Landscapes of West Africa

A Window on a Changing World

Back of cover

Landscapes of West Africa

A Window on a Changing World

USAID
FROM THE AMERICAN PEOPLE

CILSS

USGS
science for a changing world

Editorial and Production Team

Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS)
Issifou Alfari, GIS and Remote Sensing Specialist
Edwige Botoni, Natural Resources Management Specialist
Amadou Soulé, Monitoring and Evaluation Specialist

U.S. Geological Survey Earth Resources Observation and Science (USGS EROS) Center
Suzanne Cotillon, Geographer*
W. Matthew Cushing, GIS Specialist
Kim Giese, Graphic Designer*
John Hutchinson, Cartographer
Bruce Pengra, Geographer*
Gray Tappan, Geographer

University of Arizona
Stefanie Herrmann, Geographer

U.S. Agency for International Development/West Africa (USAID/WA)
Nicodeme Tchamou, Regional Natural Resource Management and Climate Change Adviser

Funding and Program Support

Regional Office of Environment and Climate Change Response
U.S. Agency for International Development/West Africa
Accra, Ghana

CILSS
03 B.P. 7049
Ouagadougou, Burkina Faso
Tel: (226) 30 67 58
www.cilss.bf

To be cited as:
CILSS (2016). *Landscapes of West Africa – A Window on a Changing World*. U.S. Geological Survey EROS, 47914 252nd St, Garretson, SD 57030, UNITED STATES.

*SGT Inc., Contractor to the U.S. Geological Survey, Contract G15PC00012

PHOTOS (COVER): GRAY TAPPAN/USGS; ROBERT WATREL/SDSU; ERIC LANDWEHR/SDSU; RICHARD JULIA

On October 12, 2015, the Lunar Reconnaissance Orbiter took this striking view of the Earth as it circled 134 km above Compton Crater on the Moon, near the terminator between day and night. The sharp black outline of the lunar horizon is from mountains still on the night side of the terminator, silhouetted against the lower limb of the Earth. This image is reminiscent of the iconic Earthrise photograph taken by the crew of Apollo 8 as they orbited the Moon on December 24, 1968. Many people credit that unique view of our home planet as having sparked the environmental movement that so shaped our thinking about our planet during the 1970s and beyond.

Apart from its beauty, this image of the Earth from the Moon shows the African continent quite prominently. A great amount of cloud cover characterizes the blue planet. Several large areas are, however, clear: the deserts of North Africa and the Middle East, and in the Southern Hemisphere, the drylands of southern Africa. The tropical regions of Africa's mid-section are partially covered by belts of clouds that mark the intertropical convergence zone, where the northern and southern circulation patterns merge.

Source: NASA, Lunar Reconnaissance Orbiter

Dr. Djimé Adoum

Since the 1970s, West Africa has experienced many forms of climate stress — heavy rains, floods, and periods of drought. Drought has had a particularly devastating impact on agricultural production, pastoral livelihoods, and natural ecosystems. Economic losses alone are estimated in billions of dollars.

The concerns raised by these climate stressors have translated into initiatives to combat desertification and to adapt to climate change. The Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS – The Permanent Interstate Committee for Drought Control in the Sahel) and the U.S. Agency for International Development (USAID) have put in place activities to benefit the population of the Sahel and all of West Africa.

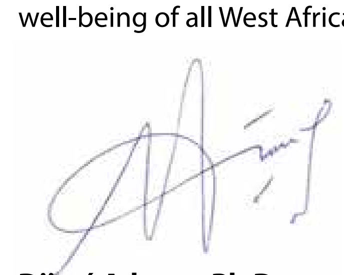
The West Africa Land Use Dynamics (LULC) Project is emblematic of this cooperation. Initiated in 1999, the LULC project has had several phases including training national experts to extract pertinent information from satellite images to characterize vegetation cover and producing tools and supporting information on land cover dynamics.

This atlas — Landscapes of West Africa: Window on a Changing World — is part of the current phase of the LULC project and provides insights into the changes occurring at national and regional levels through mapping time series data from 1975 to 2013. This work highlights landscapes that have undergone major transformations, and examines the drivers of change and their environmental and socioeconomic impacts.

The atlas showcases the accomplishments of the LULC project, and makes a case for further investment in natural resource management. Aimed at both decision-makers and the general public, the Atlas has a goal of making people aware of the changes taking place in the landscapes of the region.

Beyond raising awareness, the atlas also aims to incite action to protect the environment of West Africa and the Sahelian region. We therefore invite everyone — scientists, students, researchers, teachers, planners, managers of development or research projects, local, national and regional decision-makers, donors, members of civil society organizations, and visitors to the region — to make the most of this work.

Congratulations to the experts at CILSS, U.S. Geological Survey, USAID and the country-level teams of the LULC project for this fruitful partnership. We truly hope that this cooperation will continue and deepen, with the view of regaining the equilibrium of ecosystems. Doing so will constitute a decisive step towards realizing a green economy in West Africa, thereby enhancing the well-being of all West African people.



Djimé Adoum, Ph.D,
Executive Secretary
CILSS
Ouagadougou, Burkina Faso

USAID | WEST AFRICA
FROM THE AMERICAN PEOPLE

Alex Deprez

At the core of the U.S. Agency for International Development's (USAID's) mission is a deep commitment to work as partners in fostering sustainable development. Environments that are vulnerable to changing climate patterns are often the most reliant on agriculture for food and income, and the least able to financially protect themselves or respond to disasters. As effects of climate change are felt more severely, advanced mitigation and adaptation measures are key to resilience.

Rapid changes are occurring across West Africa's natural and human landscapes and balancing the need to preserve natural ecosystems with the need to grow more food, together with ensuring resilience in the same ecosystems, is a challenge. USAID West Africa's (USAID/WA) Environmental Threats and Opportunity Assessment and its Climate Change Vulnerability Assessment revealed that timely and accurate information, indispensable for good governance in the environmental sector, is scant and barely accessible. Mitigating climate change impacts and conserving biodiversity can support sustainable development, and prevent countries from sliding further into poverty.

USAID/WA worked in partnership with the U.S. Geological Survey (USGS) and the Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS – The Permanent Interstate Committee for Drought Control in the Sahel), to analyze changes in land use and land cover in West Africa and to better understand trends over the past 40 years with the goal of improving decision-making in land management. Products derived from these analyses include maps that provide a clear record of changes and trends in three periods — 1975, 2000 and 2013 — in 17 West African countries and aggregated to the regional level.

These maps and analyses form the foundation for future landscape scenarios and contribute to a body of best practices for the re-greening of landscapes in West Africa. Application of the atlas and associated data goes beyond informing decision-making on land use planning. The time series maps provide credible information to help countries account for their carbon emissions to the United Nations Framework Convention on Climate Change and can also be used to quantify carbon emission trends in West Africa for the past 40 years.

This achievement would not have been possible without the U.S. Landsat Program. Landsat satellites have provided the longest-ever continuous global record of the Earth's surface. A partnership of the National Aeronautics and Space Administration and the USGS, the Landsat program provides image data that show the impact of human society on the planet — a crucial measure as the world's population has already surpassed seven billion people. The first Landsat satellite was launched in 1972 and now, 44 years later, Landsats 7 and 8 are continuing to provide an unbroken record of the Earth, providing critical information for monitoring, understanding and managing our resources of food, water, and forests. No other satellite program in the world comes close to providing such a long, unbroken record of geospatial information of the planet.

Knowing that these analyses will be put to use for decision making in natural resource management, I would like to thank all of the teams that worked tirelessly to produce this Landscapes of West Africa atlas. And my sincere gratitude goes to CILSS, the USGS, and the multitude of government institutions in West Africa for their commitment to completing this influential work.

