Program to monitor impacts of desertification and climate change in Africa

Famine Early Warning System Network (FEWS NET)
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Introduction

FEWS NET is a program funded by the U.S. Agency for International Development (USAID) that seeks to establish more effective and sustainable food security information networks in Africa that reduce the vulnerability of groups at risk. This report presents a FEWS NET program to monitor and assess impacts of desertification and climate change, two global environmental phenomena that threaten food security in Africa.

Information on desertification and climate change enhances the ability of FEWS NET to assess the chronic vulnerability of farmers and herders in Africa. Such information can also help natural resource managers to better address the impacts of desertification and climate change.

The monitoring program capitalizes on the fact that FEWS NET uses the same remote sensing and field methods to track short-term environmental conditions that scientists use to monitor long-term environmental phenomena. Therefore, the monitoring program constitutes a logical extension of FEWS NET capabilities.

This report first reviews the state of knowledge of desertification and climate change in Africa. Then, it presents the objectives, implementation, and activities of the program. The report then proceeds with details of the main program components.

Desertification and climate change in Africa

The U.N. Convention to Combat Desertification (UNCCD) defines desertification as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities." The UNCCD further defines land degradation as a "reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation."

Arid, semi-arid, and dry sub-humid areas include those lands where the ratio of precipitation to potential evaporation ranges from 0.05 to 0.65 (UNEP 1997). In Africa, these conditions cover 13 million km^2 or 43% of the continent's land area, on which live 270 million people, or 40% of the continent's population (UNDP 1997).

Areas particularly at risk include the Sahel, a 3.5 million km^2 band of semi-arid lands stretching along the southern margin of the Sahara Desert, and some nations that consist entirely of drylands, *e.g.* Botswana and Eritrea. Desertification in Africa has reduced by 25% the potential vegetative productivity of over 7 million km^2, or one-quarter of the continent's land area UNEP (1997). Desertification consists more of the degradation of the productive capacity of patches well outside of open-sand deserts rather than the inexorable encroachment of open sand onto green lands.

The relative importance of climatic and anthropogenic factors in causing desertification remains unresolved. The major climatic driving forces include precipitation declines, temperature increases, and sea surface temperature anomalies. The major anthropogenic factors among the forces driving desertification are unsustainable agricultural practices, overgrazing, and deforestation. Furthermore, population growth can ultimately drive desertification if it intensifies agro-sylvo-pastoral exploitation or if it increases the land area subjected to unsustainable agricultural practices, overgrazing, or deforestation.

Since 1968, the Sahel has experienced the most substantial and sustained decline in rainfall recorded in the world within the period of instrumental measurements (Diouf *et al.* 2000, Hulme 2001). Two positive feedback mechanisms, between precipitation and surface reflectance (albedo) (Charney 1975) and between precipitation and vegetation (Aubréville 1949, Schlesinger *et al.* 1990, Taylor & Lebel 1998), combined with sea surface temperature anomalies (Lamb 1978) best explain the Sahel drought (Xue 1997, Zeng *et al.* 1999, Wang & Eltahir 2000, Hulme 2001).

In the vegetation-precipitation feedback, a reduction in vegetative cover leads to reduced evapotranspiration. The reduction in evapotranspiration, the only local input to the hydrologic cycle besides surface water, leads to a reduction in precipitation, initiating a positive feedback cycle. In West Africa, deforestation of tropical rainforests in the Congo vegetation zone from the Republic of Guinea to Côte d'Ivoire has reduced evapotranspiration inputs essential to the maintenance of the southwest monsoon. Reduced rainfall over an extended period has reduced vegetation cover in the Guinean zone to the north. This, in turn, has decreased rainfall and vegetation farther north in the Sudan, eventually reducing rainfall and vegetation in the Sahel. Therefore, degradation of vegetation cover in the moister areas south of the Sahel has likely decreased continental evapotranspiration and reduced precipitation in the Sahel.

The tragic death of up to a quarter of a million people in the Sahel drought of 1968-1973 (UNCOD 1977) demonstrated the tragic human toll of desertification. The major impacts of desertification result from decreases in soil fertility and declines in the productivity of agricultural crops, pastures, and forest species. The major impacts of these processes are the permanent loss of ecosystem services, such as proper nutrient cycling and watershed protection, the disruption of agricultural and livestock production systems, and alterations to fundamental socio-economic conditions. Desertification reduces the ability of the land to support people, often sparking an exodus of rural people to urban areas. Breaking the strong connection of people to the land produces profound changes in social structure, cultural identity, and political stability.

