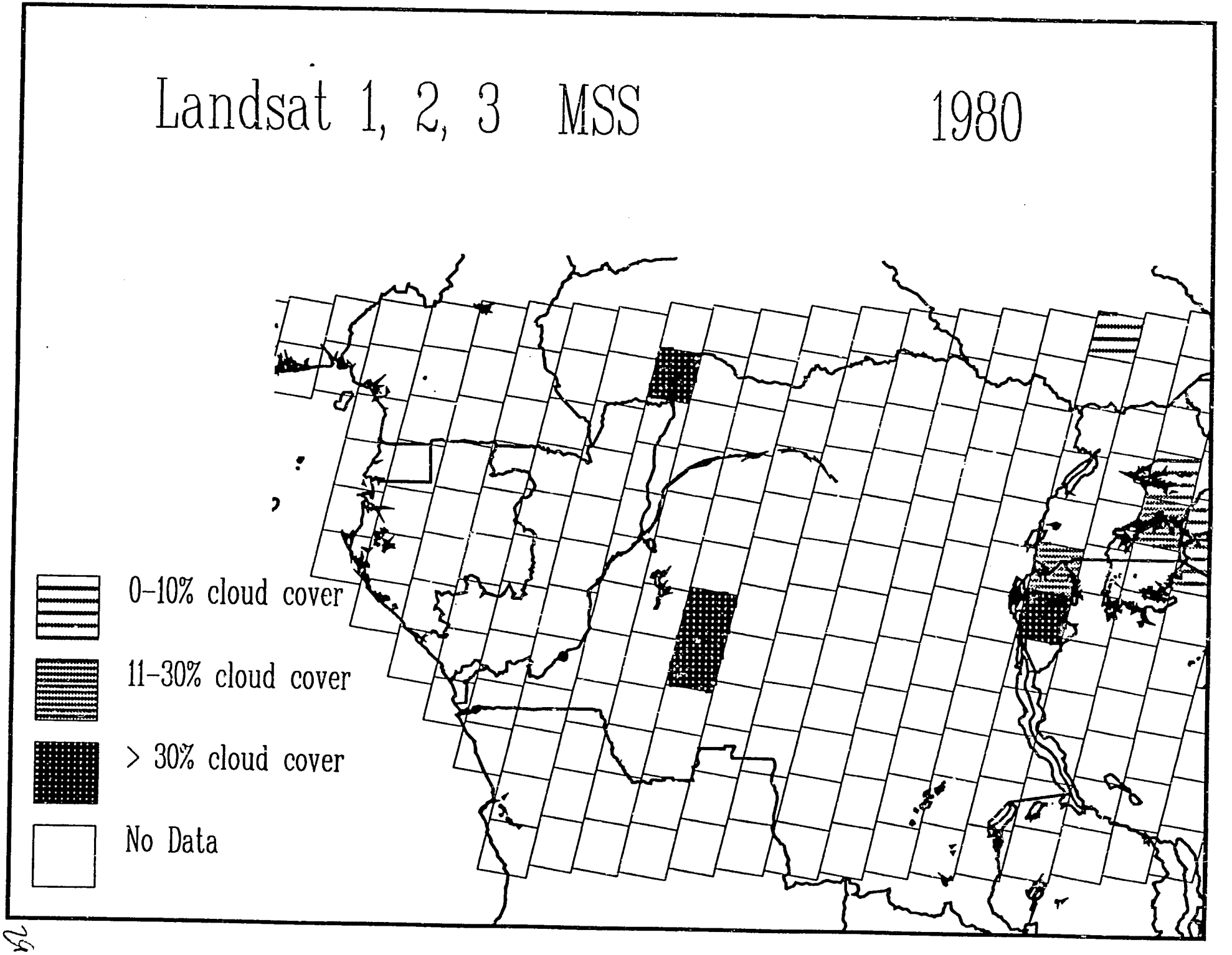

Landsat 1, 2, 3 MSS
1980
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1j

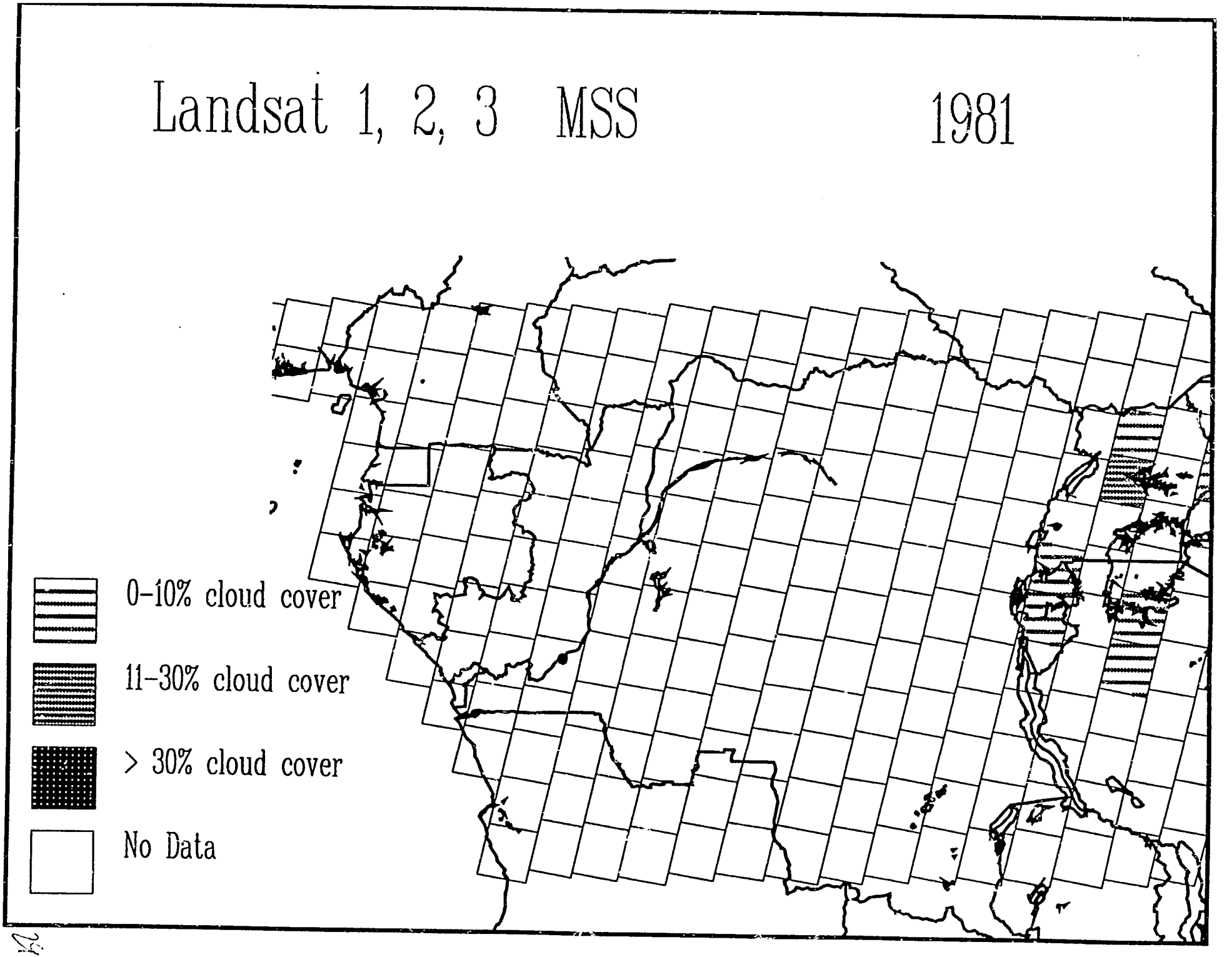
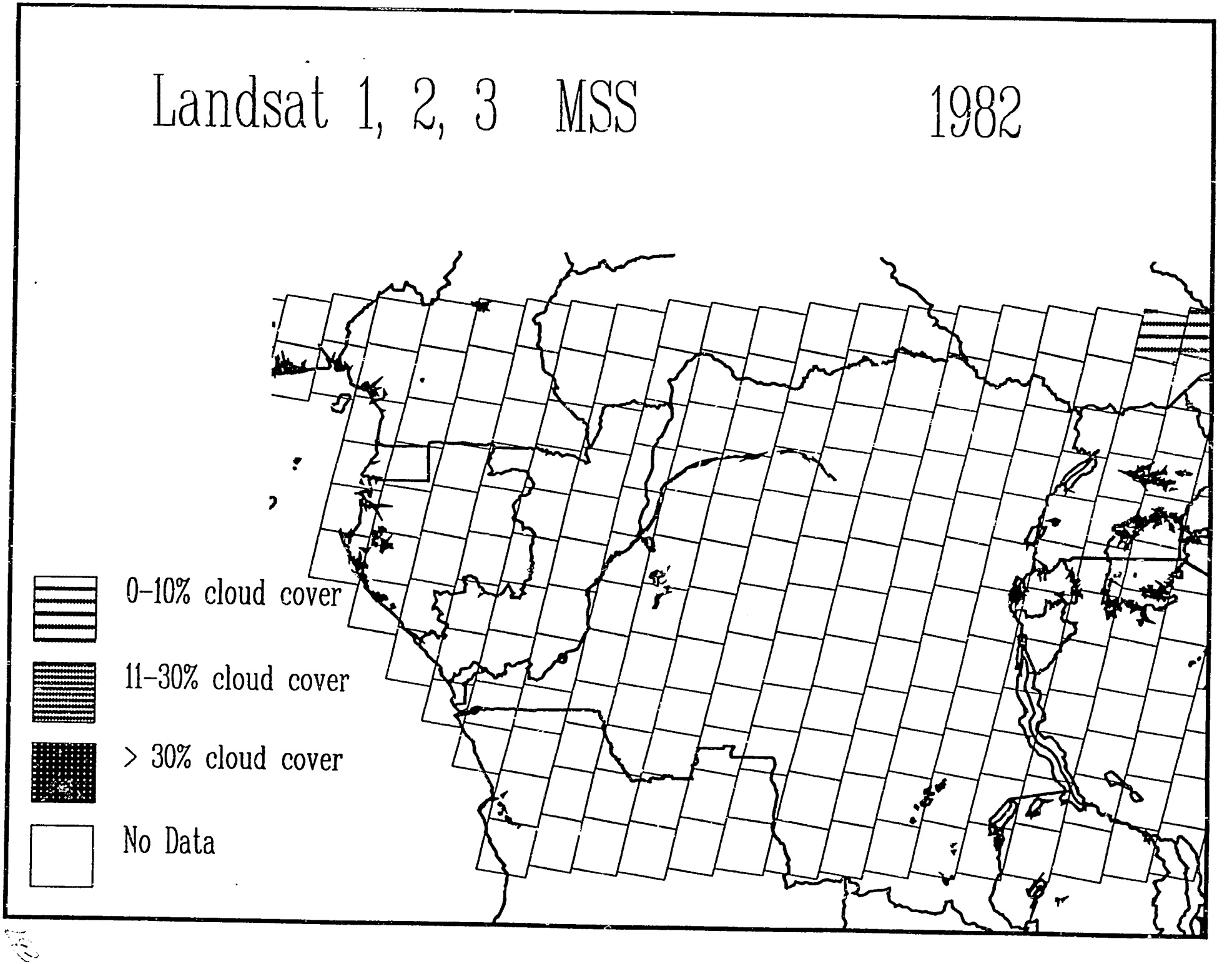