Alex Deprez
Regional Mission Director
USAID/West Africa
Accra, Ghana

On behalf of the governments and the people of West Africa who have benefitted from the West Africa Land Use Dynamics Project, the Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS – Permanent Interstate Committee for Drought Control in the Sahel) expresses its profound gratitude to all those who have contributed to the publication of this atlas. In particular, we would like to thank:

The U.S. Agency for International Development/West Africa (USAID/WA) which financed, encouraged and contributed actively to the review of this atlas;

The Resilience in the Sahel Enhanced (RISE) Program managed from USAID/Senegal's Sahel Regional Office, which supports the work of mapping best practices and re-greening, and promotes soil and water conservation in the Sahel;

The U.S. Geological Survey Earth Resources and Observation Science (USGS EROS) Center for the scientific and technical guidance, provision of satellite imagery, maps, field data and photographs, statistics and analyses;

The AGRHYMET Regional Center under CILSS for its role in the technical coordination of the work and processing of satellite imagery;

The Directors of the Centre National de Télédétection et de Suivi Ecologique (CENATEL) in Cotonou, the Agence Nationale de Gestion de l'Environnement (ANGE) in Lomé, and the Centre de Suivi Ecologique (CSE) in Dakar who hosted mapping validation workshops , and;

The national teams from across West Africa who provided valuable content for the maps and case studies.

Members of the National Teams

Benin

Cocou Pascal Akpassonou, Chef Division Coopération Technique au Centre National de Télédétection du Bénin (CENATEL) ;

O. Félix Houeto, Chef Division Télédétection et SIG au Centre National de Télédétection (CENATEL) du Bénin.

Burkina Faso

Raïnatou Kabré, Chargé de production et de diffusion de l'information environnementale au Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable (CONEDD) ;

Louis Blanc Traoré, Directeur Monitoring de l'Environnement au Secrétariat Permanent du Conseil National pour l'Environnement et le Développement Durable (CONEDD).

Cabo Verde

Maria Da Cruz Gomes Soares, Directrice, Direction des Services de Sylviculture (DGASP);

Sanchez Vaz Moreno Conceiçao, Responsable Inventaires Forestiers et Cartographie, Direction des Services de Sylviculture (DGASP).

The Gambia

Peter Gibba, Senior Meteorologist, Department Of Water Resources (DWR);

Awa Kaira Agi, Program Officer CGIS UNIT, National Environment Agency (NEA).

Ghana

Emmanuel Tachie-Obeng, Environmental Protection Agency (EPA);

Emmanuel Attua Morgan, Lecturer, Department of Geography and Resource Development, University of Ghana.

Guinea

Aïssatou Taran Diallo, Agro-environnementaliste, Ministère de l'Agriculture, Service National des Sols (SENASOL) ;

Seny Soumah, Ingénieur Agrométéorologiste et Chef de Section, Direction Nationale de la Météorologie (CMN).

Guinea-Bissau

Antonio Pansau N'Dafa, Responsable Bases de Données Changements Climatiques, Secrétariat de l'Environnement Durable;

Luis Mendes Cherno, Chargé de Bases de Données Climatiques, Institut National de Météorologie.

Liberia

D. Anthony Kpadeh, Head of Agro-meteorology, Climatology and Climate Change Adaptation, Liberia Hydrological Services;

Torwon Tony Yantay, GIS Manager, Forestry Development Authority (FDA).

Mali

Abdou Ballo, Enseignant Chercheur, Faculté d'Histoire-Géographie, Université de Bamako;

Zeinab Sidibe Keita, Ingénieur des Eaux Forêts, Système d'Information Forestier (SIFOR).

Niger

Nouhou Abdou, Chef Division Inventaires forestiers et Cartographie, Direction des Aménagements Forestiers et Restauration des terres, Ministère de l'Environnement, de la Salubrité Urbaine, et du Développement Durable;

Abdou Roro, Chef du Département Cartographie, Institut Géographique National du Niger (IGNN).

Nigeria

Kayode Adewale Adepoju, Lecturer and Scientist, Obafemi Awolowo University, Ile Ife;

Esther Oluwafunmilayo Omodanisi, Lecturer, Obafemi Awolowo University, Ile Ife;

Sule Isaiah, Lecturer, Federal University of Technology, Minna;

Mary Oluwatobi Odekunle, Federal University of Technology, Minna.

Senegal

Samba Laobé Ndao, Cartographe et Ingénieur en Aménagement du Territoire, Direction des Eaux, Forêts, Chasse, et de la Conservation des Sols (DEFCCS), Programme PROGEDE;

Ousmane Bocoum, Cartographe, Centre de Suivi Écologique (CSE).

Sierra Leone

Samuel Dominic Johnson, System Administrator, Ministry of Agriculture, Forestry and Food Security (MAFFS).

Chad

Angeline Noubagombé Kemsol, Agronome, Assistante de Recherche, Centre National d'Appui à la Recherche (CNAR);

Ouya Bondoro, Chercheur, Centre National d'Appui à la Recherche (CNAR).

Togo

Issa Abdou-Kérim Bindaoudou, Géographe et Cartographe, Direction Générale de la Statistique et de la Comptabilité Nationale;

Yendouhame John Kombaté, Responsable Suivi Evaluation et Communication, Agence Nationale de Gestion de l'Environnement, Ministère de l'Environnement.

Contributors from the AGRHYMET Regional Center

Bako Mamane, Expert en télédétection et Système d'Information Géographique (SIG);

Djibo Soumana, Expert Agrométéorologue;

Alio Agoumo, Technicien en traitement d'images;

Dan Karami, Technicien en Système d'Information Géographique.

Other Contributors

In West Africa, we would also like to acknowledge the invaluable advice, insights and assistance from:

Amadou Hadj, Geographer and Land Use Planner, Dakar, Senegal, for many fruitful years of field work and reflecting on natural resource management;

Samba Laobé Ndao, besides being part of the Senegal National Team, provided considerable support to field work, geographic databases, and logistical support to the project team;

Moussa Sall and Assize Touré at the Centre de Suivi Ecologique (CSE) in Dakar, for assistance with field work, studies on biomass and carbon sequestration, and many long years of collaboration;

Bienvenu Sambou and Assane Goudiaby, Université Cheikh Anta Diop de Dakar/Institut des Sciences de l'Environnement (ISE), for many years of exchanges with the USGS EROS team on long-term monitoring of Sudanian ecosystems.

At the USGS EROS Center, we extend special thanks to Jan Nelson and Tom Holm for guiding the publication process. Thanks also to the manuscript reviewers, Tom Adamson and Mike Budde, and to Aaron Neugebauer for his artwork on vegetation profiles. Many thanks to Melissa Mathis for her help with GIS training, and for her major role in developing the Rapid Land Cover Mapper. We are indebted to Anne Gellner for translating much of the manuscript into French.

At the World Resources Institute (WRI), we would like to thank Chris Reij and Robert Winterbottom, and Michael McGahuey at the USAID, for their many decades of work and insight into the natural resources of the Sahel, and their tireless work on landscape restoration and re-greening for the benefit of people across the region. We are also grateful for the many landscape and cultural photographs contributed by Michiel Kupers in the Netherlands, and Robert Watrel and Eric Landwehr at South Dakota State University (SDSU). Many thanks also to Scott Benton for his excellent contribution to the study of vegetation changes on the Island of Santo Antão, Cabo Verde.

In Memory

Our thoughts are with three colleagues and friends who are no longer with us. All three contributed significantly to the success of the West Africa Land Use Dynamics Project, including major content contributions to this atlas:

Yendouhame John Kombaté, Responsable Suivi Evaluation et Communication, Agence Nationale de Gestion de l'Environnement, Ministère de l'Environnement, Togo;

Kevin Dalsted, Soil Scientist and Land Resource Specialist, South Dakota State University, for his support to the land use mapping;

Richard Julia, friend and pilot based in Ouagadougou who made it possible for the project team to acquire thousands of aerial photographs in numerous countries of West Africa, and for his own photography of landscapes, wildlife and cultures of the Sahel.