Climate change is an alteration of the composition of the atmosphere that modifies temperature and other important meteorological conditions. Climate change mainly acts through the increase of gases in the atmosphere that prevent the escape of heat into space, a phenomenon known as the Greenhouse Effect. The principal greenhouse gas is carbon dioxide (CO_2). Currently, humans emit 7.9 ± 1.4 billion tons of carbon into the atmosphere each year, three-fourths from fossil fuel burning and one-fourth from land use changes (IPCC 2001b). The world's vegetation and oceans can only absorb 4.6 ± 2.1 billion tons each year, so the remainder stays in the atmosphere. From the beginning of the industrial revolution, ca. 1750, to 1998, the concentration of CO_2 in the atmosphere increased from 280 parts per million (ppm) to 365 ppm (IPCC 2001b). Since 1900, mean global surface temperature has increased 0.6±0.2°C and mean global sea level has risen 10–20 cm.

Projecting trends in population and energy use, including a stabilization of world population at 11 billion people, the concentration of CO_2 in the atmosphere would double the pre-industrial concentration by 2100 AD, causing an increase in mean global surface temperature of 1.4–5.8°C and a rise in mean global sea level of 11–77 cm (IPCC 2001b).

Regional climate modeling for Africa shows that these global impacts of climate change may translate into significant changes across Africa. While mean surface temperature in Africa has increased by only 0.5°C since 1900, it could increase 2–6°C by 2100 (Hulme *et al.* 2001). Rainfall may decrease up to 20% in many areas, but generally increase in equatorial areas (Hulme *et al.* 2001). Decreased soil infiltration may lead to significant increases in surface runoff and decreases in groundwater recharge in many areas (Feddema & Freire 2001). The rainforests of the Congo hold 25 GT of carbon (Zhang & Justice 2001), or 5% of the carbon held in the world's vegetation. Increased carbon sequestration in these rainforests may just balance out carbon losses from more arid areas (Cao *et al.* 2001).

Some of the major impacts of climate change on food security include changes in precipitation and insolation, changes in the length of growing seasons, changes in carbon uptake, increased extremes of weather events, changes in flood risks, exacerbation of desertification, changes in the distribution and prevalence of human diseases and plant pests, and changes in the availability of drinking water (IPCC 2001a). Areas that will experience reduced rainfall and increased temperature due to climate change could experience declines in agricultural yields, livestock production, and tree cover, placing local people at risk of famine. Based on crop modeling, Parry *et al.* (1999) estimate that yield reductions in drylands across Africa may lead to tens of millions of people more at risk of food insecurity by the 2080s.

Desertification and climate change remain inextricably linked because of feedbacks between land degradation and precipitation. Climate change exacerbates desertification through the alteration of spatial and temporal patterns in temperature, rainfall, solar insolation, and winds. Conversely, desertification aggravates climate change through the release of CO_2 from cleared and dead vegetation and through the reduction of carbon sequestration potential of desertified land.

Program description

Title: Monitoring impacts of desertification and climate change in Africa

Objectives:

1. To analyze original and secondary scientific data on desertification and climate in Africa.
2. To help FEWS NET staff to integrate this information on desertification and climate change into existing activities.

Program components:

1. Ecological base maps of Africa
2. Analyses of Normalized Difference Vegetation Index (NDVI) time series
3. Field surveys of trends in forest species distributions
4. Analyses of chronic vulnerability

Expected products and services:

1. Maps of aridity zones, ecological zones (Figure 1), and forest cover in Africa, in English and French
2. Statistical and spatial analysis of the 1982-2001 NDVI time series
3. Analysis of trends in forest species distributions
4. Analyses of chronic vulnerability
5. Technical briefings to USGS, USAID, and other organizations
6. Technical assistance to FEWS NET staff and to USAID field missions
7. Technical reports
8. Scientific publications

Implementation:

Patrick Gonzalez, a USGS technical advisor assigned to the USAID office in Washington, DC to work on FEWS NET, implements the program, in collaboration with FEWS NET field representatives, African organizations, international organizations, scientists of the National Aeronautics and Space Administration (NASA), other USGS staff, and staff at the World Resources Institute (WRI). Dr. Gonzalez is a member of the Intergovernmental Panel on Climate Change (IPCC) and has served on the U.S. delegation to the UNCCD. He can also respond to requests from USAID missions for technical assistance in environmental monitoring, desertification, and climate change.

