

Landscapes of West Africa

A WINDOW ON A CHANGING WORLD



Landscapes of West Africa

A WINDOW ON A CHANGING WORLD



USAID
FROM THE AMERICAN PEOPLE



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

Copyright ©2016, Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS)

No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from CILSS.

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.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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

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

Preface	ii	Acknowledgements	iv
Foreword	iii	Introduction	vii

Chapter 1: West Africa’s Changing Environment..... 1

1.1 Landscapes and Physical Geography..... 3	1.4 Land Productivity..... 38
Physical Geography.....3	
Bioclimatic Regions.....7	
<i>Landscapes of the Sahara Desert</i> 11	
Ecological Regions..... 13	
Biodiversity and Protected Areas 16	
<i>The W-Arly-Pendjari Transboundary Reserve</i> 20	
1.2 Approach to Monitoring Land Resources..... 25	1.5 Land Use and Land Cover Trends 42
Satellite Imagery 25	from 1975 to 2013
Mapping Land Use and Land Cover 26	West Africa Land Use and Land Cover Maps..... 44
Land Cover Modification 28	Land Use and Land Cover Classes 50
1.3 Drivers of Land Changes..... 30	<i>Special Landscapes of West Africa</i> 56
Population 31	Agriculture Expansion 59
Climate 34	Settlements Growth..... 62
	Deforestation of the Upper Guinean Forest..... 66
	Mangrove Changes 68
	Landscape Restoration and Re-greening..... 70

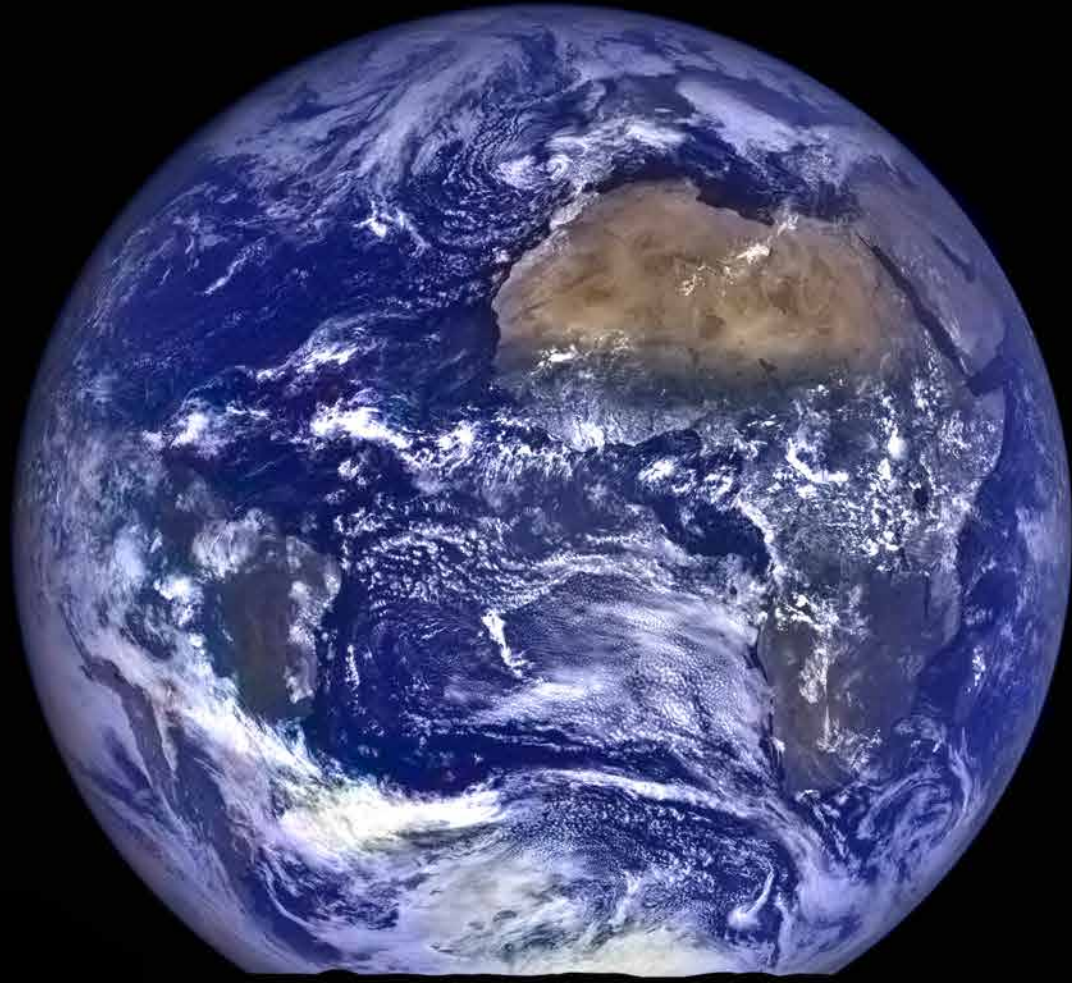
Chapter 2: Country Profiles, Land Use and Land Cover, and Trends..... 73

2.1 Benin..... 74	2.10 Mali..... 140
2.2 Burkina Faso..... 82	2.11 Mauritania..... 148
2.3 Cabo Verde..... 90	2.12 Niger 156
2.4 Côte d’Ivoire 96	2.13 Nigeria..... 164
2.5 Gambia (The) 104	2.14 Senegal..... 174
2.6 Ghana..... 110	2.15 Sierra Leone 184
2.7 Guinea..... 118	2.16 Chad 192
2.8 Guinea-Bissau..... 126	2.17 Togo..... 200
2.9 Liberia..... 132	

References.....	208
Acronyms and Abbreviations.....	214
Index	215

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.





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.

A handwritten signature in blue ink, appearing to read 'Djimé Adoum'.

Djimé Adoum, Ph.D,

Executive Secretary

CILSS

Ouagadougou, Burkina Faso



USAID | WEST AFRICA

FROM THE AMERICAN PEOPLE

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



Alex Deprez



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

Rainatou 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 Conceição, 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 Chernó, 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

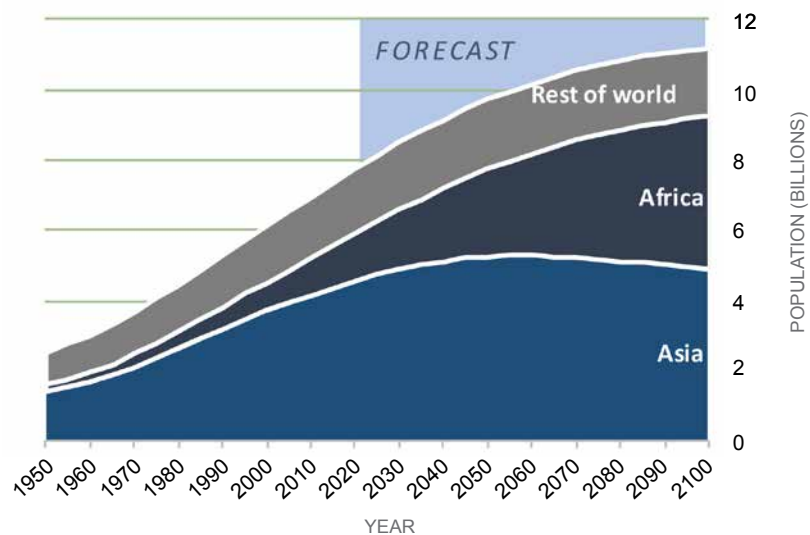
the collapse of natural systems that are essential for humans to thrive, perhaps even threatening the future of all humankind.

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)!

“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



Wooded landscape fragmented by agriculture expansion in western Burkina Faso



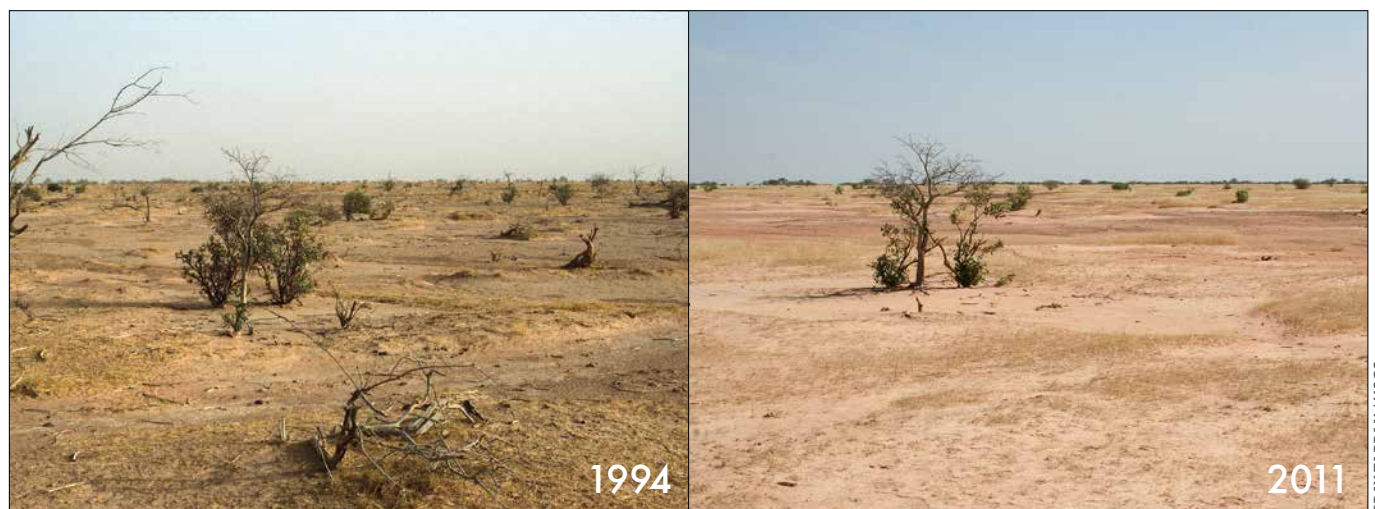
JAMES ROWLAND / USGS

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

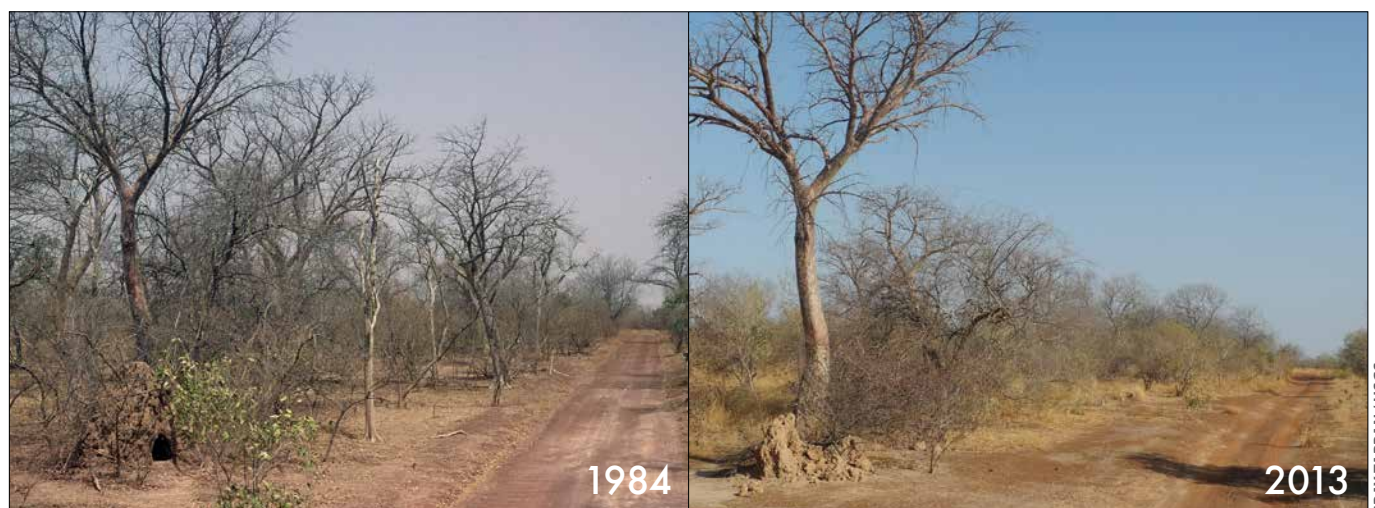
pair, opposite page). The future is unpredictable, but the trends of the past four decades projected into the future would be unsustainable.

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



Decline in vegetation cover and biodiversity in east-central Senegal

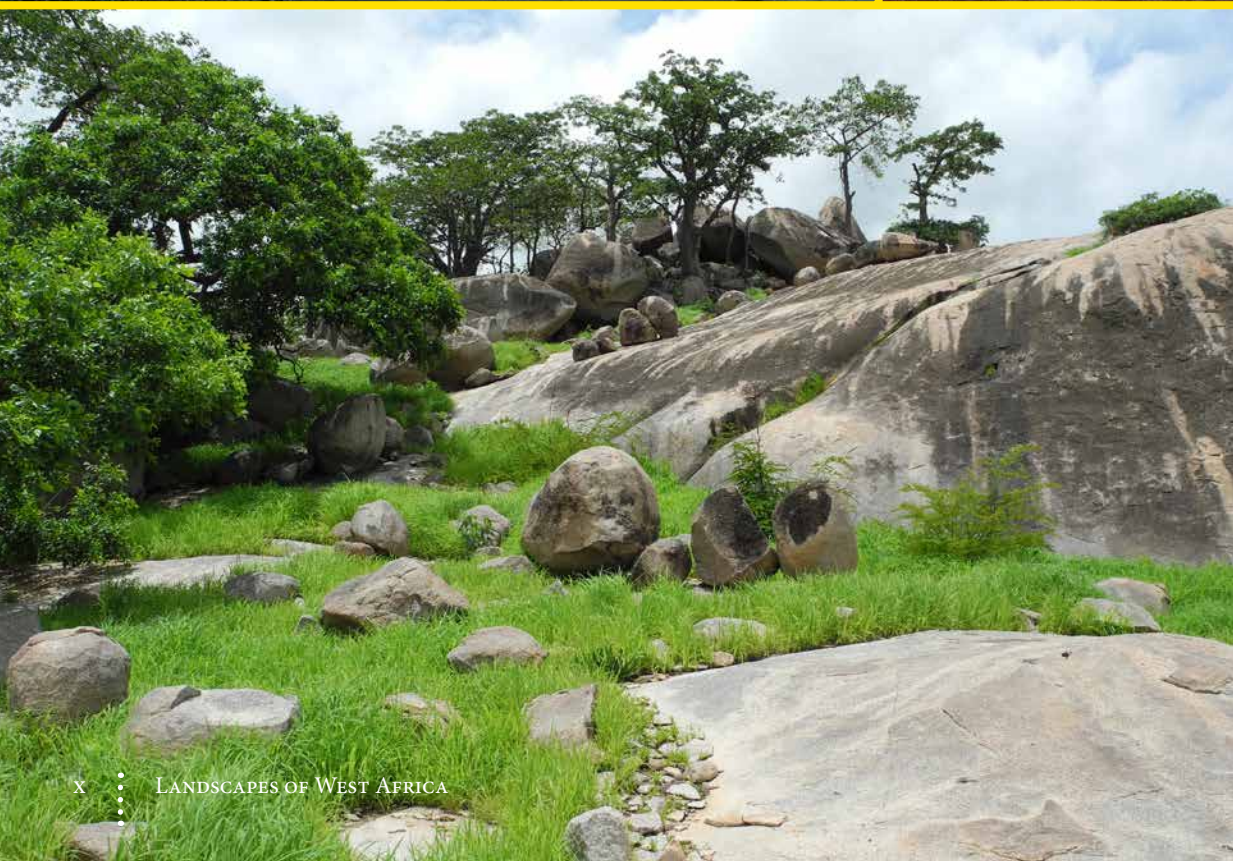
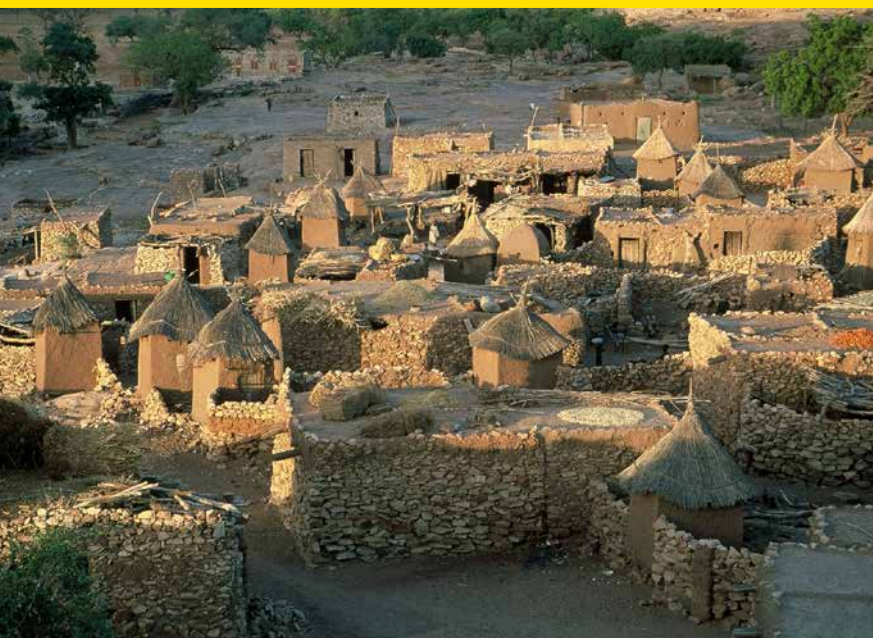


It is in the hands of today's decision makers to formulate wise, well informed choices about how to manage West Africa's land, to ensure that vital ecosystem services and agricultural productivity are able to support tomorrow's people. To make good choices the governments of West Africa need good information 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





1.1

West Africa's Landscapes and Physical Geography

Physical Geography

The 8 million square kilometers and 17 countries covered by this atlas encompass a wide range of landscapes from alluvial valleys in Senegal and Ghana, sandy plains and low plateaus across the Sahel, and rolling hills of Togo to rugged mountains with summits reaching over 1,500 m in Guinea and 1,800 m in Niger. Covering approximately one quarter of Africa, West Africa contains a broad range of ecosystems, bioclimatic regions, and habitats from rain forest to desert.

West Africa can be divided internally through its natural features. Geology, relief, climate, vegetation, soils, and the responses of people to the patterns of its biophysical resources through human land uses all tend to be arranged along east-west belts. Pastoralists in northern Senegal would likely find their livelihoods more similar to those of pastoralists 3,000 km to the east in Niger than to those of someone raising cattle just 300 km south in Guinea-Bissau. Likewise the mix of crops varies more within Nigeria — from the semiarid north to the wet southern coast — than it does from one end of the West African Sahel in Senegal to the other in Chad. The most dramatic transitions in natural features and land use occur as one moves north or south across these

belts we call bioclimatic regions. To better understand the geography of West Africa and how it drives land use, we briefly examine the geology, topography, hydrography, climate, and vegetation through these broad bioclimatic regions.

Geology

West Africa is remarkable for its geological variety. Like most of Africa, the region is largely composed of ancient Precambrian rocks (at least 541 million years old; the oldest rocks may be about 3 billion years old), which have been folded and fractured over hundreds of millions of years. These rocks are exposed over about one-third of West Africa and are part of the vast continental platform of Africa, which in West Africa has an average elevation of 400 m (Church, 1966). Numerous series of Precambrian rocks of various ages and their eroded surfaces provided a fairly level floor for the advance and retreat of shallow Palaeozoic seas (a major geologic era after the Precambrian, spanning about 289 million years). As these seas came and went, they deposited and eroded new material that formed the sedimentary rocks that overlay the ancient Precambrian



PHOTOS: GRAY TAPPAN/USGS; MICHEL KUPERS; RICHARD JULIA



Physical Geography of West Africa

floor across the region. For example, a large sedimentary basin called the Senegalo-Mauritanian Basin extends across much of western Mauritania, two-thirds of Senegal, and into Guinea. It is composed of sediments deposited when the ocean covered this part of the African plate (Michel, 1973; Stancioff and others, 1986).

For most of West Africa, continental conditions have existed since the Eocene or Oligocene, that is, since the last 23 to 34 million years. Most of West Africa's mountain massifs and highlands, such as the Air Mountains, the Tibesti Mountains, the Adrar des Ifoghas, and the Fouta Djallon, originated as Precambrian folds (Church, 1966). Much later, volcanic activity in many of these highlands deposited additional layers of igneous rock. Volcanic outpourings have occurred throughout West Africa's geologic history, with major activity as recent as the

Pliocene (2.5 to 3.6 million years ago), and even more recent activity in the Air and Tibesti Mountains.

During recent dry periods in the late Quaternary (0.5 to 1 million years ago), intensive weathering of sandstone formations produced much of the present day sand sheets that cover vast areas north of a line running approximately through Kano, Ouagadougou, Bamako and Dakar. These sand deposits fill in many irregularities of relief and mask much of the surface geology.

Relief

Relief on its own is not the source of great regional diversity in West Africa. For the most part, West Africa is relatively flat and low, which sets it apart from the other major regions of Africa. Nor does the relief do much to interrupt the zonal patterns and latitudinal belts of

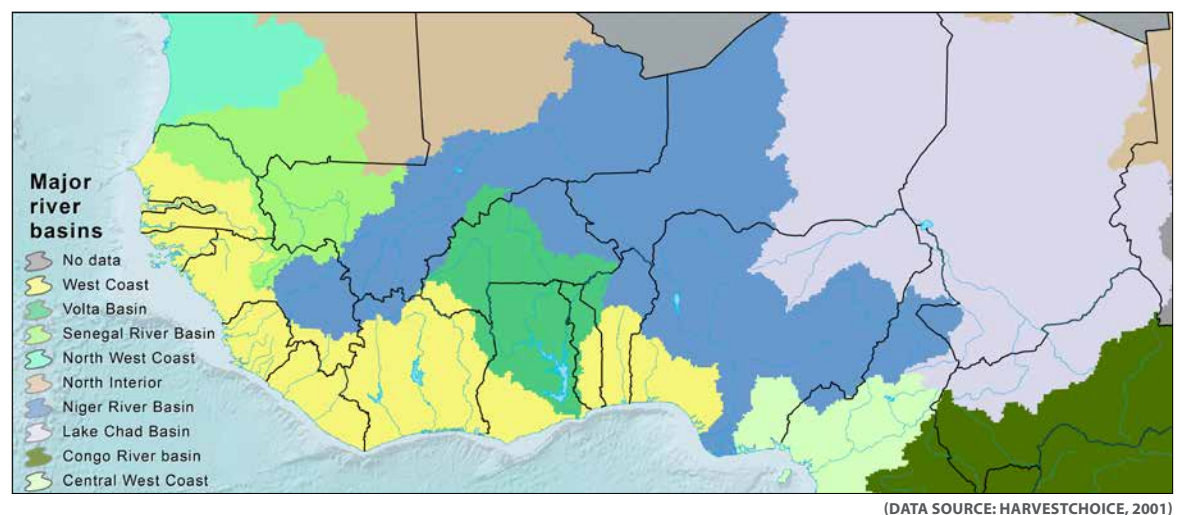


climate and vegetation, except in the mountainous regions of the Fouta Djallon, the Guinea Highlands, the Jos Plateau, and the Air Mountains. In these areas, rainfall is somewhat higher than in the low plains around them.

Hydrography

Several major rivers, including the Niger — West Africa’s longest river — originate in the Guinea Highlands, where rainfall is heavy. Other major rivers rise from Guinea’s Fouta Djallon, including the Gambia and Senegal. The Senegal River drains a major basin — the third largest in West Africa after the Niger Basin and the Lake Chad Basin. West Africa’s rivers experience great seasonal variations in river flow.

Major river basins in West Africa



(DATA SOURCE: HARVESTCHOICE, 2001)

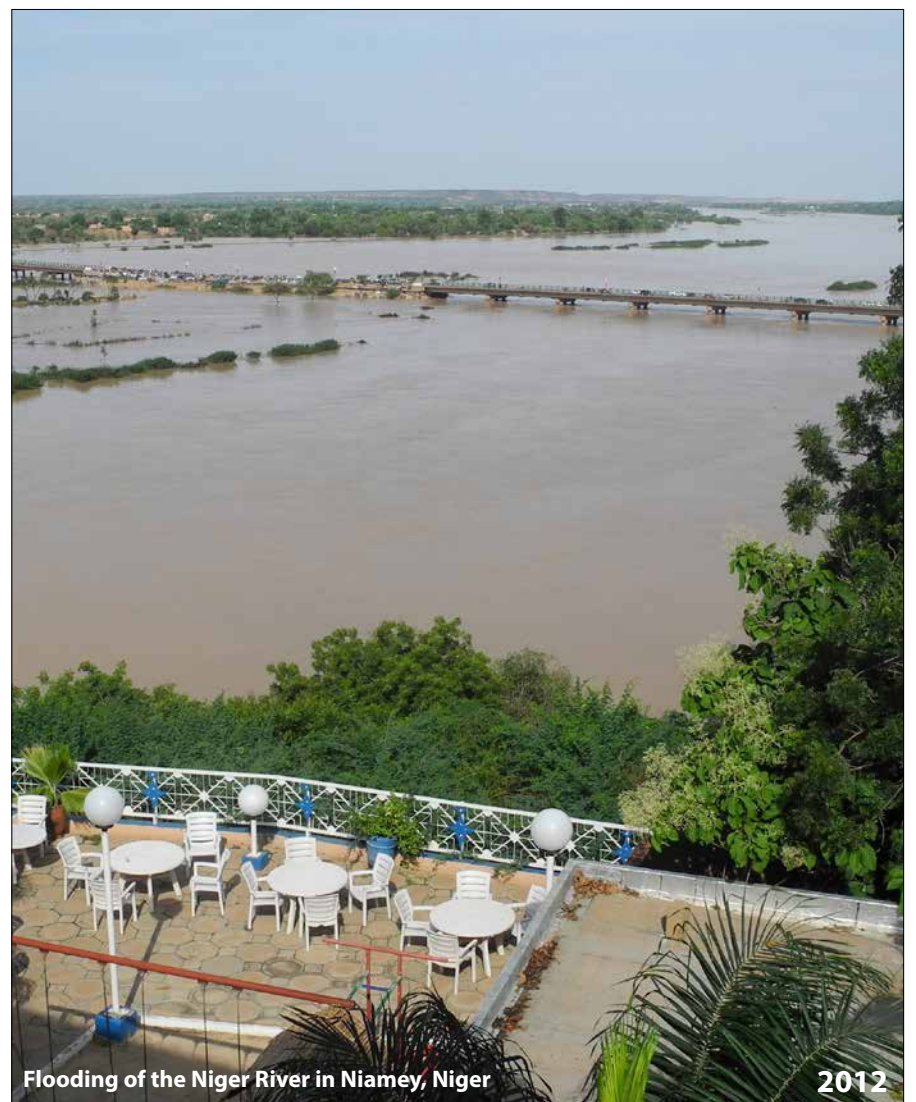
The Niger River is about 4,180 km long and passes through almost every climatic zone in West Africa. A vast inland delta has formed along its way in Mali, owing to the shallow slope of the river and sand accumulations that have obstructed its many channels. The Inland Niger Delta acts like a giant sponge, moderating the flow downstream and reducing the risk of flooding (see pages 146–147). Where the Niger arcs past Timbuktu in Mali's northern Sahel, sand accumulations push it southward. In Nigeria, the Niger River is joined by the Benue, its major tributary, which drains much of northeastern Nigeria.

The Lake Chad Basin occupies a huge area, covering parts of Niger, most of Chad, Nigeria, Cameroon, and the Central African Republic. The catchment of the Chari and the Logone Rivers comprises the southern part of the Lake Chad Basin. They feed Lake Chad, which has shrunk to a small fraction of its 1960 size.

Many separate basins are defined by smaller rivers that drain the land between the Atlantic Ocean and the basins of the Senegal and Niger Rivers. Of these, two are worth mentioning: the Gambia, which drains central Senegal and the nation of The Gambia, and the Volta River, which starts at the confluence of the Nakanbé (White Volta) and the Mouhoun (Black Volta), and reaches into the Mossi Plateau in Burkina Faso. Ghana constructed the Akosombo Dam (completed in 1965) in a gorge where the Volta cuts through the Akwapim–Togo Range, creating the world's largest artificial lake, Lake Volta.

Climate

Most of West Africa, from the southern Sahara to the humid coastal countries, has only one rainy season, which lasts from one to six months. The area of two rainy seasons, a long one and a shorter one, is limited to the southern portions of the coastal countries from Liberia to Nigeria. The climate is related to the advance and retreat of the intertropical front — the interface between two air masses — one hot and humid and the other cool and dry. This front migrates annually north and south, following the position of the sun, with a lag of 1 to 2 months. In the winter months (December to March), there is an anticyclonic high pressure area centered over the Sahara. It drives the Harmattan, a desiccating, dusty wind that blows rather persistently from the northeast, drying out landscapes all the way to the coast. In the summer the high pressure area is replaced by a depression, bringing warm, moist winds in from the Atlantic in the southwest (from the Gulf of Guinea) (Arbonnier, 2000; Zwarts and others, 2009). Generally, the dry season lengthens and annual rainfall decreases with increasing latitude. Conversely, in the southern latitudes, rainfall increases and the dry season shortens, often to just four months (December to March). Maximum temperatures and temperature ranges also increase with latitude. In the humid south, temperatures vary little, whereas in the arid north one temperatures range from 0°C to more than 45°C (Church, 1966).



From north to south — from the Sahara to the humid southern coast — West Africa can be subdivided into five broad east-west belts that characterize the climate and the vegetation. These are the bioclimatic zones known as the Saharan, Sahelian, Sudanian, Guinean, and Guineo-Congolian Regions, shown in the map on page 8. The lines between these regions represent more of a transition along a continuous ecological gradient than sharp boundaries. There is considerable variation among different authors in the definition and geographic delineation of these regions, though most use long-term rainfall averages to define the boundaries. Since long-term rainfall levels have generally decreased since the 1960s (but increased somewhat in the past two decades), some authors consider these bioclimatic regions to have shifted somewhat southward (Gonzalez, 1997). Since these regions are often referenced in this atlas, it is useful to present their general characteristics. They are presented from driest to wettest climatic regimes.

Saharan Region

The Sahara, or Saharan Region, stretches across the whole northern extent of West Africa, formed by the Sahara Desert. It consists of a variety of arid landscapes varying from sandy sheets and dune fields to gravel plains, low plateaus, and rugged mountains. Vegetation cover is sparse to absent, except in depressions, wadis, and oases, where water is present at or just below the surface. Average annual rainfall ranges from 0 to 150 mm per year.

Sahelian Region

The Sahel, or Sahelian Region, is a broad semiarid belt, extending from the Atlantic Ocean to Sudan (and to the Red Sea), averaging about 350 km wide. Climatically, it is characterized by average annual rainfall between 150 and 600 mm, with great variability in amount and timing in a given year. It has an ecologically dry season of 8 to 9 months. Vegetation in the Sahel is generally characterized by open herbaceous types (steppe and short grass savanna) often mixed with woody plants. It is known for its thorny trees, particularly from the genus *Acacia*, and mostly annual grasses from the genera *Aristida* and *Cenchrus*. The number of woody plant species is relatively low. The present physiognomy of Sahelian vegetation results from long-term human and animal presence. Annual grass fires often sweep across its landscapes where there is ample grass cover. The Sahel is also home to countless small wetlands, like in eastern Mauritania, as well as some major ones including the Senegal Delta, the Inland Niger Delta, and the Lake Chad area.

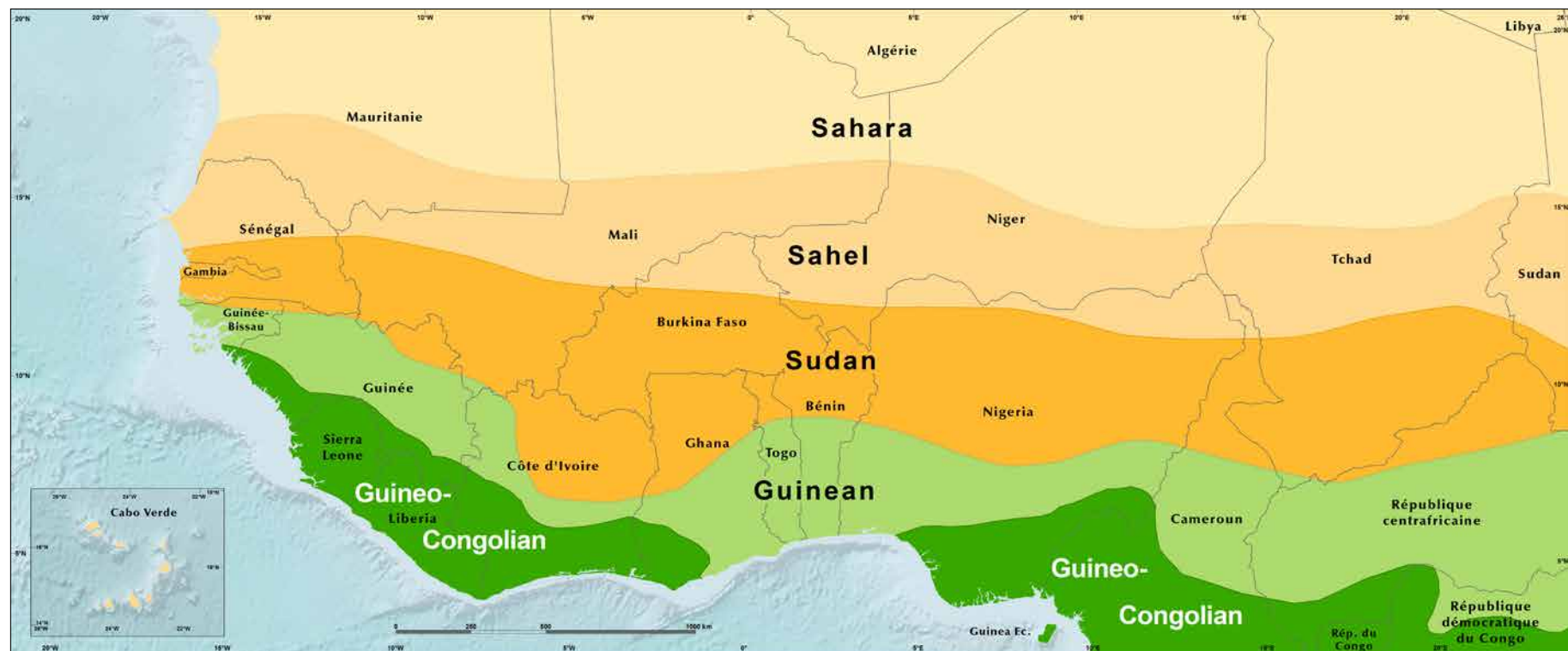
Sudanian Region

The Sudan, or Sudanian Region, consists of a very large belt immediately south of the Sahel, with average annual rainfall between 600 and 1,200 mm and an ecologically dry season of 5 to 7 months. It is the domain of the savanna — ranging from open tree savannas to wooded savannas to open woodlands. As in the Sahel, rainfall is spread over the months when the sun is high



Temet, Niger: a wadi in the Sahara

Bioclimatic regions



(typically May to October). The short, annual grasses of the Sahel are replaced in the Sudan Region by tall, perennial grasses, mainly of the genus *Andropogon*.