Landsat 1, 2, 3 MSS
1981
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1k


Landsat 1, 2, 3 MSS
1982
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

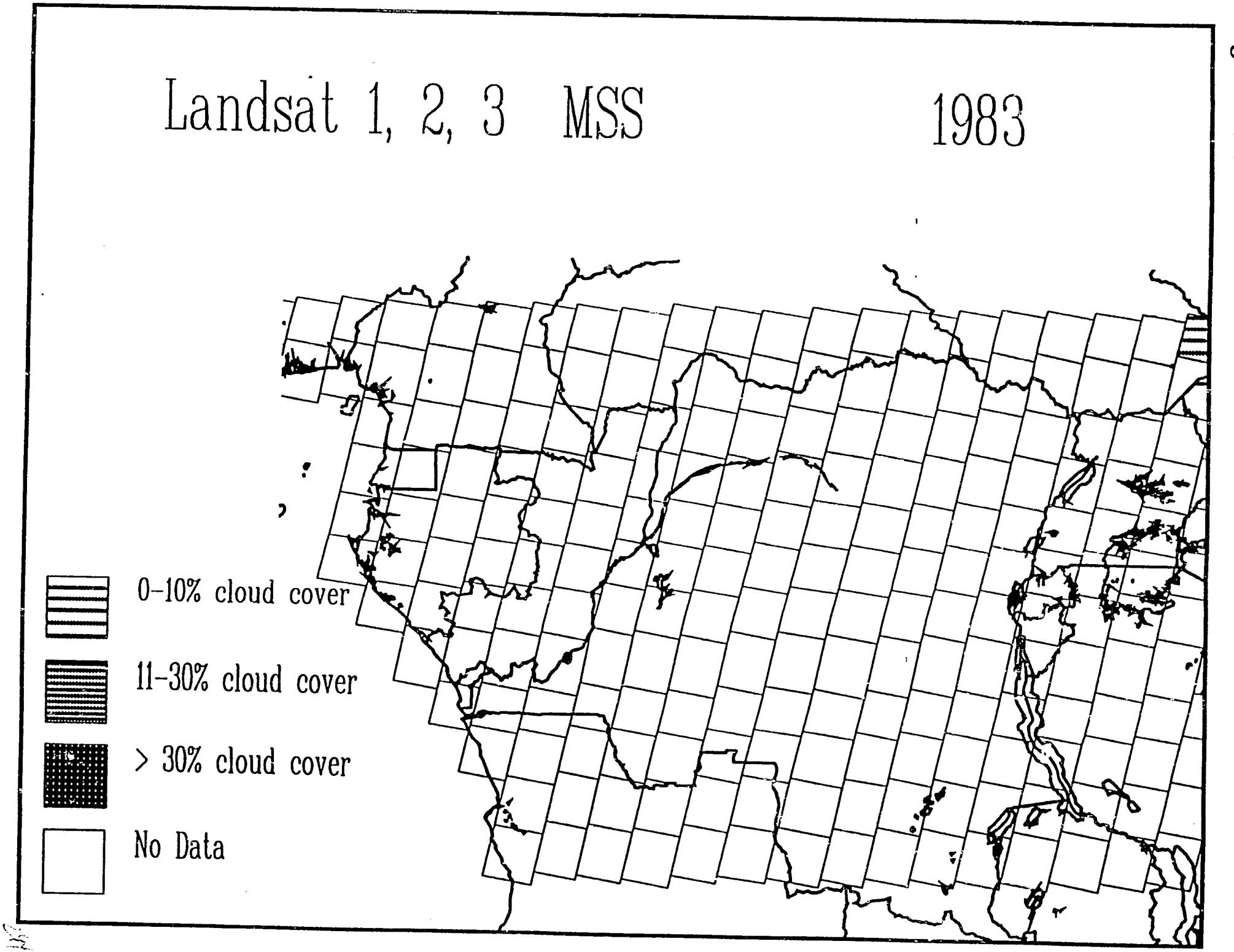

Landsat 1, 2, 3 MSS
1983
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.11