Introduction

Our global ecosystem is and has always been complex, dynamic, and in constant flux. Science tells us how natural forces of enormous power have shaped and reshaped Earth's surface, atmosphere, climate, and biota again and again since the planet's beginnings about 4.5 billion years ago. For most of the planet's history those environmental changes were the result of the interaction of natural processes such as geology and climate, and were described on the geological time scale in epochs spanning millions of years.

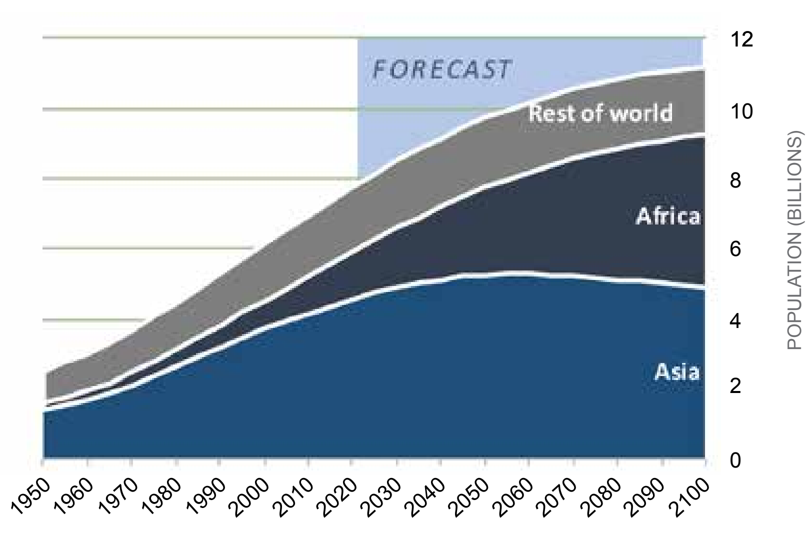
When humankind appeared on Earth around 200,000 years ago the influence of human activity on the environment must have been small and localized. The influence of scattered small groups of people on the global ecosystem would have been overwhelmed by the forces of natural systems (Steffen and others, 2007). Human population would not grow to 50 million (about 0.7 percent of the Earth's current population) for another 197,000 years. Population growth accelerated over the centuries that followed until the planet was adding more than that 50 million people every year. Our planet is now home to roughly 7.3 billion people and we are adding 1 million more people roughly every 4.8 days (US Census Bureau, 2011). Before 1950, no one on Earth had lived through a doubling of the human population, but now some people have experienced a tripling in their lifetime (Cohen, 2003).

With hunting and the use of fire, later agriculture and urbanization, and eventually the industrial revolution and modern technology, the ability of humans to shape their environment also grew exponentially. Earth scientists use the geologic time scale to describe time periods where different processes and forces shaped events in the Earth's history, such as ice ages and mass extinction events. They use periods of time they call epochs, which range from 11,700 years (the Holocene) to millions of years (the Pleistocene and Neogene). In about 2000, Earth scientists coined a new word — Anthropocene — to describe a new epoch where "the human imprint on the global environment has become so large and active that it rivals some of the great forces of nature in its impact on the functioning of the Earth system" (Steffen and others, 2011). Many in the Earth sciences believe that epoch has begun and that humankind with its vast numbers and its power to change the face of the Earth is at risk of putting the Earth system out of balance and causing the collapse of natural systems that are essential for humans to thrive, perhaps even threatening the future of all humankind.

"Mai lura da ice bashin jin yunwa" — He who takes care of trees will not suffer from hunger.

– Hausa proverb

Population growth in Africa and the rest of the world from 1950 to 2100



In 2015, the 17 countries included in this atlas are estimated to have a total population of over 369 million, representing a nearly 5-fold increase since 1950 — outstripping global population growth, which grew by 2.9 fold during the same time (UN, 2015). The young age structure of the West African population assures continued rapid population growth until 2050 and beyond. If United Nations estimates are correct the 17 countries in this atlas will grow to 835 million people by 2050; that would equate to 11.1 times as many people as lived on the same land in 1950 (UN, 2015)!

PHOTO (OPPOSITE PAGE): SUZANNE COTILLON / SGT

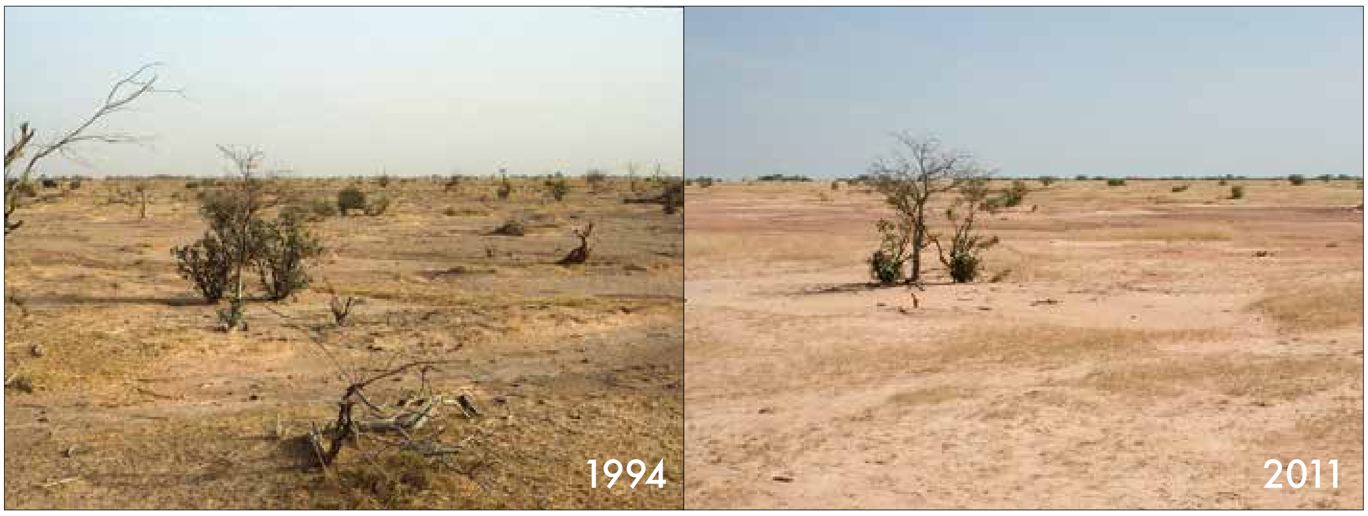
Wooded landscape fragmented by agriculture expansion in western Burkina Faso

JAMES ROWLAND / USGS

Parallel trends can be seen in the land cover changes of West Africa. With so many new families to feed, West Africa doubled the area covered by farms between 1975 and 2013. Vast areas of savanna, woodland, and forest landscape have been replaced or fragmented by cropland. At the same time villages, towns, and cities have grown in area — taking up 140 percent as much land as they had in 1975. In part to make way for those farms and settlements more than a third of the forest cover present in 1975 has been lost. In savanna and steppe landscapes of West Africa, drought, in some cases made worse by unsustainable land use practices, has degraded the vegetation cover contributing to a 47 percent increase in sandy areas (see top images pair, opposite page). The future is unpredictable, but the trends of the past four decades projected into the future would be unsustainable.