The savannas almost always have a woody component, with trees growing among the tall grasses. There are at least 80 species of trees specific to this bioclimatic region (Aubréville, 1938). In the northern part of the Sudanian Region, tree savannas tend to dominate, whereas the southern reaches of this region typically transition into denser wooded savannas and open woodlands. Fire has been part of the region's ecology for millennia. Both natural and human-induced bush fires sweep through the savanna areas, burning up to 80 percent of their area each year. Gallery forests, with tall tree species more common in the Guinean Region to the south, follow watercourses, penetrating deep into the Sudanian Region. They are generally not affected by bush fires and often act as natural fire breaks.

Guinean Region

The Guinean Region lies immediately south of the Sudanian Region, generally defined by average annual rainfall between 1,200 and 2,200 mm. This is the domain of the seasonally wet-and-dry deciduous or semi-deciduous forest. Despite the relatively high rainfall, this region has a distinct dry season of 7 to 8 months, which distinguishes it from the Guineo-Congolian Region. The forest canopy is generally dense and closed, forming over a heterogeneous woody understory. Tree height is high, averaging 18 to 20 m. Guinean forests in their

natural setting are generally not affected by bush fires. Present day landscapes of the Guinean Region are mostly altered by human activity, particularly slash-and-burn agriculture, so that the actual extent of Guinean forest is rather limited. Most of what remains has been modified by humans. The tree and wooded savannas are also extensive. Some authors consider that the forests have been replaced by "derived savanna," a mosaic of cropland, bush fallow, and secondary forest resulting from centuries of human influence (Keay, 1959). Gallery forests of varying width follow watercourses.

Guineo-Congolian Region

The Guineo-Congolian Region is the wettest in West Africa, with average annual rainfall between 2,200 and 5,000 mm. The rainfall can be distributed across most of the year, or in two rainy seasons with short drier periods between the rains. This region is split geographically into western and eastern blocks, separated by the Dahomey Gap where savanna reaches the coast. These blocks are often referred to as the Upper Guinean and Lower Guinean Forests, respectively (Church, 1966). This region is thought to have been mostly forested in the past, but today only a fraction of the land is forested. Nevertheless, the forest flora is the richest in West Africa. The forests are dense, with trees reaching over 60 m. The upper tier usually has a discontinuous canopy, towering over a lower, dense canopy. In the undergrowth, woody climbers and epiphytes are characteristic. Herbaceous ground cover may be found but can also be absent.

Sahara



Sahel



Sudan

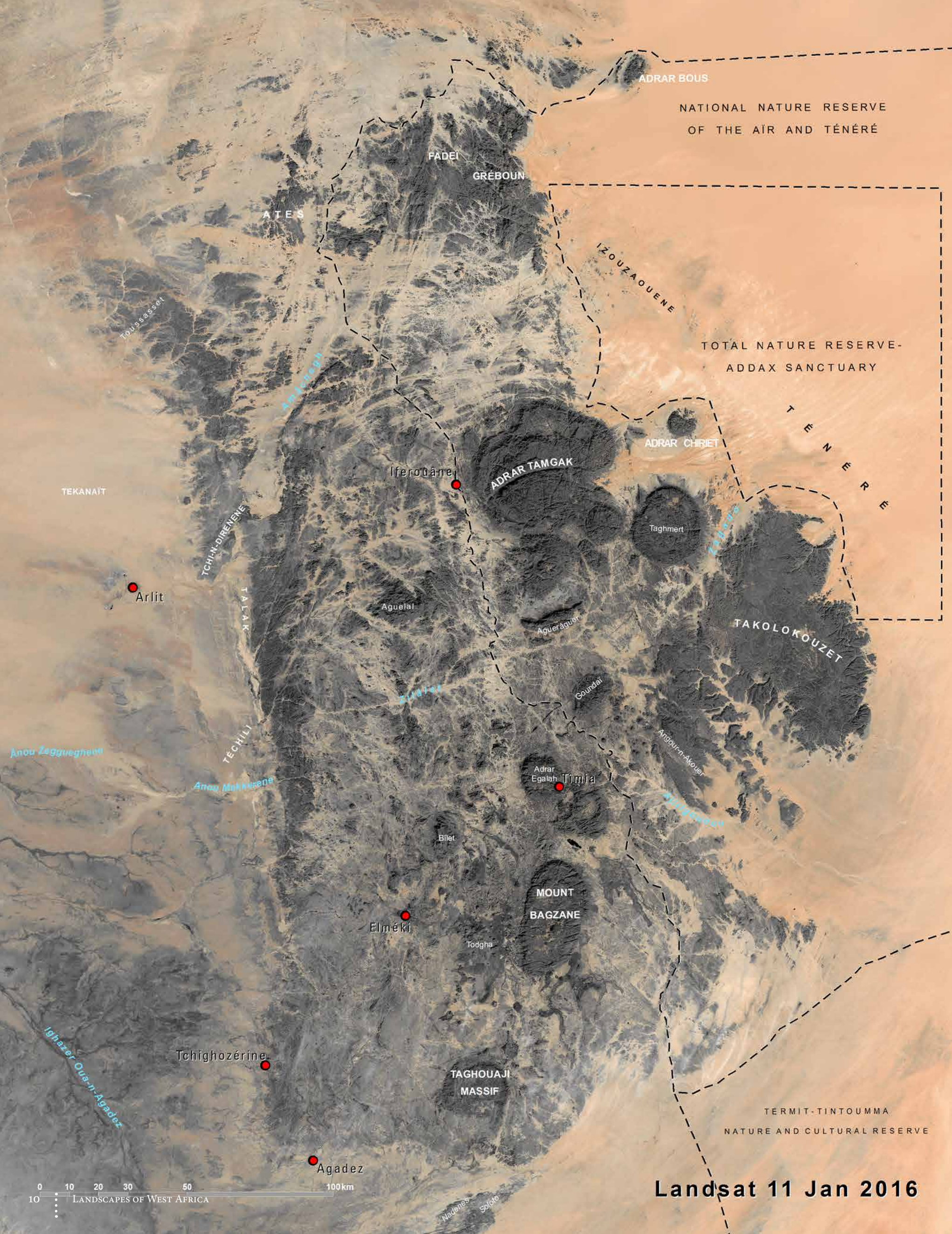


Guinean



Guineo-Congolian





NATIONAL NATURE RESERVE
OF THE AIR AND TÉNÉRÉ

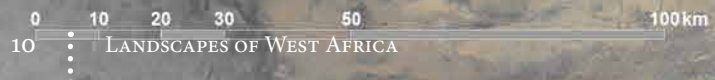
TOTAL NATURE RESERVE-
ADDAX SANCTUARY

T
E
N
E
R
É

TAKOLOKOUZET

TERMIT-TINTOUMMA
NATURE AND CULTURAL RESERVE

Landsat 11 Jan 2016



LANDSCAPES OF WEST AFRICA

Landscapes of the Sahara Desert

Among the most striking natural features of the Sahara Desert are the Aïr Mountains, rising from the sands of central Niger. These mountains, which extend over an area of 72,000 sq km — about the size of Sierra Leone — have some of the most spectacular scenery in West Africa. They evolved from a long volcanic history, with impressive peaks, the highest being Mount Bagzane (2,022 m). Most of the massif is underlain by Precambrian igneous and metamorphic rocks, characteristic of other major massifs found in North Africa (Lowman, 1968). Note the prominent round mountain masses, some over 45 km wide, seen in the Landsat image mosaic. Massive sand dunes from the Ténéré Desert, east of

the Aïr, pile up against the outcrops and escarpments of the eastern side of the mountains, juxtaposing two extraordinarily beautiful landscapes.

Humans have lived among its rocks and valleys for thousands of years. The Aïr contain a treasure trove of Neolithic art, with paintings that capture a lush savanna, replete with many of the large mammals that would rival today’s national parks. Deep valleys and natural springs support oasis life in the midst of these desert mountains. The village of Timia is a green gem of date palms and verdant gardens. For centuries, the Aïr have been inhabited by the Tuareg people — traditionally nomadic pastoralists who live in a vast area of the central and western Sahara. Many have settled in small towns like Timia and Iferouane, or in Agadez, the gateway to northern Niger.



MICHAEL FITZGERALD ; MICHAEL FITZGERALD ; MICHAEL FITZGERALD ; MICHAEL FITZGERALD ; RICHARD JULIA ; MICHAEL FITZGERALD ; MICHAEL FITZGERALD ; RICHARD JULIA ; MICHAEL FITZGERALD



The map of ecological regions of West Africa (see pages 14–15) captures the variety and complexity of West Africa’s landscapes and presents a way of organizing them into smaller units. Ecological regions, or ecoregions, are areas of relative homogeneity with respect to ecological systems involving the interrelationships of plants, animals, and their environment. Ecoregions are a holistic concept: The spatial patterns that help identify them arise from the interplay and integration of many factors — geology, geomorphology, soils, vegetation cover, climate, hydrology, and finally human modification of the land.

As some of these factors vary along gradients, not all ecoregion boundaries represent sharp or concrete differences in the landscape. Nonetheless, the identification of discrete regions of similar environmental makeup offers a helpful spatial framework for land use planning and management. Operating as integrated systems, ecoregions provide logical reporting units on a variety of biophysical and socioeconomic conditions and can be useful in many complex tasks, such as setting priorities for conservation and development, studying the impact of climate change, and assessments of carbon stocks and sequestration potential.

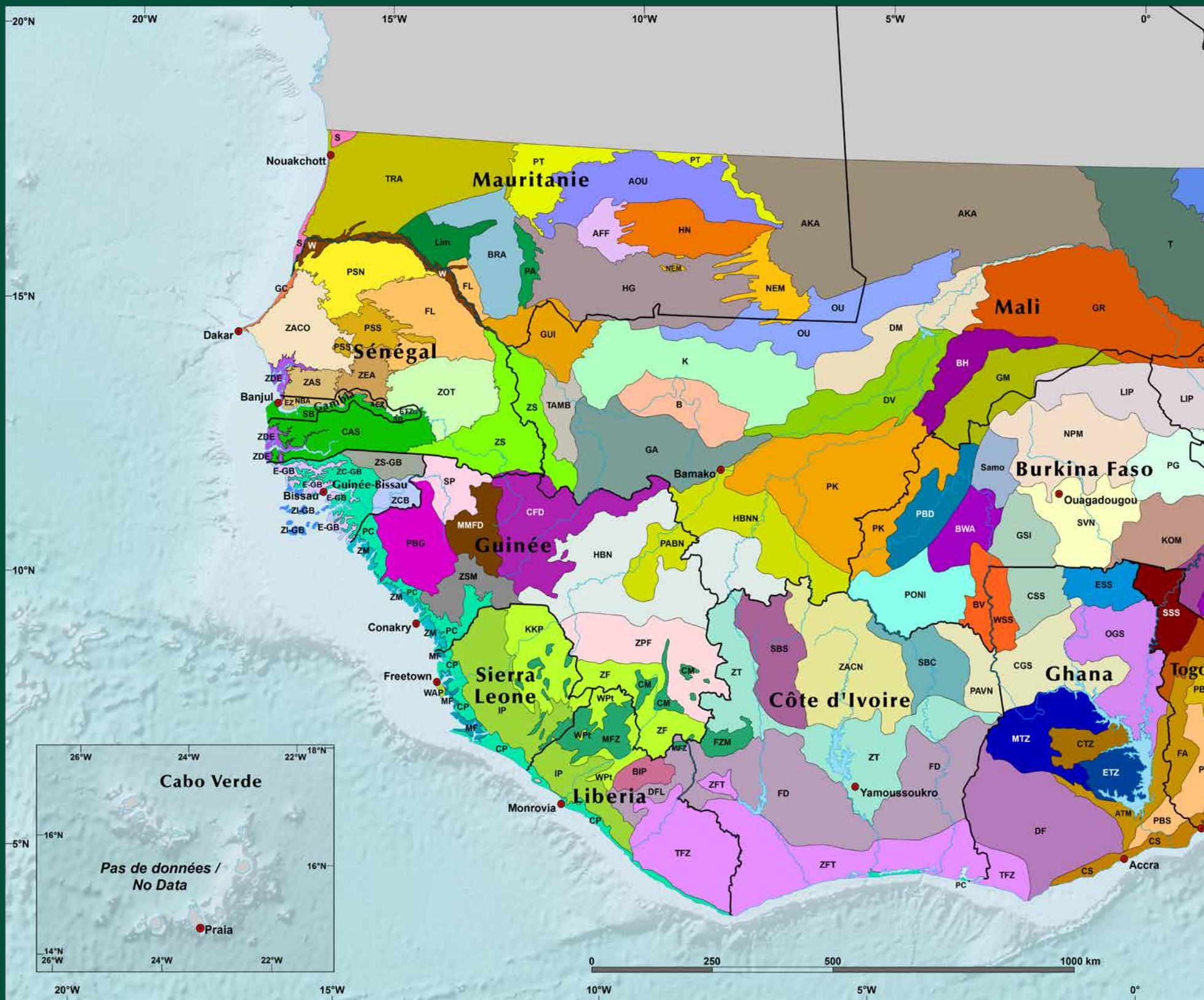
Satellite remote sensing is an effective tool for ecoregion mapping because it already integrates many biophysical and man-made elements, depicting the complex character of the land surface in image form. Landsat imagery in particular offers the ideal characteristics for delineating and classifying ecoregions from spatial patterns of the land surface at national and regional scales. Ecoregion mapping was one of the early steps in the process that culminated in mapping the land use and land cover of 17 West African countries.

The ecoregions map of West Africa was compiled from national draft maps prepared by 12 country teams during a workshop held at the AGRHYMET Regional Center in Niamey. The country teams delineated ecoregions based on visual interpretation of a Landsat image mosaic, drawing on their extensive knowledge of the biophysical and human geography of their respective countries. Their interpretation of the Landsat imagery was also supported by thematic maps of individual environmental properties (e.g., soils, geology, climate, vegetation) where available. Because the regional map was stitched together from individual national maps, ecoregion boundaries and names are not always consistent across international borders. Ecoregion names were retained in their original language.



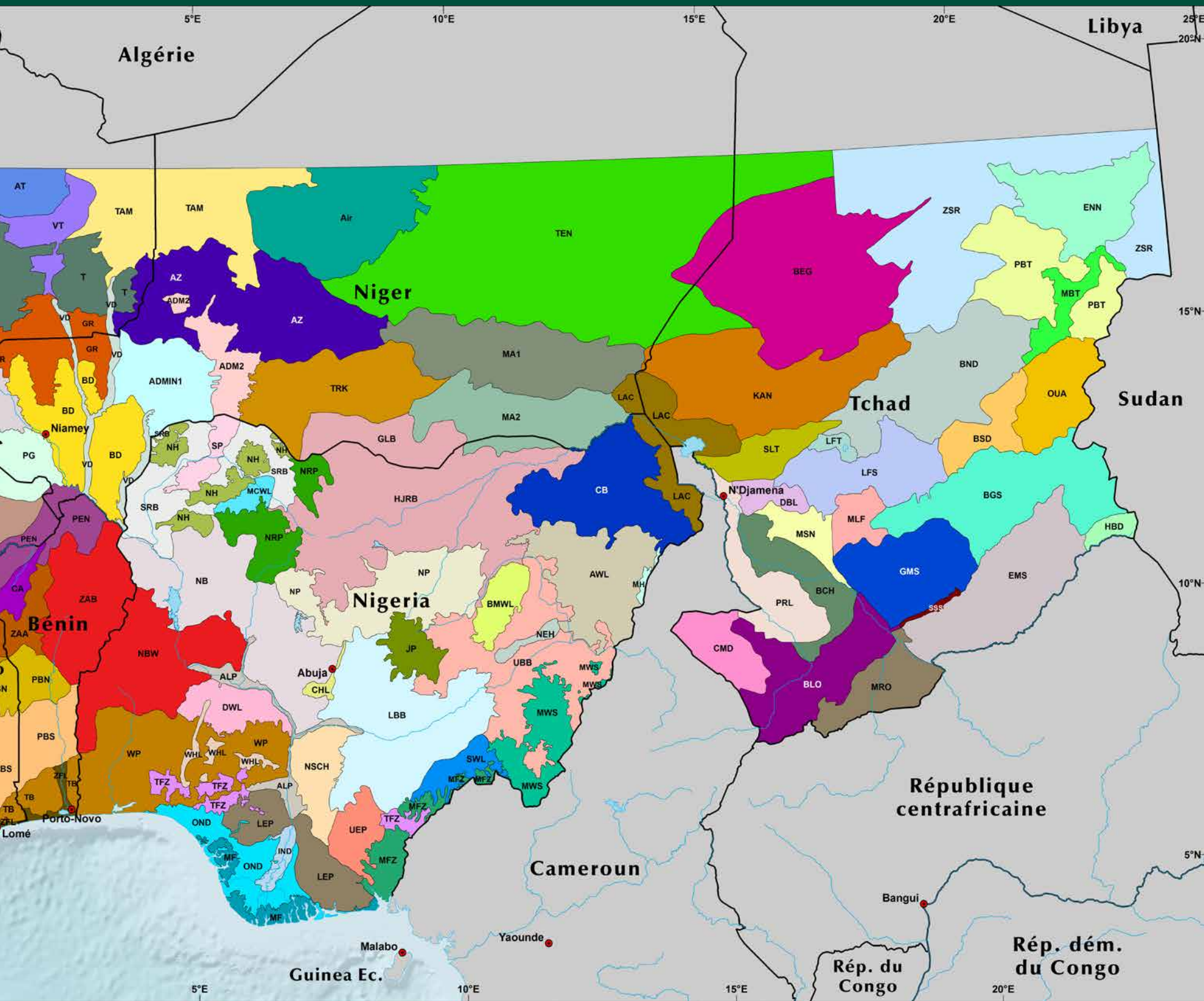
Agricultural landscape in the commune of Kourteye, Niger

SUZANNE COTILLON / SGT



Ecoregions

- | | | | | | |
|---|--|---|---|--|---|
| <p>Sénégal</p> <ul style="list-style-type: none"> CAS Casamance CFD Contrefort du Fouta-Djallon E-GB Zone des Estuaires de Guinée-Bissau FL Zone Pastorale Ferrugineuse GC Grande Côte PSN Zone Pastorale Sableuse du Nord PSS Zone Pastorale Sableuse du Sud S Littoral W Vallée du Fleuve ZACO Zone Agricole du Centre-Ouest ZAS Zone Agricole du Saloum ZDE Zone des Estuaires ZEA Zone d'Expansion Agricole ZOT Zone Orientale de Transition ZS Zone du Socle <p>Gambia</p> <ul style="list-style-type: none"> AEZ Agricultural Expansion Zone ETZn Eastern Transition Zone EZ Estuary Zone NBA North Bank Agricultural Zone SB South Bank Zone | <p>Guinée-Bissau</p> <ul style="list-style-type: none"> E-GB Zone des Estuaires de Guinée-Bissau ZCB Zone de Colline de Guinée-Bissau ZC-GB Zone Côtière de Guinée-Bissau ZI-GB Zone Insulaire de Guinée-Bissau ZS-GB Zone Soudanienne de Guinée- <p>Sierra Leone</p> <ul style="list-style-type: none"> CP Coastal Plains IP Interior Plains KKP Koinadugu and Kono Plateaus MF Mangrove Forest MFZ Montane Forest Zone WAP Western Area Peninsula | <p>Mauritanie</p> <ul style="list-style-type: none"> AFF Plaines de l'Affolé AKA Akle Azaouad AOU Dunes vives de l'Aouker BRA Plaine du Brakna FL Zone Pastorale Ferrugineuse GUI Plaines du Guidimaka HG Dunes atténuées du Hodh Gharbi HN Dunes des Hodhs - nord Lim Plaine limoneuse du Brakna NEM Collines et Dépressions de Nema OU Ouagadou PA Plateaux de l'Assaba PT Plateaux du Tagant S Littoral TRA Trarza W Vallée du Fleuve | <p>Guinée</p> <ul style="list-style-type: none"> CFD Contrefort du Fouta-Djallon CM Chaînes de Montagnes HBN Haut Bassin du Niger MMFD Massifs Montagneux du Fouta-Djallon PABN Plaines Agricoles du Bassin du Niger PBG Hauts Plateaux de la Basse-Guinée PC Plaines Côtières SP Socle Précambrien ZF Zone Forestière ZM Zone de Mangrove ZPF Zone Pré-Forestière ZSM Zone de Savanes et de Montagnes <p>Liberia</p> <ul style="list-style-type: none"> BIP Bong Interior Plateau CP Coastal Plains DFL Degraded Forest IP Interior Plains MFZ Montane Forest Zone TFZ Tropical Forest Zone WPI Wooded Plateaus | <p>Mali</p> <ul style="list-style-type: none"> AKA Akle Azaouad AT Adrar-Timétrines AZ Steppe d'Azaouak B Béliédougou BH Plateau Bandiagara-Hombori CFD Contrefort du Fouta-Djallon DM Delta Mort DV Delta Vif GA Gangaran GM Gondo - Mondoro GR Gourma Malien GUI Plaines du Guidimaka HBN Haut Bassin du Niger HBNN Haut Bani Niger HG Dunes atténuées du Hodh Gharbi K Kaarta LIP Liptako Sahel NEM Collines et Dépressions de Nema OU Ouagadou PK Plateau de Koutiala (Kenedougou) T Tilemsi TAM Azaouak-Tamesna TAMB Tambaooura | <ul style="list-style-type: none"> VD Vallée des Dallois VT Vallée du Tilemsi ZS Zone du Socle <p>Côte d'Ivoire</p> <ul style="list-style-type: none"> FD Forêt Dégradée FZM Forêt Montagnarde PAVN Plateau Agricole de la Volta Noire PC Plaines Côtières SBC Savanes du Bassin de la Comoé SBS Savanes du Bassin de la Sassandra ZACN Zone Agricole du Centre-Nord ZFT Zone Forestière Tropicale ZT Zone de Transition |
|---|--|---|---|--|---|



Burkina Faso

- BV Plateau Lobo-Dagara
- BWA Plateau Bwa
- GM Gondo-Mondoro
- GR Gourma Malien
- GSI Plateau Gourounsi
- KOM Plaine Komienga-Singou
- LIP Liptako Sahel
- NPM Nord Plateau Mossi
- PBD Plateau de Bobo Dioulasso
- PEN Plaine de la Pendjari
- PG Plateau Gourmantché
- PK Plateau de Koutiala (Kenedougou)
- PONI Bassin Comoé Poni
- SVN Sud Vallée Nakambe-Nazinon
- Samo Plateau Samo

Ghana

- ATM Akwapim Togo Mountains
- CGS Closed Guinea Savanna
- CS Coastal Savanna
- CSS Central Sudan Savanna
- CTZ Central Transitional Zone
- DF Deciduous Forest

- ESS Eastern Sudan Savanna
- ETZ Eastern Transitional Zone
- MTZ Main Transitional Zone
- OGS Open Guinea Savanna
- PBS Pénéplaine bénino-togolaise sud
- TFZ Tropical Forest Zone
- WSS Western Sudan Savanna

Togo

- FA Forêt sur Atakora
- PBN Pénéplaine bénino-togolaise nord
- PBS Pénéplaine bénino-togolaise sud
- SSS Savane Soudanienne Sèche
- TB Terre de Barre
- ZAA Zone Agro-pastorale de l'Atacora
- ZFL Zone Fluvio-lagunaire

Niger

- ADM2 Zone des Plateaux d'Ader-Doutchi-Mi
- ADMIN1 Bassin d'Ader-Doutchi-Maggia
- AZ Steppe d'Azauak
- AIR Massif de l'Air
- BD Bassin des Dallols
- BEG Bassin du Bahr El Gazal ou Soro

- GLB Zone Agricole de Goulbi
- GR Gourma Malien
- KAN Kanem
- LAC Lac Tchad
- LIP Liptako Sahel
- MA1 Manga Désertique
- MA2 Manga Sahélien
- PEN Plaine de la Pendjari
- PG Plateau Gourmantché
- TAM Azaouak-Tamesna
- TEN Désert de Ténéré
- TRK Plaine de Tarka
- VD Vallée des Dallols

Bénin

- CA Chaîne de l'Atacora
- PBN Pénéplaine bénino-togolaise nord
- PBS Pénéplaine bénino-togolaise sud
- PEN Plaine de la Pendjari
- TB Terre de Barre
- ZAA Zone Agro-pastorale de l'Atacora
- ZAB Zone Agro-pastorale du Borgou
- ZFL Zone Fluvio-lagunaire

Tchad

- BCH Bas Chari
- BEG Bassin du Bahr El Gazal ou Soro
- BGS Bande Guera-Salamat
- BND Batha Nord
- BSD Batha Sud
- CMD Collines du Mayo-Dala
- DBL Dourbali
- EMS Est Moyen-Chari et Salamat
- ENN Ennedi
- GMS Sud Guera, Nord Moyen-Chari, Ouest Salamat
- HBD Hadjer Bandala
- KAN Kanem
- LAC Lac Tchad
- LFS Lac Fitri Sud-Est
- LFT Lac Fitri
- MA1 Manga Désertique
- MBT Massif du Biltine
- MLF Melfi
- MRO Maro
- MSN Massenya
- OUA Ouaddai

Nigeria

- ALP Alluvial Plains
- AWL Agricultural - Woodland
- BMWL Biu Mixed Woodlands
- CB Chad Basin
- CHL Central Highlands
- DWL Dry Woodland
- HJRB Hadejia-Jamaare River Basin
- IND Inner Niger Delta
- JP Jos Plateau
- LAC Lac Tchad
- LBB Lower Benue Basin
- LEP Lower Eastern Plains
- MA2 Manga Sahélien
- MCWL Mixed Combretaceous Woodlands
- MF Mangrove Forest
- MFZ Montane Forest Zone

- MH Mandara Highlands
- MWS Mixed Wooded Savanna
- NB Niger Basin
- NBW Niger Basin Wilderness
- NEH North East Highlands
- NH Northern Highlands
- NP Northern Central Plains
- NRP Northern Rocky Plains
- NSCH North South Central Highland
- OND Outer Niger Delta
- SP Socle Précambrien
- SRB Sokoto Rima Basin
- SWL Savanna Woodlands
- TFZ Tropical Forest Zone
- UBB Upper Benue Basin
- UEP Upper Eastern Plains
- WHL Western Highlands
- WP Western Plains

Biodiversity and Protected Areas in West Africa



GRAY TAPPAN / USGS

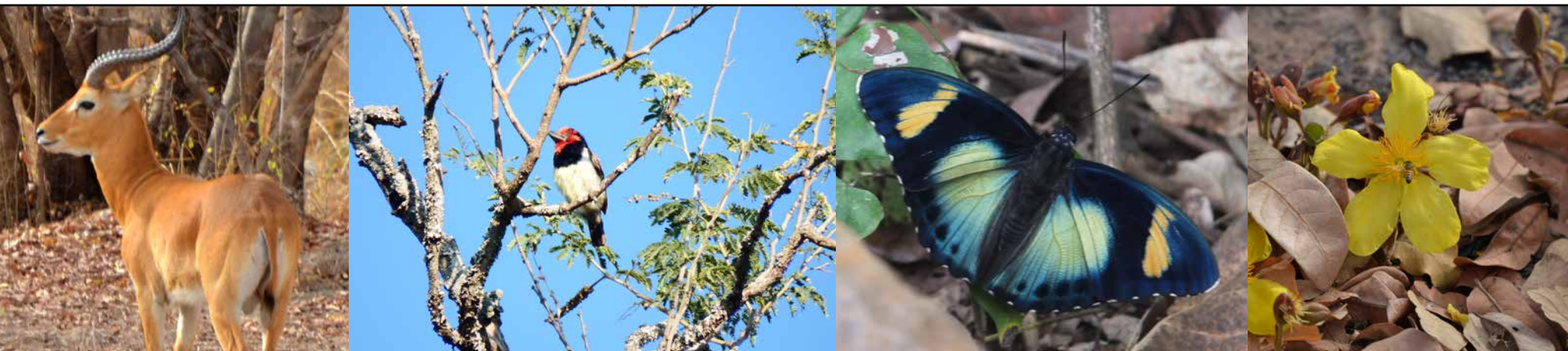
The rosewood tree (*Pterocarpus erinaceus*), rapidly disappearing from savannas and woodlands due to logging for its valuable timber.

Biological diversity, or biodiversity, refers to the variety of life. It can be measured in many ways including species richness, ecosystem complexity, and genetic variation. Biodiversity may be the greatest natural resource, as it is a source of food, fuel, medicines, clothing, building materials, clean water, tourism and many other benefits (Norse and others, 1986). Biodiversity possesses marked economic value that in many areas enables conservation to serve as a competitive form of land use (Stock, 2012). The importance of biodiversity in West Africa is well established. The various ecosystems, ranging from dry savanna to tropical forest, provide habitats to more than 2,000 amphibian, bird and mammal species (Mallon and others, 2015). The region's tropical forest in the Upper Guinean countries is the main locus for biodiversity in the region. These lowland forests of West Africa are home to approximately 320 mammal species (which represents more than a quarter of Africa's mammals), 9,000 vascular plant species, and 785 bird species (Bakarr and others, 2004). The Upper Guinean forest is renowned for its primate diversity, with nearly 30 distinct species, and has been identified as one of Africa's most critical primate conservation areas. The West African forest ecosystem is also home to two of Africa's great apes, including remaining scattered populations of the endangered western chimpanzees and a small population of western lowland gorillas on the Nigeria-Cameroon border.

The West African countries are also home to a population of over 7,500 African elephants, although many groups reside in northern savanna habitats outside the forest ecosystems (Mallon and others, 2015). The Upper Guinean forest ecosystem of West Africa, however, is one of the most critically fragmented regions on the planet. Indeed, only 68,500 sq km, or 10 percent of its original forest cover, remains (see pages 66–67). Much of this remaining forest is exploited for timber and does not represent intact habitat. Moreover, hunting and indiscriminate trapping are prevalent throughout the forest zone, and accelerating rates of animal harvest put increasing pressure on populations of primates

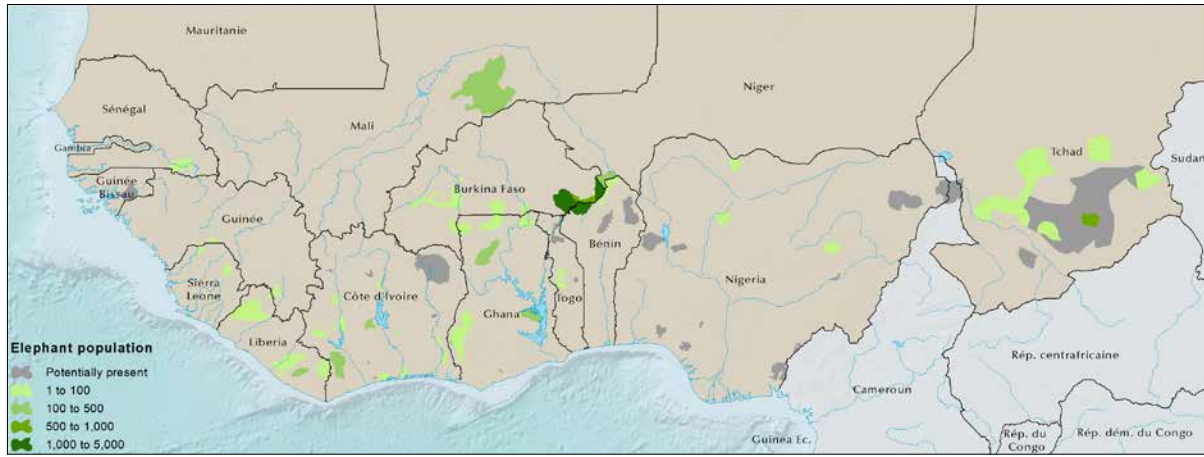
and forest antelopes. Similarly, hunting — whether for meat, trophies or sport — has resulted in a catastrophic decline of large mammals across the Sahel and Sahara zones in the north of the region (Durant and others, 2013; Mallon and others, 2015). The reduced prey base adversely impacts carnivore numbers, such as the African lion, across the region.

In West Africa today, most of the endangered species and highly biodiverse habitats are confined to protected areas. A total of 1,936 nationally protected areas have been identified in the region, currently covering around 9.6 percent of West Africa (see Protected Areas map pages 18–19). Approximately 90 percent of these protected areas are small and dominated by forest reserves. In addition, 53 protected areas have international designations, including 17 biosphere reserves. Protected areas vary widely in size, from less than 1 sq km to 97,300 sq km. However, large protected areas, including clusters of sites, are critical to supporting viable populations of larger species or ensuring fully-functioning, dynamic ecosystems (Mallon and others, 2015). More extensive areas or buffer zones provide connectivity between habitats, safeguard dispersal corridors between core populations and natural migration routes, and enhance resilience to the effects of climate change (Mengue-Medou, 2002). Since international borders rarely coincide with ecosystem boundaries, transboundary sites and landscapes are of great importance. These better preserve ecosystem function, show the value of managing biodiversity conservation at a sub-regional scale in spite of institutional difficulties, engage local communities, and may lead to harmonization of legislation. For instance, Diawling National Park in Mauritania and Djoudj Bird Reserve in Senegal lie on opposite sides of the Senegal River Delta, but the joint site is recognized as an International Biosphere Reserve. Similarly, the W-Arly-Pendjari complex (Benin, Burkina Faso and Niger) is a transboundary Biosphere Reserve that covers roughly 32,250 sq km and protects a highly biodiverse savanna ecosystem (see pages 20–23).