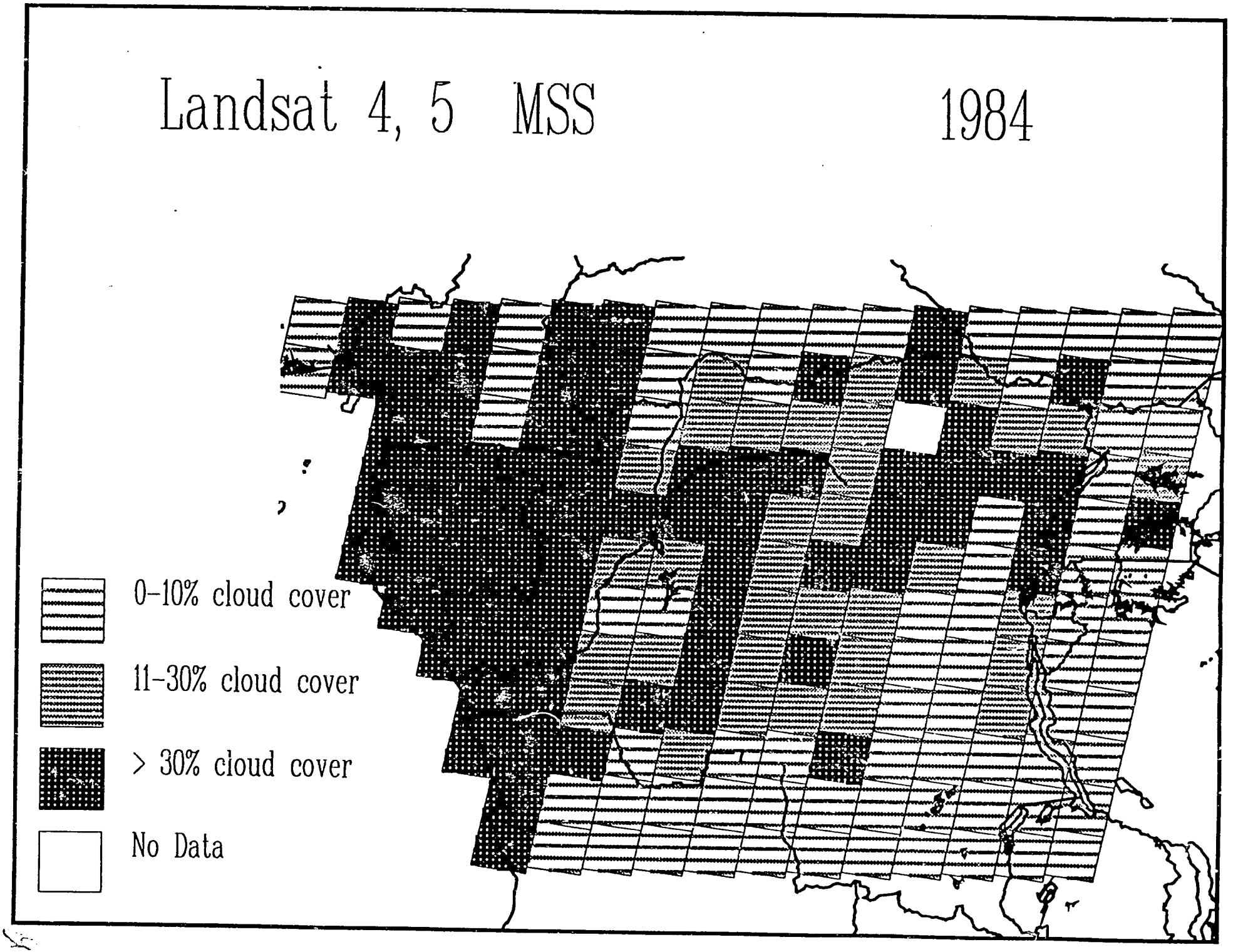

Landsat 4, 5 MSS
1984
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1m

Figure A2.1n

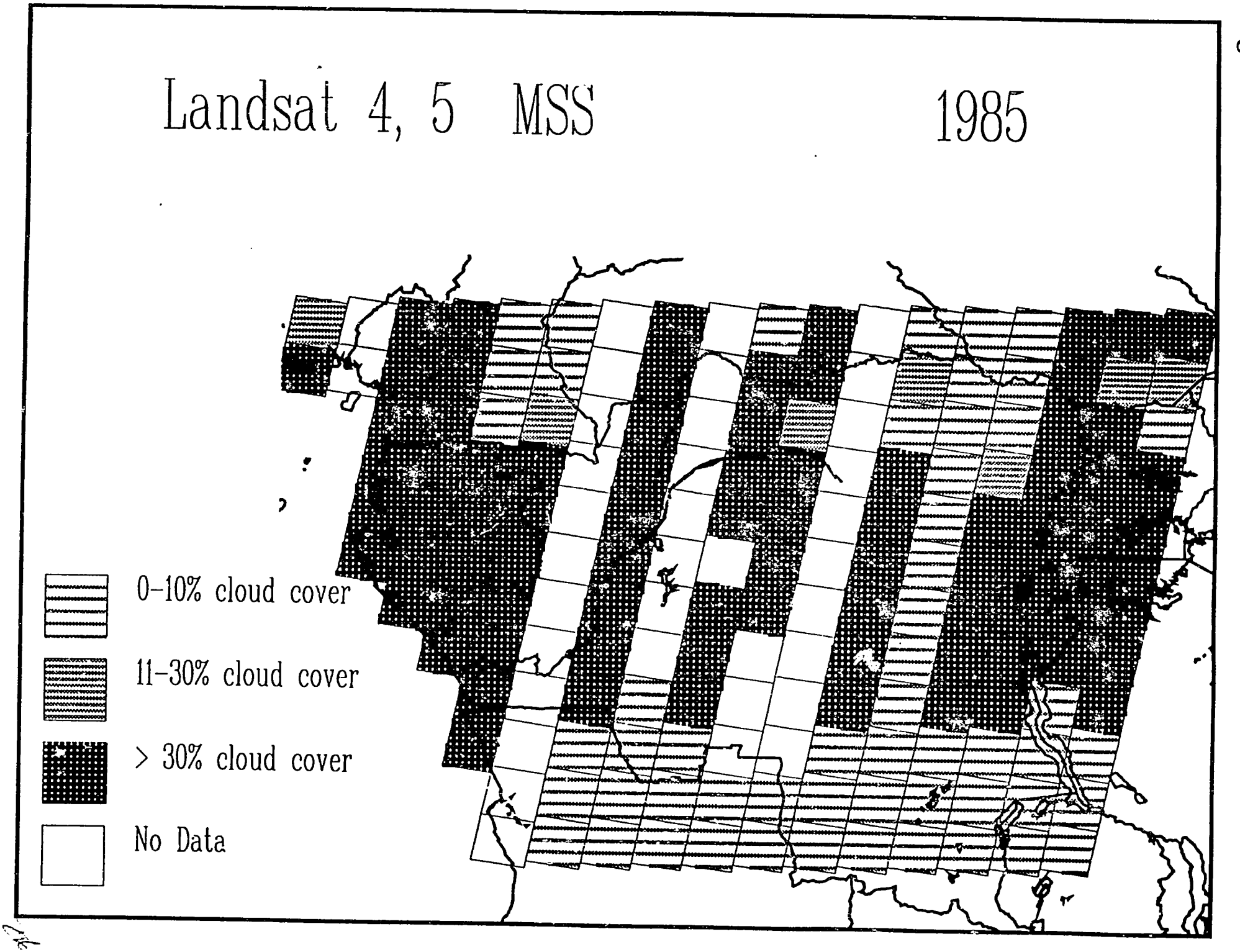

Landsat 4, 5 MSS
1985
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1o