Results since the start of the program in October 1999:

1. Maps of aridity zones, ecological zones, and forest cover in Africa, in English
2. Forest species surveys in Burkina Faso, Chad, Mali, Mauritania, and Niger
3. Map of forest species loss in the Sahel 1960-2000
4. Technical assistance to FEWS NET staff in West Africa, through field trips, distribution of technical reports, and e-mail exchanges
5. Technical presentations on desertification and climate change in Africa to FEWS NET staff (May 2000, June 2000), Peace Corps (May 2001), UNCCD (June 2001), USGS (June 2001, Sept. 2001), USAID (August 2001), Canadian International Development Agency (Dec. 2001)
6. Technical report "Advances in desertification monitoring and drought early warning" for the UNCCD Ad Hoc Panel on Early Warning Systems
7. Two scientific publications (Desanker *et al.* 2001, Gonzalez 2001)

Activities in progress for completion in 2002:

1. Collaboration with NASA on the NDVI analyses and on a scientific publication
2. Analyses of chronic vulnerability
3. Summary of desertification and climate change issues in Southern Africa for the FEWS NET Regional representative
4. Collaboration with NASA on use of IKONOS and other high-resolution imagery to examine environmental change in the Sahel
5. Collaboration with WRI on analysis of drylands goods and services
6. Posting of information on the FEWS NET, NASA, and USGS web sites
7. Full technical report of all results

Normalized Difference Vegetation Index (NDVI) time series analyses

Ecologically, desertification reduces the potential primary productivity of land. The principal remote sensing tool for monitoring primary productivity, and for providing early warning of drought, is the Normalized Difference Vegetation Index (NDVI) (Tucker 1979), derived from Advanced Very High Resolution Radiometer (AVHRR) data from the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellite series. The program will produce an original analysis of the 1982-2001 NDVI data series for Africa to reveal spatial and temporal changes in potential primary productivity. Areas of persistent decline will indicate desertification.

NASA maintains a key global archive of 8 km resolution AHVRR data. NASA has calibrated the data for inter-sensor differences and orbit geometry and corrected the data for atmospheric anomalies. Nevertheless, noise originating from clouds, solar zenith angle, and surface bi-directional reflectance properties of topography and soil introduces non-vegetation variation into NDVI. Researchers have attempted to remove this noise by maximum value compositing, by Fourier analysis, and by weighted least-squares regression, yet these methods still do not accurately remove all non-vegetation elements of the NDVI signal (Pinzón *et al.* 2001).

Recent research has developed an effective method, Empirical Mode Decomposition (EMD), for analyzing nonlinear and non-stationary data and for removing noise (Huang *et al.* 1998). EMD separates a complex data set into a finite number of intrinsic mode functions that represent embedded periodic components of the larger time series and into a residual intrinsic trend that represents the change in the data over time. EMD separates NDVI into four components: noise, seasonal variation, inter-annual variation, and the intrinsic trend. The sum of these four components equals the original raw NDVI (Figure 2).

The intrinsic trend is a smooth function that shows the gradual longer-term change in NDVI. It is an index of potential primary productivity. The slope of a linear regression of the intrinsic trend will indicate whether vegetative productivity is increasing, decreasing, or not changing. Therefore, mapping the slope pixel-by-pixel for Africa will reveal trends in desertification over the past two decades.

By removing the noise from the NDVI time series, EMD makes possible the integration of NDVI over time. NDVI is an index of Net Primary Productivity or production of biomass per unit area per unit time. Integration of the area under the NDVI curve produces an index of standing biomass per unit area (Tucker *et al.* 1981). Standing biomass more completely indicates the state of the permanent vegetation cover, including of trees, shrubs, and other perennials. Integrating EMD NDVI for each year will produce a time series of 20 data points for each pixel (Figure 3). The integrated EMD NDVI and 0.1° latitude-longitude rainfall estimates for Africa from NOAA (Herman *et al.* 1997) (Figure 3) and from University of California, Santa Barbara doctoral candidate Chris Funk will permit calculation of an index of rain use efficiency (Le Houerou 1984), or vegetation production per unit of rainfall (Figure 3). Mapping the slope of the linear regression of rain use efficiency over time will produce a second map revealing possible trends in desertification. Original field work on shifts in the ranges of forests species in Africa (next section) and any other field information documenting permanent vegetation changes will provide independent data to ground-truth the analysis of remote sensing data.