SUZANNE COTILLON/SGT; GRAY TAPPAN/USGS

Distribution of the African elephant (*Loxodonta africana*)



(DATA SOURCES: BLANC, 2008; MALLON AND OTHERS, 2015)

The original range of the African elephant covered all countries in West Africa, but the elephant is now extinct in at least The Gambia and Mauritania, where the last population in the Assaba Mountains disappeared in the 1980s (Mallon and others, 2015). The recent population estimate of African elephants in West Africa is about 7,500. The largest elephant population can be found in the transboundary W-Arly-Pendjari complex in Benin, Burkina Faso, and Niger. The Gourma elephant population in Mali is the most northerly in the world.



RICHARD JULIA

Distribution of the African lion (*Panthera leo*)



(DATA SOURCES: RIGGIO, 2011, 2013; HENSCHEL AND OTHERS, 2015; MALLON AND OTHERS, 2015)

Historical data indicate that lions were formerly distributed throughout West Africa, with the exception of coastal rain forests and the interior of the Sahara Desert. Recent surveys confirm lions' presence in only six countries of the region, which means that lions have lost almost 99 percent of their former range habitat in West Africa (Henschel and others, 2015). Less than 500 lions remain in West Africa, of which less than 250 are considered "mature individuals." Around 85 percent of them occur in the W-Arly-Pendjari (WAP) complex of protected areas, shared between Burkina Faso, Niger and Benin (Henschel and others 2015). A large continuous area of distribution remains in southeastern Chad around Zakouma National Park. A small relict population survives in Niokolo-koba National Park in southeastern Senegal, as well as in Yankari and Kainji Lake National Parks in Nigeria.



GRAY TAPPAN / USGS

Distribution of the western chimpanzee (*Pan troglodytes verus*)



(DATA SOURCES: BRNCIC AND OTHERS, 2010; HUMLE AND OTHERS, 2008; MALLON AND OTHERS, 2015; KORMOS, 2003)

Formerly distributed in nine countries of West Africa from Senegal to Nigeria, recent surveys estimate the western chimpanzee population at 18,960–59,290 individuals. About two-thirds of the remaining representatives of this subspecies are thought to occur in Guinea, Sierra Leone and Liberia. Senegal is thought to have only a few hundred individuals remaining in the southeast of the country. However, they are likely extinct in Benin, Burkina Faso, The Gambia and Togo (Humle and others, 2008). Western chimpanzees occur in many prominent protected areas, such as Outamba-Kilimi and Gola Rain Forest National Parks (Sierra Leone), Haut Niger National Park and Nimba Reserve (Guinea), Sapo National Park (Liberia), and Taï and Comoé National Parks (Côte d'Ivoire).



KELLY BOYER ONTIL



Protected Areas in West Africa

Internationally designated sites

-  Biosphere Reserve / Réserve de Biosphère
-  Ramsar Site / Site Ramsar

Nationally designated sites

-  National Park / Parc National
-  Nature Reserve / Réserve Naturelle
-  Faunal Reserve / Réserve de Faune
-  Wildlife Sanctuary / Sanctuaire de Faune
-  Forest Reserve / Forêt Classée

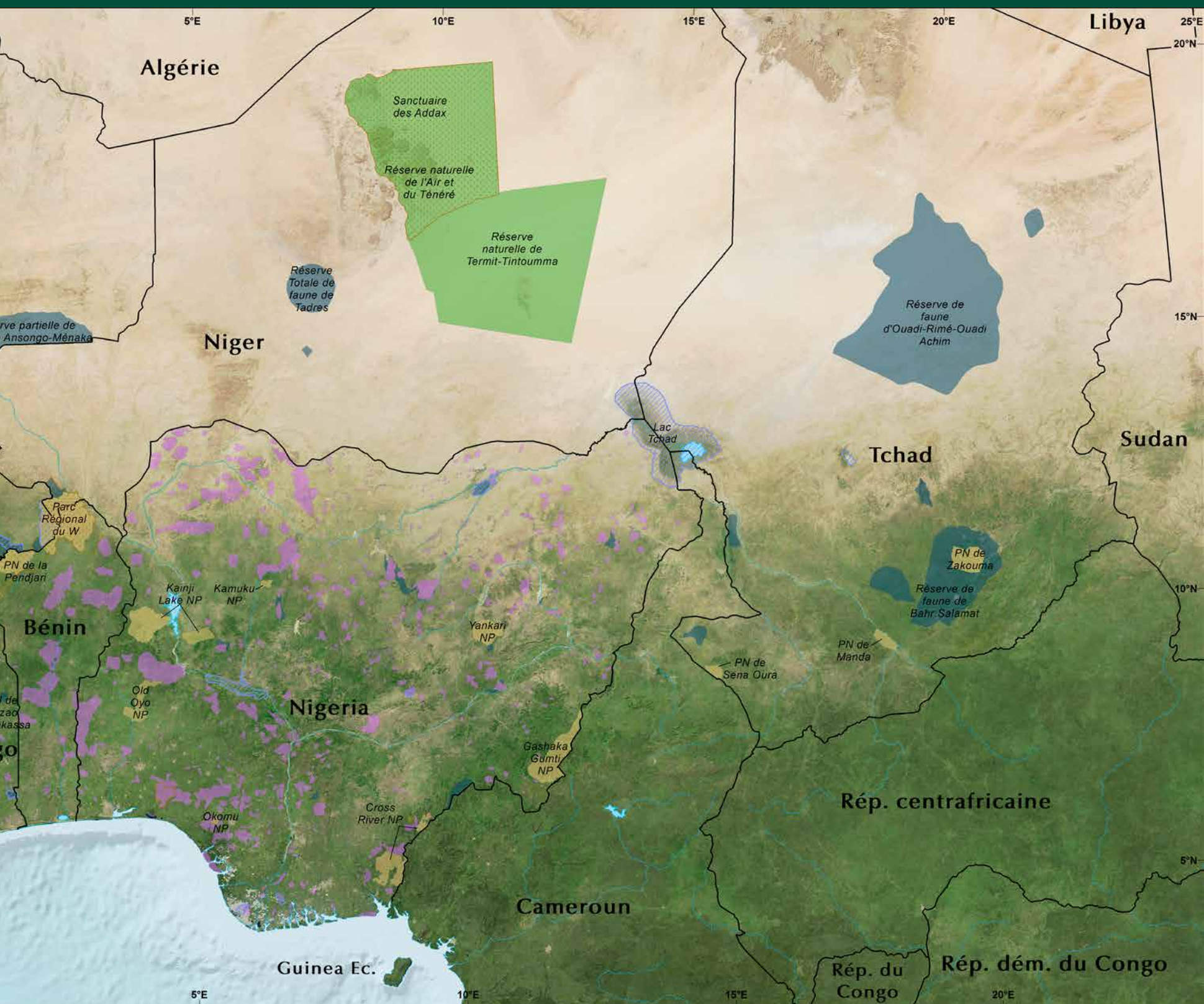
The protected areas map was compiled from the World Database on Protected Areas (WDPA) (IUCN and UNEP-WCMC, 2016). However, the WDPA database is not complete and some protected areas are not listed or are missing spatial data. Other sources were consulted in order to present an accurate and up-to-date protected areas map. Protected areas under the "Proposed" status were not included unless other sources stated they had been formally designated. Hunting zones were not included because they do not offer the level of protection inherent in other categories of protected areas.

The International Union for Conservation of Nature (IUCN) defines a protected area as, "A clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008). IUCN has also developed a system for categorizing protected areas according to their management goals and governance, but many protected areas in West Africa have not been assigned to a category and have an unclear management status. Because the 17 countries of West Africa are physically and politically diverse, the category designation and management goals of protected areas can vary greatly between countries (Mallon and others, 2015). To lessen confusion and to simplify the data for purposes of making this map, West African protected areas were grouped as follows.

Internationally designated sites

Biosphere Reserve: Sites recognized under the international UNESCO Man and the Biosphere (MAB) Programme for their ecosystem and biodiversity conservation importance. World Heritage sites that were not designated as Biosphere Reserve are not included on the map.

Ramsar site (Wetlands of International Importance): Wetlands of high conservation importance for their resources.



Nationally designated sites

National Park: Area set aside for the protection, conservation, and propagation of natural resources of particular scientific or aesthetic interest. Prohibited activities, unless authorized by permit, include the collection or removal of any forest products, hunting, trapping, damaging natural resources, setting fire, mining, and building infrastructure (IUCN, 1992). In addition to the areas designated as “National Park,” this category also includes “Natural Park” (Guinea-Bissau).

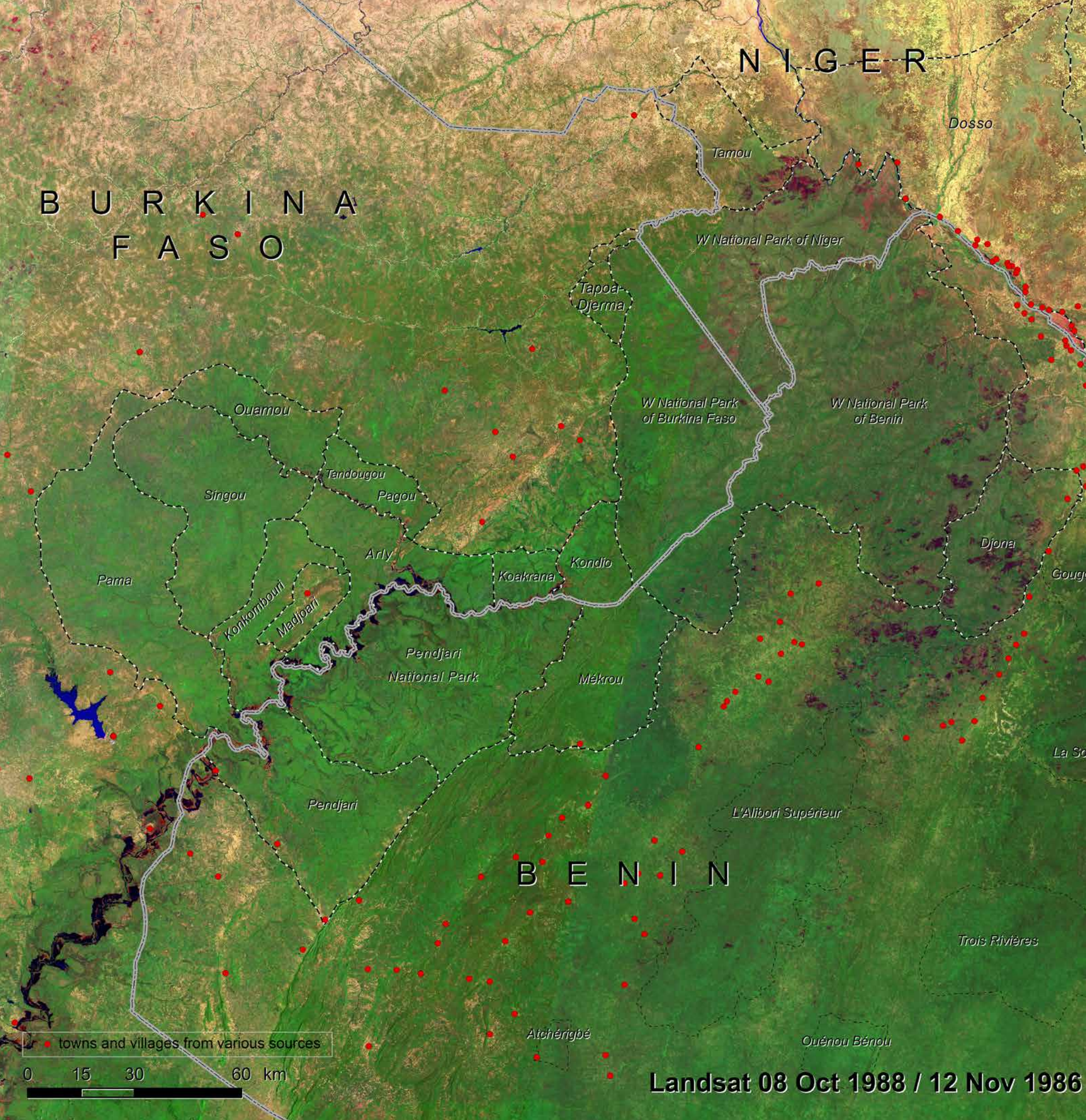
Nature Reserve: Area of importance for wildlife, habitats, or features of geological or other interest which is managed for conservation and to provide special opportunities for study or research. Management and level of protection differ by local laws. In addition to the areas designated as “Nature Reserve,” this category includes the “Natural Reserve,” “Wetland Reserve,” “Strict Nature Reserve,” “Botanical Reserve” and “Marine Community protected area.”

Wildlife Sanctuary: Area set aside to assure the natural conditions necessary to protect nationally significant species or physical features of the environment where these require specific human manipulation for their perpetuation.

Hunting, killing or capture of fauna is prohibited. In addition to the areas designated as “Wildlife Sanctuary,” this category includes the “Game Sanctuary” and “Chimpanzee Sanctuary.”

Faunal Reserve: Area established for the conservation, management and propagation of wild animal life, threatened animal or plant species, and the protection and management of its habitat. Hunting, killing or capture of fauna is regulated. In addition to the areas designated as “Faunal Reserve,” this category includes the “Game Reserve,” “Partial Faunal Reserve,” “Bird Reserve,” and “Wildlife Reserve.”

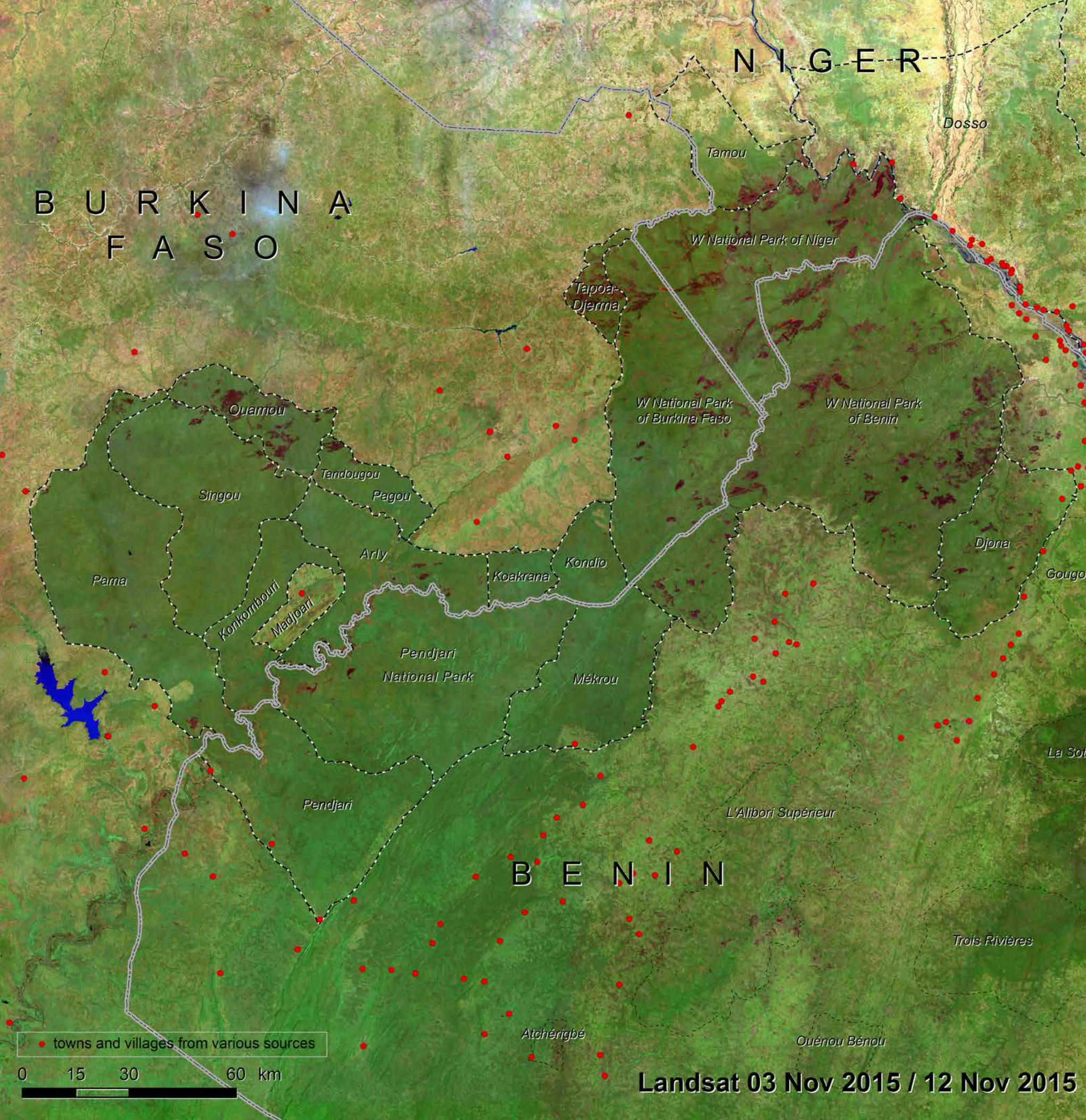
Forest Reserve: Area where conservation is considered necessary to maintain the ecological equilibrium for the benefit of populations and the conservation of species recognized to be endangered. Sustainable exploitation of wood is permitted but regulated. Activities prohibited, unless authorized by permit, include farming, grazing of livestock, mining, fires, hunting, and damage to any natural resources (IUCN, 1992). In addition to the areas designated as “Forest Reserve,” this category includes the “Classified Forest,” “Community Forest,” and “National Forest.”



The W-Arly-Pendjari Transboundary Biosphere Reserve

The W-Arly-Pendjari (WAP) ecological complex in West Africa is a major expanse of intact Sudano-sahelian savanna. The two core areas of the complex are the W Regional Park straddling the borders of Benin, Burkina Faso and Niger, and the Arly Total Faunal Reserve and Pendjari National Park in Burkina Faso and Benin. However, as many as 16 additional reserves, partial reserves and hunting zones surround the two core transboundary

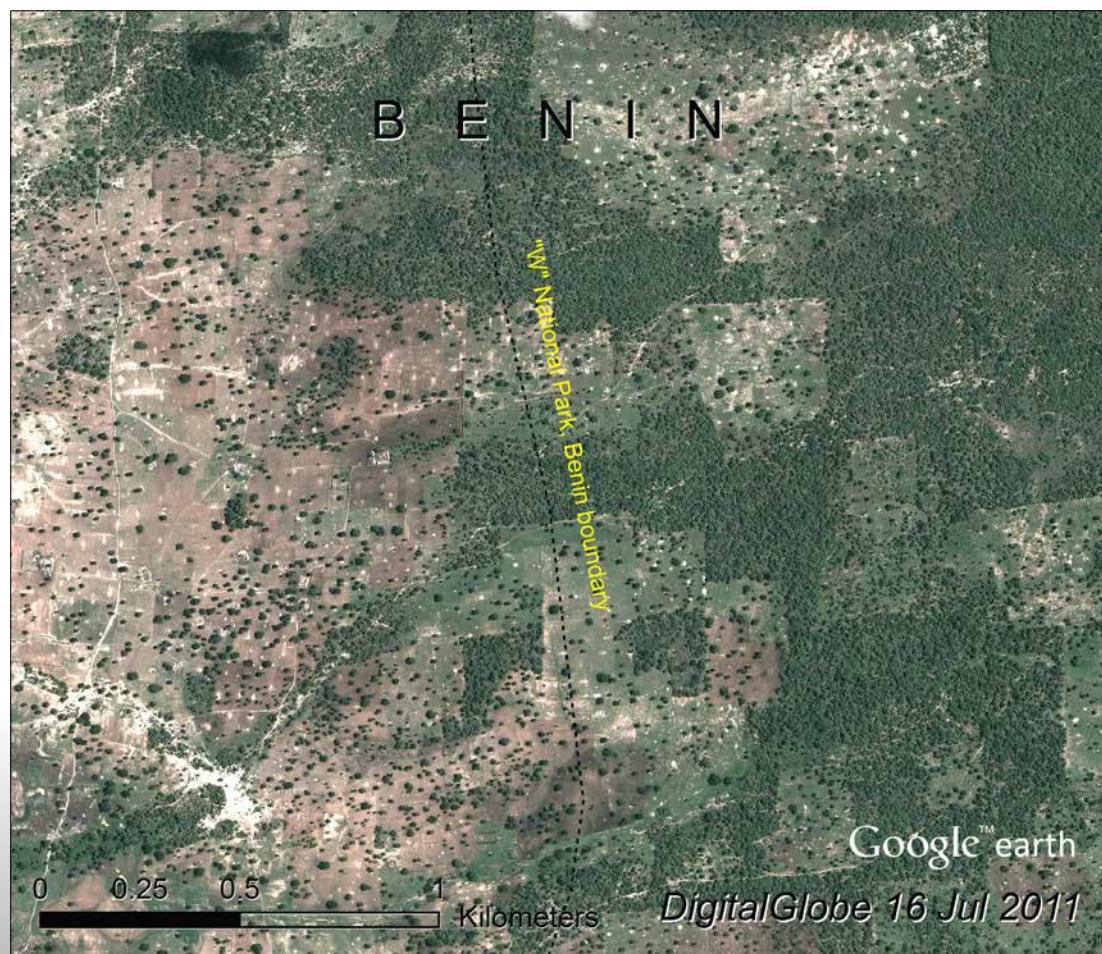
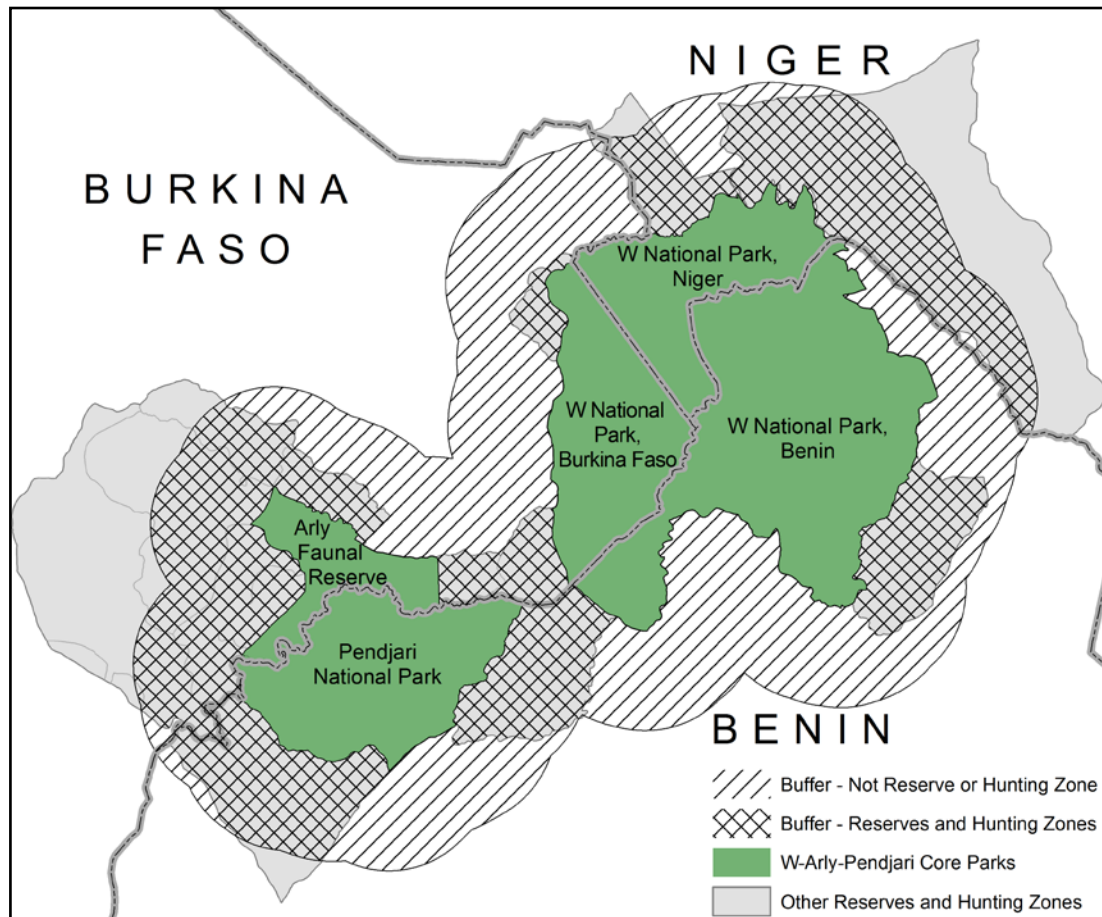
reserves, bringing the total area of the complex to roughly 32,250 sq km. While the condition and level of protection varies among the various parks and reserves, the complex nevertheless represents an extremely important contiguous body of intact West African habitat, crucial to the preservation of regional biodiversity and natural heritage (Clerici, 2007).



Between 1990 and 2015 the estimated population within a 30-km buffer surrounding all of the various designated protected areas of the complex more than doubled, from 1.67 million people to 3.52 million people (CIESIN, 2005), putting growing pressure on reserve boundaries. In the key agricultural region of northwestern Benin, food crops and a rapid expansion of cotton growing have converted the savanna landscape bordering the WAP reserve to one dominated by small holder farm fields (Kokoye and others, 2013). At the northern edge of the WAP where the Niger River forms the W shape, which gives the transboundary national

park its name, dozens of new villages have appeared in recent decades. Food insecurity in the 1970s led to the decommissioning of almost half of the Tamou Total Faunal Reserve there, leading to a wave of migration to the fertile soils along the Niger floodplain. In eastern Burkina Faso, while many villages are not new (Price and others, 2002), a growing population and increasingly intense farming and cattle-raising have made the boundary between the inside and outside of the protected area a sharp unmistakable line in the 2015 satellite images.

W-Arly-Pendjari complex and surrounding buffer zones



The W-Arly-Pendjari complex is recognized internationally for its important biodiversity. Pendjari National Park in Benin in 1986 and the W National Park in Niger in 1996 were designated UNESCO Biosphere Reserves. In 2002 the Benin and Burkina Faso W National Parks were added to form the W Transboundary Biosphere Reserve (TBR) (Michelot and Ouedraogo, 2009). In 2007 the wetlands of the W TBR were designated "wetlands of international importance" under the Ramsar Convention (UNESCO, 2005). The W National Parks in Niger, the W and Pendjari Parks in Benin and the Arly, W and Singou Reserves in Burkina Faso were all designated as Important Bird Areas by Birdlife International in 2001.

The size and structure of the WAP complex is unusual if not unique in West Africa where protected forests tend to be relatively small and suffer high levels of encroachment (Joppa and others, 2008). Following the biosphere reserve concept adopted by UNESCO, the WAP complex's core areas of biodiversity and intact ecosystems (green areas on the adjacent map) are protected by buffer areas and transition zones (UNESCO 1996). Nevertheless, the pressure to feed and provide livelihoods for a rapidly growing population is evident in the dramatic loss of wooded savanna and gallery forests surrounding the WAP complex's borders.

For the W-Arly-Pendjari Complex the partial reserves and hunting zones serve as buffers for much of the core's perimeter but do not completely encircle the core. Land cover maps from 1975, 2000 and 2013 (pages 44–49) show that within the core area of the three contiguous W National Parks, Pendjari National Park and the Arly Total Faunal Reserve, land cover has been very stable since 1975. Outside the core areas but within the partial reserves and hunting zones (gray with crosshatch), agriculture has increased from 8 percent in 1975 to 15 percent in 2013, while intact savanna decreased from 71



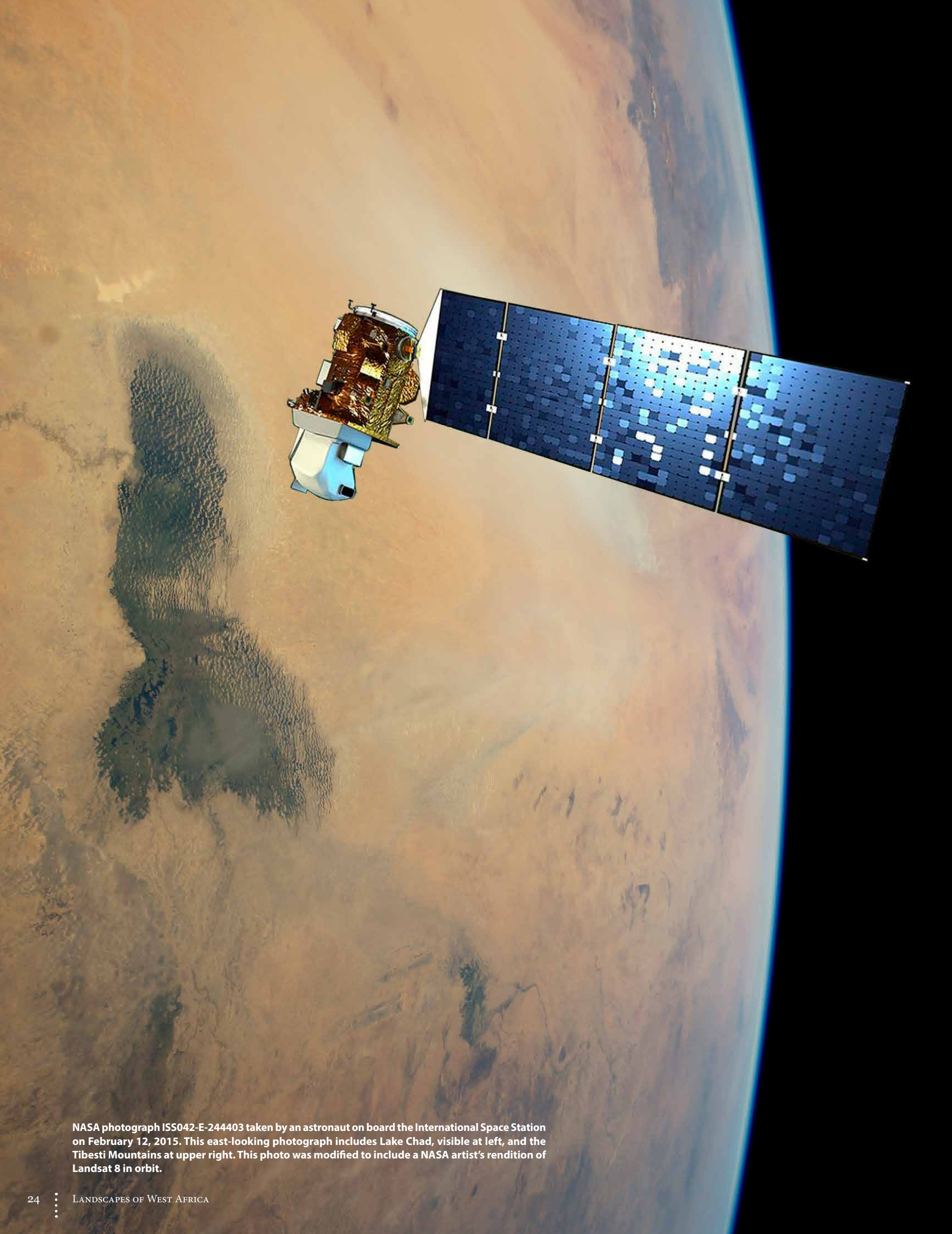
percent to 68 percent. In the areas outside the core and not designated as reserves or hunting zones (diagonal hatch marks), the loss of savanna was much greater. Savanna covered 70 percent of unprotected land in 1975 but just under 45 percent in 2013, as agriculture grew from 16 percent to over 44 percent.

In spite of the high levels of protection that have been established, especially for the core areas, ongoing encroachment can be seen occurring at some locations along boundaries of the reserves. The high-resolution image from July 2011 (see opposite page) shows some farm fields that have been cleared within the bounds of W National Park, Benin. Most of this sort of encroachment occurs away from the designated hunting zones and reserves, which appear to provide effective buffers for the core parks where they have been established.

It is estimated that the W Regional Park is a seasonal home to 3,800 African elephants, more than half the West African population (Clerici, 2007). Data collected from a variety of surveys taken between 2004 and 2014 sets the number of elephants in the larger complex of 19 protected areas at over 5,500 (IUCN, 2015). The WAP complex supports populations of several other large mammals including giraffe, hippopotamuses, and West African savanna buffalo, big cats such as lions, leopards, and cheetahs and a number of antelope species including roan antelope, kobs, topi, defassa waterbuck, western hartebeest, red-fronted gazelle, and oribi. The WAP complex protects hundreds of bird species, as well as many species of fish, insects and other organisms, all of which are a part of the biodiversity of this invaluable natural ecosystem.



RICHARD JULIA; RICHARD JULIA; JOAQUIM JULIA; RICHARD JULIA; SUZANNE COTILLON / SGT; GRAY TAPPAN / USGS



NASA photograph ISS042-E-244403 taken by an astronaut on board the International Space Station on February 12, 2015. This east-looking photograph includes Lake Chad, visible at left, and the Tibesti Mountains at upper right. This photo was modified to include a NASA artist's rendition of Landsat 8 in orbit.

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.