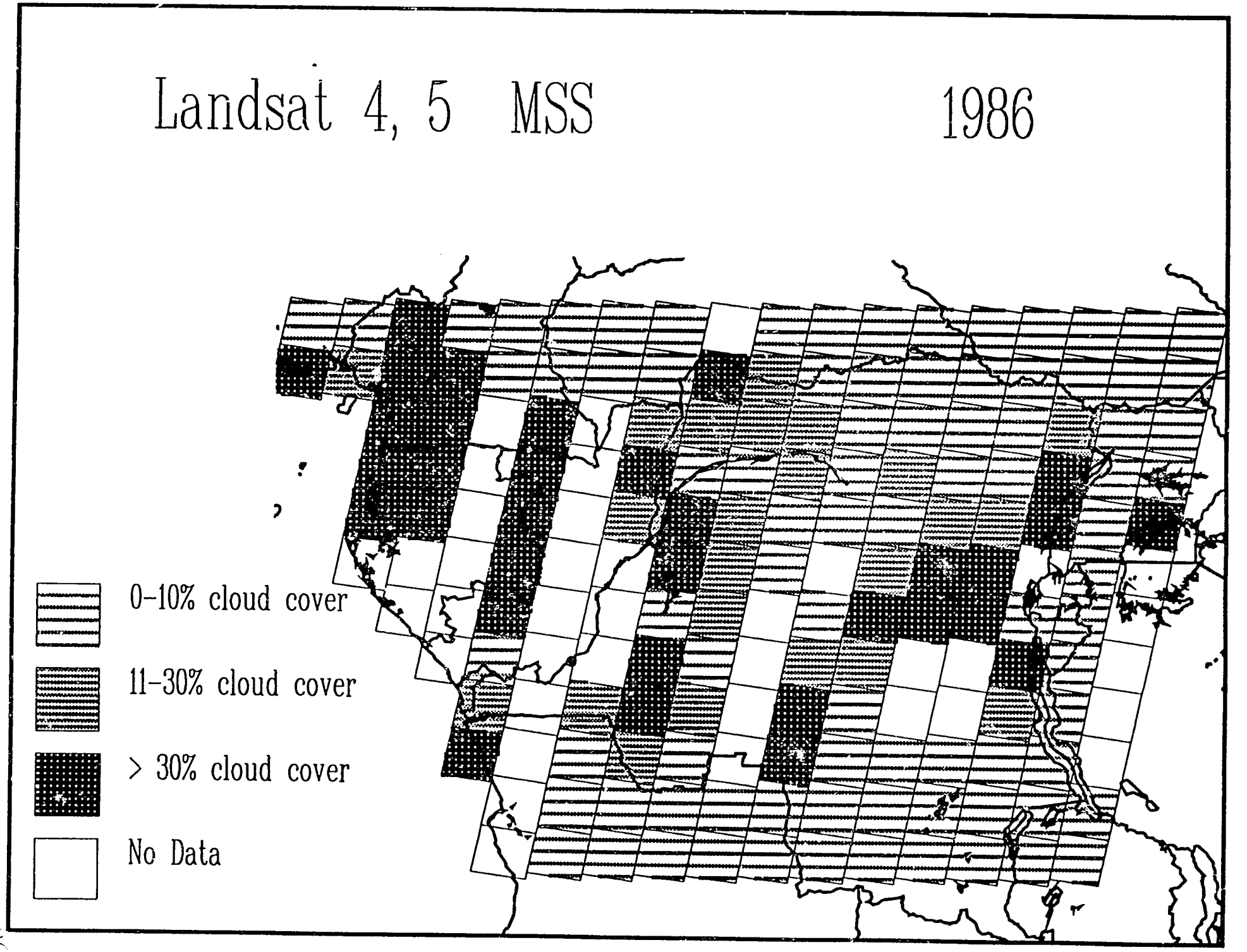

Landsat 4, 5 MSS
1986
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1p

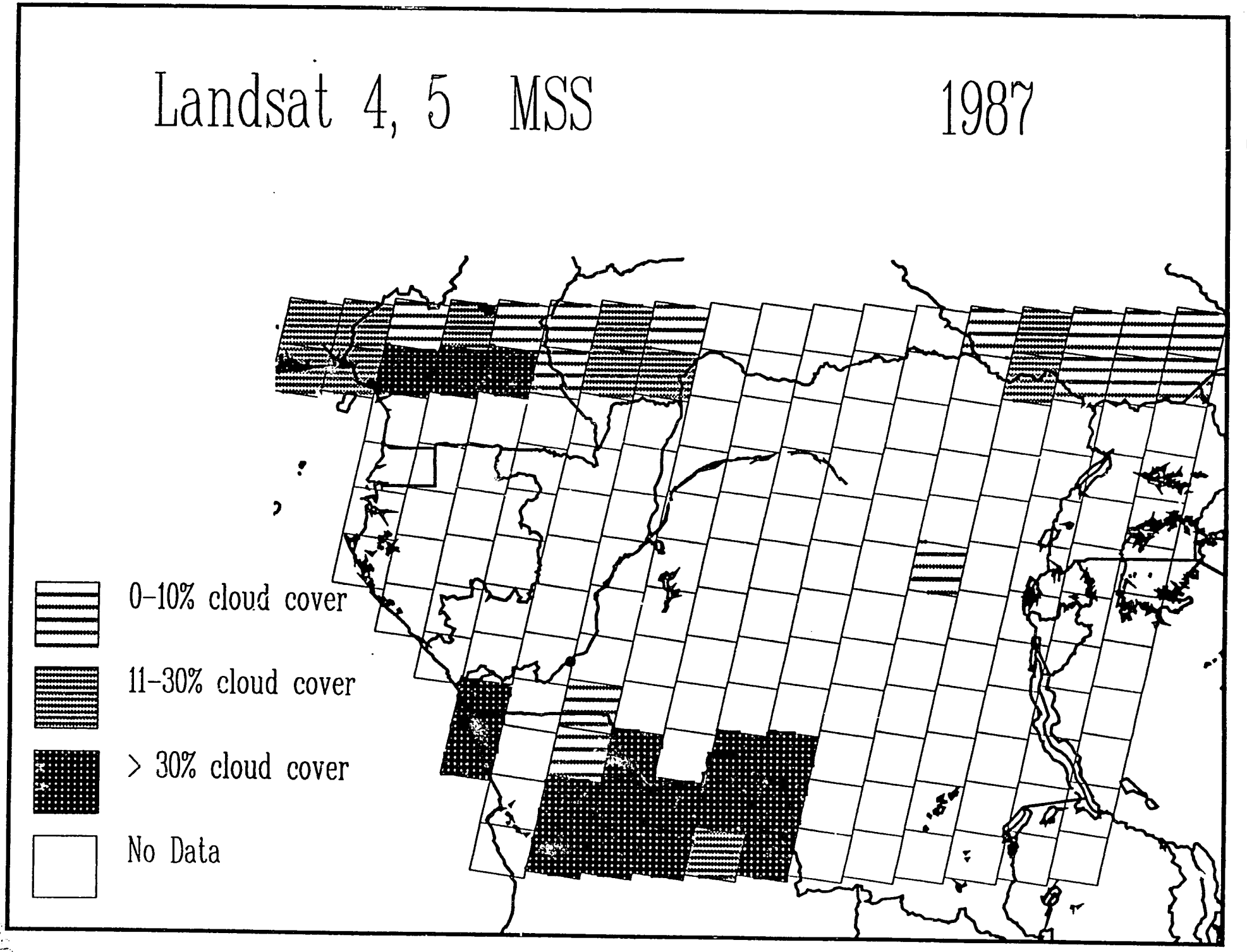

Landsat 4, 5 MSS
1987
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.1q

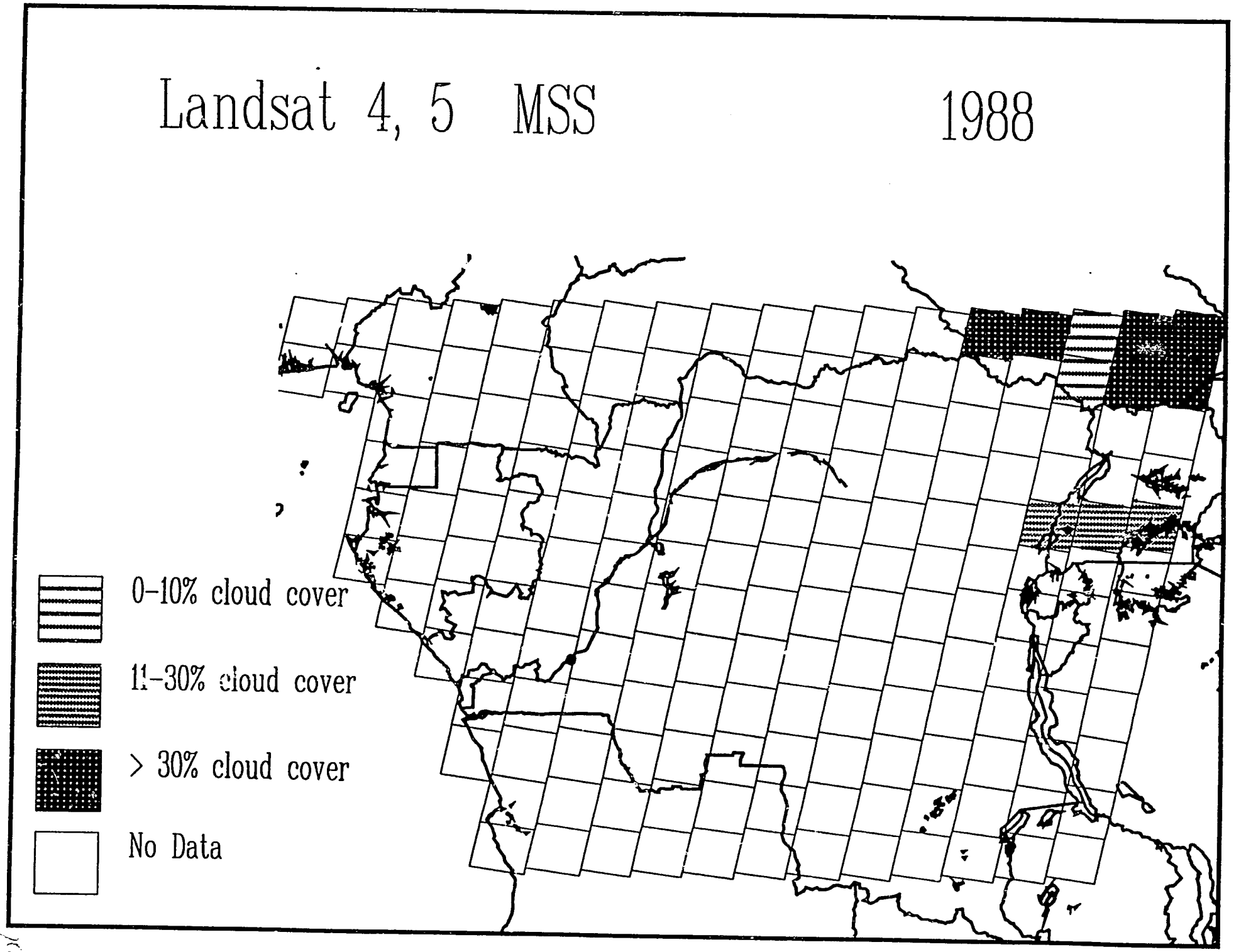