Field surveys of forest species trends

Farmers and herders depend on trees and shrubs both for subsistence and for emergency resources in times of severe drought. Furthermore, trees and shrubs serve vital ecosystem functions, especially the maintenance of soil fertility and assuring the proper functioning of the hydrologic cycle.

Field research in Senegal demonstrates the impacts of desertification. Field inventories of forest species have documented a 25–30 km shift of the Sahel, Sudan, and Guinean vegetation zones in the past half century of desertification (Gonzalez 2001). Arid Sahel species expanded in the northeast, tracking a concomitant retraction of mesic Sudan and Guinean species towards areas of higher rainfall and lower temperature to the southwest. Densities of trees of height >3 m declined from 10 trees ha^{-1} in 1954 to 7.8 trees ha^{-1} in 1989, while the species richness of trees and shrubs fell from 64 species per 4 km^2 area ca. 1945 to 43 per 4 km^2 area in 1993.

As a result of these changes, human carrying capacity fell by 1993 to approximately 13 people km^{-2} , at observed patterns of resource use, compared to an actual 1988 rural population density of 45 people km^{-2} (Gonzalez 2001). The fall in species richness has also reduced people's options qualitatively. For example, rural women depend on two particular shrub species for firewood because of the size of the branches, high wood density, and ease of collection. Beyond that, few fallback species remain. With respect to traditional medicine, 25 useful species have diminished significantly. Furthermore, eight species that provided fruit, leaves, and gum in past droughts have disappeared from as much as 53% of their range. If a grave famine hit the area in its current condition, people would not be able to find the emergency foods that saved others in past episodes.

In order to examine changes in forest species and the impact on food security, Sahel field representatives for the Famine Early Warning System (FEWS), the predecessor to FEWS NET, conducted forest species inventories and semi-structured interviews on environmental change in 13 villages in Burkina Faso, Chad, Mali, Mauritania, and Niger in 1999 and 2000 (Figure 4). In these trips, the Sahel representatives also established relationships with villages, facilitating later field work on other subjects.

The forest species inventory consisted of a systematic listing of the presence or absence of all forest species in a village's lands. Village elders provided information on distributions around the time of independence in 1960 and field observations gave current distributions. In semi-structured interviews, village elders also discussed their observations of environmental change and identified the forest species most important both for normal nutritional needs and for emergency food in times of famine. For example, in times of famine, rural people in the Sahel harvest the seeds of the shrub *Boscia senegalensis,* process them to remove acidic compounds, and prepare a form of cous-cous. In normal times, the fruits of *Zizyphus mauritiana* (jujube), *Adansonia digitata* (baobab), and other species form an important part of people's diet. Forest species diversity has dropped across the Sahel (Figure 4). A full report of the quantitative and qualitative results is in progress.

Vulnerability analyses

The tragic death of up to a quarter of a million people in the Sahel Drought of 1968-1973 (UNCOD 1977) demonstrates the vulnerability of humans to desertification. Desertification and climate change can cause declines in the potential productivity of land and alter fundamental socio-economic conditions, rendering people chronically vulnerable to food insecurity. Indeed, Parry *et al.* (1999) estimate that a doubling of CO_2 in this century may lead to tens of millions more at risk of food insecurity in Africa.

From 1990 to 1999, FEWS conducted annual food security vulnerability assessments for Burkina Faso, Chad, Mali, Mauritania, and Niger. As analysis of the ten year data set will identify those administrative units consistently rated as highly or extremely food-insecure. This analysis, combined with the NDVI and forest species analyses and with a U.S. Department of Agriculture Natural Resources Conservation Service analysis of the vulnerability of soils to desertification, will provide information to map out areas of chronic vulnerability.