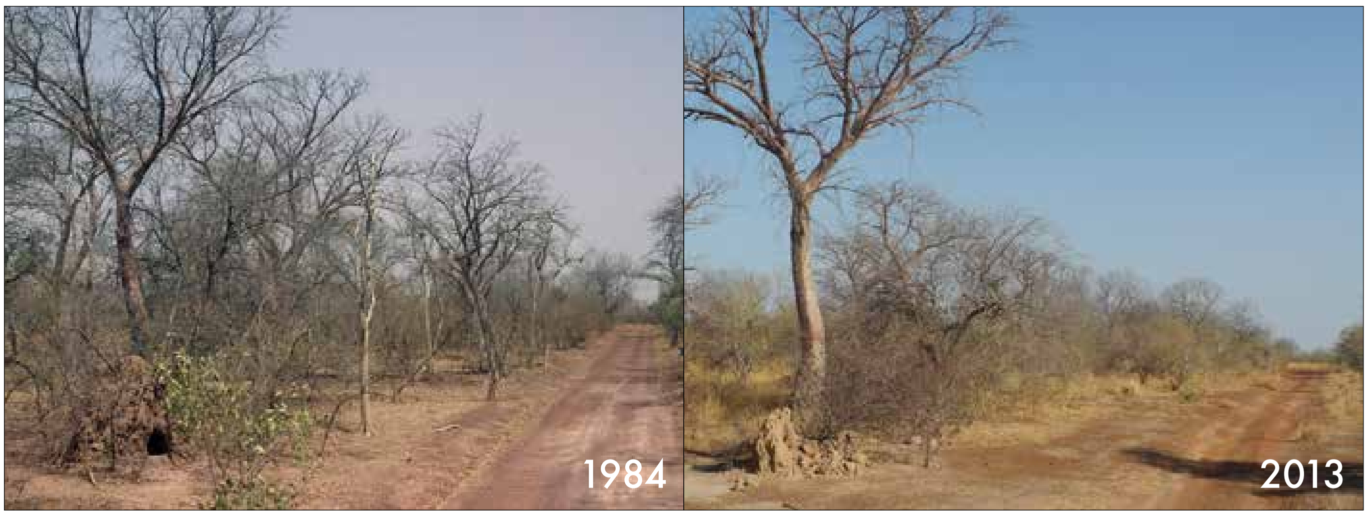
Conversion of the natural landscapes of West Africa to agriculture greatly reduces the natural biodiversity, and exposes the soil to wind and water erosion. The savanna, woodland, forest, and wetland ecosystems that are lost have some relatively tangible impacts such as the loss of natural ecosystem goods and services like wood for fuel and construction, honey, nuts, medicines, game animals, berries, and forage. There are also many important goods and services lost that are less visible such as biodiversity, carbon storage, water quality, water runoff versus infiltration, and regional climate functions.

Expansion of degraded land in the Ferlo region of Senegal



GRAY TAPPAN / USGS

Decline in vegetation cover and biodiversity in east-central Senegal

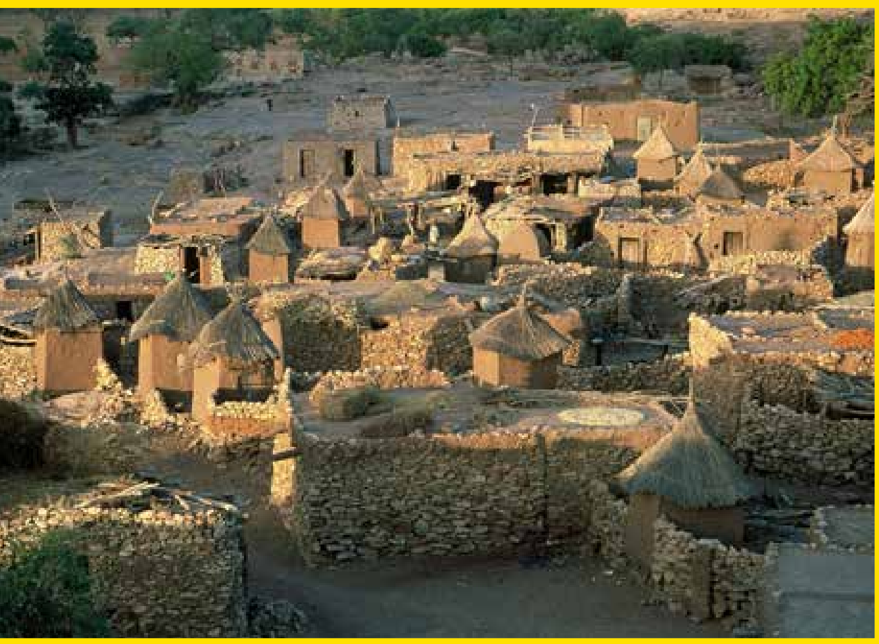


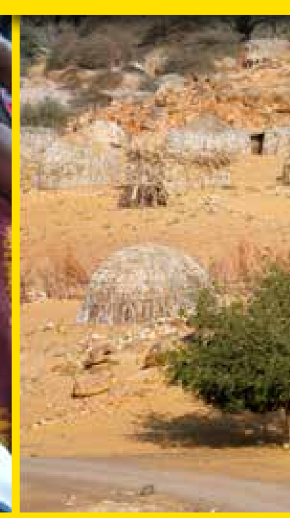
GRAY TAPPAN / USGS

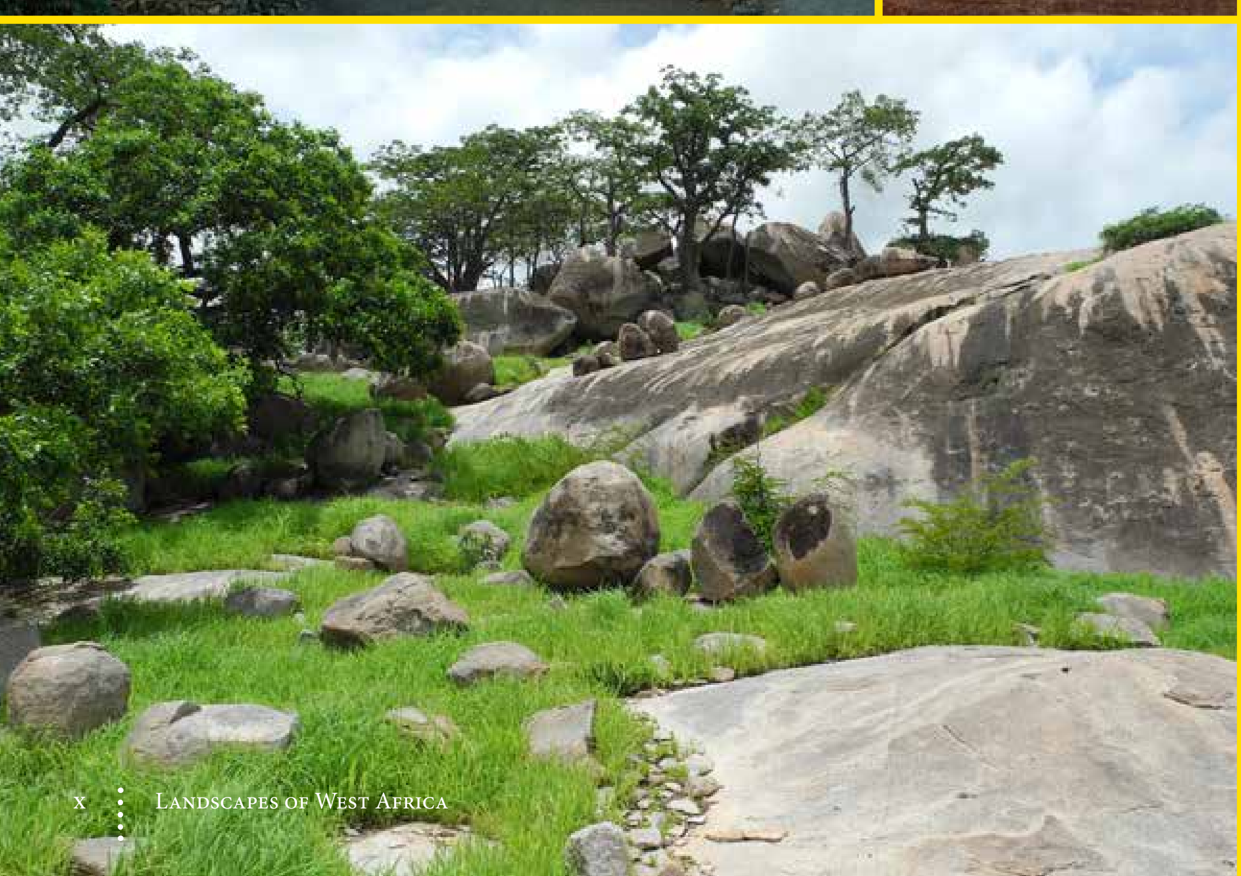
It is in the hands of today's decision makers to formulate wise, well informed choices about how to manage West Africa's land, to ensure that vital ecosystem services and agricultural productivity are able to support tomorrow's people. To make good choices the governments of West Africa need good information about the rapid changes now occurring, the causes of those changes, and the interactions occurring between climate, land use, other human activity, and the environment.