Landsat 4, 5 MSS
1988
0-10% cloud cover
11-30% cloud cover
> 30% cloud cover
No Data

Figure A2.2

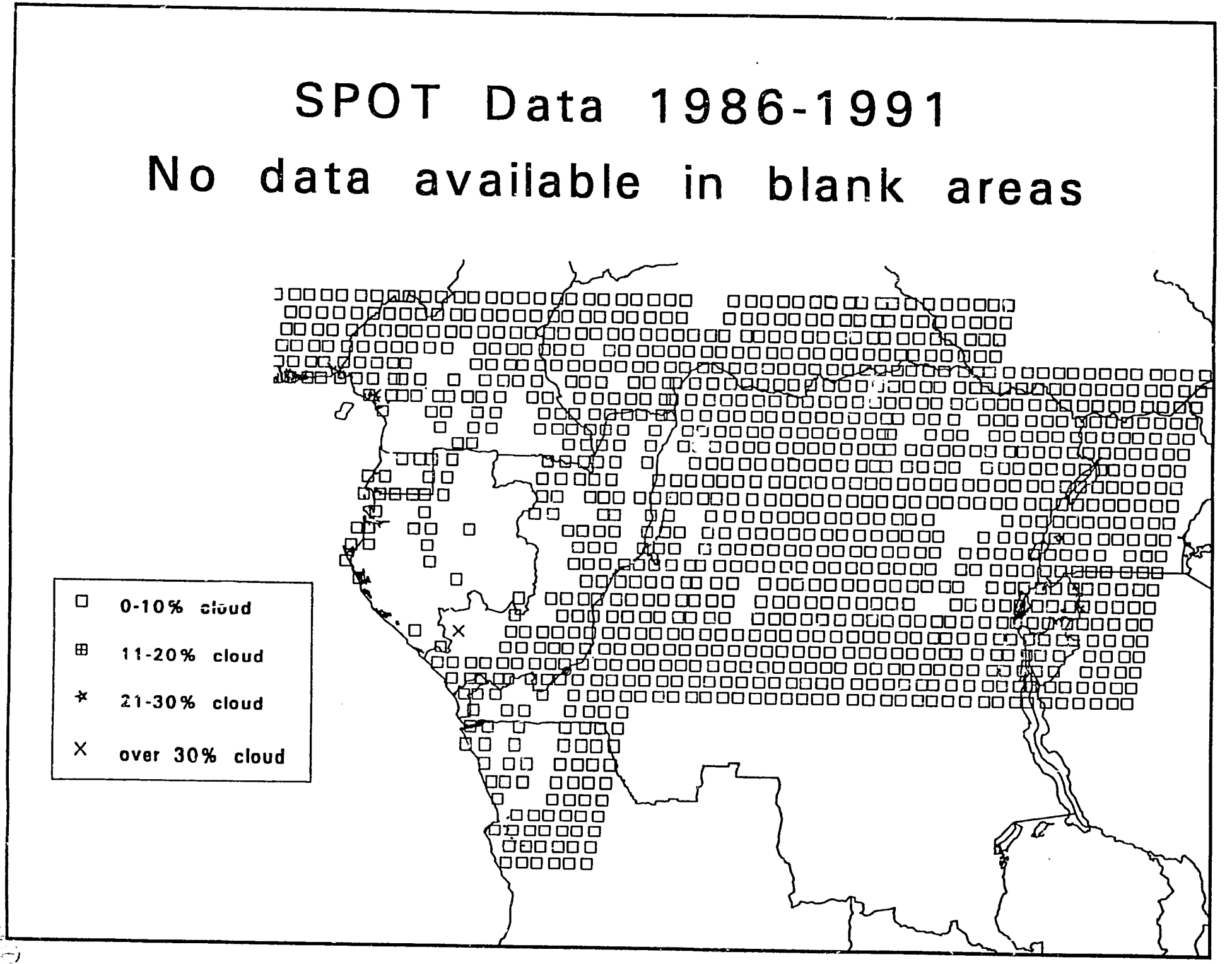

SPOT Data 1986-1991
No data available in blank areas
0-10% cloud
11-20% cloud
21-30% cloud
over 30% cloud