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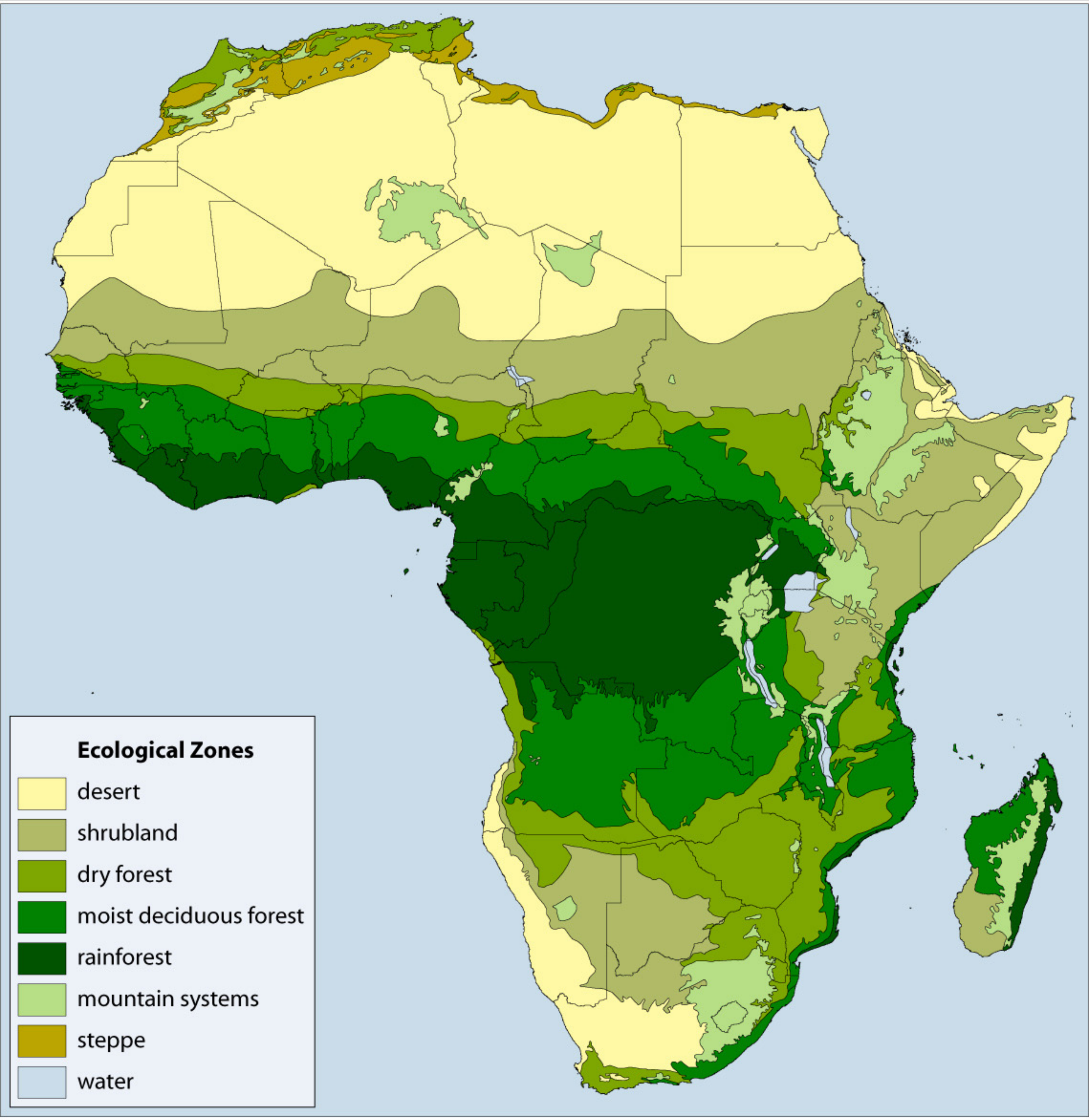
Figure 1. Ecological zones of Africa.