Experts from institutions in 17 countries in West Africa have partnered with the Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS – The Permanent Interstate Committee for Drought Control in the Sahel), the U.S. Agency for International Development (USAID) West Africa and the U.S Geological Survey (USGS) to map changing land use and land cover and associated factors across much of West Africa through the West Africa Land Use Dynamics Project. This publication presents the results of that work. The following chapters present maps, graphs, tables, and images detailing the natural environment of these 17 countries and changes that have taken place over the past four decades.

This atlas tells a story of rapid environmental change with both hopeful and worrisome chapters. The story is told with maps and numbers detailing the rate, magnitude, and location of land cover change but also with words and images that seek to make the story more real for the people living in West Africa and around the globe. The hope is that this information helps to build a clearer picture of past and current land use and land cover in order to guide us all in making informed choices that will support the livelihoods and well-being of ours and future generations.

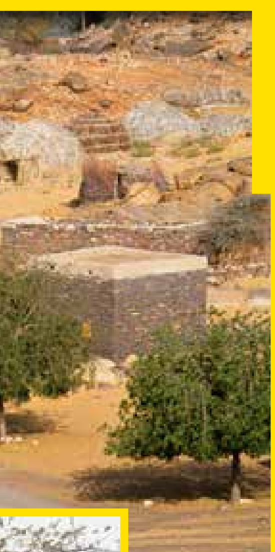






Chapter I

West Africa's Changing Environment



1.2
Approach to Monitoring Land Resources

Satellite Imagery

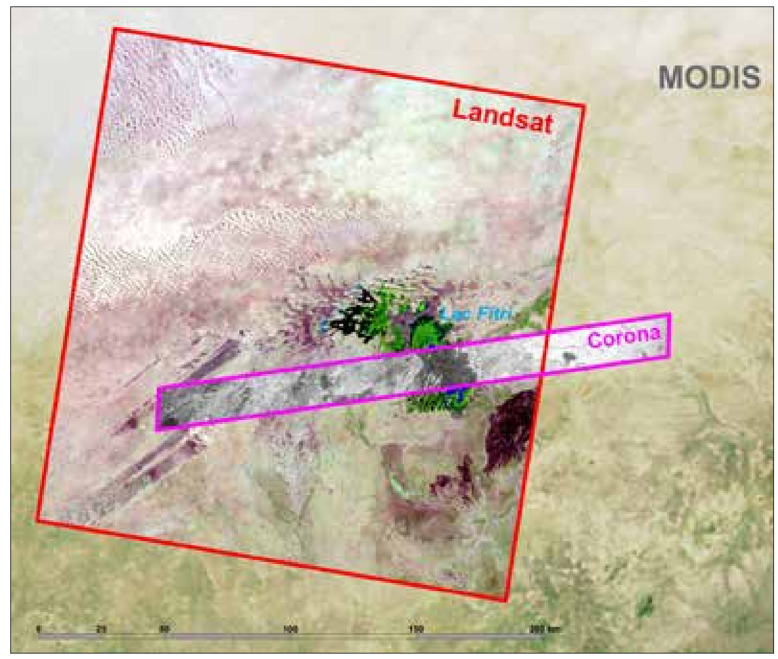
The maps, photographs, and remote sensing images in this atlas were all created with the goal of assessing land cover and land conditions, and measuring change over time. Maps show a broad view of a country or region, and ground photographs can document landscapes for a particular location, but remote sensing images are the key tools to detect and record surface conditions and understand changes happening on the landscape, both natural and human-caused. Remote sensing images are an objective, cost-effective way to measure and analyze long-term change, including the change in land cover from 1975 to 2013 that is at the heart of this book.

Some of the images are taken from Google Earth and credited as such, but the majority come from one of three sources: Landsat, Corona, or the Moderate Resolution Imaging Spectroradiometer (MODIS). Each has its own characteristics and advantages.

The first Landsat satellite was launched in 1972, and the program has been in continuous operation since then. Landsat was designed specifically to study and map land resources. Landsat 8 now orbits the Earth at an altitude of 705 km and records data as 30-m pixels in images approximately 170 km by 185 km. Landsat images revisit the entire Earth every 16 days.

Corona was a national reconnaissance mission, flown on satellites from 1960 to 1972. Corona recorded photographs on high quality film stock, which was jettisoned and recovered in the atmosphere by airplane. The high quality film meant that Corona photos recorded fine details, but coverage was limited to areas of interest to U.S. military programs during the Cold War. Nevertheless, Corona photography of West Africa covers virtually all of West Africa, dating back to as early as 1962. Corona film was declassified in the interest of science in 1995. Project staff at the U.S. Geological Survey (USGS) EROS Center coordinated the scanning and georegistration needed to convert Corona film photography into digital image data.

The MODIS instrument is mounted on the Terra and Aqua satellites, launched in 1999 and 2002, respectively, that orbit at the same altitude as Landsat. However, MODIS images cover a swath 2,330 km wide at a relatively coarse resolution of 250 m. As a result, MODIS images are less detailed than Landsat, but instead of every 16 days, MODIS has the advantage of covering the entire Earth every one or two days. MODIS provides the data for calculating a widely used index of vegetation condition, the normalized difference vegetation index, or NDVI (see section 1.4, pages 38–41).



MODIS data serve as the backdrop to a 2014 Landsat image of Lake Fitri in Chad, with 1967 Corona photography on top.

The Landsat program has served longer than any other Earth-observing satellite system. For that reason, Landsat provides the bedrock dataset for land cover mapping and land cover change analysis for most of the maps in this book. Landsat is detailed enough at 30-m resolution to map and measure many types of landscape changes, for example the growth of agriculture and of cities, as well as the fragmentation of forests and savannas. Landsat's 16-day repeat cycle is frequent enough to make it possible to overcome the frequent heavy cloud cover in some parts of West Africa. The consistency of Landsat imagery makes it possible to make objective observations of land cover change from 1972 to the present.

Corona serves the important function in several areas of pushing the observation window back another 10 years before Landsat, with satellite photography from the early 1960s that complements Landsat imagery. MODIS data at 250-m resolution serve as a base for several national and regional maps in this atlas and for assessing vegetation condition. The differences in footprint and visual characteristics among the three systems can be seen in the comparison above.