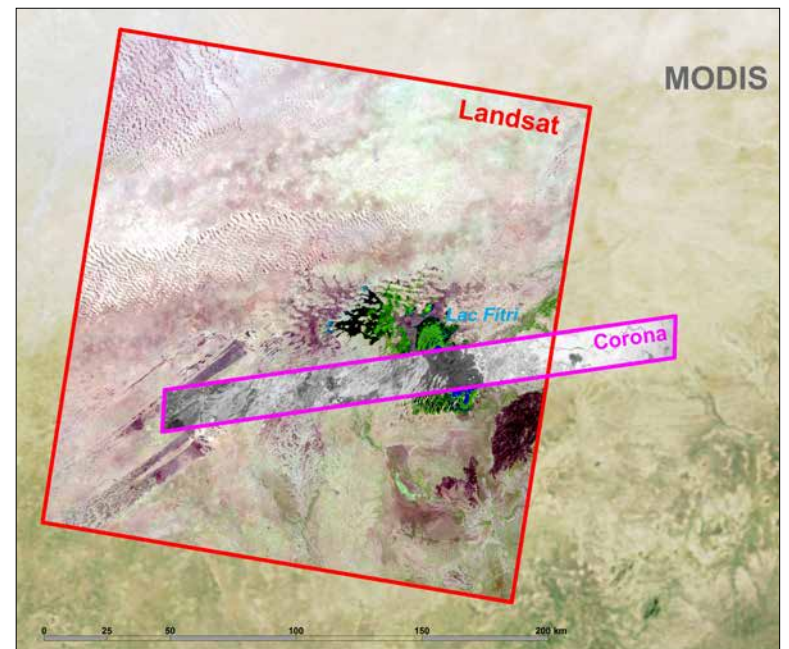
Corona was a national reconnaissance mission, flown on satellites from 1960 to 1972. Corona recorded photographs on high quality film stock, which was jettisoned and recovered in the atmosphere by airplane. The high quality film meant that Corona photos recorded fine details, but coverage was limited 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).

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.



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

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.

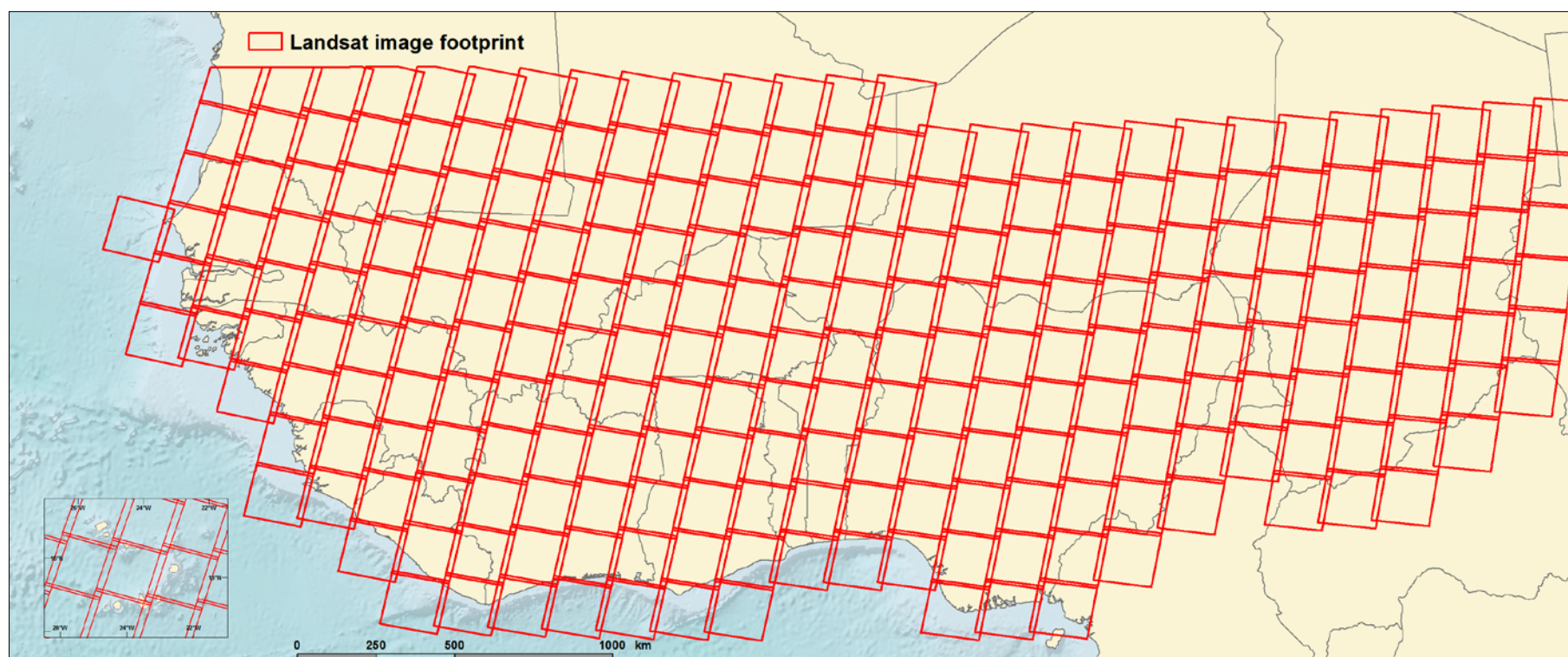
The most common approach in land use and land cover mapping is automated classification — throwing huge amounts of digital image data into an image classifier. However, earlier experiences with automated classification in Mali, Senegal and Niger produced disappointing results. Important land use and 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

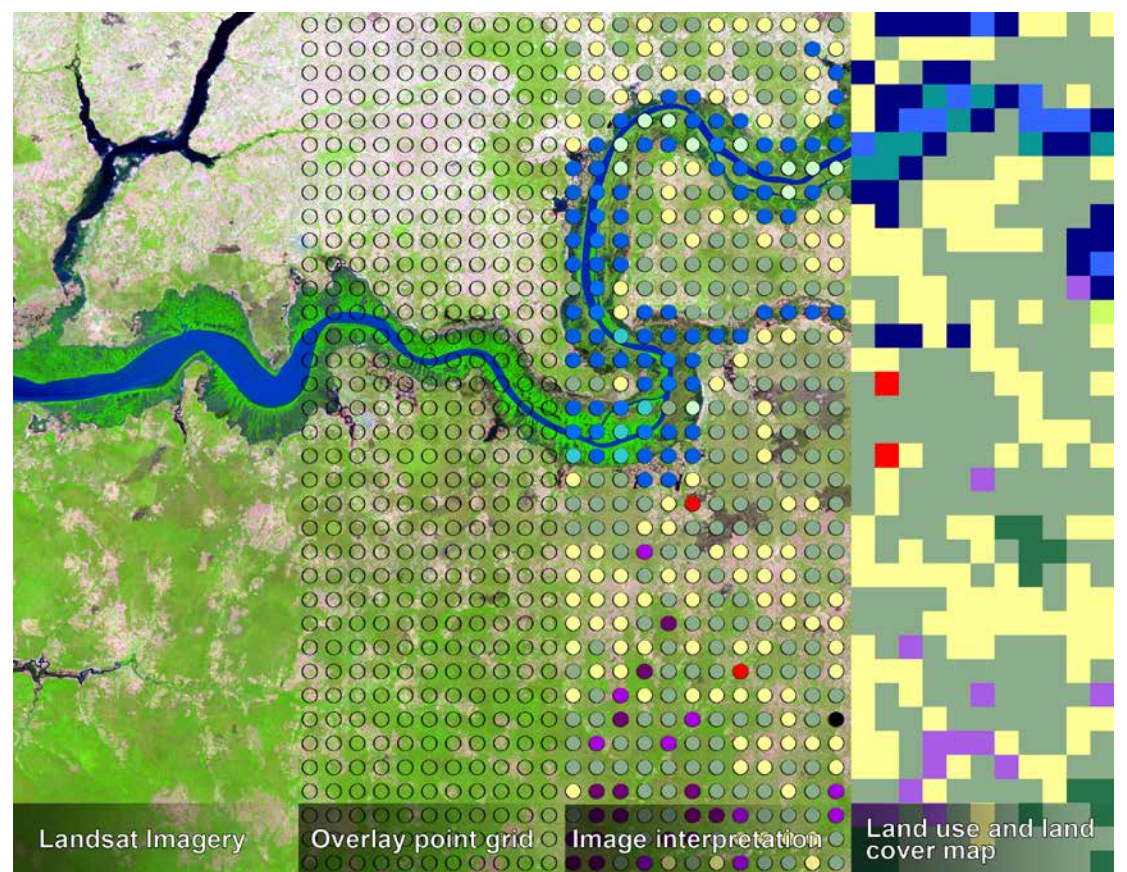
Landsat 8 nominal image footprint for the West Africa mapped area



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.

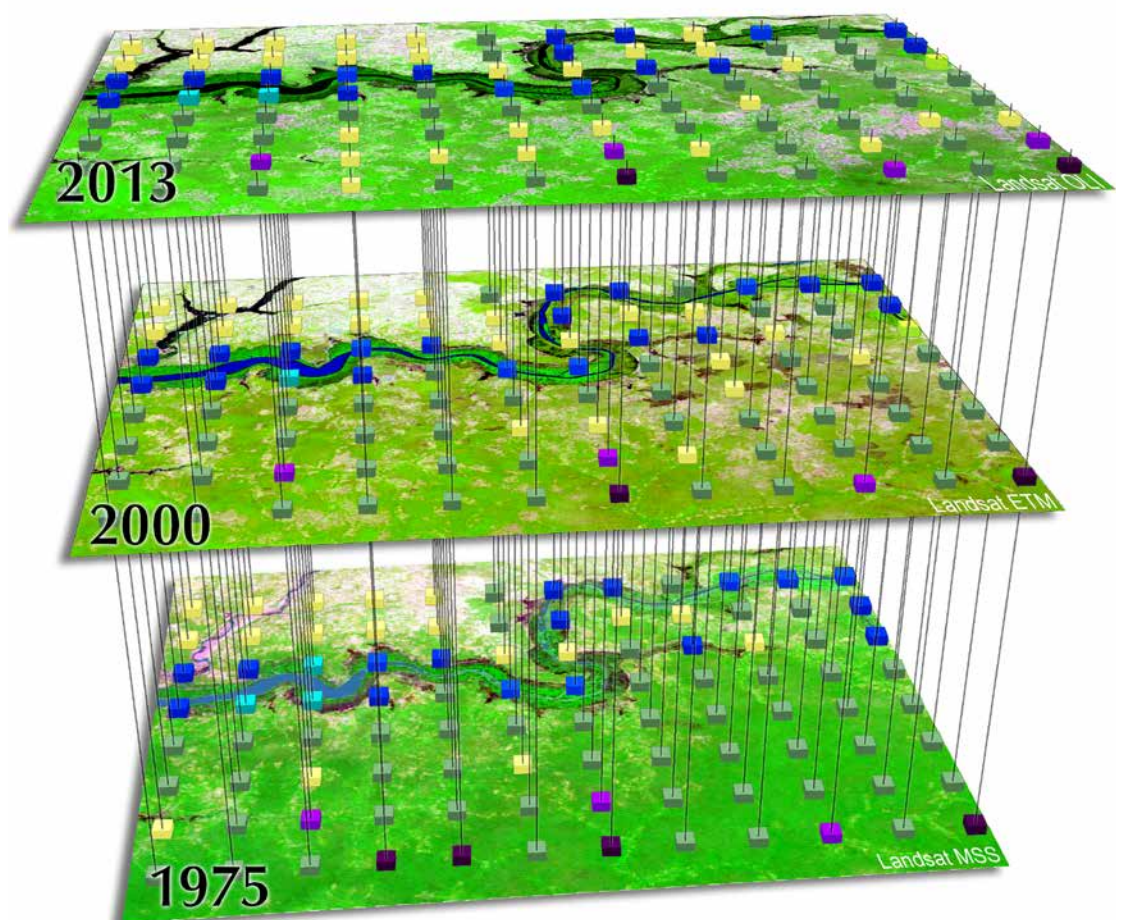
The traditional method of visual interpretation is ideal for the reasons given above, but it is also labor-intensive, particularly for such a vast area; mapping millions of square kilometers for three points in time would have been insurmountable using the traditional method. To expedite the interpretation 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 (Schumacher 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.

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.

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



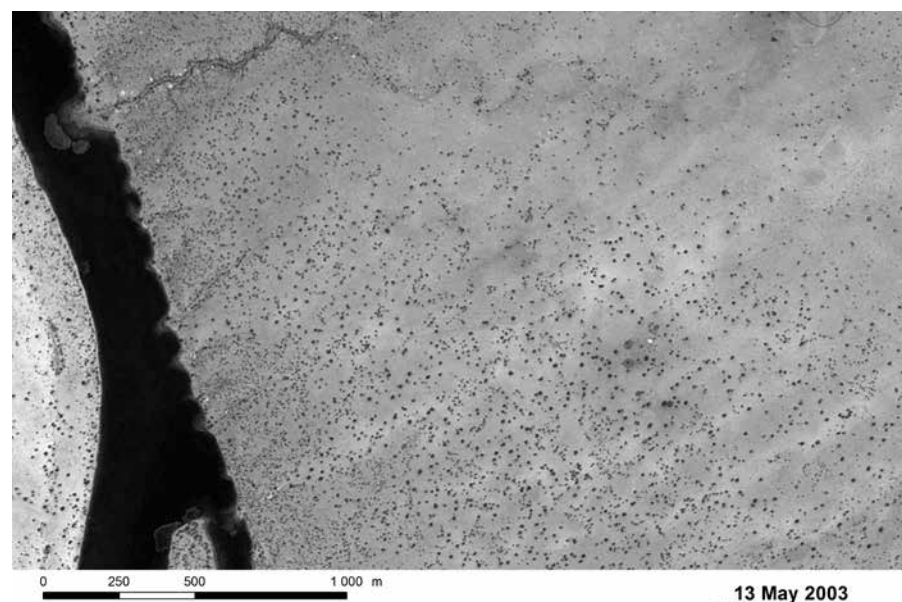
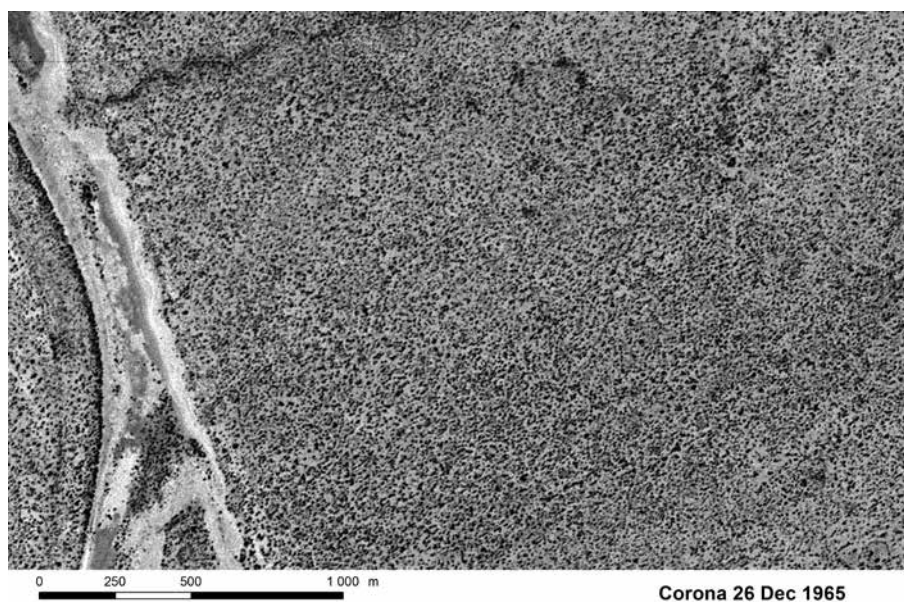
This atlas presents West Africa's changing landscapes through land use and land cover maps for three periods in time. The changes between each period represent one of two main types of landscape change: land cover conversions and land cover modifications. Land cover conversions are the transitions from 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

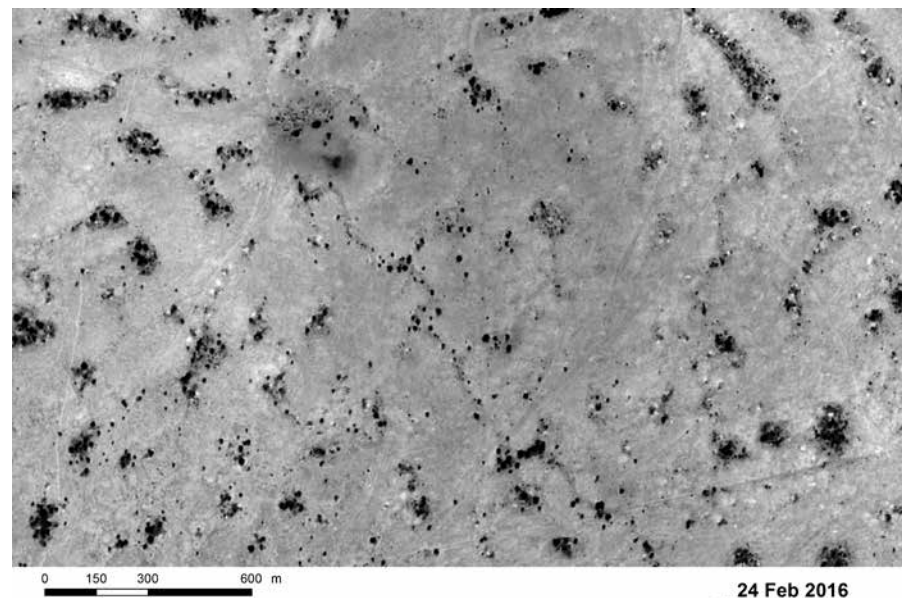
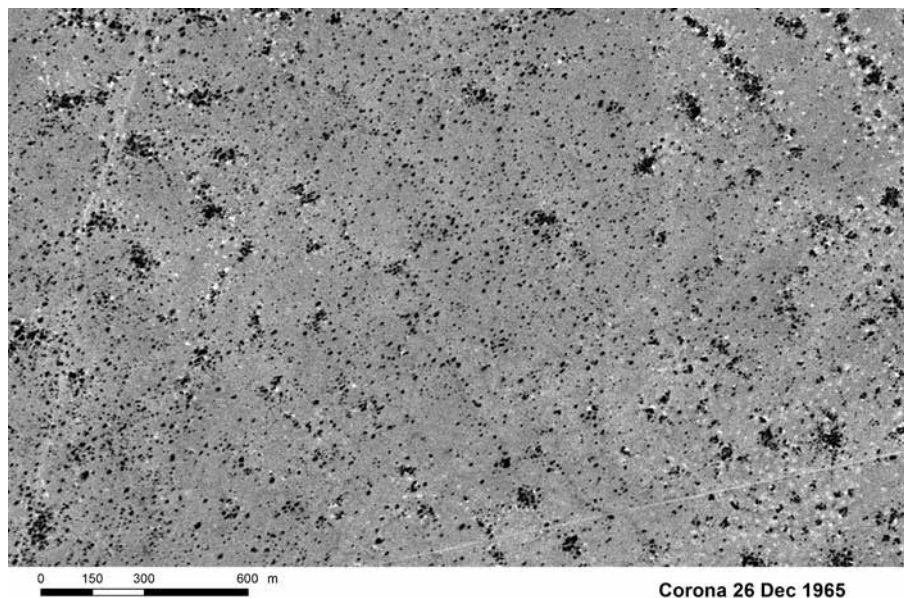
vegetation cover in Senegal were a result of land cover modification rather than the conversion of land cover from one class to another (Woomer and others, 2004; Tappan and others, 2004). Land cover modification is much harder to map and quantify at national and regional levels than land cover conversion. 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





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



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.

GRAY TAPPAN / USGS; CHRIS REIL / WRI

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).

1.3

Drivers of Land Changes

Changes in land use and land cover result from a myriad of factors acting on the land surface. These factors fall into two large groups, those originating from human activity and those originating from natural forces. Among the human factors, the size and growth of the human population plays a large role, but it is not the only underlying human cause of land cover change. The impacts of population growth are amplified or attenuated by institutional factors and national and regional policies, as well as processes of globalization, all of which shape economic opportunities that the populations of West Africa respond to in complex and interrelated ways that ultimately affect land use and land cover patterns (Lambin and others, 2001). For example, the progressive integration of West Africa into a global market economy has led to expansion of foreign investment in the mining and timber industries of the Guinean forest countries, which increases the rate of forest loss. Structural adjustment programs have encouraged agricultural specialization toward a small number of cash crops, such as cotton and peanuts in the Sahelian countries, which replace a more diverse mix of local grains and tubers. Finally, increasing affluence of the growing population affects consumption patterns, such as the increased demand for processed food, meat, and dairy by the wealthy urban populations, with repercussions on natural resources and land use (Godfray and others, 2010).

In addition to human factors, natural factors have also contributed to changes on the land. With geology and landforms stable over long periods of time, climate is the most dynamic natural factor to affect land cover at annual to decadal time scales. Most importantly, the recurrence and persistence of drought conditions in the semiarid swaths of West Africa have directly changed the land cover by desiccating soils, shrinking water bodies, stressing the vegetation, and exposing bare soil and sandy substrate to erosion. Indirectly, it has affected people's ability to use the land for crop cultivation and for foraging by livestock, forcing them to find other ways of securing their livelihoods, which in turn have altered the land use and land cover. For example, the threat of drought to agriculture in the Sahel pushed farmers and pastoralists to migrate from the arid frontier toward more humid stretches of land, or into the urban areas in search of jobs. In other instances, the combined pressures of drought and population increase have spurred investments in soil and water conservation, and in agricultural intensification in southern Niger and central Burkina Faso (Reij, Tappan, and Smale, 2009).

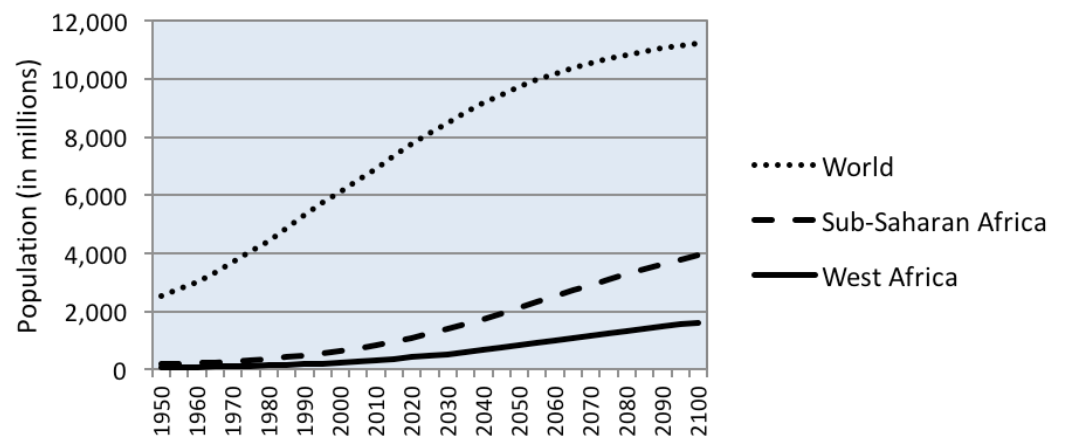
With the understanding that driving forces of land use and land cover change interact in complex ways, two key underlying drivers of change will be given particular attention: (1) population, which determines the demand and pressure on land resources, and (2) climate, which affects the supply or constraints of land resources.



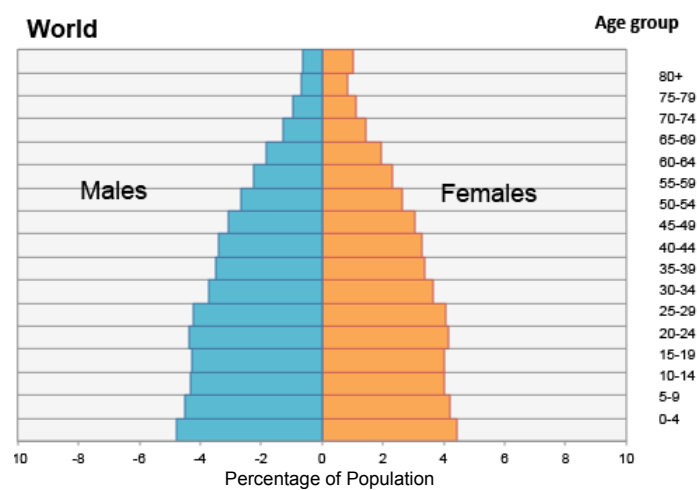
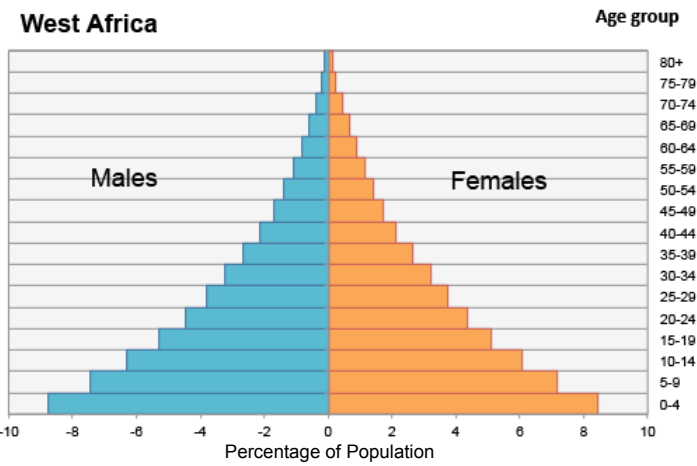
Drought in the Sahel Region, Senegal

With a 2015 population of 367 million (UN, 2015), West Africa is home to 5 percent of the world's population. This is a five-fold increase in population since 1950, when 73 million people lived in the region, which makes West Africa the fastest growing of any of the world's regions. For comparison, the world population has increased less than three-fold during the same time period. The young age structure of the West African population — almost half of West Africans are 15 years old and younger — assures continued population growth into the near and medium future. Assuming a medium fertility model, the population of the region is projected to exceed one billion by 2059, when almost one in 10 of the world's people will be West African (UN, 2015).

Projected population growth from 1950 to 2100



Age structures of the populations of West Africa and the world in 2013



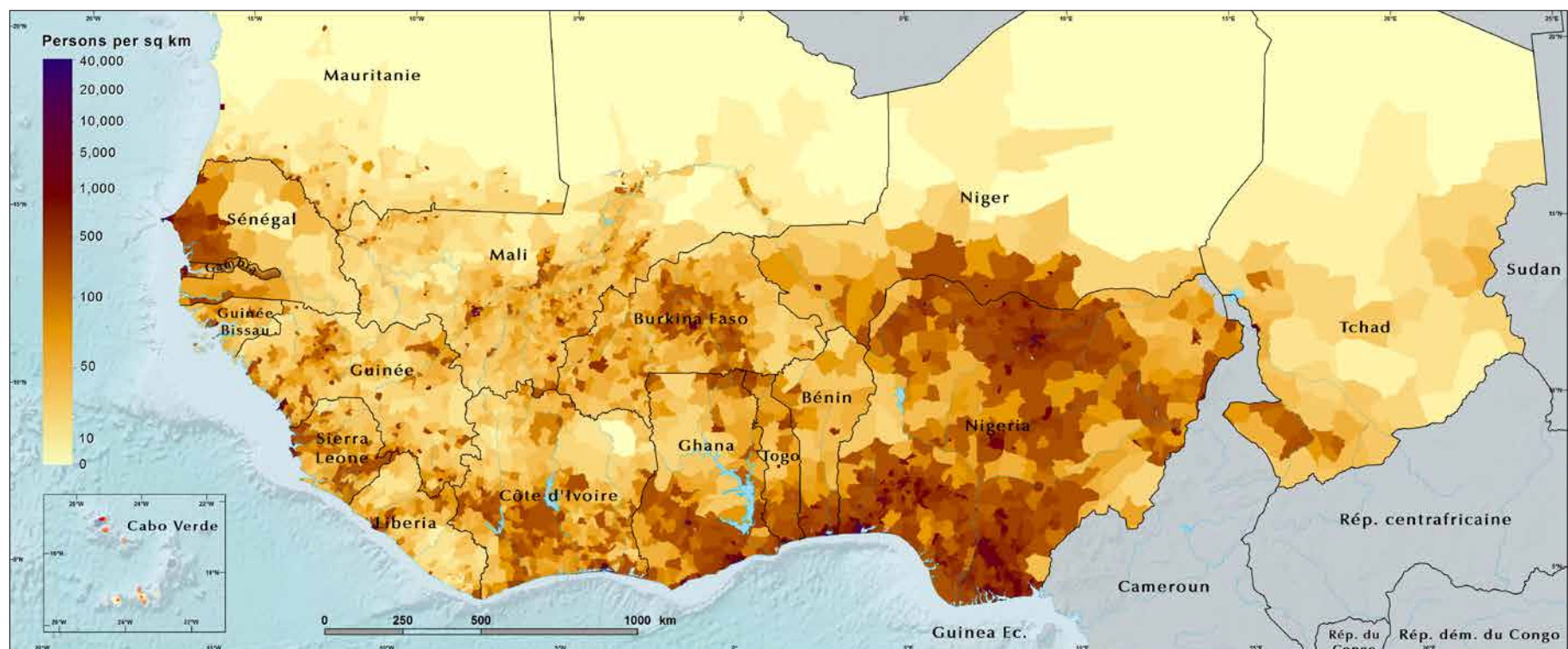
The age structure of West Africa's current population forms the shape of a pyramid with a wide base and concave sides, indicating a high birth rate and a relatively high death rate, resulting in rapid growth. By comparison, the age structure of the global population has moved toward a more rectangular shape, describing a population that is only slowly expanding, with lower birth and death rates and more people living to old age.



Niger, Filingué department

STEFANIE HERRMANN / U. OF ARIZONA

Population densities by administrative units in West Africa in 2015



(DATA SOURCE: CIESIN, 2005)

West Africa's population is unevenly distributed throughout the region, reflecting differences in the physical environment as well as the history of human settlement (see map above). In the arid northern part of the region, only a small, sparse population can be sustained. In the arable regions, where soils are fertile and the climate is favorable for crop cultivation, higher population densities are found. Thus, the Peanut Basin of western Senegal, the Niger-Nigeria border region, central Burkina Faso, and southwestern Chad stand out by their relatively high rural population densities.

Settlements are also concentrated in the riverine plains of the Senegal and Niger rivers, where perennial water availability supports irrigated agriculture of rice and high value garden crops. In the densely forested southern part of the region, which has historically been more difficult to develop, rural population densities are generally lower than in the open savanna. However, along the coast, population densities are driven up by a large number of coastal settlements, including some major urban agglomerations.



The map of population densities (opposite page) shows higher population densities in Nigeria than in any other West African country. Indeed, almost half of West Africans are Nigerian, and with over 172 million inhabitants, Nigeria is the most populous country in the entire African continent. The remaining 16 countries account for the other half of the West African population, with Ghana coming in at a distant second (7.5 percent of West Africa's population). What might explain this noticeable difference between Nigeria and the rest of West Africa? People tend to settle where the climate is clement, the soils are fertile, and economic opportunities are present. Nigeria encompasses an extensive savanna region, without the extreme aridity found in the northern countries, and a large delta and coastal plains. Two important perennial rivers, the Niger and the Benue, as well as their tributaries, assure sufficient water provision. While civilizations flourished across the region in the 15th through 19th centuries, the high concentration of kingdoms, empires and particularly city states — such as Kano, Katsina, Oyo, Ife, Benin, Nri, Igbo and others — is unique to the territory that became modern Nigeria. Two out of the three ancient trans-Saharan trade routes originating from North Africa and Arabia ended in Nigeria, which brought an influx of people to settle and trade. As an already very densely populated country today, Nigeria provides a preview of the pressures on the land resources that other parts of West Africa will likely have to face in the future.

Not only has West Africa's population been growing rapidly at an average annual rate of 2.75 percent, it has also become more urban, with some major cities recording mean annual growth rates of up to 9 percent.

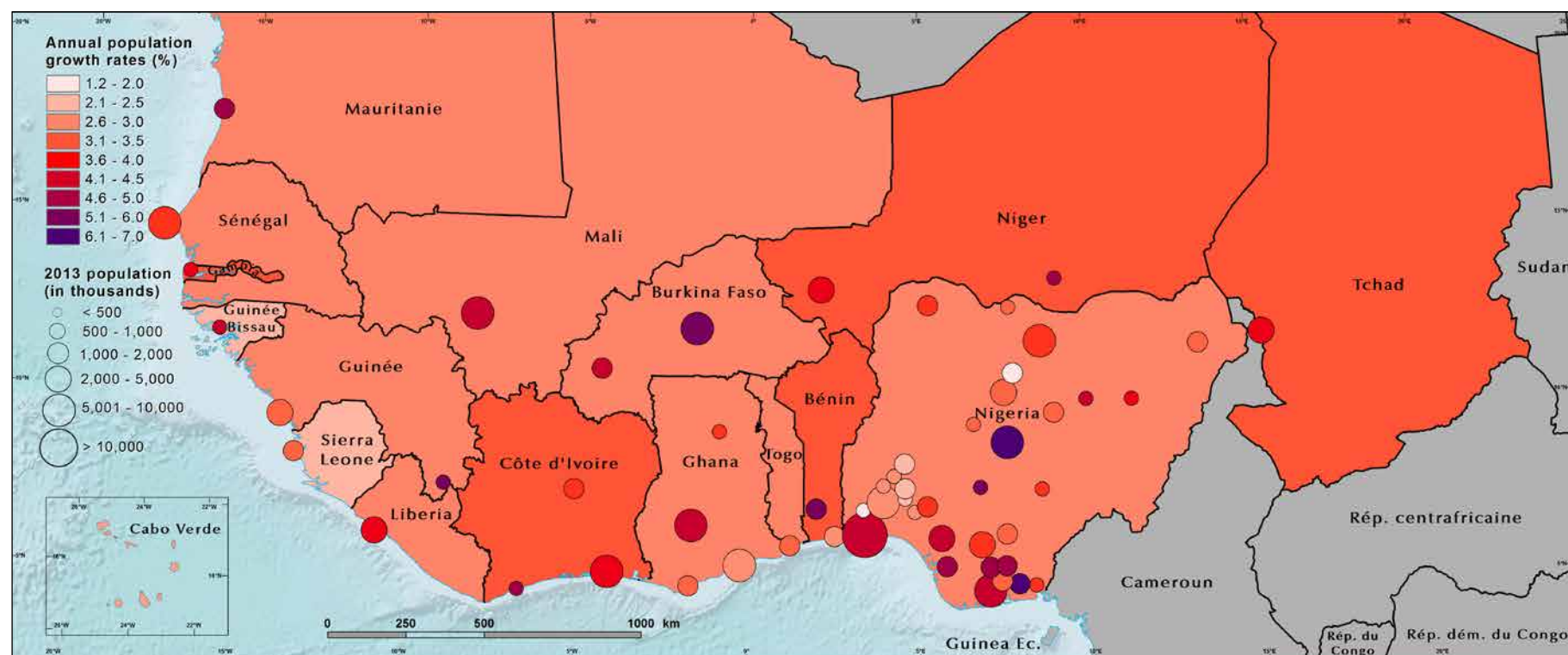


Kejetia Central Market, Kumasi, Ghana

STEFANIE HERRMANN / U. OF ARIZONA

A majority of West Africans still live in rural areas, yet the urban population has increased from only 8.3 percent in 1950 to almost 44 percent in 2015. The changes in lifestyle and consumption patterns associated with a progressive urbanization of the population affect land use and land cover patterns beyond the obvious increase of built-up area (Rindfuss and others, 2004). Dietary demands of the urban population translate into land demands in the urban periphery, in particular for the cultivation of high-value, perishable crops, such as fruits and vegetables. Part of the wages earned in the city reach the rural areas in the form of remittances to the homelands of the new urbanites, where they spur investments in economic activities that potentially affect the land cover, such as through abandonment or intensification of agriculture. These are just a few of the linkages between population and land use/land cover (Lambin and others, 2001).