Ecological Zones of Africa

Geographic Projection

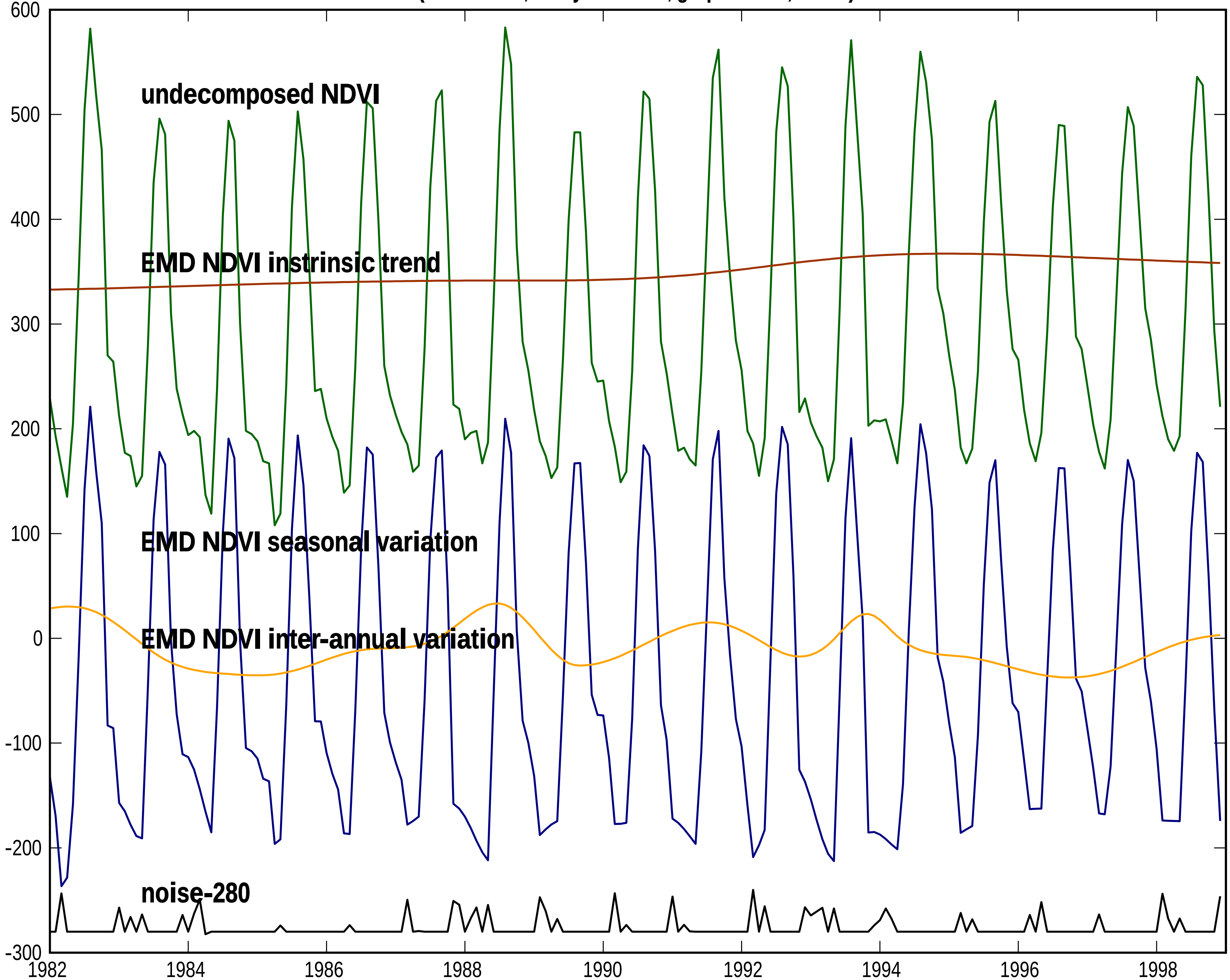


Data:
Köppen, W. 1931. Grundriss der klimakunde. Walter de Gruyter, Berlin, Germany.
White, F. 1983. The vegetation of Africa. United Nations Educational, Scientific, and Cultural Organization, Paris, France.

Analysis:
Food and Agriculture Organization (FAO). 2001. Global Forest Resources Assessment 2000. FAO, Rome, Italy.

Map:
U.S. Geological Survey, Earth Resources Observation Systems (EROS) Data Center, 2002.