PHOTO (OPPOSITE PAGE): NASA

Mapping Land Use and Land Cover

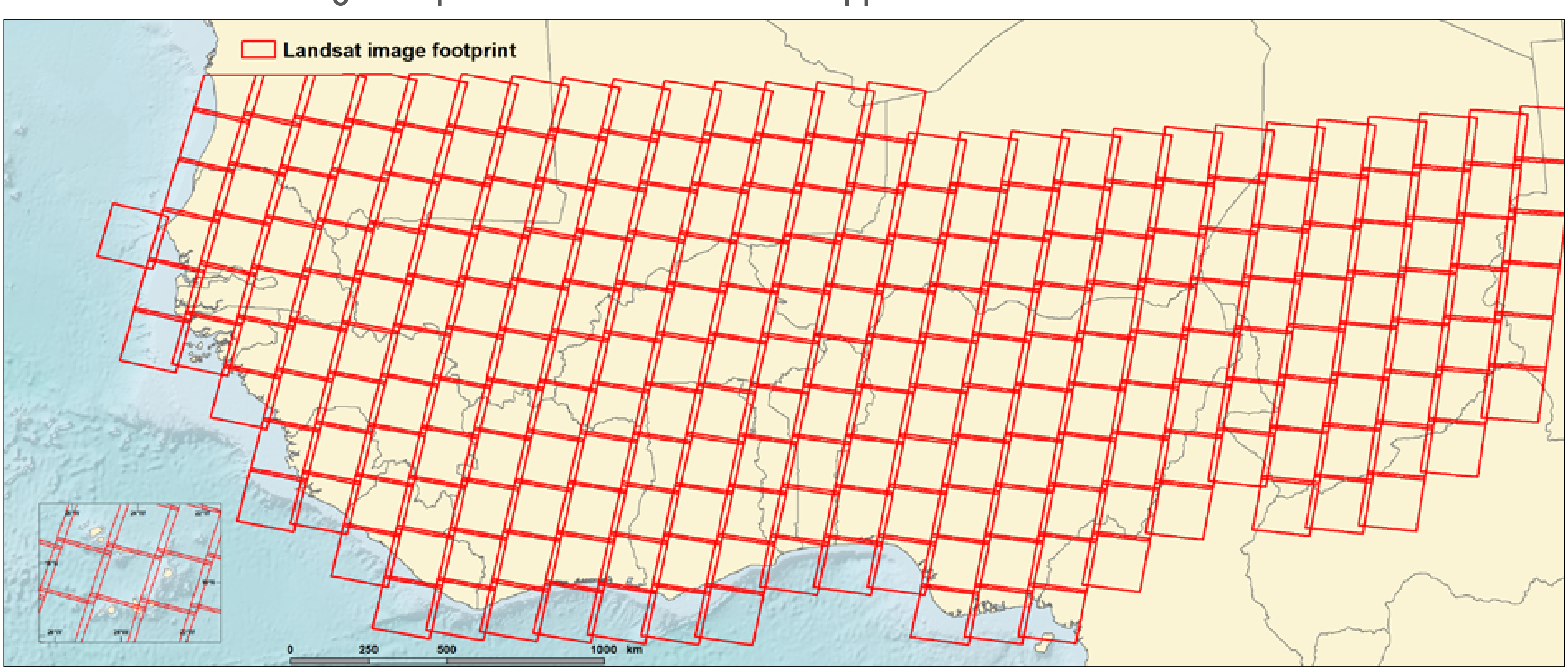
Mapping the land use and land cover of all of West Africa for three periods in time (1975, 2000 and 2013) using many hundreds of Landsat images required careful consideration with regard to a methodology. Mapping land cover over time requires an approach that generates consistently accurate maps over time for reliable change detection. Of two basic mapping approaches — computer automated classification and visual image interpretation — one needed to be chosen.

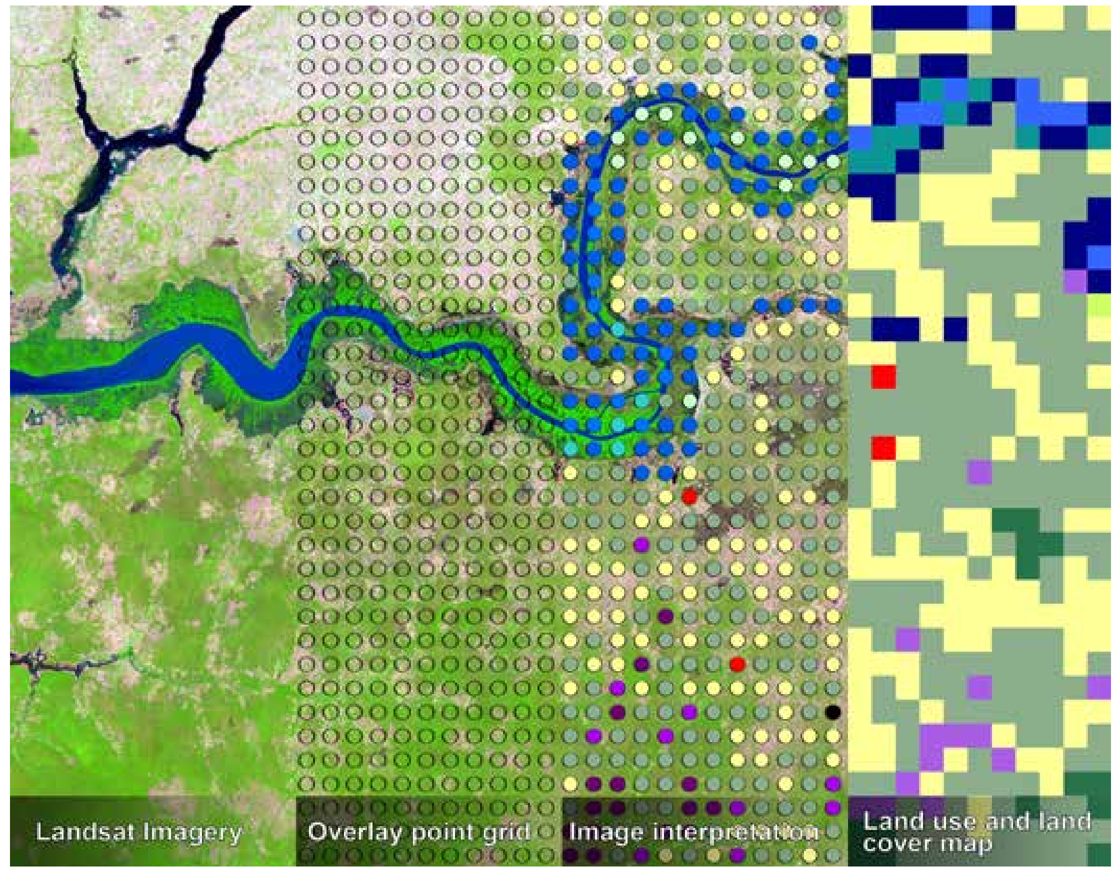
The most common approach in land use and land cover mapping is automated classification — throwing huge amounts of digital image data into an image classifier. However, earlier experiences with automated classification in Mali, Senegal and Niger produced disappointing results. Important land use and land cover types, such as agriculture in the Sahel, could not be uniquely differentiated from other types based on their spectral reflectance properties. Automated methods of image classification are based on spectral image data and are often plagued by problems of misclassification. Spectral reflectance of land surfaces — and more broadly spectral response patterns — measured by remote sensors may be quantitative but they certainly are not absolute. They may be distinctive but they are not necessarily unique. In reality, there is often extreme variability of spectral reflectance associated with various land cover types (Lillesand and Kiefer, 1994). This variability poses major challenges in mapping and analyzing land cover types based solely on their spectral properties. For these reasons, the project chose visual image interpretation rather than the semi- or fully-automated approaches.

Mapping land use and land cover using visual interpretation is not without its own challenges, but the combination of firsthand knowledge of the landscapes and reliance on multiple dimensions of information inherent in imagery is a powerful approach to producing highly accurate maps. Mapping land cover from satellite images requires special skills and detailed local knowledge about the area of interest — including its physical, biological and human components. Satellite images, much like aerial photographs, contain a detailed record of features on the Earth's surface at the time of acquisition. Drawing upon training, field experience, geographic knowledge, an acute power of observation and patience, image analysts mapped the land use and land cover using visual interpretation. They relied on the basic elements of image interpretation: shape, size, pattern, color, tone, texture, shadows, geographic context, and association. The time of year when each image was acquired was also an important factor in identifying the land features. The image interpretation process was facilitated through the use of interpretation guidelines, which included written and illustrated definitions of all of the land use and land cover classes.