Figure A2.3a

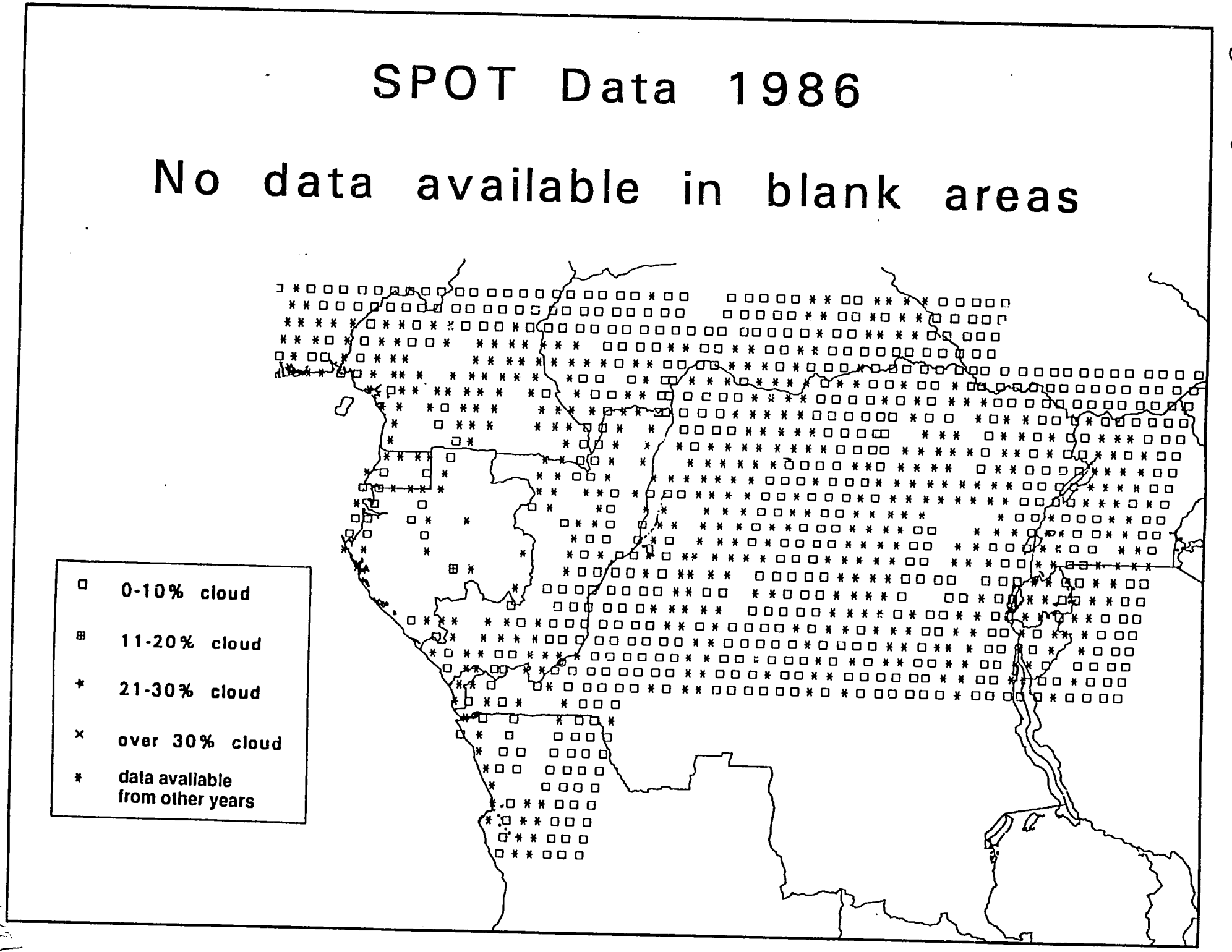

SPOT Data 1986
No data available in blank areas
0-10% cloud
11-20% cloud
21-30% cloud
over 30% cloud
data available from other years

Figure A2.3b

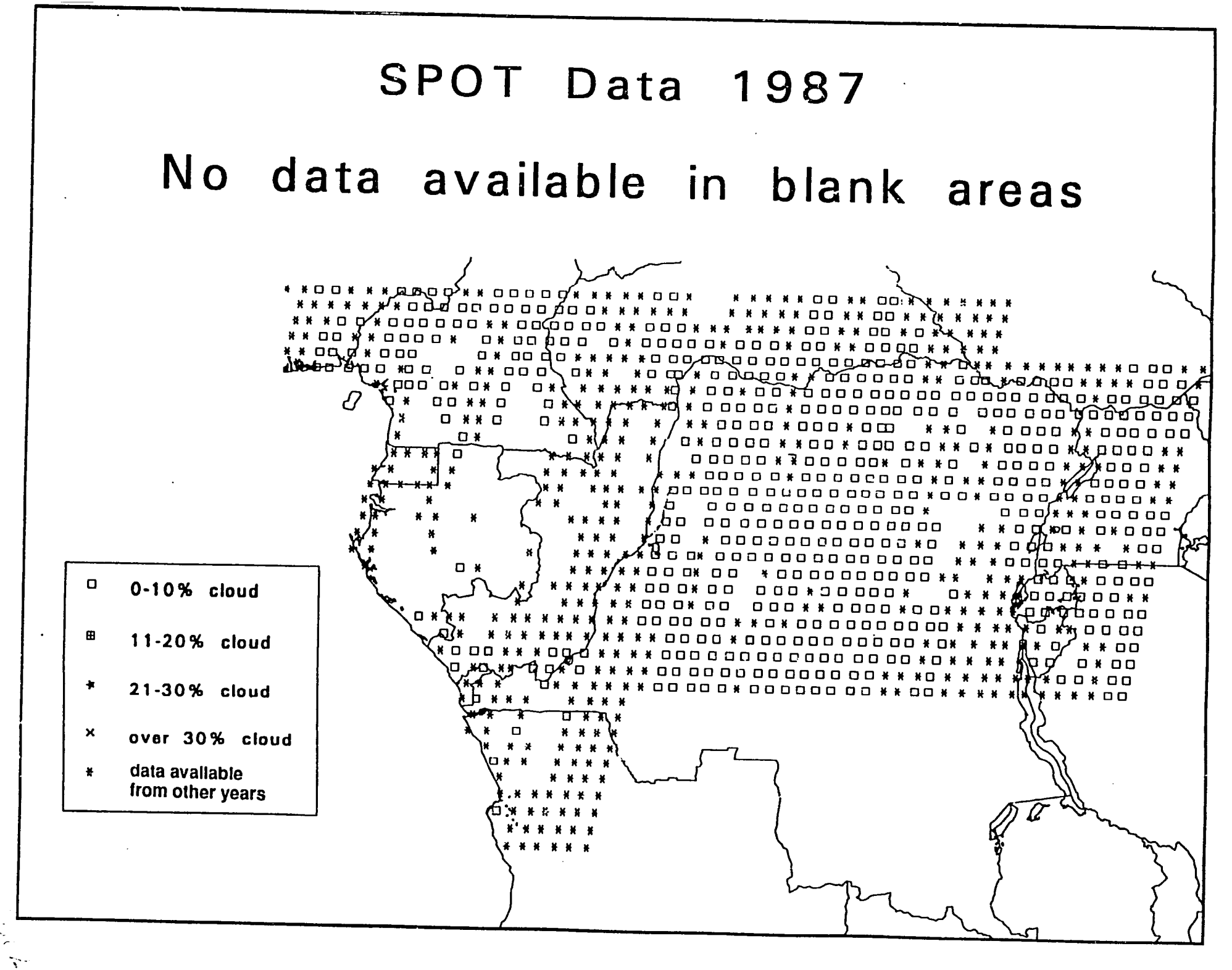

SPOT Data 1987
No data available in blank areas
0-10% cloud
11-20% cloud
21-30% cloud
over 30% cloud
data available from other years