Annual population growth rates 1975–2013 by country and by urban agglomeration of over 100,000 inhabitants



(DATA SOURCE: UN, 2015)

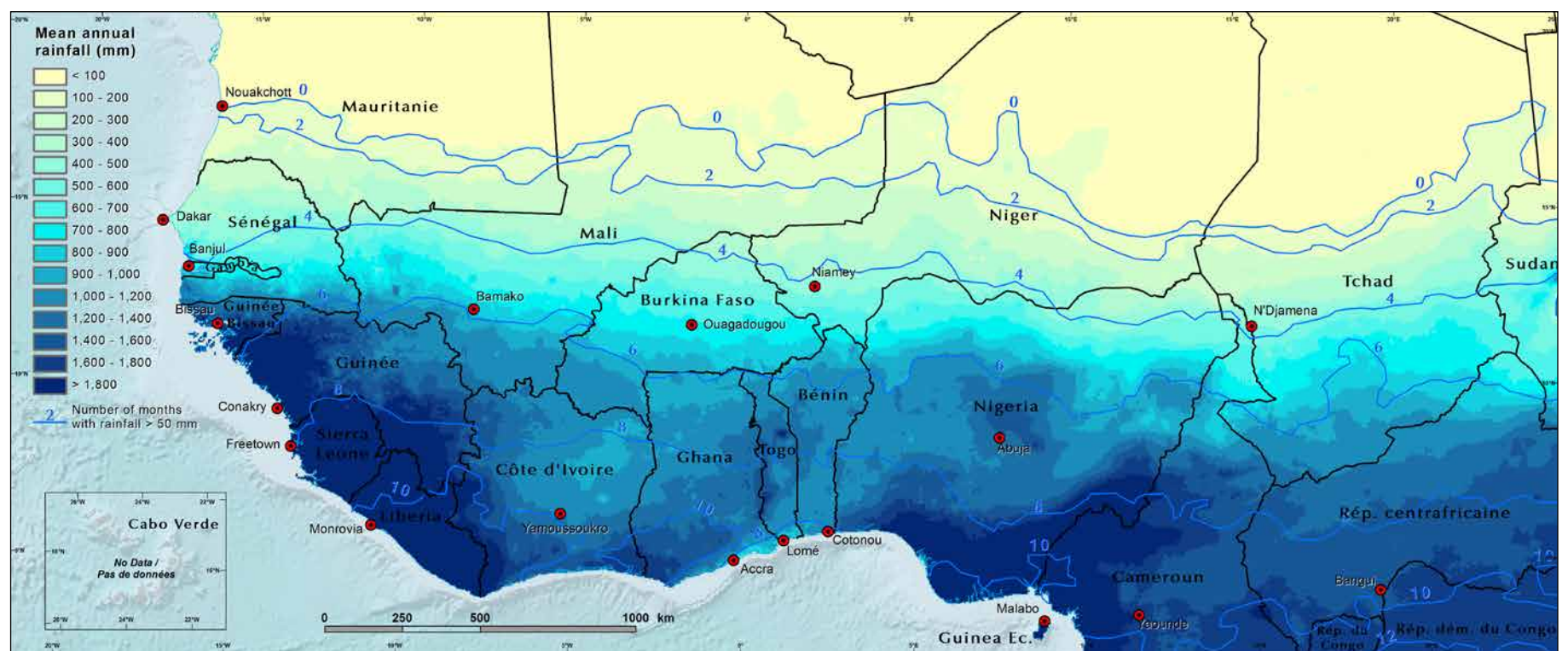
West Africa's climate is controlled by the interaction of two air masses, the influence of which varies throughout the year with the north-south movement of the Intertropical Convergence Zone (ITCZ). Hot, dry continental air masses originating from the high pressure system above the Sahara Desert give rise to dusty Harmattan winds over most of West Africa from November to February. In summer, moist equatorial air masses originating over the Atlantic Ocean bring annual monsoon rains (Nicholson, 2013).

As a result of these interacting air masses, West Africa's precipitation regime is characterized by latitudinal belts of decreasing rainfall and wet season length. At the Gulf of Guinea, precipitation is abundant year-round without a marked dry season. At higher latitudes, precipitation decreases and is limited to a wet season of decreasing duration. This latitudinal pattern is somewhat modified by altitude, with higher mountain elevations, e.g. the Guinean Highlands and the Jos Plateau in central Nigeria, receiving more precipitation than lowlands of the same latitude. Along the south-north gradient of decreasing rainfall, Abidjan, Côte d'Ivoire (5° north latitude) records a mean annual rainfall of 1,600 mm; Ouagadougou, Burkina Faso (12° northern latitude) 700 mm within a 5-month rainy season; and Agadez,

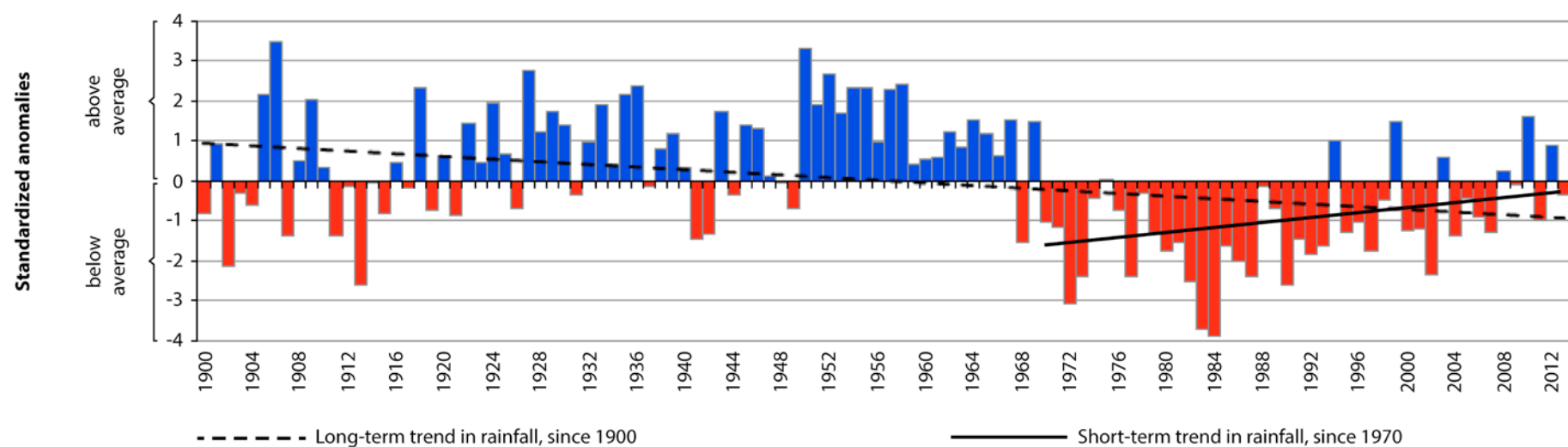
Niger (18° northern latitude) 165 mm annually in a short 2.5-month rainy season. Temperatures in the lowlands of West Africa are high throughout the year, with annual means usually above 18°C. In the Sahel, maximum temperatures can reach above 40°C.

Not only scarcity of rainfall, but also its variability and unpredictability become more significant with latitude. Thus, year-to-year rainfall variability ranges from 10 to 20 percent in the coastal areas to over 40 percent in the northern Sahel (FAO, 1983). Drought is a recurring phenomenon in semiarid West Africa, where average rainfall conditions seldom prevail, and rainfall is skewed to dryness, i.e., a few heavy rainfall years are balanced out by a larger number of below-average rainfall years. From the late 1960s through the 1980s, the Sahel zone experienced droughts of unprecedented spatial extent and duration (Hulme, 2001). These droughts followed a period of more favorable rainfall in the 1950s and early 1960s, which had encouraged government planners and farmers to expand agriculture northward (Glantz, 1994). The great Sahelian droughts forced the abandonment of agriculture at the arid margin, triggered a famine crisis that killed thousands of people and their livestock, and has been blamed for widespread environmental degradation in the region.

Mean annual rainfall 1981–2014, with number of months of 50 mm or more of rainfall



Standardized rainfall anomalies in the Sahel region (10–20°N, 20°W–10°E) derived from station data



(DATA SOURCE: MITCHELL, 2013)

Average annual rainfall has recovered some from the low point of the early 1970s, however it has not been enough to erase the long-term drying trend since 1900 — the earliest available rainfall records (Nicholson, 2005). Moreover, for agro-pastoralists not only annual rainfall totals are important, but also the frequency and distribution of rainfall events throughout the wet season. Too much rain at once can damage crops or change pasture composition in unfavorable ways. Heavy rainstorms also cause severe soil erosion, particularly on cleared cultivated land.

The great Sahelian droughts provide the most dramatic worldwide example of multi-decadal climate variability that has been directly measured. However, for lack of an observational rainfall record before the 20th century, or sufficient proxy indicators, it remains unclear how unique these droughts have been at time scales

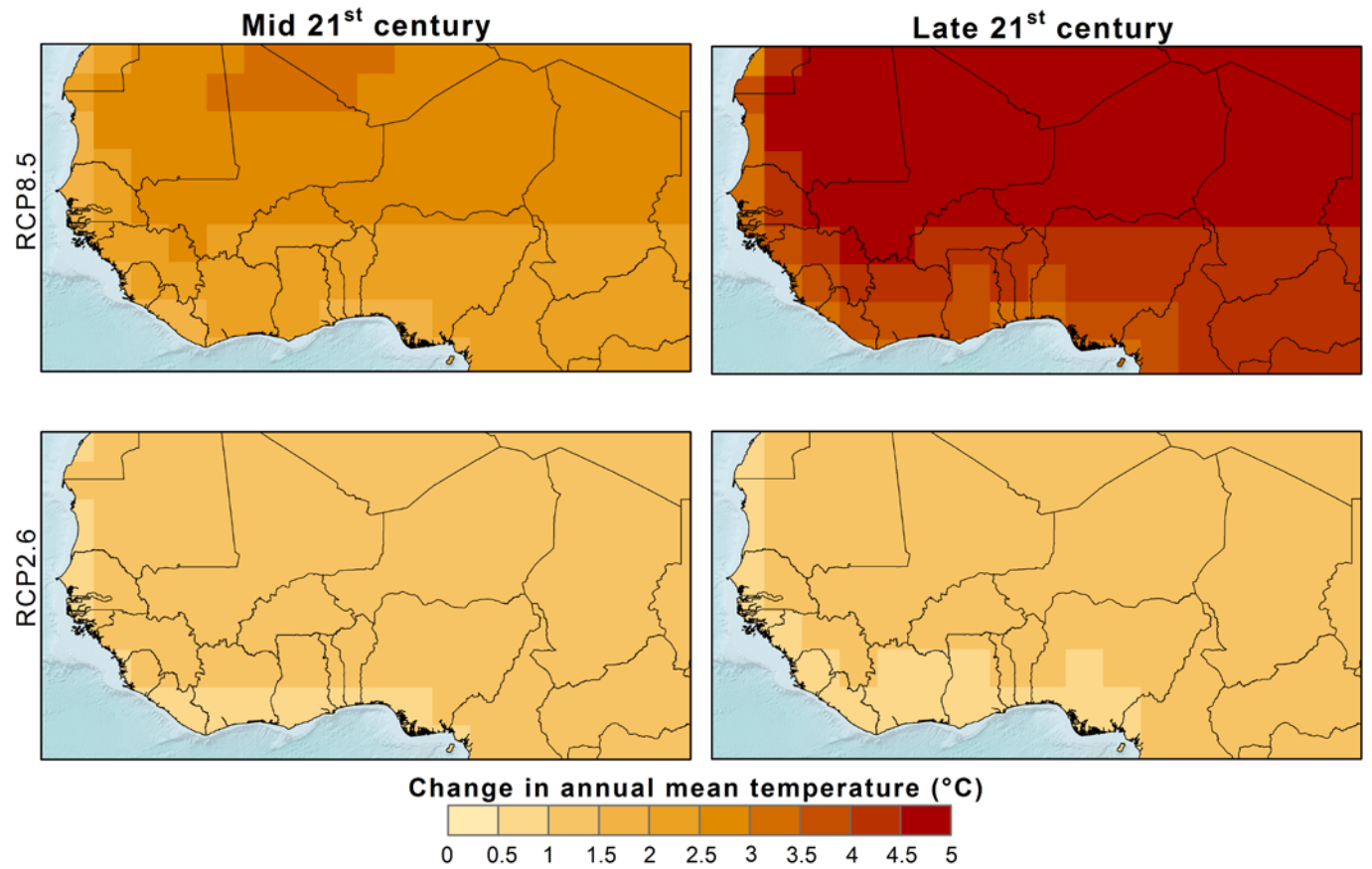
of centuries and millennia (Hulme, 2001). Are they part of the normal variability of this semiarid climate, or harbingers of human-induced climate change? Understanding the climatological processes behind the droughts is a prerequisite for attributing them to natural or human causes and to eventually predicting the impacts of future climate change on rainfall in the region. The current understanding is that variations in sea surface temperatures in the global oceans play the largest role in Sahelian rainfall variability, amplified by land cover (Giannini, 2016). Thus, climate is not only driving land use and land cover change, but to some extent is also driven by it. Particularly at local scales, the effects of vegetated versus bare soil on temperatures and humidity are quite noticeable, as illustrated in the examples of farmer-managed natural regeneration (see pages 70–71) (Reij Tappan, and Smale, 2009).



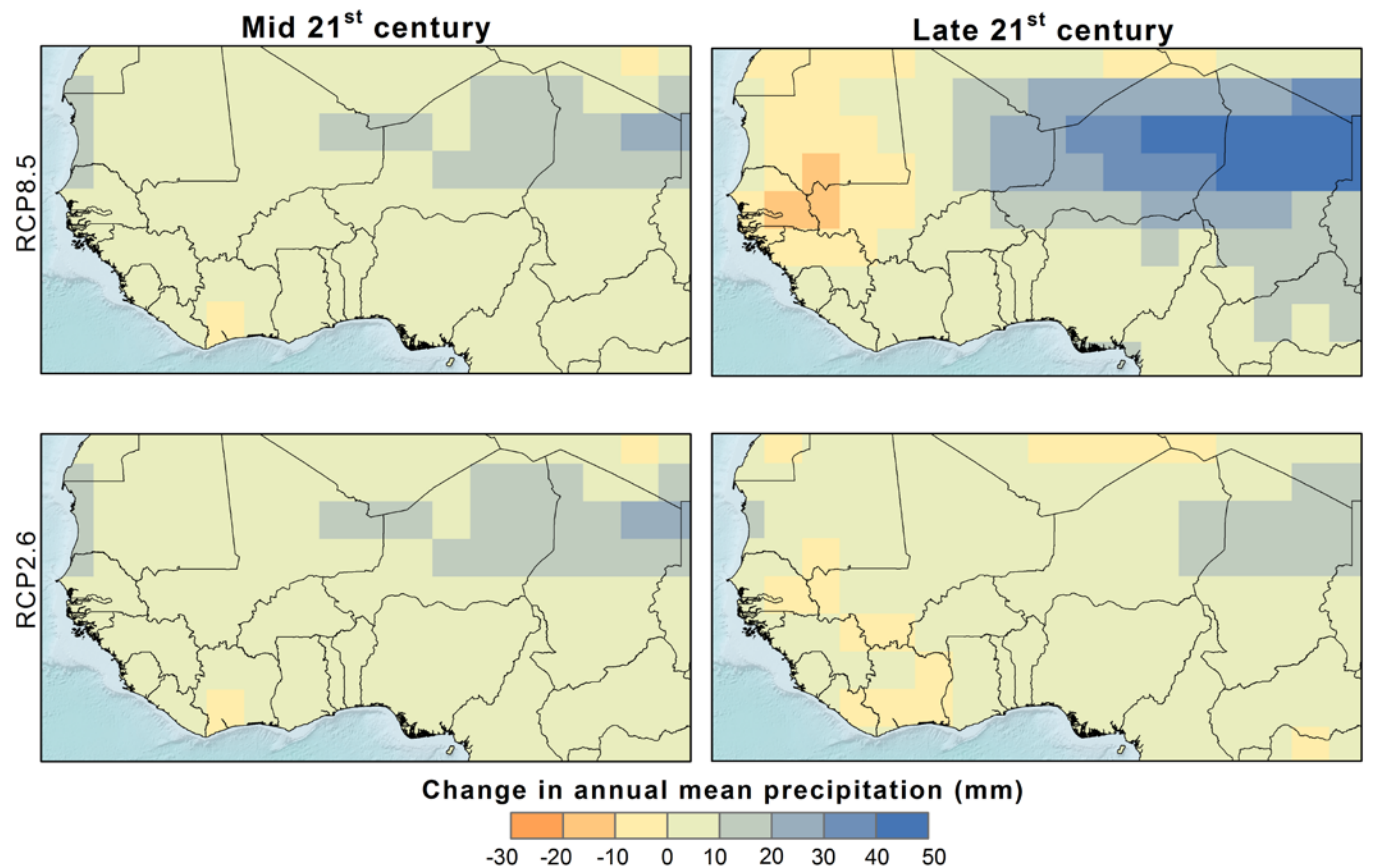
Dust storm, Winde Mborni, Mauritania, July 2008

STEFANIE HERRMANN / U. OF ARIZONA

Predicted temperature change for the mid- and late 21st centuries



Predicted rainfall change for the mid- and late 21st centuries



Models of projected changes in temperature and annual mean precipitation of West Africa were commissioned by the Intergovernmental Panel on Climate Change (IPCC). The scenarios predict temperature and precipitation for both the mid-21st century (2046-2065) and the late 21st century (2081-2100) relative to the late 20th century (1986-2005), based on two alternative greenhouse gas emission scenarios, RCP2.6 and RCP8.5 (RCP stands for Relative Concentration Pathways). Model projections based on these two extreme pathways are contrasted here, with RCP2.6 assuming that global greenhouse gas emissions peak between 2010 and 2020 and decline substantially thereafter, and RCP8.5 assuming that emissions continue to increase throughout the 21st century. The projections shown are multi-model averages. The averages tend to level out the considerable variability and disagreement between the individual models.

As the maps show, both scenarios predict a warming trend and predominantly positive changes in annual rainfall for most of West Africa. While most changes are small and insignificant, a wetter future is predicted for Niger and Chad, whereas the RCP8.5 scenario indicates a possible drying trend for the western part of West Africa.

These maps were reproduced for West Africa from data from the IPCC 5th Assessment Report (Niang and others, 2014).



Flooded village along the Niger River south of Niamey in 2012.

GRAYTAPPAN / USGS

Temperatures over West Africa have increased over the last 50 years, in line with an increase in global temperatures (Niang and others, 2014). The impact of global warming on rainfall in West Africa, however, remains notoriously difficult to assess in a climate that is susceptible to significant variation at multiple time scales. Different climate models, which differ in their representation of atmospheric processes, show significant variation, and disagreement, in their projections of future rainfall in West Africa. While there is a high level of confidence that temperatures will continue to increase in West Africa (between 3°C and 6°C above the late 20th century baseline by 2100), some models project a drier future, others a wetter future, and yet others no significant change in rainfall totals (see bottom adjacent figure). An increase in the

frequency of extreme rainfall events has been observed over the past 50 years and is likely to continue into the future. Future soil suitability for major crops is expected to be affected by climate change; in particular beans, maize and banana production might face declines and require cropping system transformations (Rippke and others, 2016). The coastal countries of West Africa are also vulnerable to sea level rise resulting from global warming, leading to flooding and coastal erosion.

Climate variability and change have impacted, and are continuing to impact, land cover in West Africa by changing the amount and timing of water availability to vegetation cover. Land use decision making responds to these changes in ways that further alter the land cover, from slight modifications of the quality of the land cover to outright transformations of the land cover type.

1.4

Land Productivity

In contrast to the discrete land use and land cover classes, land productivity is a continuous variable, which represents land cover through vegetation density and vigor. Land productivity can indicate the land's ability to support and sustain life and is useful for identifying land degradation. A common measure of land productivity is derived from time series of the Normalized Difference Vegetation Index (NDVI), which is a greenness index obtained from satellite-measured reflectances of the land. The index represents the differences in reflectance between green vegetation and bare ground. It senses the presence and vigor of green vegetation using the plant chlorophyll-absorbing red and the non-absorbing near-infrared (NIR) portions of the electromagnetic spectrum. NDVI is calculated as (Tucker, 1979):

$$\text{NDVI} = \frac{(\text{NIR}-\text{red})}{(\text{NIR}+\text{red})}$$

NDVI is a numerical measure ranging from 0 (low) to 1 (high). Because the NDVI is strongly related to the absorption of energy for photosynthesis by chlorophyll pigments of green plants, it can be used as a proxy for the amount of green biomass (Huete and others, 2016).

On a regional scale, land productivity follows the climatic gradient. With the exception of the moist coastal regions on the Gulf of Guinea, rainfall is a major constraining factor of land productivity in West Africa. Rainfall decreases from south to north — so does land productivity. Climate is not the only driver of land productivity. Soils, topography, land use and management also play a role in modulating land productivity at finer scales. While land productivity is associated with land use and land cover to some extent — e.g., the class “bare soil” has consistently very low land productivity whereas the class “forest” typically has high land productivity — it also cuts across land use and land cover classes and captures within-class

Range of land productivity within the land cover class “savanna”

12°N 18°E – mean NDVI of 0.32



PHILIPPE BURTIN

14°N 13°W – mean NDVI of 0.41



SABINE F AND BERND S

9°N 2°E – mean NDVI of 0.58



HELMUT RESCH AND BABS COLEMAN

Different land cover types represented by a mean annual NDVI of around 0.45

14°N 13°W – Savanna



SABINE F AND BERND S

11°N 3°E – Agriculture



HELMUT RESCH AND BABS COLEMAN

5°N 8°E – Settlement



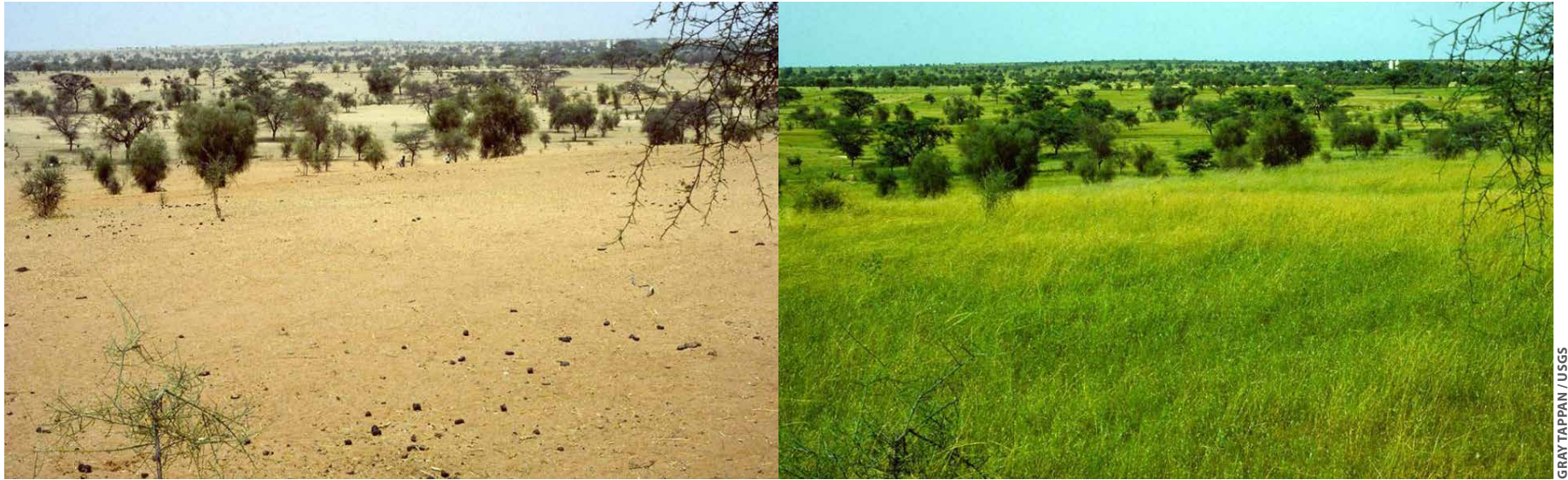
HELMUT RESCH AND BABS COLEMAN

variability. Particularly in the land cover class “savanna,” land productivity varies widely from place to place.

Land productivity varies not only in space, but also in time. This variability in land productivity occurs at different time scales, from seasonal to inter-annual, in response to the variability in rainfall. Moving from the Gulf of Guinea, which receives adequate rainfall for vegetation activity year round, to the north, the difference between dry and wet season becomes

increasingly marked (see pictures below). Thus, in the semiarid Sudan and Sahel zones, the vegetation cover appears lush and green during the wet season. In the dry season, the herbaceous cover dries out, whereas some — but not all — of the woody species retain their green leaves. In addition to this seasonal ebb and flow, rainfall and the vigor of the vegetation cover also vary between years. As a rule, the lower the long-term mean annual rainfall, the more variable and unpredictable it is from year to year (see climate, pages 34–37).

Dry versus wet season ground photographs of a tree savanna area in north-central Senegal

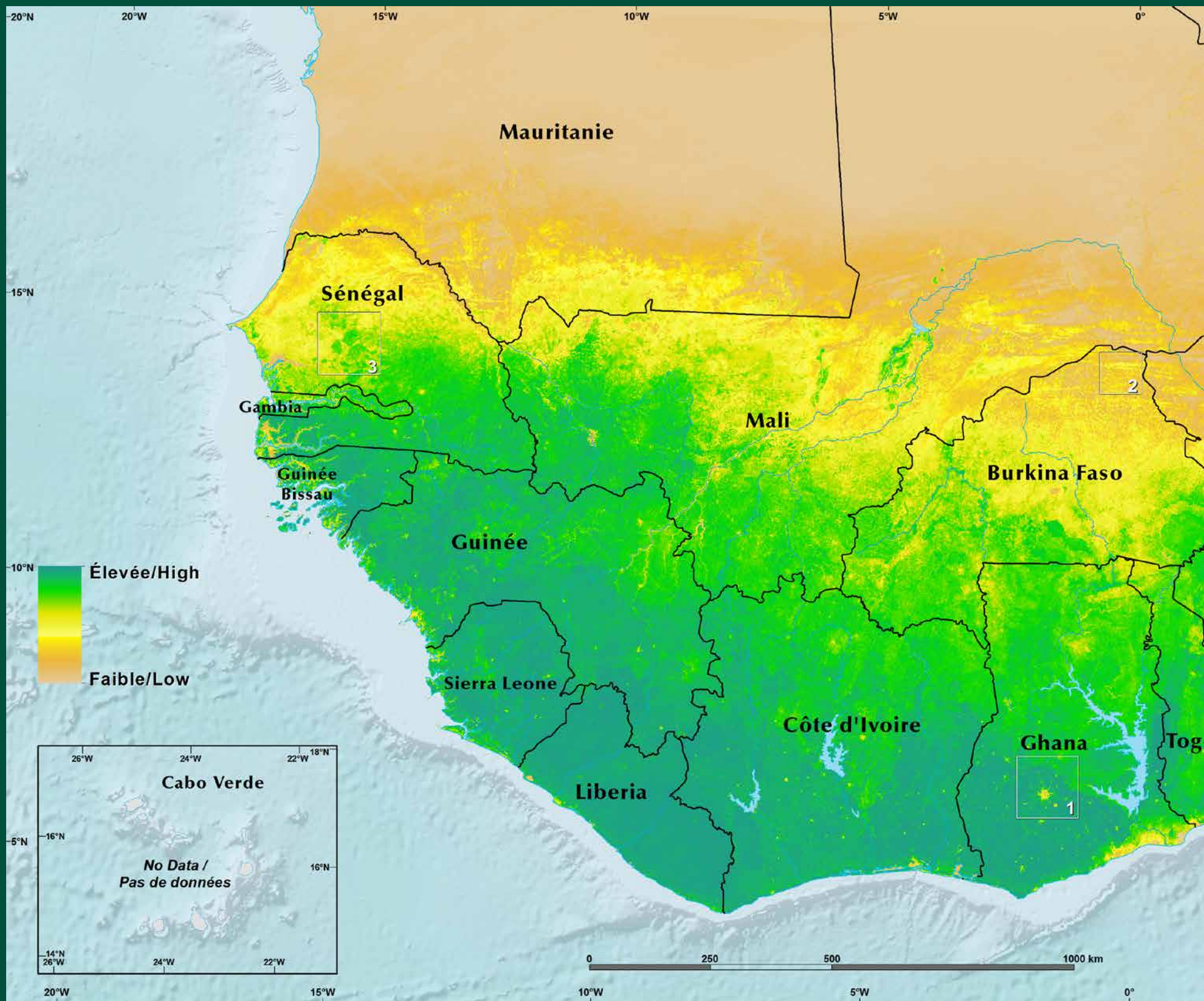


Dry versus wet season ground photographs of a wooded savanna in north-central Senegal



Dry versus wet season ground photographs of a woodland in south-central Senegal

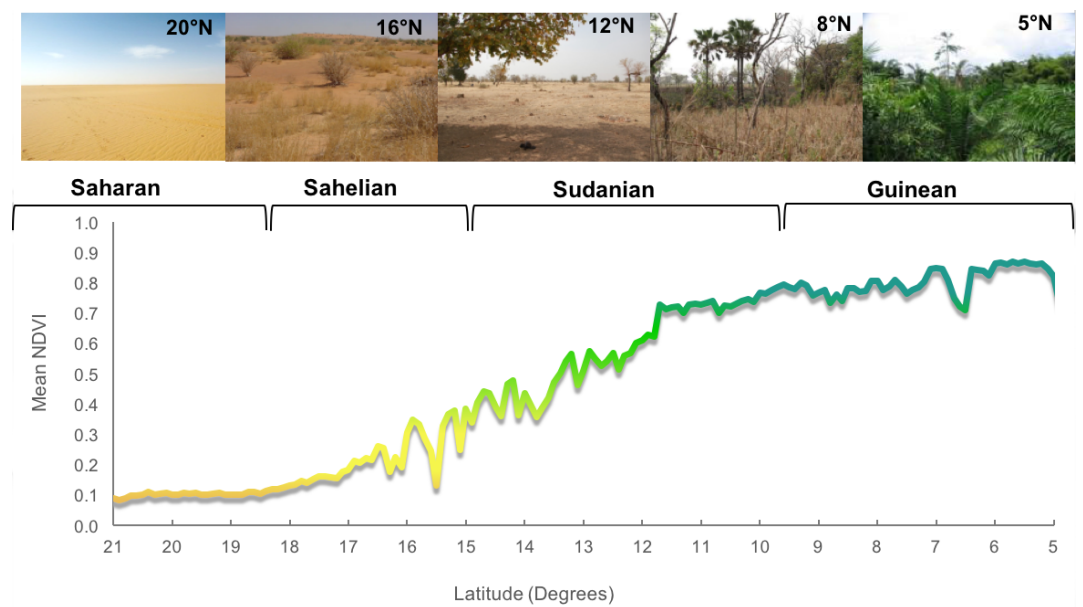


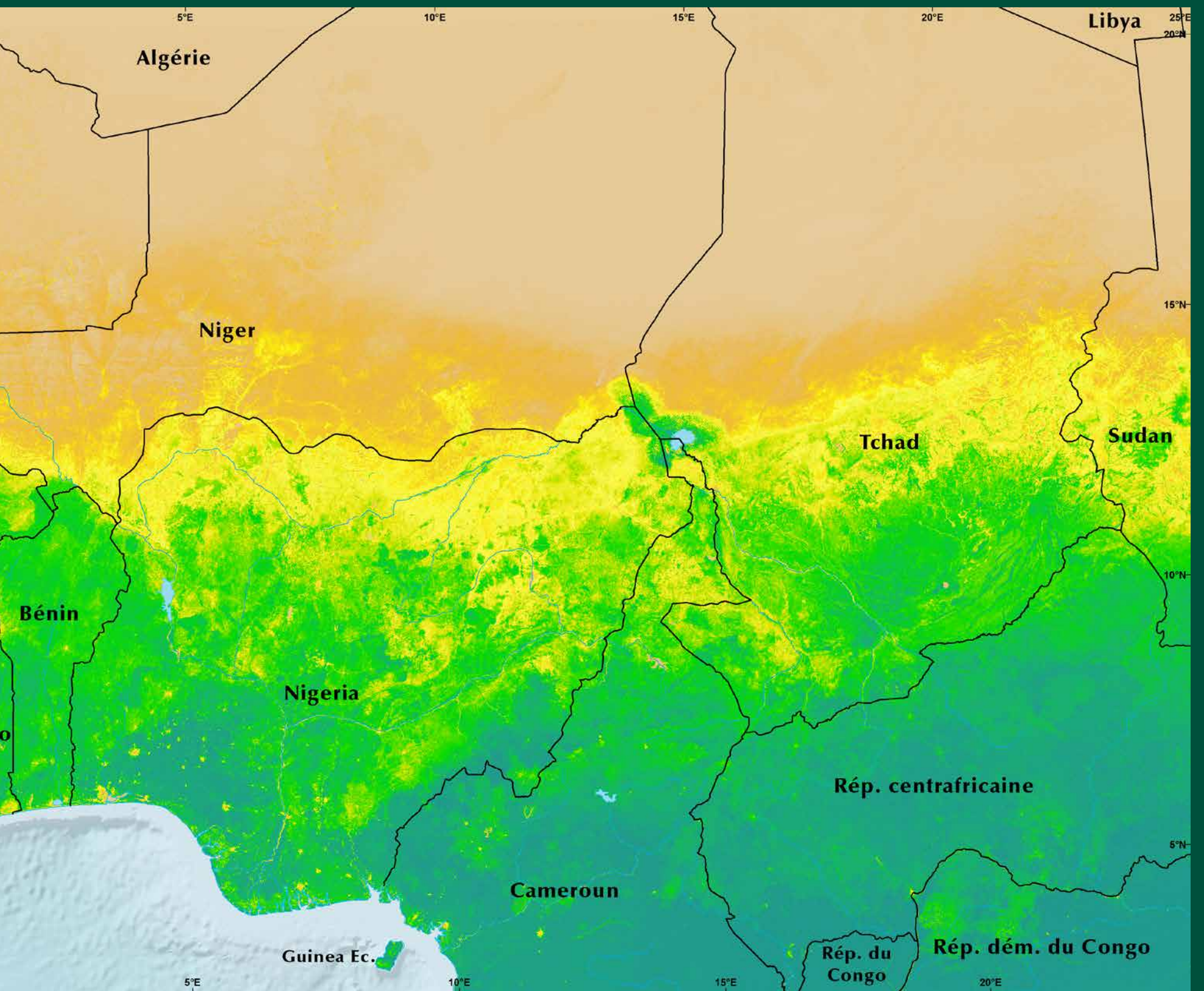


Land productivity in West Africa

The land productivity map of West Africa was produced from 15 years (2001–2015) of 250-m spatial resolution MODIS NDVI data. From each year of data, which comprises 72 observation periods per year, the value of the maximum NDVI was retained. The maxima of the 15 years were then averaged to create a mean maximum NDVI image. This simplistic technique is adequate for eliminating many of the atmospheric effects that influence the satellite-measured reflectances throughout the years and minimizes the impact of the seasonal variability in rainfall. The resulting map provides an overview of the spatial pattern of land productivity in West Africa and a basis for identifying areas of high and low productivity.