The visual image interpretation method works well for several important reasons. First, it lends itself well to working with photographs and images from different satellite systems and formats. Second, it allows

Landsat 8 nominal image footprint for the West Africa mapped area





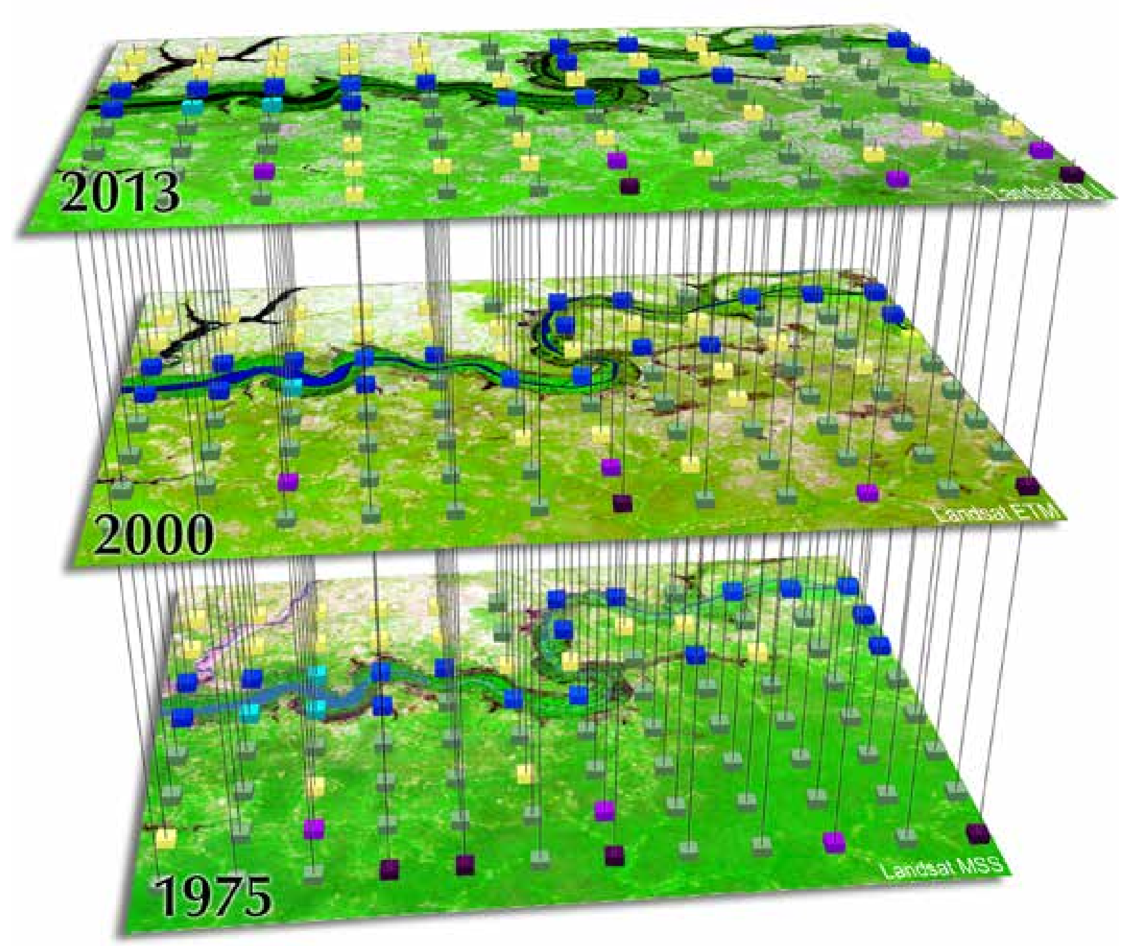
Steps in making a land use and land cover map using the RLCM Tool; 1) selecting imagery, 2) overlaying a grid of points, 3) interpreting and attributing, and 4) making land use and land cover map.

expert interpreters to integrate local knowledge with the many dimensions of information contained in images. Third, image interpreters can readily account for, and work around, problems related to seasonal differences from image to image, as well as differences in illumination and atmospheric effects. For example, the human interpreter can effectively distinguish real land changes from many of the ephemeral changes on the land such as burn patterns from annual grass fires. Image interpretations were systematically validated with high-resolution satellite imagery and, in many countries, with visits to the field. Fourth, in order to maintain high accuracy and reduce confusion among land cover types, we defined land use and land cover classes that could be consistently identified and mapped from Landsat satellite imagery (see pages 50–55). Fifth, the requirement of mapping land use and land cover at multiple periods of time necessitated high accuracy in order to confidently characterize the changes from period to period. When done properly, the visual interpretation method provides the high accuracy needed.

In order to check the accuracy of the maps, the analysts used multiple sources of ancillary data, including thousands of aerial photographs taken by the project team, and recent high-resolution satellite images viewable in Google Earth. The Google Earth tool was particularly useful in systematically checking the mapping of land cover from recent Landsat imagery.

The traditional method of visual interpretation is ideal for the reasons given above, but it is also labor-intensive, particularly for such a vast area; mapping millions of square kilometers for three points in time would have been insurmountable using the traditional method. To expedite the interpretation process while still maintaining temporal accuracy, the U.S. Geological Survey (USGS) EROS Center team developed the Rapid Land Cover Mapper (RLCM) tool. The RLCM tool is a Geographic Information System (GIS) vector/raster hybrid approach that lends itself to both multiple resolutions and time series mapping. Conceptually, the RLCM is based on the traditional dot grid method for calculating area, employed by foresters for over a century (Schumaher and Chapman, 1972). The RLCM tool generates a digital grid of points that overlays an image (see top figure). Using standard photo interpretation techniques, the interpreter identifies the discrete land use and land cover class for each point. The RLCM tool facilitates the selection and assignment of the point's land cover class. This is accomplished by simultaneous point selection and cascading period classification. Simultaneous selection allows the interpreter to select many points of a common class and assign them to that specific class with one action. Cascading is a method of completing the classification of a first time period for a given area, then pushing that classification information forward or back in time (see figure below). After copying the attributed points into another time period, they are displayed over images that correspond to the "new" time period. The interpretation process is repeated, and in this case the previously attributed points are reviewed to determine if they should remain unchanged or be edited to reflect a change in the land cover. Generally, the image analysts began with the most recent period, then worked back in time to the earlier periods. This resulted in the production of multi-period land use and land cover maps and associated statistics that characterize the changing landscapes at national and regional scales.

A simplified time series representation of three land use and land cover interpretations using the RLCM Tool. The cubes symbolize the grid points that are placed over the imagery, color coded by land cover class. The vertical lines show the spatial alignment of the points through time.