Figure 2. Empirical Mode Decomposition (EMD) of Normalized Difference Vegetation Index (NDVI)
One 8 km pixel in the Sahel at 15º12' N, 13º24' W
(data NOAA; analysis NASA; graph NASA, USGS)



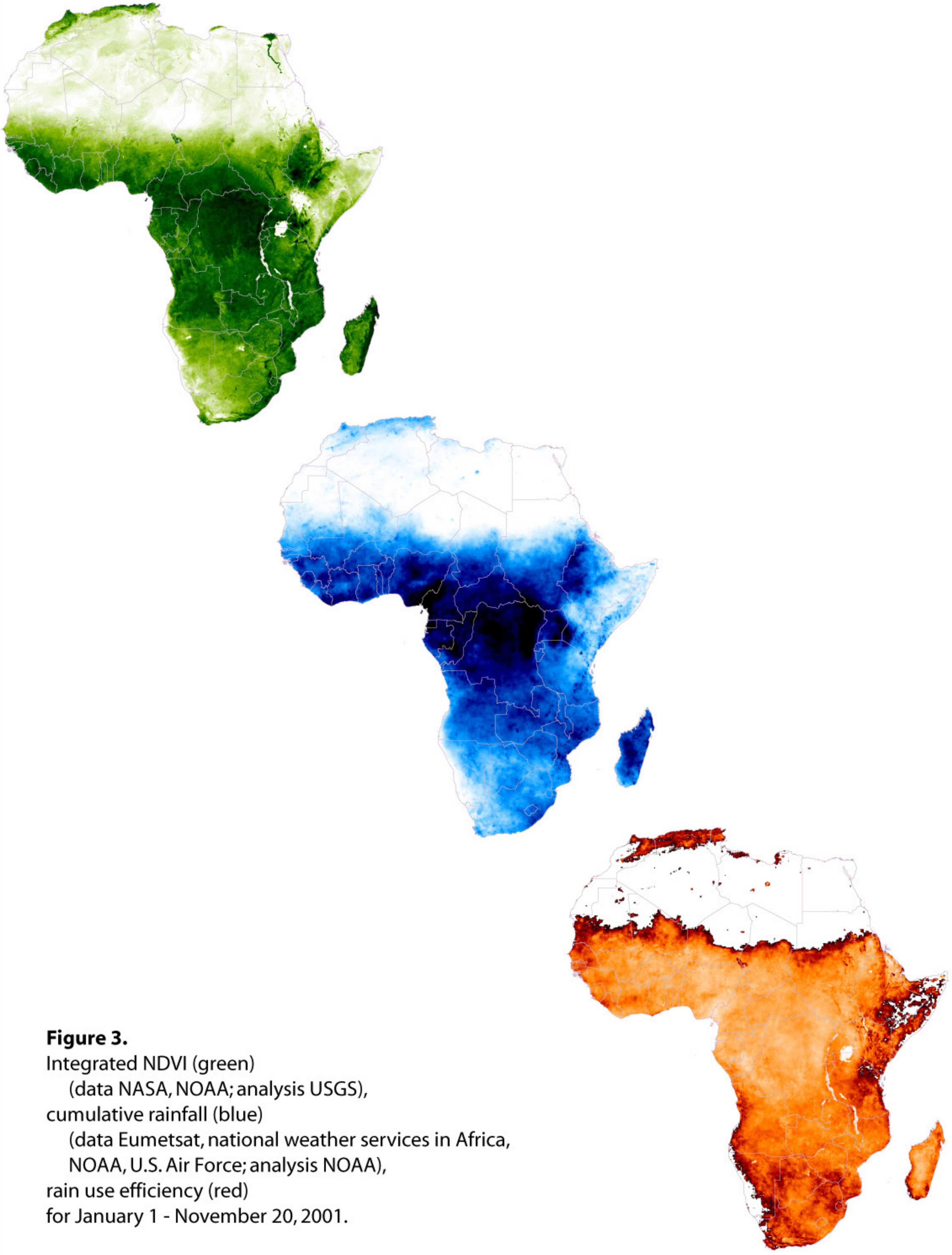


Figure 3.
Integrated NDVI (green)
(data NASA, NOAA; analysis USGS),
cumulative rainfall (blue)
(data Eumetsat, national weather services in Africa, NOAA, U.S. Air Force; analysis NOAA),
rain use efficiency (red)
for January 1 - November 20, 2001.