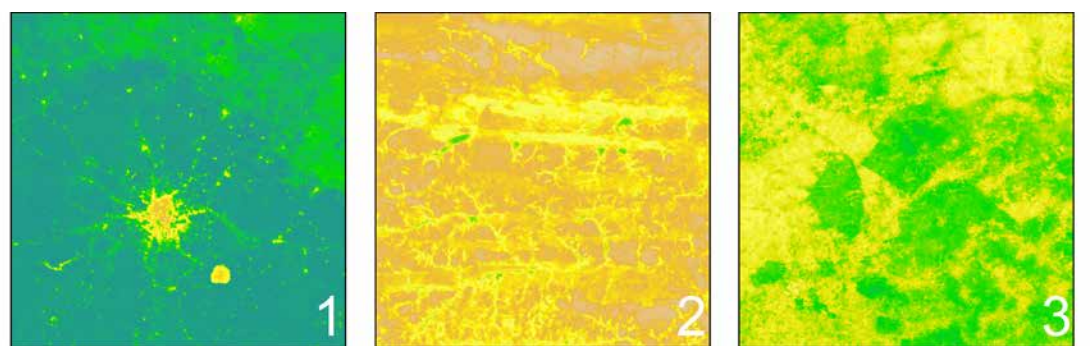
Longitudinal cross section of West Africa showing land productivity gradient





While the regional-scale map emphasizes the north-south land productivity gradient, three smaller subsets zoom in on finer-scale patterns. Subset 1 highlights the stark contrast in land productivity between the built-up area of the city of Kumasi in Ghana and the surrounding forest zone. Subset 2 shows a dune-interdune landscape aligned east-to-west in northern Burkina Faso, in which the lower-lying interdune spaces are occupied by unproductive steppes in contrast to the much more productive open savannas on the sandy soils that cap the stabilized dunes. Subset 3 illustrates the impact of land management on land productivity at three large sylvo-pastoral reserves in central Senegal (Doli, Mbégué and Siné Saloum), which form higher productivity areas against the surrounding agricultural land that blur where agriculture is encroaching into the reserves.

Land productivity for three subsets: (1) Kumasi, Ghana, (2) Northern Burkina Faso, (3) Central Senegal



1.5

Land Use and Land Cover Trends

The 1975, 2000, and 2013 West Africa land use and land cover maps presented in the following pages tell a complex story of change — a story that we are only now able to visualize for the first time. While we cannot do justice here to everything that the multi-period maps show, we can point out some of the main trends at the regional level.

Large areas of northern Mauritania, Mali, Niger, and Chad fall within the Sahara Desert. In this arid landscape, land cover and vegetation are quite stable over time. For this reason, only the southern parts of these countries were mapped.

In 1975, natural habitats of the Sahelian and Sudanian Regions such as steppe, sahelian short grass savanna, and sudanian savanna were still the dominant land cover classes across West Africa, representing 18.5, 15, and 32.2 percent of the mapped area, respectively (see 1975 land cover map, pages 44–45). From north to south, vegetation of the semiarid regions gradually transitions into the more forested landscape of the Upper Guinean countries (from Guinea to Togo) and southern Nigeria. In the 1970s, the extent of West African forest was about 131,000 sq km (2.7 percent of the mapped area), often interspersed with tracts of degraded forest totaling an additional 168,000 sq km (3.4 percent of the mapped area). Cropland was seen widely scattered among the natural landscapes, covering 10.7 percent of the area. Two agricultural regions stood out, the Peanut Basin of

Senegal and the Grain Belt of northern Nigeria, whose landscapes were almost totally devoted to cropland.

Fueled by high demographic growth — population grew from 120,000,000 to 334,500,000 inhabitants in 38 years — and a growing demand for food, agricultural expansion accounts for the most spectacular form of landscape change. Cropland expanded rapidly, initially along the country's main transportation routes, now pervading the whole region. The fastest average annual rates of cropland expansion over the 38-year period were found in Togo, Benin, Chad, Mauritania, and Burkina Faso. Between 1975 and 2013, the area covered by crops doubled in West Africa, reaching a total of 1,100,000 sq km, or 22.4 percent, of the land surface. In every country, agriculture is exerting pressure on the natural landscapes, replacing and fragmenting savannas, woodlands, and forests. Only scattered protected areas are spared from the tide of change and stand out against the agricultural landscape. These protected areas are particularly visible in Burkina Faso, Ghana, Togo, Benin, and Nigeria. Chad and Liberia still maintain great expanses of unbroken wilderness. But change has begun here too.

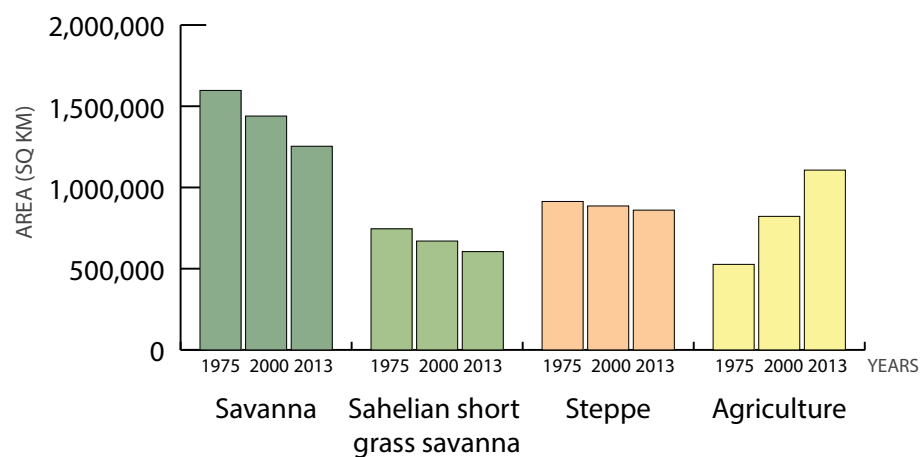
Another important land cover change in West Africa is the loss of forest. The forests of the southern tier countries have become fragmented and degraded where they occur outside of protected areas. Between 1975 and 2013, forest cover was reduced by 37 percent.

Today, Liberia has the greatest extent of forest of any country, covering about 37 percent of the national area. To the east, Côte d'Ivoire lost 60 percent (22,000 sq km) of its forest in 38 years, Ghana lost 24 percent (4,000 sq km), and Nigeria lost 45 percent (9,570 sq km). In Guinea, Sierra Leone, and Togo, little remains of the once-extensive forests.

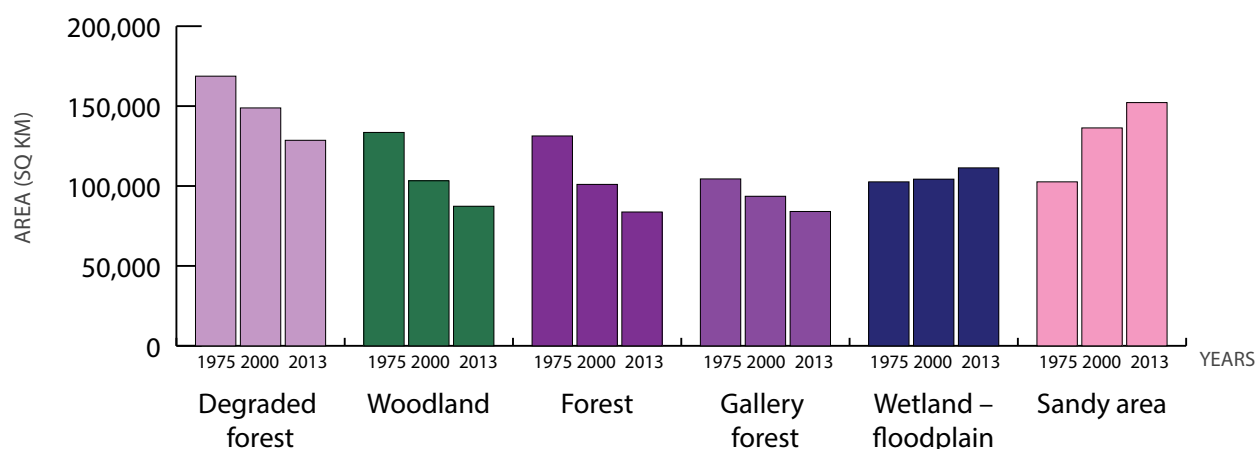
In addition to the changes of large geographic extent, changes among some of the smaller area land cover types are also significant due to their environmental importance. In Mauritania, Mali, Niger, and northern Sahel, the droughts of the 1970s and 1980s degraded or reduced some of the savannas and steppes, removing protective cover and destabilizing the sandy soils. This resulted in a 47 percent increase in sandy areas, or 49,000 sq km. Moreover, driven by population growth, the area devoted to human settlements increased by 140 percent in West Africa. Most of this urbanization occurred in the coastal region.

West African countries have lost—and are still losing—large extents of their natural land cover classes, replaced by a heavily human-influenced landscape dominated by agriculture.

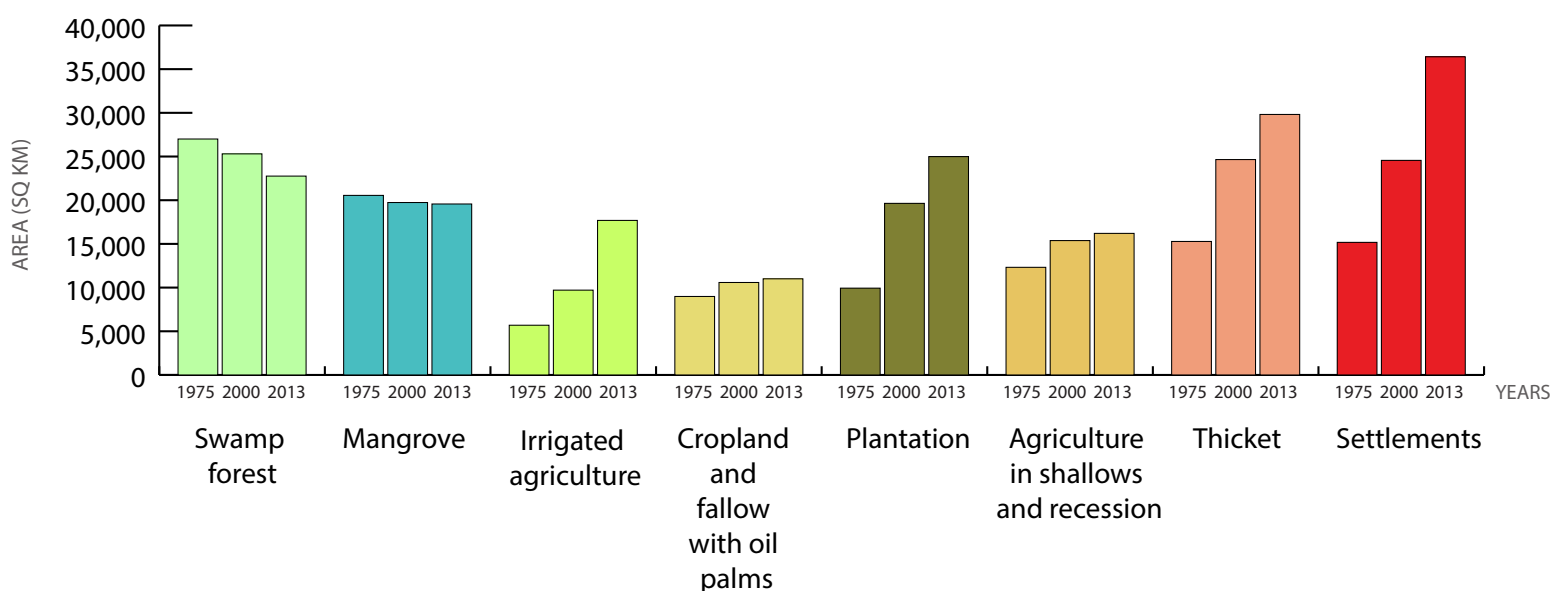
Large area classes

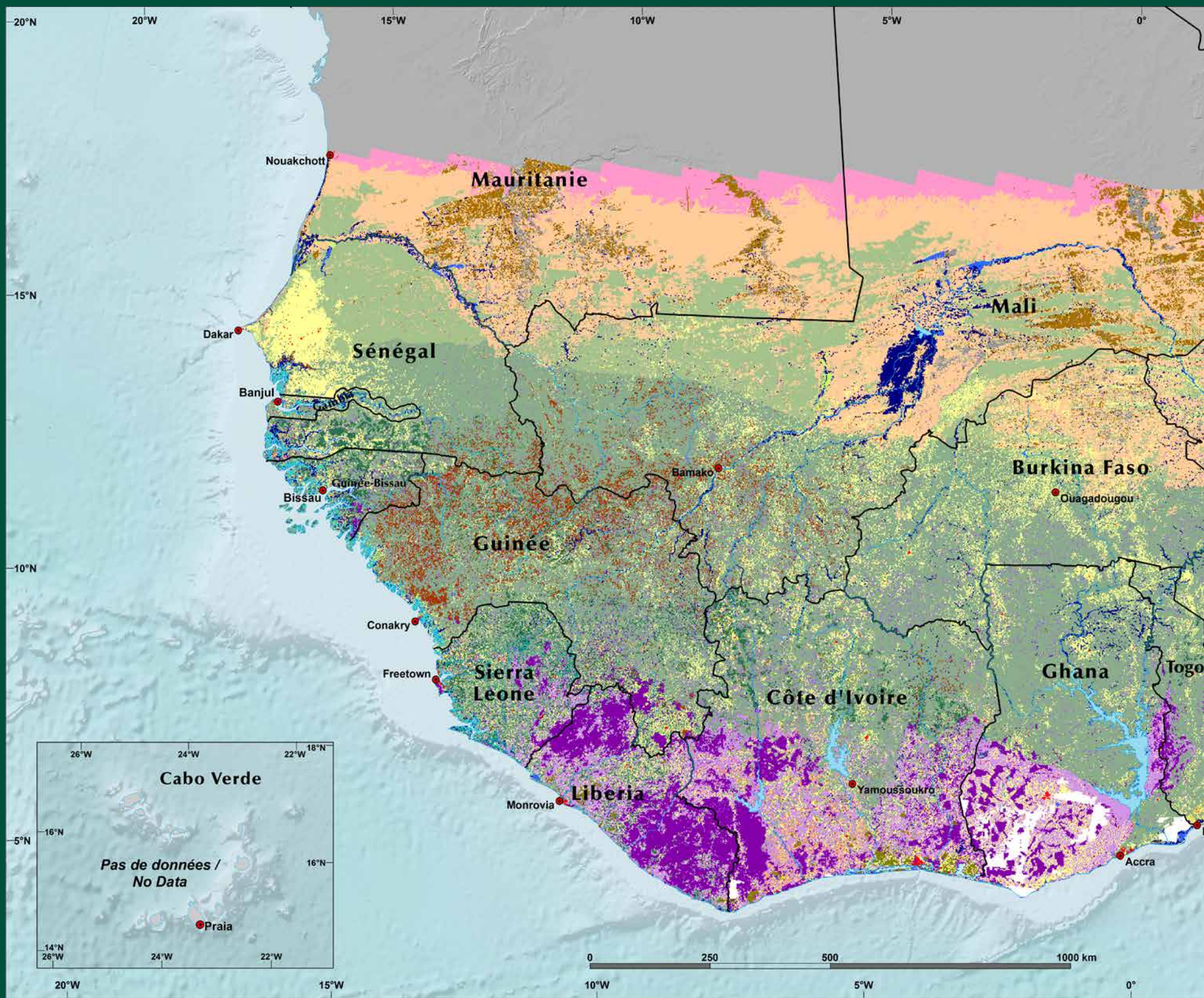


Medium area classes

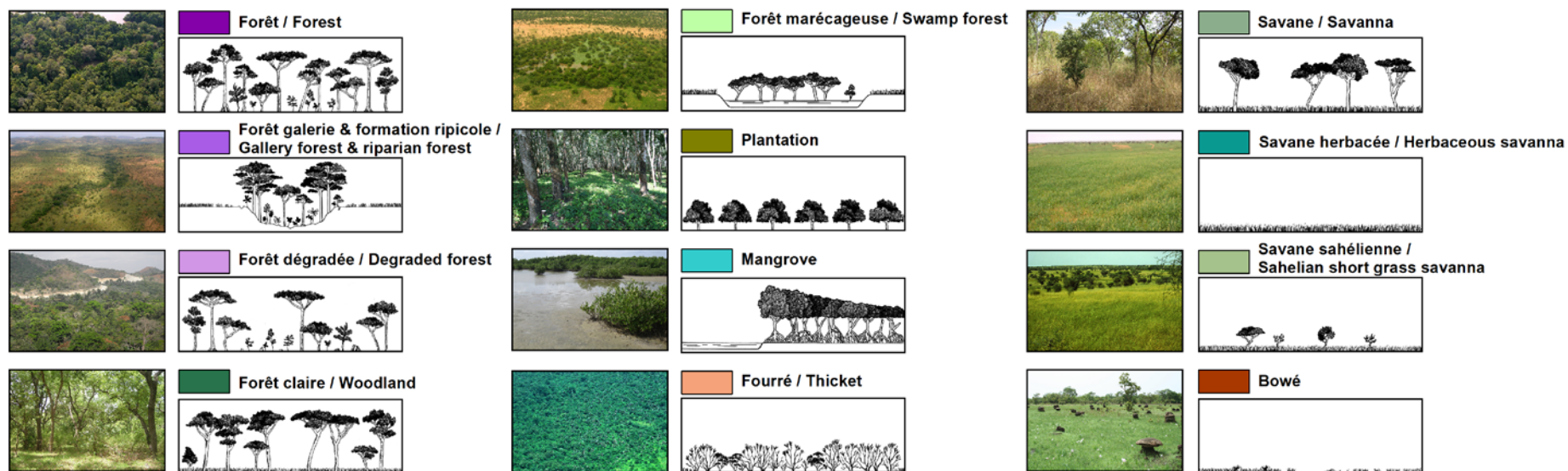


Small area classes

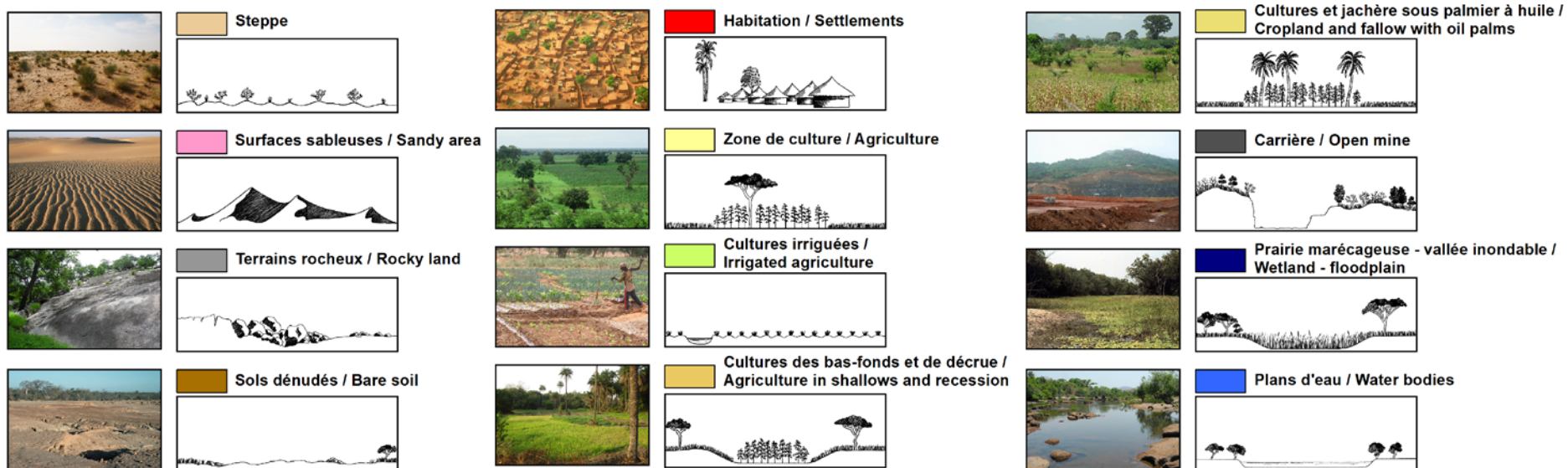
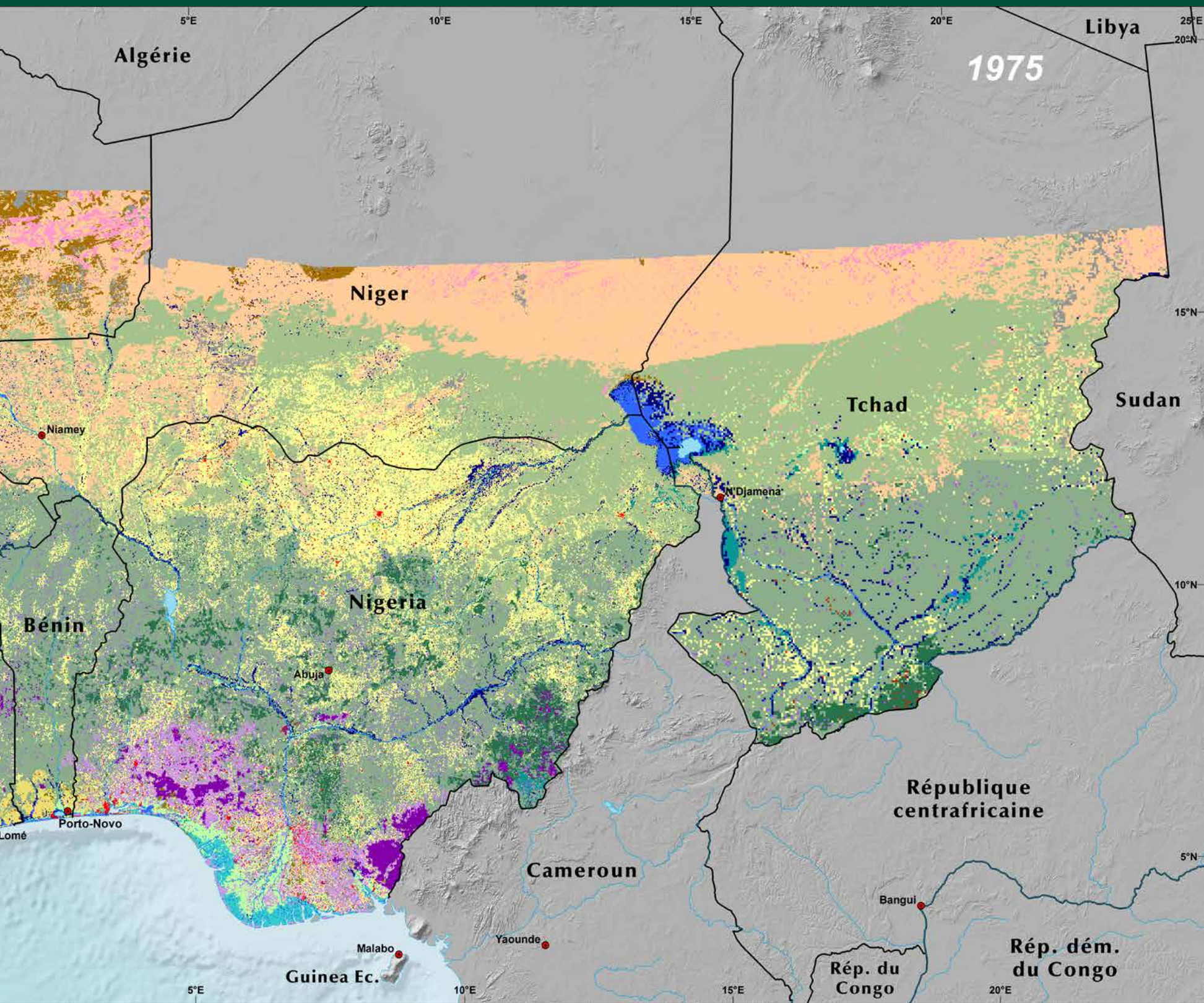


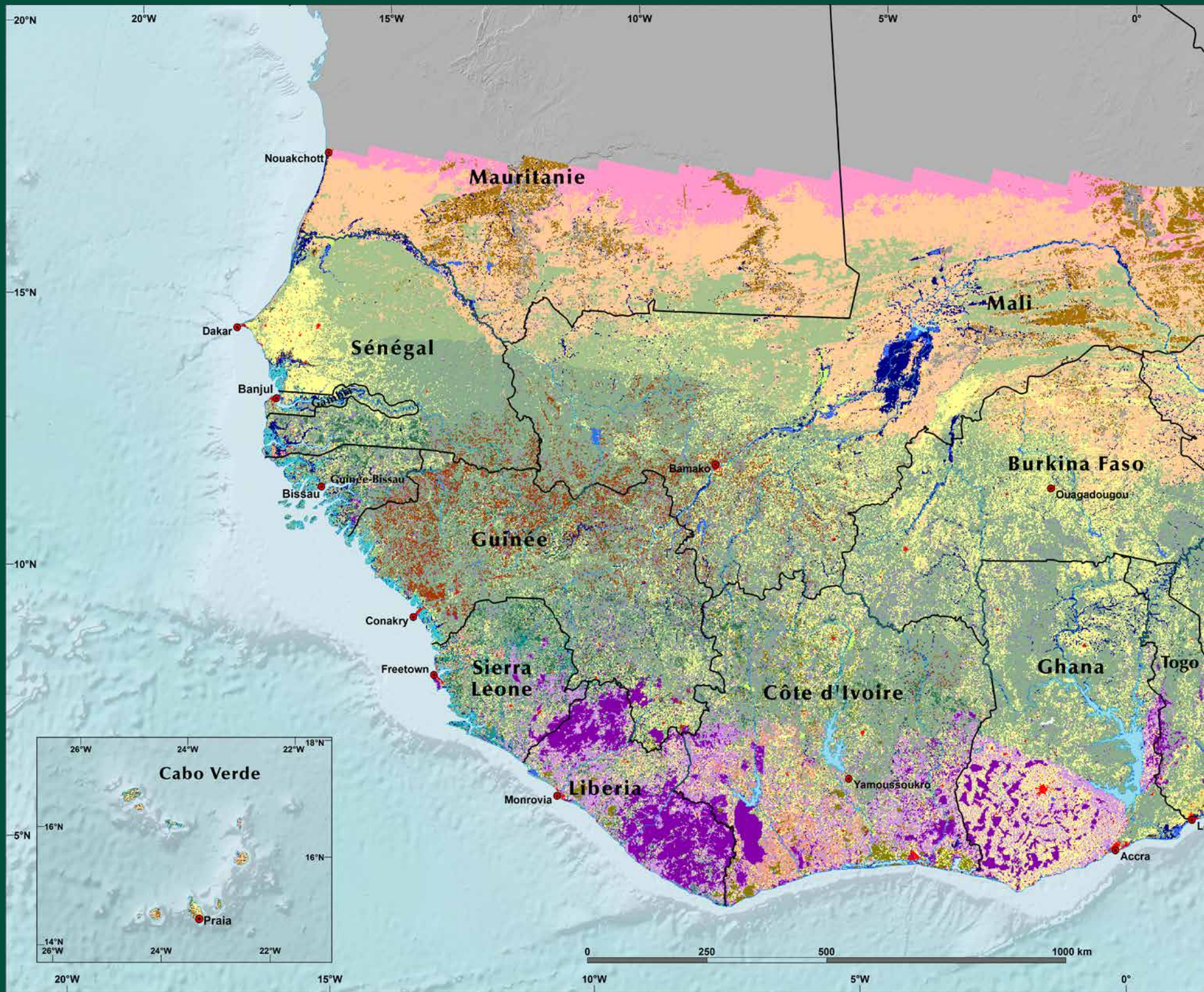


West Africa Land Use and Land Cover in 1975

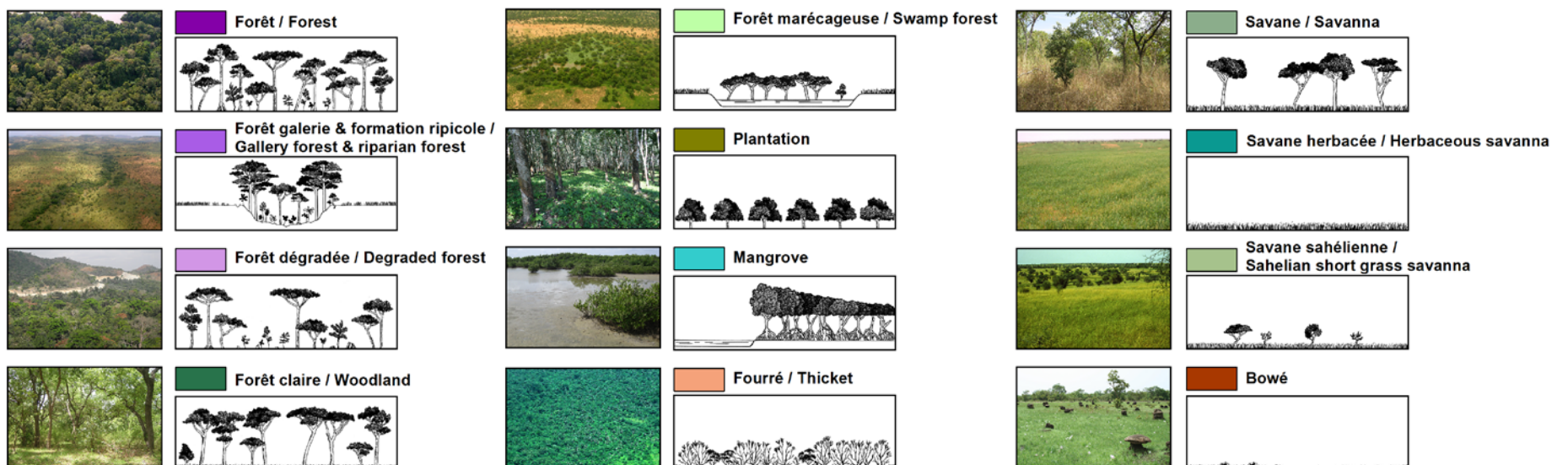


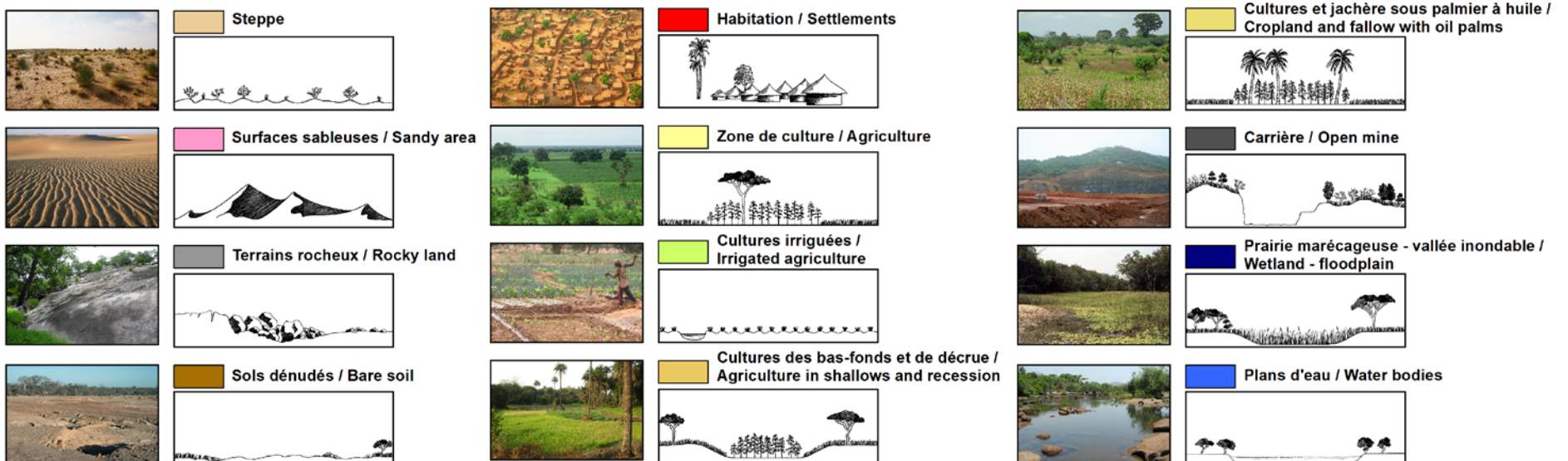
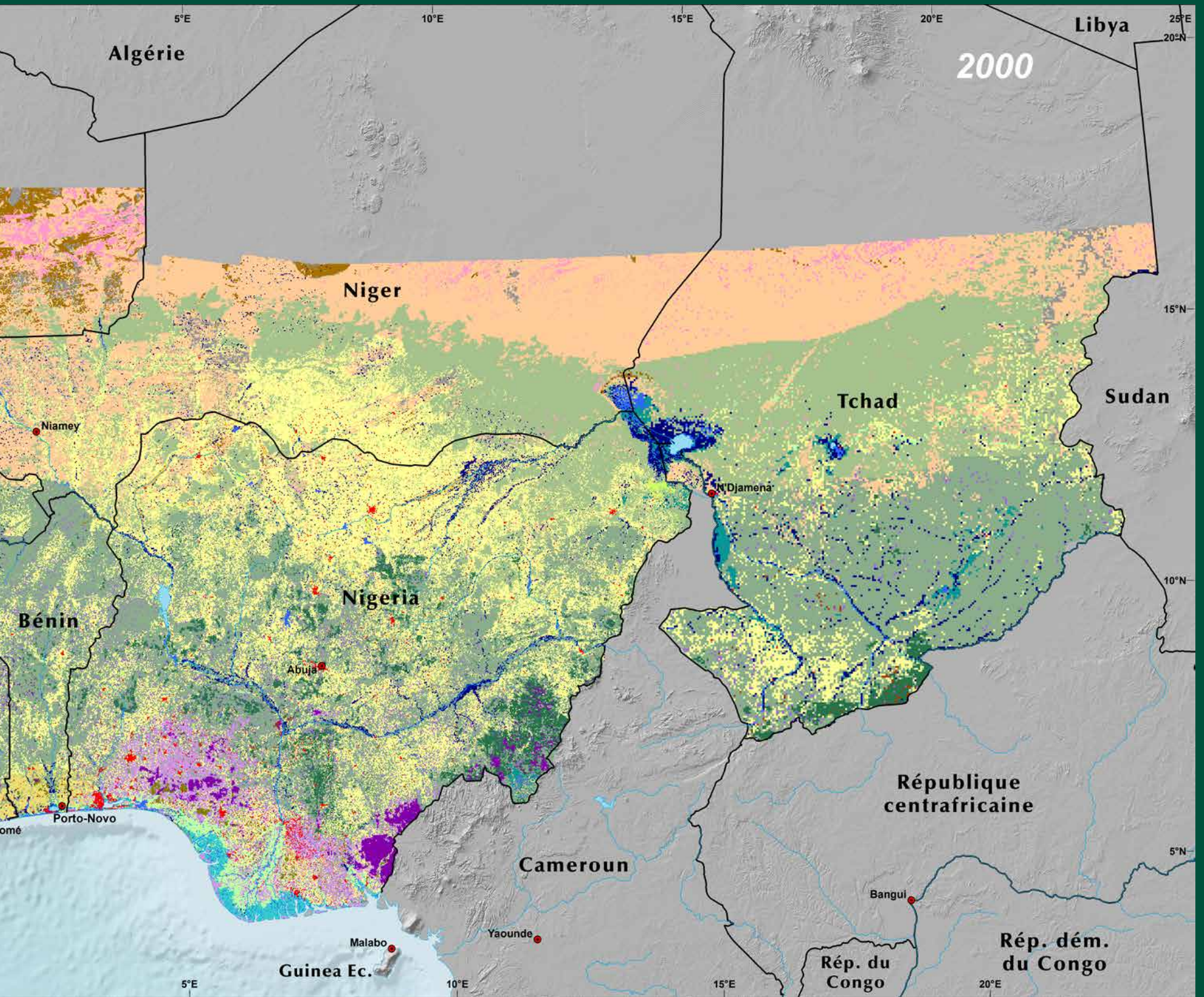
White areas in Côte d'Ivoire and Ghana represent data gaps caused by persistent cloud cover.