Figure A2.3c

SPOT Data 1988

No data available in blank areas

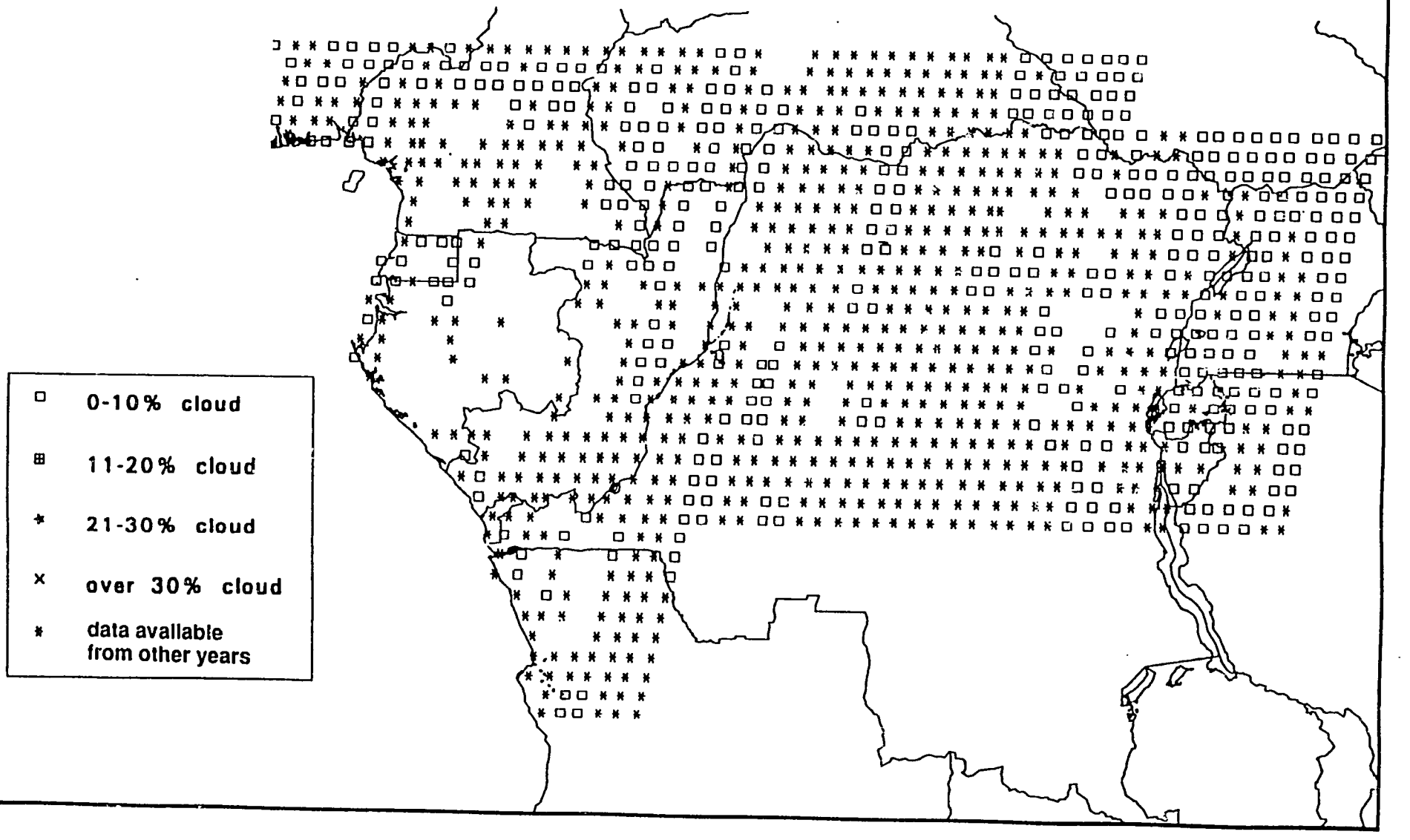


Figure A2.3d

SPOT Data 1989

No data available in blank areas

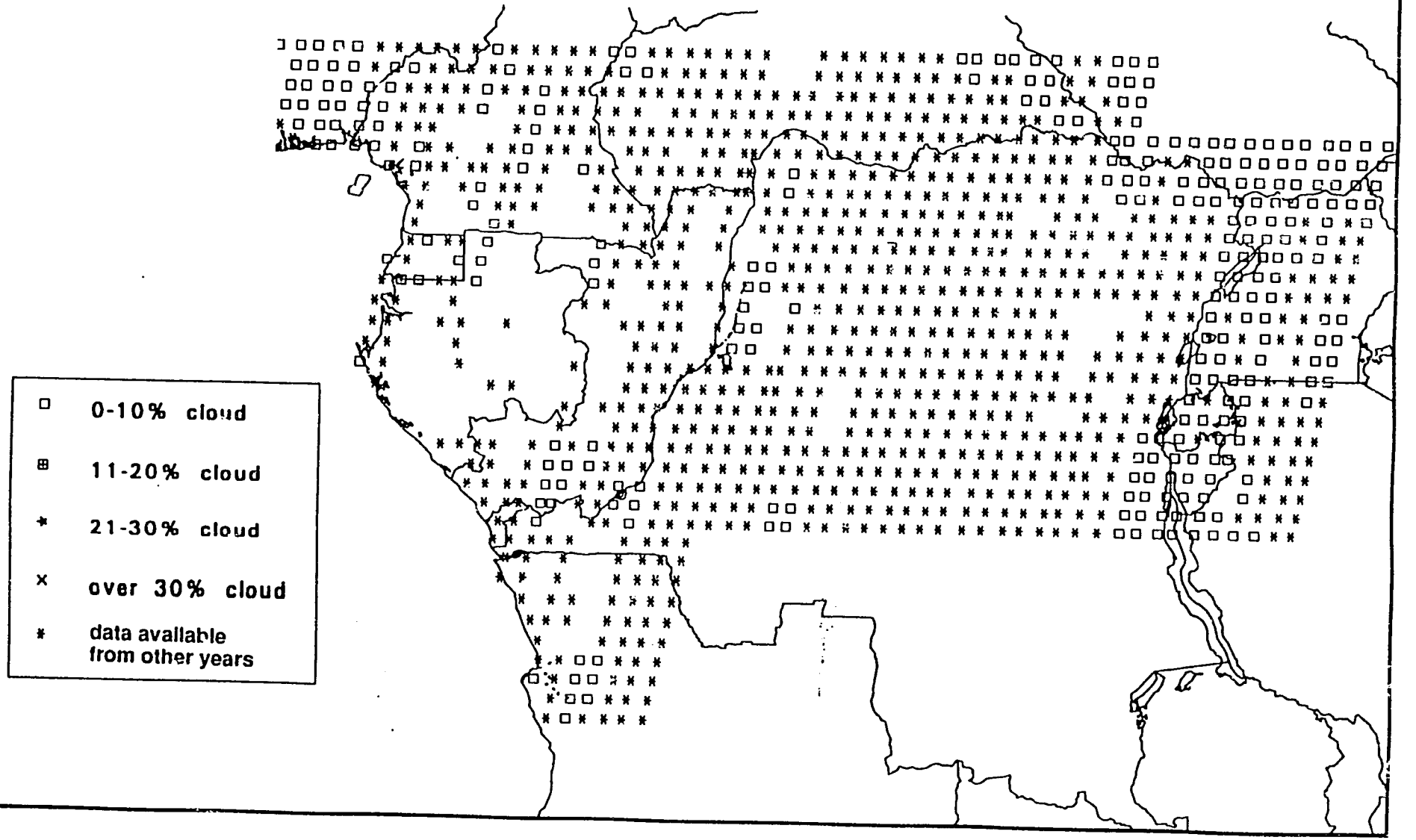
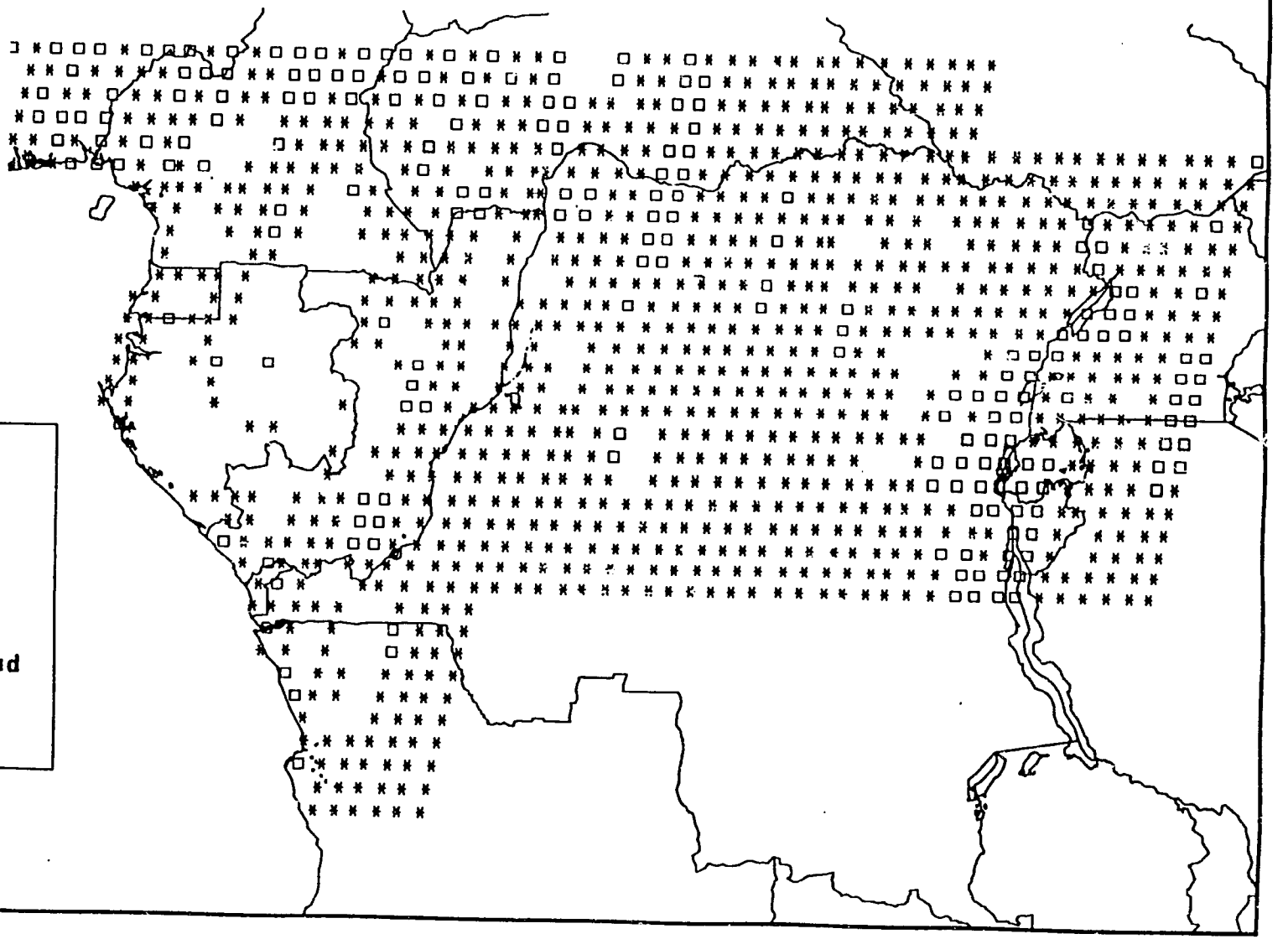