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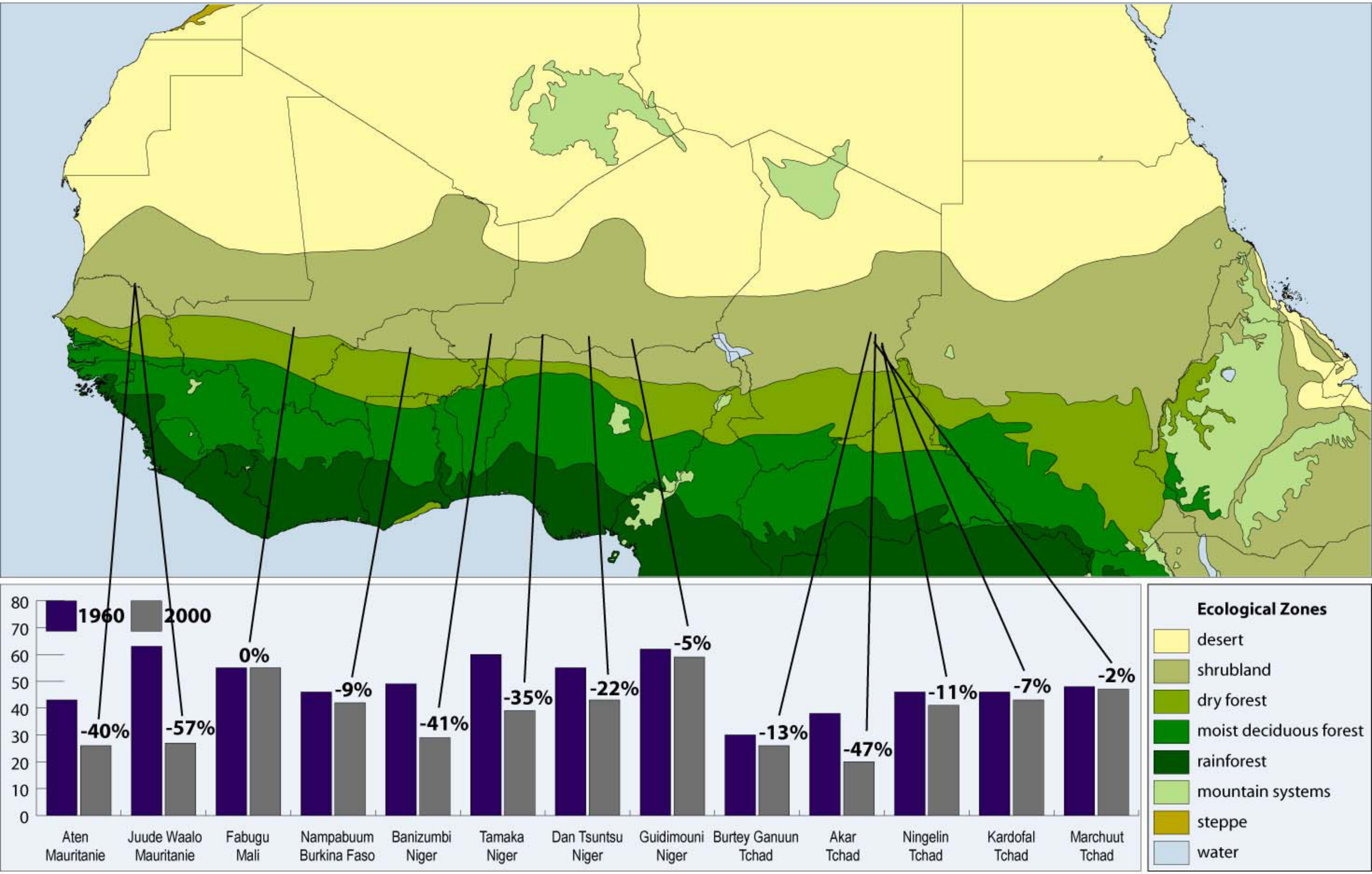
Figure 4. Forest species loss in the Sahel, 1960-2000.

Forest species loss in the Sahel 1960-2000, field data

Total number of forest species on village lands and percent decline



Forest species: villagers, U.S. Geological Survey (USGS), field representatives of the Famine Early Warning System Network (FEWS NET).

Ecological zones: Food and Agriculture Organization (FAO). 2001. Global forest resources assessment 2000. FAO, Rome, Italy.

Map: USGS Earth Resources Observation Systems (EROS) Data Center, 2002.