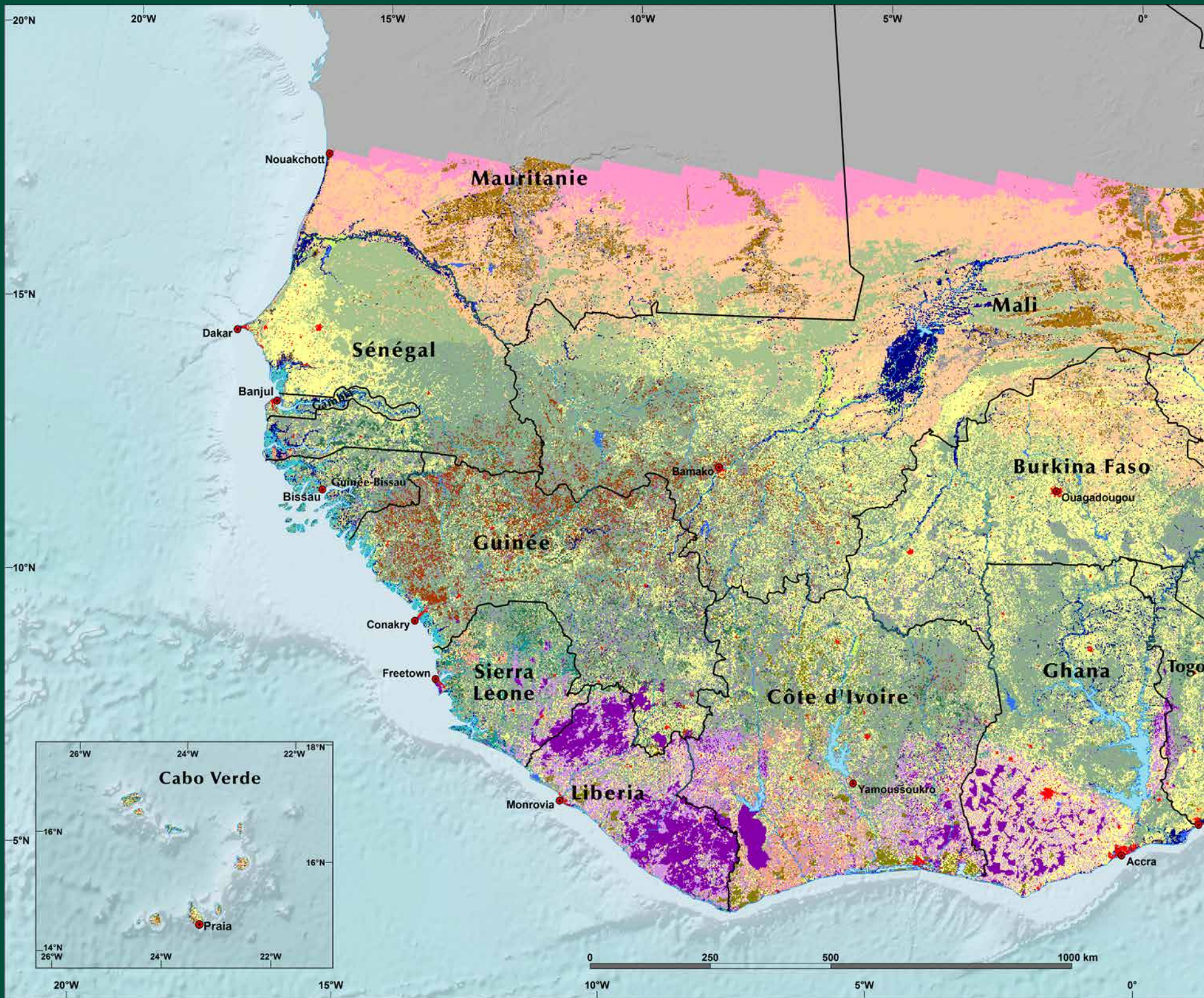




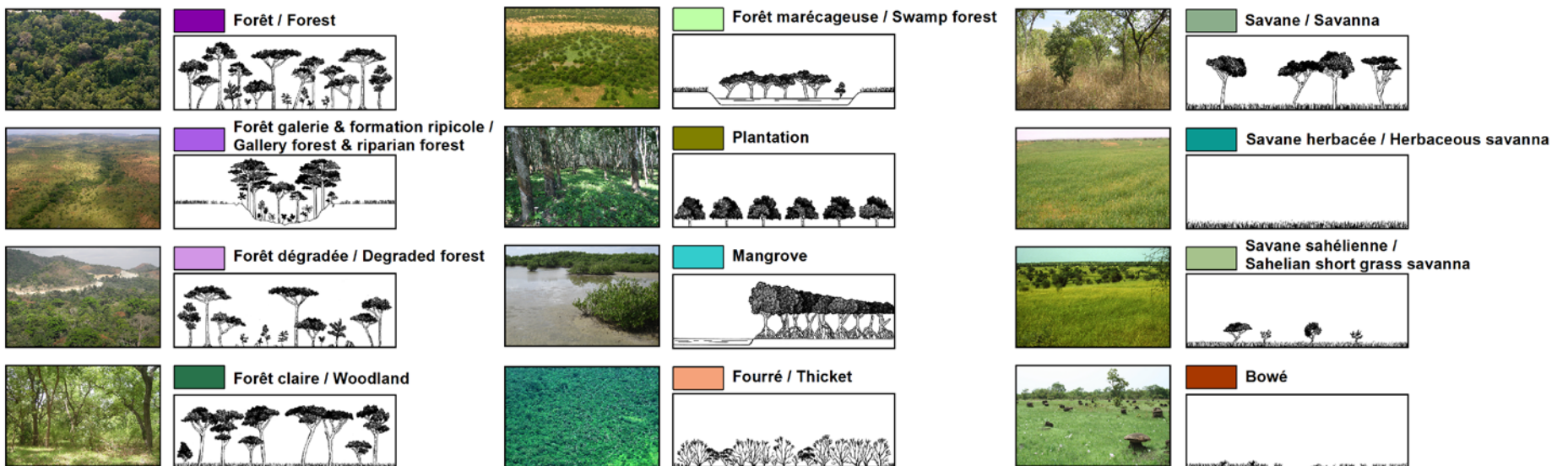
West Africa Land Use and Land Cover in 2000

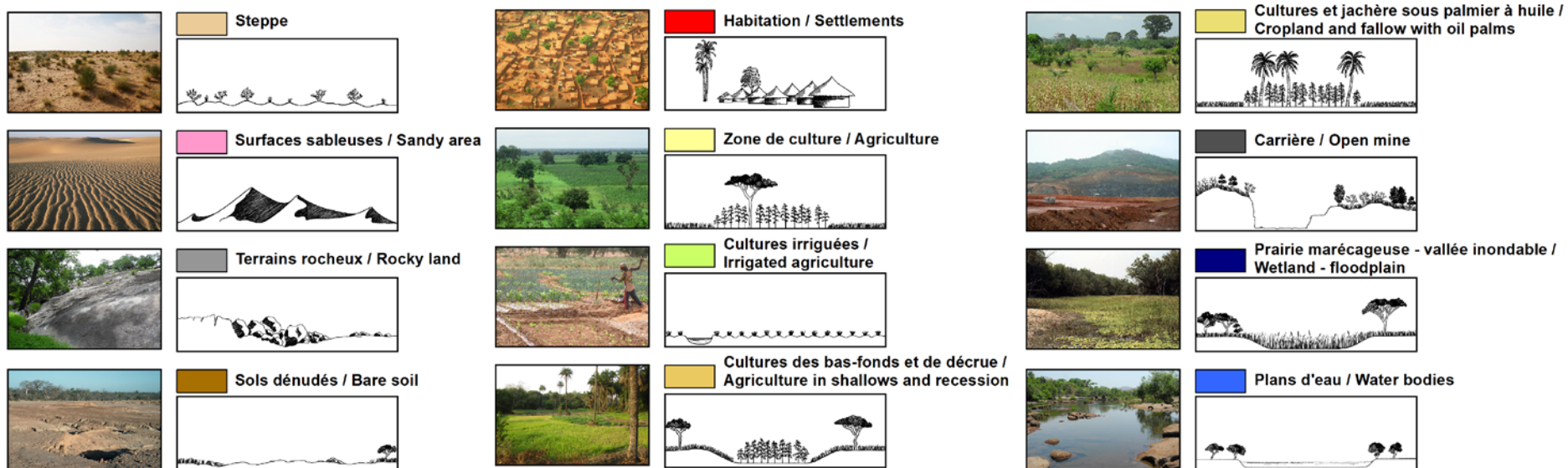
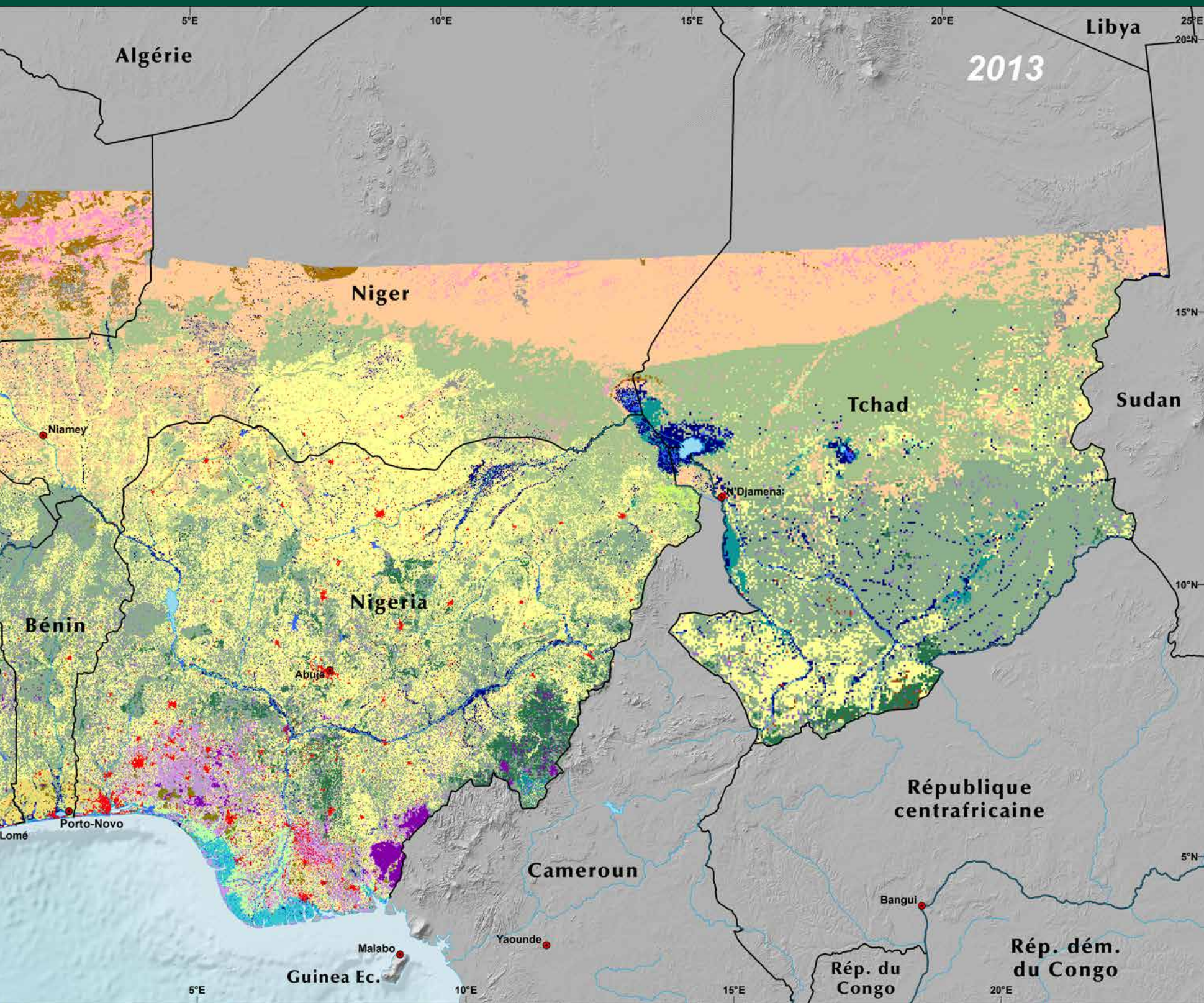






West Africa Land Use and Land Cover in 2013





Land Use and Land Cover Classes: Definitions and Visual Presentation

The land use and land cover maps presented in this atlas are based on a classification system inspired largely from the “Yangambi Classification,” well known in West Africa since 1956, when it was introduced as a standardized guide to the nomenclature of vegetation types of inter-tropical Africa, particularly West and Central Africa (Trochain (1957), Monod (1963), PNGIM (undated), Bâ and others (1997), PGRN (2001) and Adam (1966)). The Yangambi Classification has strongly influenced the mapping and preparation of vegetation maps in many countries over the past half century, and has been inspirational to a number of national nomenclatures

currently in use. Its nomenclature, and the definitions of the various land cover or vegetation types, have guided the present mapping effort. Since land use and land cover maps integrate both vegetated and non-vegetated surfaces, the Yangambi classification applies mainly to the descriptions and understanding of vegetated land cover types. Thus, the 24 classes of land use and land cover presented in this atlas integrate both Yangambi classes for the vegetated surfaces, and other classes commonly used in West Africa to represent various land uses.

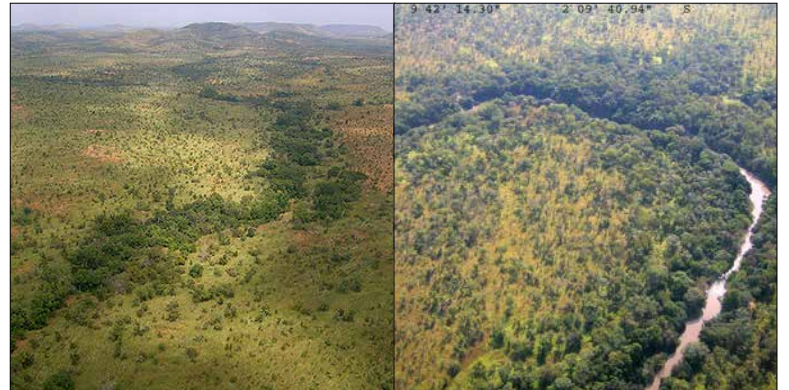
Forêt / Forest

Dense, closed canopy formation of evergreen or semi-evergreen broadleaf vegetation with a multiple strata structure that includes scattered emergent trees. Upper stratum of trees over 30 m tall. Understory composed of evergreen or semi-evergreen shrubs; herbaceous cover is discontinuous.



Forêt galerie & Formation ripicole / Gallery forest & Riparian forest

Forest formations forming a band or corridor of dense vegetation along permanent or temporary watercourses; generally closed canopy and similar in structure to forest; their width, extent, and luxuriance depend on the width, and depth of the valleys they follow, as well as the depth and dynamics of the water table. Riparian forest is similar in structure but is found bordering the edges of streams and rivers.



Forêt dégradée / Degraded forest

Dense, evergreen broadleaf forest with closed or partially closed canopy whose integrity has been degraded by logging or other forms of exploitation. Degraded forest can also be immature forest, or forest in various stages of regrowth after disturbance. Trees 10 to 30 m tall.



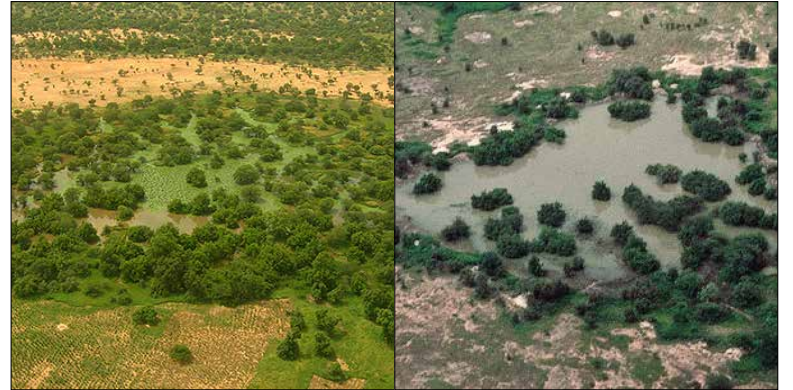
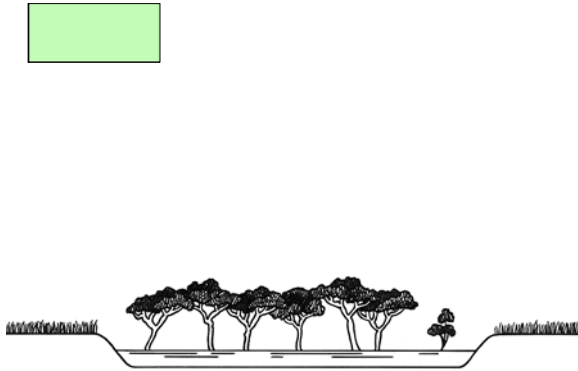
Forêt claire / Woodland

Open formations of small to medium height trees; tree height over 10 m and tree cover generally between 50 and 75 percent; canopies are often contiguous, with open areas between trees; grass understory can be scattered to dense, often associated with other herbaceous plants.



Forêt marécageuse / Swamp forest

Open to dense forests associated with temporarily or permanently waterlogged soils; these forests are generally found in natural depressions, seasonally inundated.



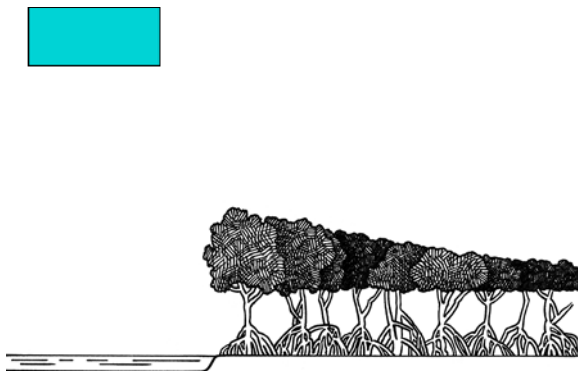
Plantation

Regular stands of trees planted for the purpose of producing food, beverages, vegetable oils, raw materials for industry, wood, or for protection against wind and water erosion.



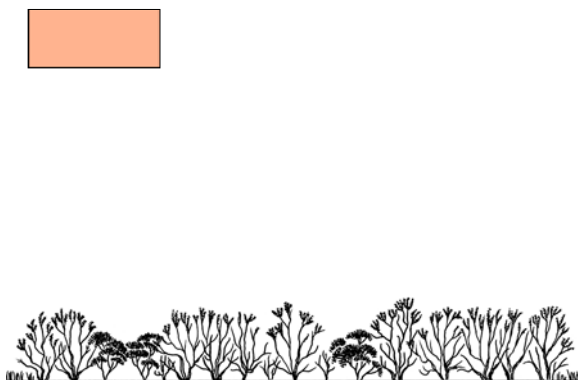
Mangrove

Coastal forests of stilted shrubs or trees bordering the ocean or coastal estuaries, composed of one or several mangrove species.



Fourré / Thicket

Dense stand of shrubs, often thorny, forming generally impenetrable cover, with minimal or no herbaceous ground cover.



Savane / Savanna

Herbaceous vegetation with mainly grasses that generally exceed 80 cm in height; dominated by annual and perennial grasses typically associated with the Sudan and Guinea zones; ground cover often consumed by annual fires; woody vegetation is usually present. The savanna class includes several major types or subclasses, based on density of shrubs and trees; the land use/land cover maps do not distinguish between shrub savanna, tree savanna, and wooded savanna; nevertheless, it is useful to define them:



Savane arbustive / Shrub savanna

Scattered shrubs dominate the woody vegetation, with continuous herbaceous cover usually dominated by grasses; woody cover between 1 and 25 percent.

Savane arborée / Tree savanna

Scattered trees and shrubs with a continuous herbaceous understory usually dominated by grasses; woody cover between 1 and 25 percent.

Savane boisée / Wooded savanna

Shrubs and trees in an open formation with a continuous herbaceous understory usually dominated by tall grasses; woody cover between 25 and 50 percent.

Savane herbacée / Herbaceous savanna

Continuous herbaceous ground cover; trees and shrubs normally absent; this class is represented on the land use / land cover maps.



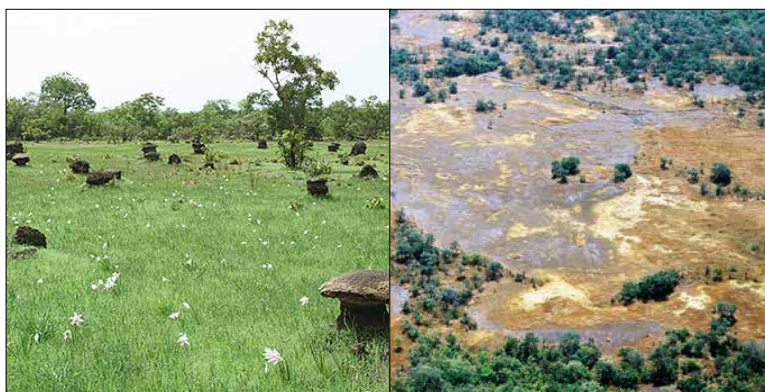
Savane sahélienne / Sahelian short grass savanna

Scattered trees and shrubs (or only shrubs) with a continuous herbaceous understory usually dominated by annual grasses generally associated with the Sahelian zone; woody cover between 1 and 25 percent.



Bowé

Flat, open surfaces that generally occur as lateritic plateaus; the skeletal, ferruginous soils form a hardened, impenetrable surface, generally absent of woody vegetation, but supporting varying quantities of herbaceous cover during the rainy season.



Steppe

Open, discontinuous herbaceous ground cover, often mixed with shrubs and trees; insufficient cover to carry fire; scattered annual grasses accompanied by widely spaced perennials.



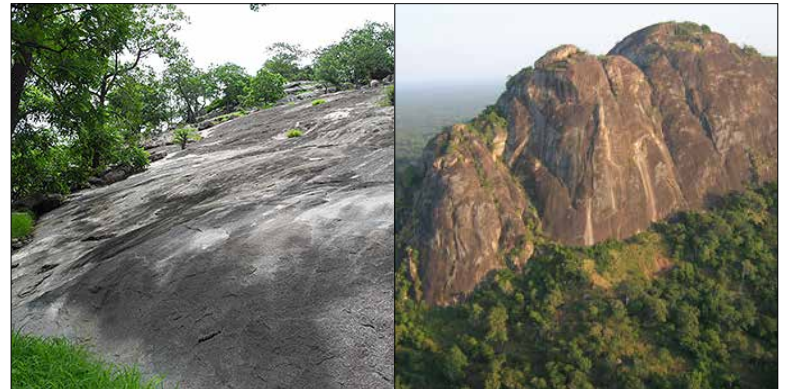
Surfaces sableuses / Sandy area

Beach sand or shifting mounds of sand, formed by wind; active dunes.



Terrains rocheux / Rocky land

Areas of rocky surfaces or outcrops, consisting of rocky peaks, batholiths, talus slopes, crest lines, cliffs, conglomerates, etc.



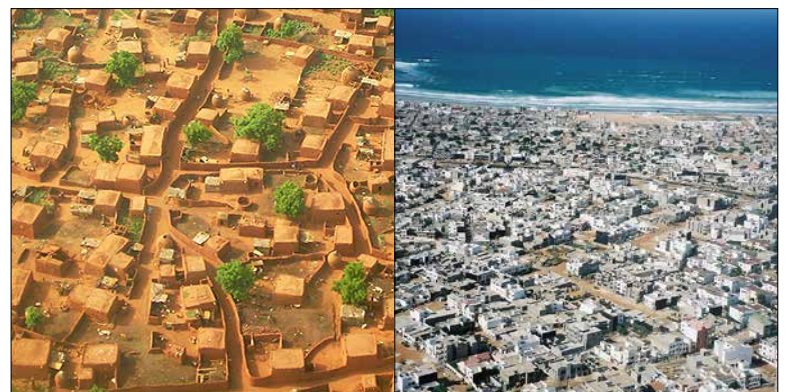
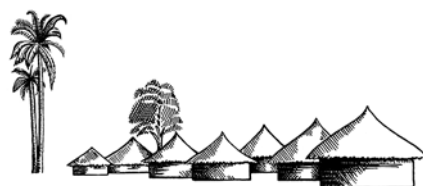
Sols dénudés / Bare soil

Land with little or no vegetation cover, exposing the soil; examples include eroded slopes, gravel plains, sebkhas, and badlands.



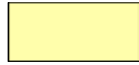
Habitations / Settlements

Built up areas comprising human communities in a village, town or city.



**Zone de culture /
Agriculture**

Cultivated areas, with crops dependent on rainfall.



**Cultures irriguées /
Irrigated agriculture**

Cultivated areas where crops receive water through an irrigation system to support their growth without relying on rainfall.



**Cultures des bas-fonds et
de décrue / Agriculture in
shallows and recession**

Cultivated areas in depressions or along river banks where crop development occurs as the waters recede during the dry season.



**Cultures et jachères sous
palmier à huile / Cropland
and fallow with oil palms**

Cultivated areas, with scattered oil palms in the fields; crops are mainly dependent on rainfall.



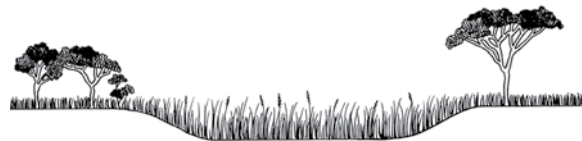
Carrière / Open mine

Open pit where rock material is mined



Prairie marécageuse – vallée inondable / Wetland – floodplain

Herbaceous or aquatic vegetation
in permanent or semi-permanent
wetlands and swamps.



Plans d'eau / Water bodies

Any area with permanent or semi-
permanent surface water.



PHOTO (BOTTOM): GRAY TAPPAN / USGS



Special Landscapes of West Africa

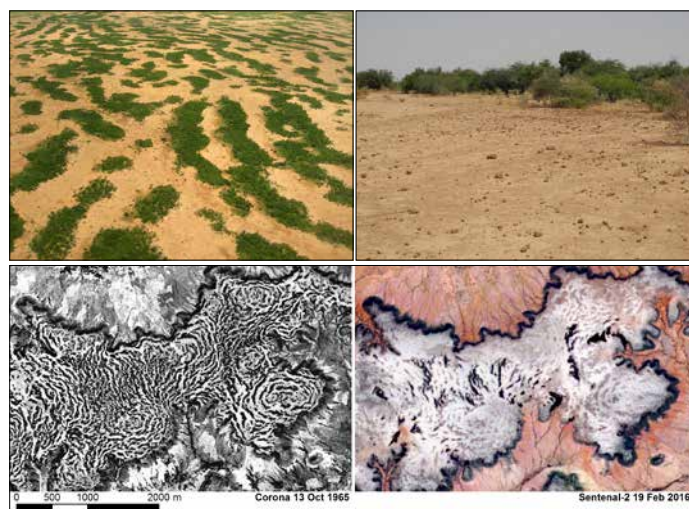
The landscapes of West Africa are very diverse, with countless combinations of vegetation, geomorphology and land use. Maps of land cover must simplify this diversity into a manageable set of land cover classes. This grouping together of landscapes with much in common facilitates mapping of land cover and measuring of land cover change but masks some of the unique and fascinating diversity in the process. Within the general land cover classes, such as savanna, many

sub-types have been defined for West Africa, some of them covering many thousands of square kilometers. A small number of such vegetation sub-types defined in the Yangambi classification system (Trochain, 1957) are highlighted below. These six examples capture some of the diversity of West African landscapes that hide within broader classes like savanna, steppe, forest and wetland.

Tiger Bush

There are several types of banded vegetation patterns in West Africa, of which the best known example is the tiger bush. It is difficult to appreciate on the ground, but clear to see from the air. This pattern is composed of regularly spaced densely vegetated bands interspersed with bare areas. The pattern is reminiscent of a tiger's fur, thus it is commonly called tiger bush. These formations often extend over several square kilometers on plateaus. In West Africa, tiger bush landscapes are found in the Gourma region in Mali, in northern Burkina Faso, and in southwestern Niger. They are found almost exclusively on ferruginous plateaus with medium-textured soils and little or no sand. Tiger bush develops on sites with semiarid climate, internal drainage, underlying sedimentary geology, and shallow slope (Tongway and others, 2001). Scientists still speculate as to why they form. Some suggest they are relatively new, forming in recent centuries. Others suggest they formed over thousands of years. Most agree that wind and water are the causal agents, with water being the predominant factor. The development of vegetative bands is thought to be related to small obstructions to the sheet-flow of water across these hard-surfaced plateaus, trapping sediments (and seeds), and localized water infiltration (Tongway and others, 2001).