Figure A2.3e

SPOT Data 1990

No data available in blank areas

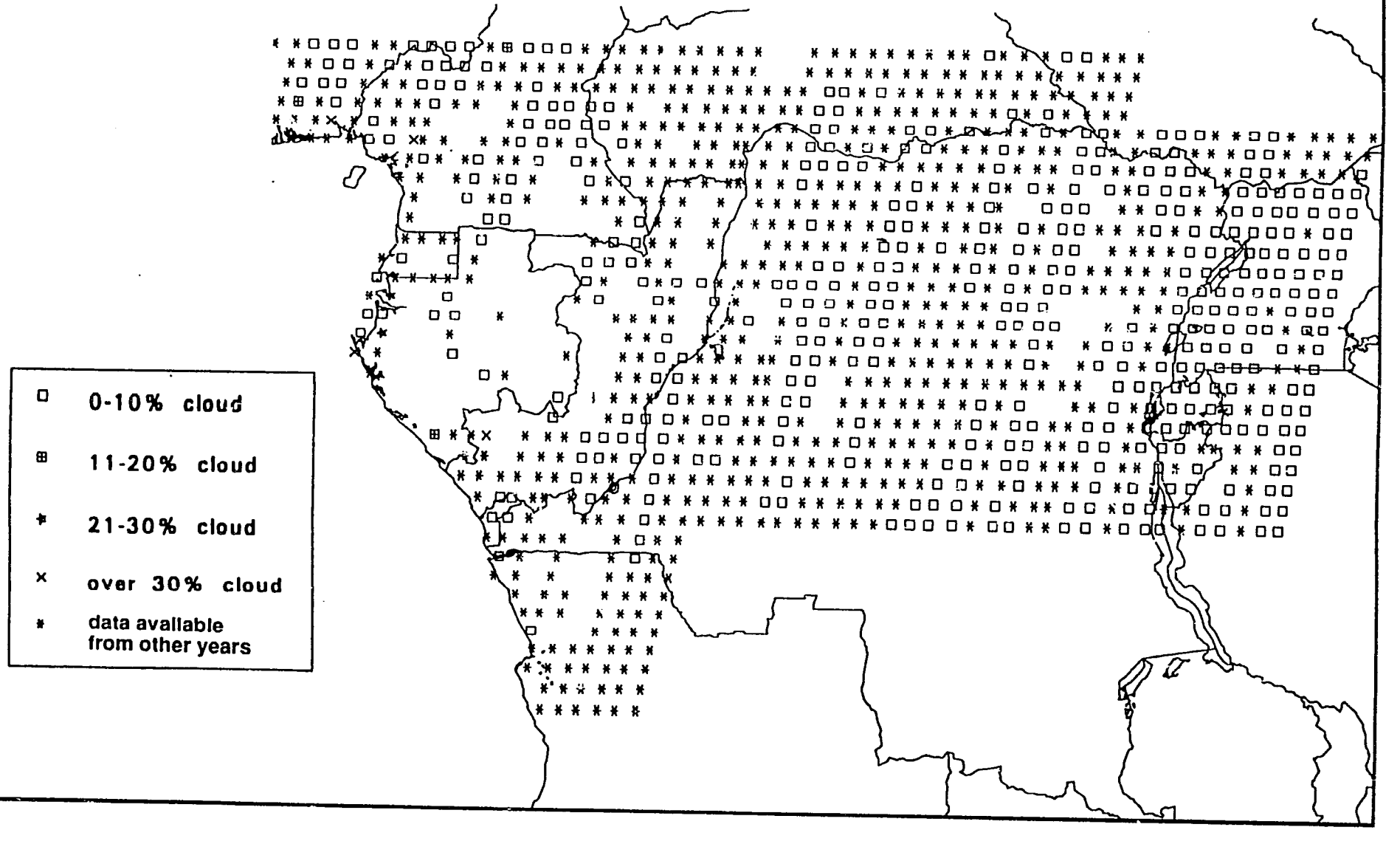


- 0-10% cloud
- 11-20% cloud
- 21-30% cloud
- over 30% cloud
- data available from other years

Figure A2.3f

SPOT Data 1991

No data available in blank areas



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