Land Cover Modification

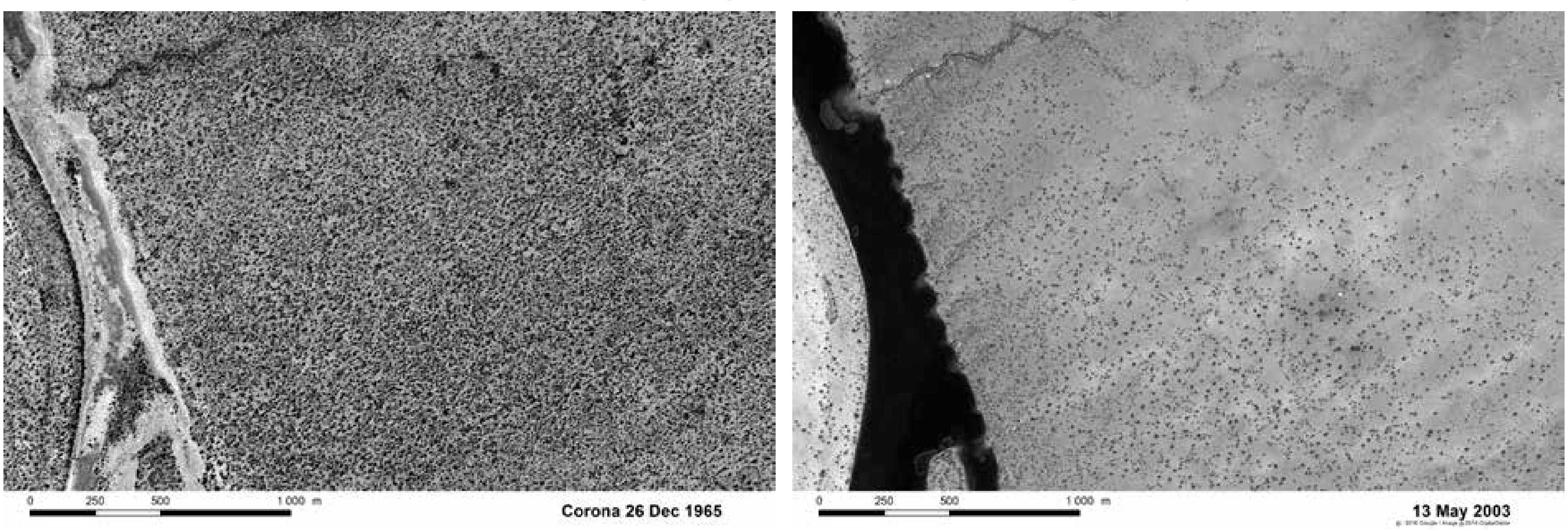
CHRIS REIJ / WRI

This atlas presents West Africa's changing landscapes through land use and land cover maps for three periods in time. The changes between each period represent one of two main types of landscape change: land cover conversions and land cover modifications. Land cover conversions are the transitions from one land cover or use type to another (e.g., forest to agriculture). As the maps show (see pages 44–49), this type of change can be quite dramatic, such as the loss and fragmentation of the Upper Guinean forest (see pages 66–67).

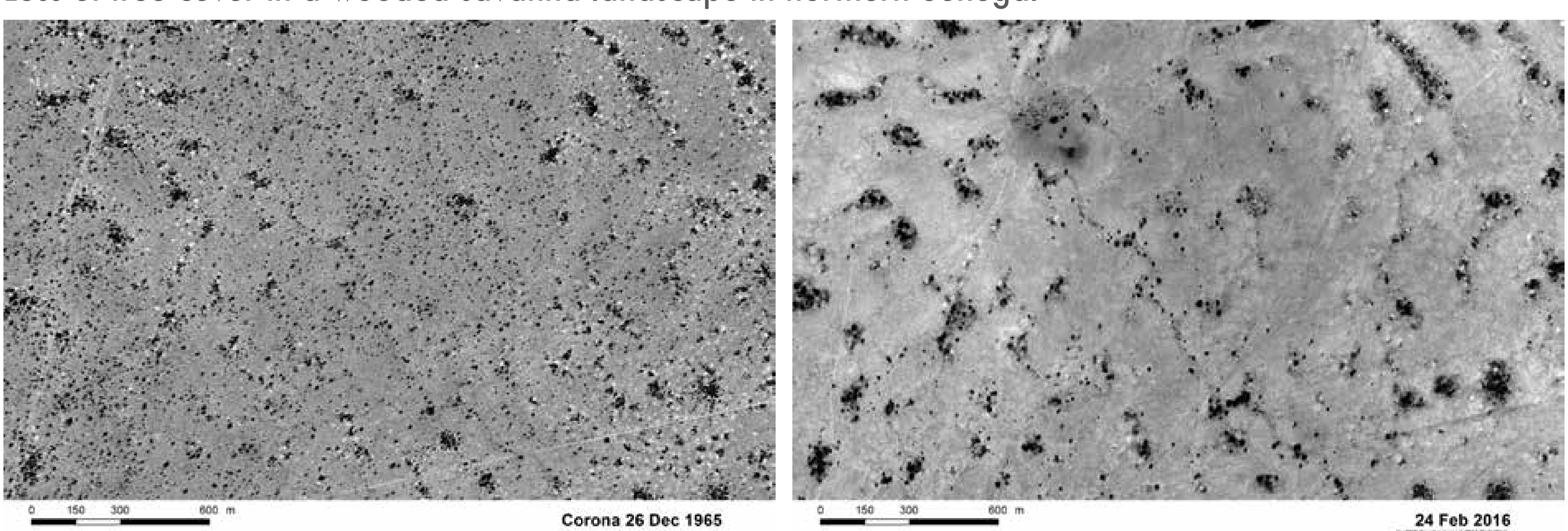
In land cover modification, the general land cover or use type does not change, but there is a change in its attributes. This type of change is more subtle but can be very significant. An example is the effect of logging in a woodland: the land cover is still "woodland," but its quality — the tree density and biodiversity — has been diminished by selective tree harvesting. Assessing these more subtle land cover modifications generally requires high resolution imagery. For example, most of the loss in woody biomass found in the various types of vegetation cover in Senegal were a result of land cover modification rather than the conversion of land cover from one class to another (Woomer and others, 2004; Tappan and others, 2004). Land cover modification is much harder to map and quantify at national and regional levels than land cover conversion. The recent, widespread availability of high-resolution imagery is helping environmental scientists gain a more complete picture of land cover modification in West Africa.

Land cover modification is clearly seen in the pairs of satellite images below, which compare two Sahelian landscapes in northern Senegal at a time interval of 38 and 51 years. The first pair (top images) shows a relatively dense tree savanna on a sandy plain in December 1965 (Corona, left). The May 2003 image (DigitalGlobe, right) shows that the same landscape has become an open tree savanna. This area experienced high tree mortality during the droughts of the 1970s and 1980s, exacerbated by increased browsing by livestock as grass cover became scarce. The Ferlo Valley

Loss of tree cover in a tree savanna landscape adjacent to the Ferlo Valley, Senegal



Loss of tree cover in a wooded savanna landscape in northern Senegal



GRAY TAPPAN / USGS

Comparative views of the same landscape in central Senegal 1994 and 2010 showing the regeneration of woody cover after years of harvesting shrubs and trees for wood fuels.

GRAY TAPPAN / USGS

Comparison of an agricultural landscape in Senegal in 1984 and 2004 showing the increase in on-farm vegetation including hedges, and fruit tree planting to diversify production.

GRAY TAPPAN / USGS

Left photo: Aerial view near Madaoua, Niger of regeneration of trees along rock lines on the contour. Rainfall is captured, runoff and erosion are minimized, and crop production is increased.

Right photo: Farmer-managed natural regeneration in the broad valley near Rissiam, northern Burkina Faso. Nearly all of the land under the trees is devoted to growing cereal crops.

GRAY TAPPAN / USGS; CHRIS REIJ / WRI

Left photo: Part of the biodiverse forest created by Yacouba Sawadogo, a farmer innovator near Ouahigouya, Burkina Faso. In 1979, this was a barren plateau until he began rehabilitating his land by planting trees and capturing rainfall and protecting trees on his land.

Right photo: This productive field was barren in 1980. Ousséni Kindo, another farmer innovator in northern Burkina Faso, experimented with techniques to establish native grasses and trees while cultivating millet among them.

was dry in 1965 (left image) but began to flood in 1988 when the Diama Dam was constructed on the Senegal River.

The next pair (opposite page , bottom images) shows land cover modification on a more complex landscape that evolved from ancient sand dunes. This example is also from northern Senegal, 25 km southeast of Dagana. In December 1965 (Corona, left) trees (black points) are scattered throughout continuous grass cover, with clusters of trees forming wooded stands in many small natural depressions. Half a century later, the 2016 image (DigitalGlobe, right) shows that most of the trees have disappeared — also from drought and livestock pressure — except in the wooded depressions where water collects during the brief rainy season. A seasonal camp of semi-nomadic Fulani herders is visible in the upper left quarter of the image. The stark contrast between wooded depressions and the surrounding open country has increased with time — a typical phenomenon in many landscapes across the Sahel.

Land modification, however, is not always negative. Across West Africa, many examples of positive land modification, such as the regeneration of woody cover, the increase of biodiversity on cropland, or the use of soil and water conservation practices to improve cropland productivity, can be cited (see examples above, and cases of land restoration on pages 70–71).