In many areas, tiger bush vegetation shows evidence of degradation and even disappearance in just the past three or four decades. This is particularly true in southwestern Niger. The prolonged drought of the 1970s and 1980s was likely a contributing factor, but not nearly as

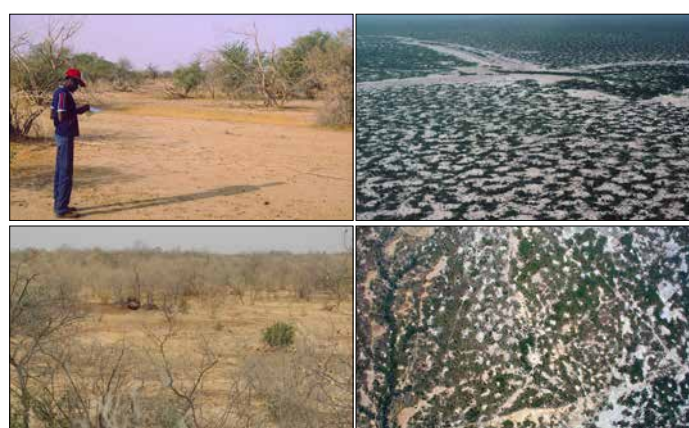


important as the intensive harvesting of tiger bush shrubs and trees for domestic energy needs. Some restoration of tiger bush is being done through various projects in Niger. On the land use and land cover maps, it is generally included in the steppe class because of the discontinuous aspect of ground cover.

Spotted bush

Spotted bush is another type of vegetation cover distributed in a pattern that is quite distinct from the air. It is composed of shrubs and small trees in a "spotted" distribution of concentrated vegetation areas interspersed with bare areas.

Spotted bush is similar to tiger bush, also occurring on plateaus and uplands in the Sahel Region. It also occurs on areas of medium-textured soils, with little or no sand cover. Spotted bush occurs where the slope gradients are very shallow — generally less than 0.2 percent gradient (Tongway and others, 2001). Spotted bush is more common than tiger bush. It occurs over tens of thousands of square kilometers in Niger, Burkina Faso, Mali, and Mauritania. On the land use and land cover maps, it is often included in the steppe class because of the discontinuous aspect of the ground cover, but it can also occur in the Sahel short grass savanna class when the proportion of grass and shrub cover is high relative to the bare areas.



Spotted bush with termite mounds

Termite mound spotted bush is another patterned type of vegetation cover. Like the spotted bush, it is composed of shrubs and small trees in a "spotted" distribution, except that the bare areas are associated with both active and abandoned termite mounds. Termites build large, complex structures that significantly alter soil texture, structure, and nutrients. They alter the surrounding hydrology and vegetation structure. Termite mounds in West Africa tend to be large and bare, though some are found with certain species of shrubs. They may reach up to 7 m in height, and over 10 m in diameter at the base, often with a much larger erosional outwash pediment. This pediment is the bare spot clearly seen from the aerial view. Termite mound spotted bush covers tens of thousands of square kilometers in Senegal, Mali, Mauritania, Burkina Faso, Niger, and Chad.



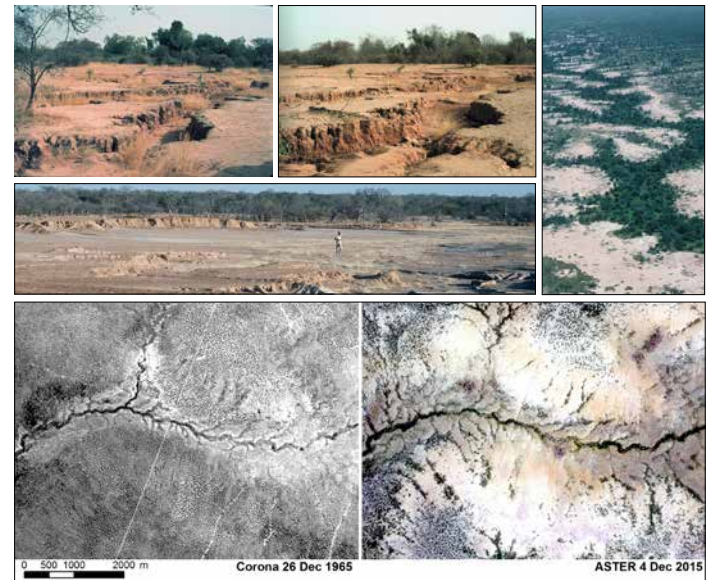
Wooded savanna with bamboo

This land cover is a type of wooded savanna with an understory dominated by savanna bamboo commonly called Bindura bamboo (*Oxytenanthera abyssinica*). Bindura bamboo often grows in dense, tall stands under the open tree canopy and tends to occur in localized areas. In West Africa it is found in the Sudanian Region but is also widespread across Africa from Senegal to Ethiopia, and south to Tanzania and Mozambique. Bindura bamboo is widely used for building materials, textiles and fibers, food, wood fuel, and traditional medicine. Its natural habitat is under threat as wooded savannas decline from land use pressure across West Africa.



Badlands and eroded landscapes

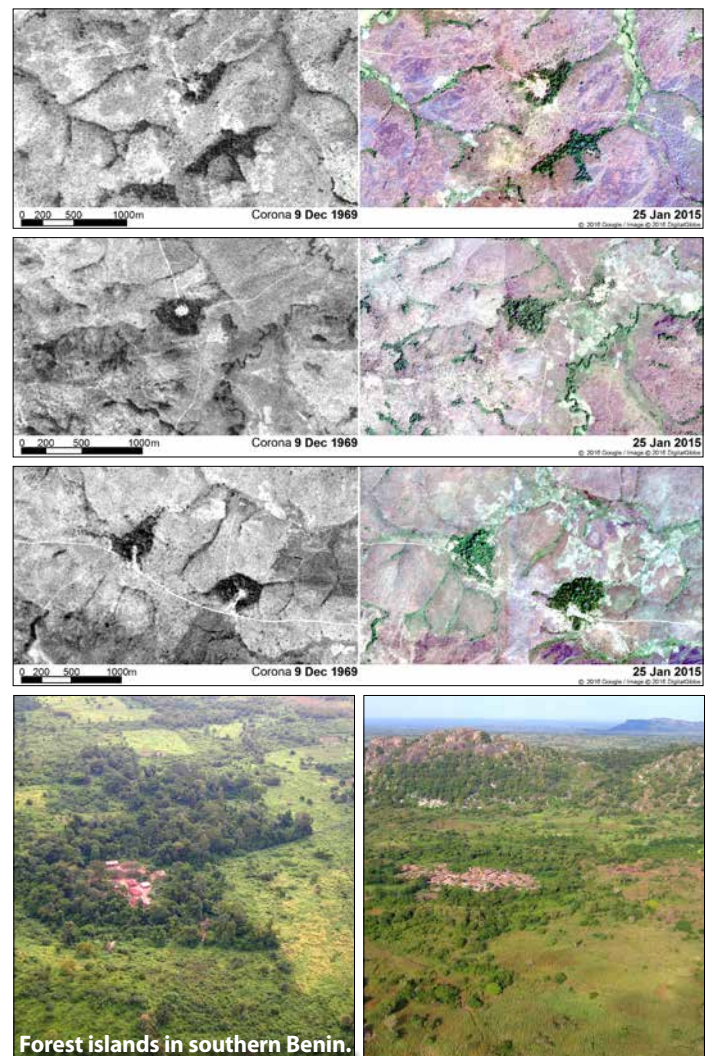
Badlands are highly eroded surfaces, included under the bare soil land cover class. They are predominantly the result of water erosion, usually driven by land use pressures that have removed some or all of the protective vegetation cover in the recent past. These pressures include high concentrations of livestock and overgrazing, disturbances from construction such as new roads, and clearing of vegetation for agriculture. When combined with land that has a slight to moderate slope, the removal of vegetation cover can create conditions for the erosive power of water to remove the topsoil, creating deep gullies and degraded landscapes or “badlands” (Tappan and others, 2004). This phenomenon has spread quickly in many areas across the Sahel and Sudanian regions in recent decades, as seen in the pair of satellite images showing the Tiangol Lougguéré valley in northeastern Senegal in 1965 and 2015. The bright patches are eroded surfaces that have lost most of their vegetation cover along gently sloping valleys. These images exemplify the process of desertification — defined as land degradation in arid, semiarid, and sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD, 1994).



Forest Islands

Half a century of satellite imagery shows that the contiguous blocks of forest in southern Guinea have been diminished by land use pressures, yet many hundreds of small forest islands have persisted through time. Forest islands are scattered among open savannas of south-central Guinea, particularly in the Kissidougou Region. They are generally circular, and most have a village at their center. There is evidence that for over a century many people have been misreading these landscapes — believing that these forest islands were the last relics of a vast, dense forest that once covered this region (Fairhead and Leach, 1996). This view of widespread deforestation prevailed throughout the colonial period and continues to be widely held in Guinea to this day. However, numerous accounts from late 19th century colonial reports speak not of a forest but rather of a savanna landscape. Village elders living within these forest islands also shed light on these landscapes — telling us that the forest islands are not relics of deforestation, but old forests established by earlier generations in a savanna landscape. The remote sensing record confirms this view, beginning with aerial photo coverage from 1952, which provides solid evidence of a savanna landscape with scattered forest islands — much the same as it looks today (Fairhead and Leach, 1996).

The three pairs of satellite images at right show examples of forest islands in 1969 and 2015, exhibiting remarkable stability over time. These are just a few among the hundreds of forest islands that persist in this region. The concentration of forest islands in Guinea is remarkable, but not unique in West Africa. They can be found in all of the southern tier countries. Among these, Benin stands out for its nearly 3,000 sacred forests (Sinsin and Kampmann, 2010) — many of which resemble the forest islands of Guinea. Most are associated with a village, as seen in these oblique aerial views. The forests become sacred if they protect a sacred site or a sacred spring. Sacred forests can also be the place of initiation, benediction, and malediction. These forests are not completely closed to the local population, but usually require authorization from the forest guards before extracting forest products. The forests provide timber, firewood, medicinal plants, edible fruits, and game (Sinsin and Kampmann, 2010).



Forest islands in southern Benin.

ALL AERIAL AND LANDSCAPE PHOTOS: GRAY TAPPAN / USGS



Clearing of a wooded savanna for cropland, southern Senegal

Agricultural Expansion Across West Africa

West Africa is composed of a wide variety of ecosystems and an equally high number of food production systems. Agriculture is the basic driver of West Africa's economy, on which the majority of people depend for their livelihood (Gyasi and Uitto, 1997). Most farms are small, typically 1 to 5 hectares. Although the small size of farms reflects a scarcity of land in heavily populated areas as in parts of Nigeria, it is also a result of the limited technology available to rural households (Stock, 2012).

West African agriculture ranges from nomadic pastoralism in the far north to root-crop and tree-crop systems in the south. In general, the crop-producing areas are roughly horizontal belts following bioclimatic zones (Bossard, 2009). In the Sahelian zone, millet and sorghum are the predominant crops, transitioning to maize, groundnuts, and cowpeas farther south in the Sudanian zone. These food crops are among the top five harvested crops in the Sahelian countries — Mauritania, Senegal, Mali, Burkina Faso, Niger, and Chad. Root crops such as cassava and yams are found mostly across the Guinean zone, especially in Sierra Leone, Ghana, Nigeria, and Côte d'Ivoire. Finally, tree crops such as cocoa, palm trees, or cashew trees are found in the Guineo-Congolian zone. In this humid climate, rice is also one of the most harvested crops in terms of area; it ranks first in Guinea, Liberia, and Sierra Leone. Rice is the most rapidly growing staple food in West Africa and constitutes a major part of the population's diet. The crop production figures in the table below reflect the strong correlation of crop distribution patterns with the climate zones.

Fueled by high population growth and a growing demand for food, agricultural expansion accounts for most land cover change across West Africa. In 1975, cropland was widely scattered among the natural landscapes, covering 10.7 percent of the mapped area (see 1975 land cover map pages 44–45). In the next several decades, cropland has expanded rapidly and now pervades the whole region. By 2013, the area covered by cultivated areas doubled, reaching a total of 1,100,000 sq km, or 22.4 percent of the land surface (see 2013 land cover map pages 48–49). In every country, agriculture has been exerting pressure on the natural landscapes, replacing and fragmenting savannas, woodlands, wetlands, and forests.

Across the Sahel, agriculture expanded into most of the suitable soils that were occupied by the natural Sahelian savanna, and cut into the traditional pastoral areas of northern Mali, Niger, and Chad. Niger's vast south-central agricultural zone, already heavily cultivated in 1975, became fully saturated with cropland and expanded eastward into the pastoral zone. In Senegal, cropland spread into the central and southern wooded savannas and woodlands, creating a new patchwork of farmland and settlements. Meanwhile, Senegal's Peanut Basin is also notable by the extent of cropland loss, with large areas being put into long-term fallow, mapped as savanna. This is one of the manifestations of the agriculture crisis as cultivation is abandoned, young men and women leaving the land to seek opportunities in urban areas. Mauritania and Togo stand out with high annual rates of agriculture expansion, 7 and



Crop rank by country

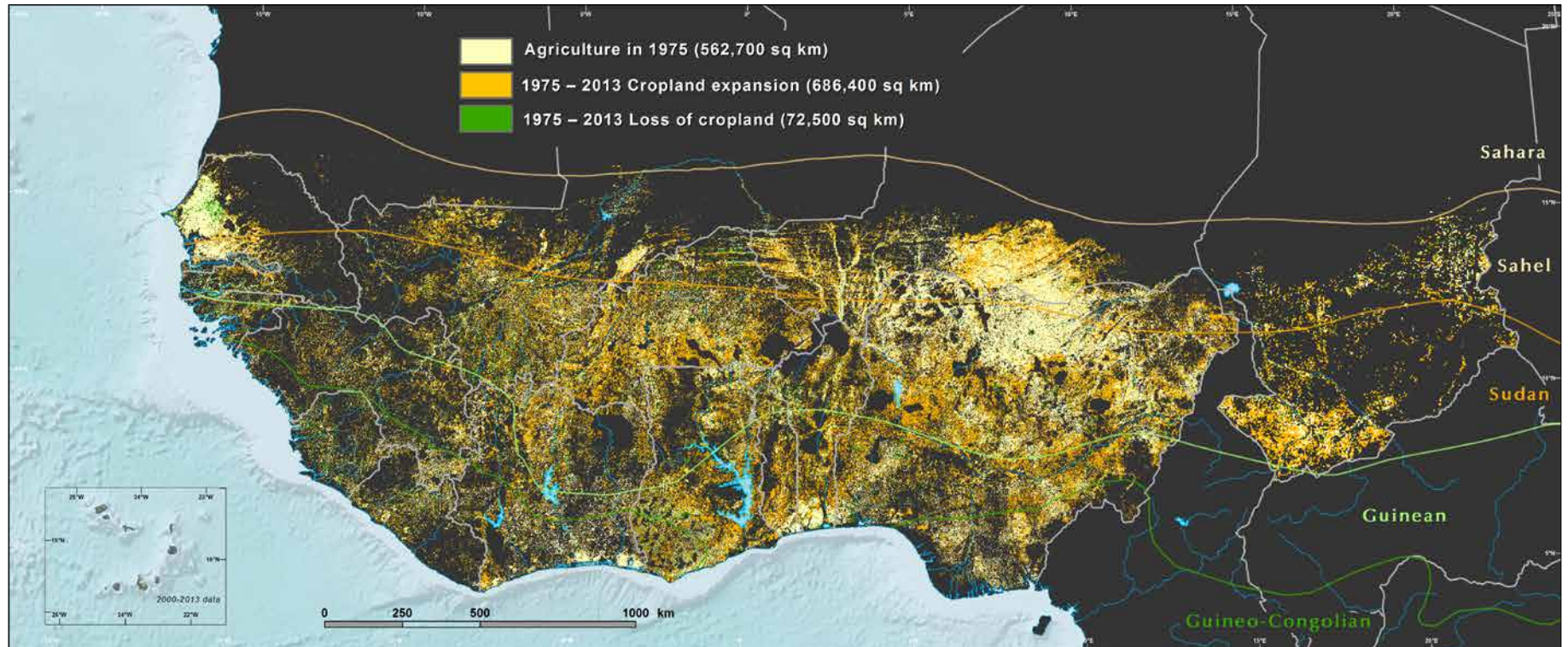


Top 5 harvested crops per country in West Africa (as a percent of country total harvested area, based on 2010–2013 average)

Crops	Bénin	Burkina Faso	Cabo Verde	Côte d'Ivoire	Gambia	Ghana	Guinea	Guinea-Bissau	Liberia	Mali	Mauritania	Niger	Nigeria	Senegal	Sierra Leone	Tchad	Togo
Millet	1%	19%		1%	30%	3%	8%	3%		30%	3%	43%	6%	34%	2%	24%	3%
Sorghum	3%	27%		1%	8%	4%	1%	4%		22%	42%	19%	11%	6%	2%	26%	13%
Maize	31%	12%	46%	4%	9%	15%	14%	3%		11%	5%		12%	5%	2%	7%	32%
Cassava	9%		1%	5%	1%	13%	4%	1%	11%				12%	1%	22%	1%	10%
Cow peas		18%						1%		4%	10%	30%	7%	5%			
Rice	2%	2%		5%	16%	3%	27%	22%	42%	11%	9%		6%	5%	41%	4%	4%
Yams	7%			11%		6%							9%			1%	4%
Groundnuts	5%	6%		1%	29%	5%	6%	6%	1%	6%		5%	6%	37%	6%	12%	3%
Cocoa				32%		24%			10%				3%		3%		6%
Oil, palm fruit	1%			4%	1%	5%	9%	2%	3%				7%		2%		1%
Seed cotton	9%	8%		3%			1%	1%		7%			1%	1%		5%	5%
Cashew nuts	15%	1%		12%		1%		44%					1%	1%			
Sugar cane			2%						4%								
Pulses	1%		40%		3%	4%	2%	1%	1%		15%				7%	1%	1%
Tomatoes	1%		2%			1%							1%				
Natural rubber				2%					13%				1%				
Beans, dry	4%			1%		3%					3%					3%	13%
Sesame seed		2%			2%					1%		1%	1%			3%	
Plantains				6%		5%	3%	3%	4%				1%				
Coconuts	4%		3%					2%									
Fonio							9%			1%							
Peas											8%						

(DATA SOURCE: FAOSTAT, 2015)

Agriculture expansion between 1975 and 2013 and bioclimatic zones of West Africa*

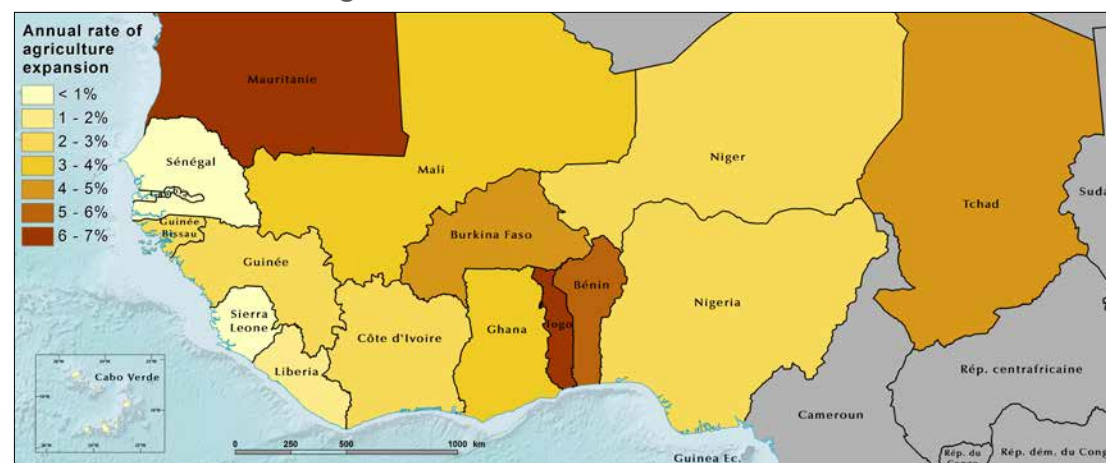


* includes rainfed agriculture, irrigated agriculture, plantations, agriculture in shallows and recession, and cropland and fallow with oil palms.

6.4 percent per year on average, respectively. Indeed, in 1975 agriculture represented only 0.2 percent of southern Mauritania, but cultivated area expanded by more than 3 times in the past four decades. In Togo, cropland, which already covered about 10 percent of the country area in 1975, was also multiplied by three — to cover 34 percent of the land by 2013. The core of agriculture expansion, however, occurred within the Sudanian zone where climate is more suited for a large variety of crops. From southwestern Senegal to southern Chad, cropland has expanded — replacing biodiverse savannas, woodlands, and gallery forests. The

most dramatic change occurred in Burkina Faso where cropland became the dominant land cover, reaching 39 percent of the national area in 2013. In northern Côte d'Ivoire, Ghana, Togo, Benin, central Nigeria, and southern Chad, the pattern and extent of cropland profoundly modified and fragmented the landscape. West Africa's Sudanian zone is rapidly transforming into human-crafted landscapes leaving scattered islands of semi-natural vegetation cover. In southern Chad, notably in the Logone Basin, cultivated areas are establishing a foothold in the savannas and woodlands.

Annual rate of agriculture expansion in West African countries (1975–2013 average)



The growing agricultural footprint appears to be slower and more scattered in the Guinean and Guineo-Congolian zones, with the exception of the southern regions of Côte d'Ivoire, Ghana, Togo, and Benin, where cropland and plantations already dominated the landscape in 1975. Togo and Benin have seen some of the fastest rates of agricultural spread; these two countries are in first and third place, respectively, in terms of average annual agricultural expansion rates between 1975 and 2013. Nigeria stands out as having the highest percentage of cultivated land in West Africa, with 41.5 percent of its land area devoted to agriculture in 2013. In the Guinean and Guineo-Congolian climate zones, which are more humid, the spread of cultivated

Cropland of peanuts and millet near Koungheul, Senegal.

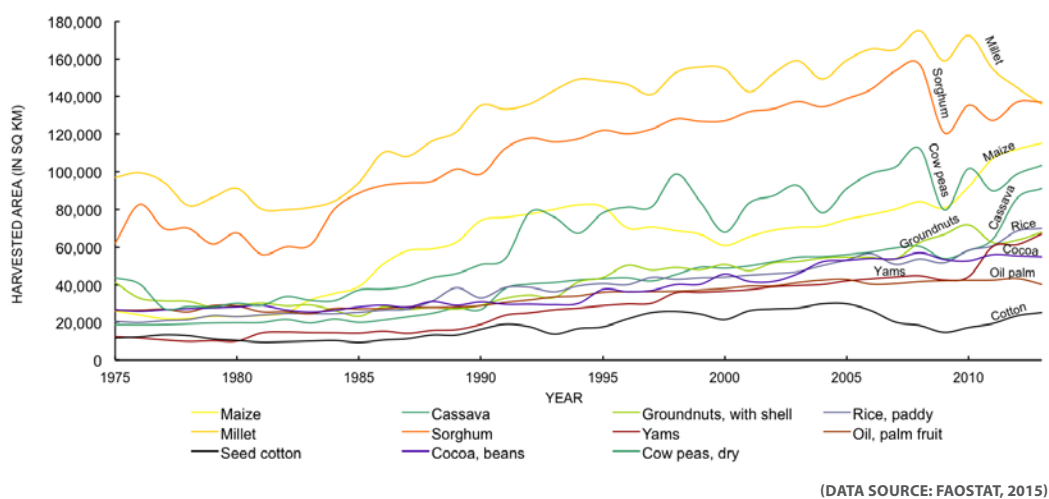
areas has exerted great pressure on the remaining forests. Forests have become fragmented and degraded where they occur outside of protected areas.

The change in cultivated area masks an evolution in the agricultural systems as well. In the early 1970s, cash crops (coffee, cocoa, cotton, groundnuts, oil palm, and rubber) were promoted as a means of involving West African farmers in the global commercial economy and ensuring a supply of tropical products for European markets and industry (Stock, 2012). After 1975, the area devoted to cash crops continued to increase and became even larger in the late 2000s (see graph). Cash crops, however, often competed with food crops such as sorghum and millet, and per capita food production has been decreasing in the region (Stock, 2012).

Across West Africa, there is a tug-of-war between the need to protect the remaining natural landscapes — biodiverse forests,

wooded savannas, and grazing areas important to the livelihoods of agro-pastoralists — and the need to increase agricultural output rapidly to meet increasing demand for food and fiber. In many places, the days of agricultural “extensification” are ending as arable land available to expand farming disappears. The land frontier is closing, making intensification — producing more food on the same surface area — a critical agricultural and environmental goal. Intensification can be accomplished in a way that meets food and fiber supply goals and helps the environment on-farm and off. Sustainably intensifying farmland use can also protect the commons — forests, savannas, wetlands, steppes. Degradation of farmlands and forests undermines the national economies. Protecting farmlands is thus crucial to farm productivity, and protecting the commons is crucial to maintaining biodiversity and ecosystem services on which African societies depend.

Trends in harvested area by crop in West Africa, from 1975 to 2013



Rubber plantation in Ghana

GRAY TAPPAN / USGS



Dry season gardening in Niger

GRAY TAPPAN / USGS



Slash-and-burn in Sierra Leone

GRAY TAPPAN / USGS

Conversion of wooded savanna to agriculture (millet and peanut, post harvest) in central Senegal, south of Kaffrine



1994

GRAY TAPPAN / USGS



2010

GRAY TAPPAN / USGS

Settlements Growth



In the past 50 years, West Africa has been experiencing intensive urbanization, which has affected the region's largest and smallest urban centers (Cour and Snrech, 1998). In 1975, the distribution and pattern of West Africa's settlements were little changed compared to their historical size and extent. These settlements — built up areas comprising human communities in a village, town, or city — were located near land most favorably suited to subsistence cereal farming and to the trans-Saharan trade routes, the region's main source of wealth in the past (Moriconi-Ebrard, Harre, and Heinrigs, 2016). As a result, the Sudanian and Sahelian zones were relatively densely populated, especially the Peanut Basin of Senegal, the central plateau of Burkina Faso, and the Niger–Nigeria agricultural region. Other settlement zones were developed along the coasts of Côte d'Ivoire, Ghana, Togo, Benin, and Nigeria, as trade in gold and slaves, and eventually tropical products got under way (Cour and Snrech, 1998). Independence and the development of market economies, however, brought about a drastic change in the economic landscape, which influenced the settlement pattern of the region. New road networks in the region as well as the emergence of the industrial sector in the cities set in motion a massive shift in the West African population toward large urban areas (Moriconi-Ebrard, Harre, and Heinrigs, 2016).

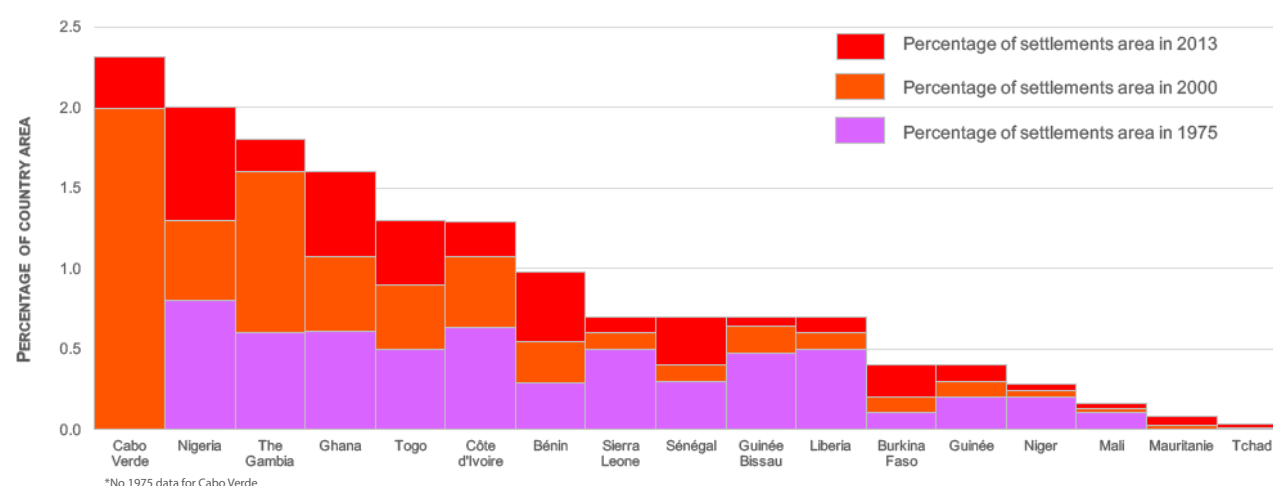
Settlement growth is a useful proxy for analyzing population growth and population distribution. Land use maps show that settled or built-up areas increased by 140 percent in West Africa between 1975 and 2013 — to occupy 36,400 sq km by 2013 (0.7 percent of the land surface). The settlements distribution map (opposite page) indicates both sprawl of existing urban centers ("top-down metropolisation") and an increase in the number of small towns ("bottom-up urbanization") (Beauchemin, 2005) (see image pairs, pages 64–65). Since 1975, settlements have expanded westward and southward—from the inland to the coast, but also from rural to urban areas, creating major secondary cities, especially across the Sahel.

In 1975, urban areas were confined mainly to the coast of the Gulf of Guinea. By 2013 West Africa's settlements network had grown denser and expanded throughout the entire region, including the Sahara Desert where towns have sprung up across arid areas of Niger, Mali, Mauritania, and Chad despite an overall low population density in these countries. Across the region, numerous towns have grown into large urban centers or secondary towns like Bobo-Dioulasso (Burkina Faso), Bouaké (Côte d'Ivoire), Touba (Senegal), Kumasi (Ghana), and several large cities in Nigeria. The number of small agglomerations has also multiplied spectacularly across the region.

In the coastal countries, settlements sprawled around the main urban areas and their immediate hinterland. This dramatic coastal urban expansion is particularly visible from Accra (Ghana) to Lagos (Nigeria). In this coastal corridor, population has grown fast and population density is the highest in the West African region. With the exception of the small countries of The Gambia and Cabo Verde where settlements are concentrated in one large metropolis, the Gulf of Guinea countries are the most urbanized in the region, with settlements occupying between 1 percent (Benin) and 2 percent (Nigeria) of their national territory in 2013 (see graph). In the western part of the Atlantic coast, some areas remain relatively underpopulated and also under-urbanized. The prolonged political uprisings and conflicts in Liberia¹ and Sierra Leone², as well as the Casamance³ conflict in Senegal, still hinder trade and the movement of people (Moriconi-Ebrard, Harre, and Heinrigs, 2016). During these conflicts, economic growth and infrastructure development were impeded, and part of the population migrated not only toward rural areas but also to neighboring countries (especially Guinea and Côte d'Ivoire).

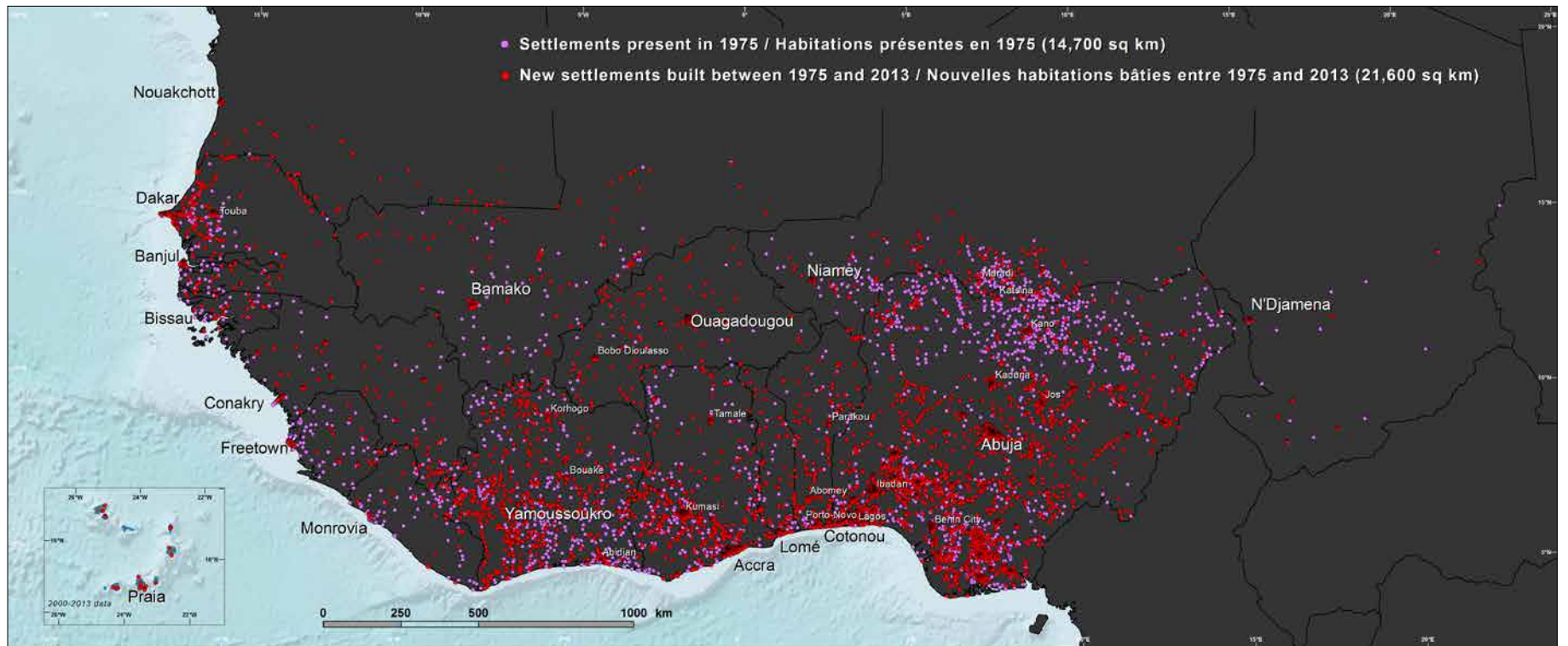
In the recent decade (2000–2013), settlements have greatly expanded along several axes perpendicular to the coastline — inwards from the coast, such as Dakar–Touba, Accra–Kumasi, or Lagos–Ibadan, and also following

Percentage of settlements area by country in 1975*, 2000, and 2013



¹ First Liberian Civil War — 1989–1996;
 Second Liberian Civil War — 1999–2003
² Sierra Leone Civil War — 1991–2002
³ Casamance Conflict — 1982–2014

Distribution of settlements in 1975 and 2013 based on a systematic sample of points spaced 2 km apart

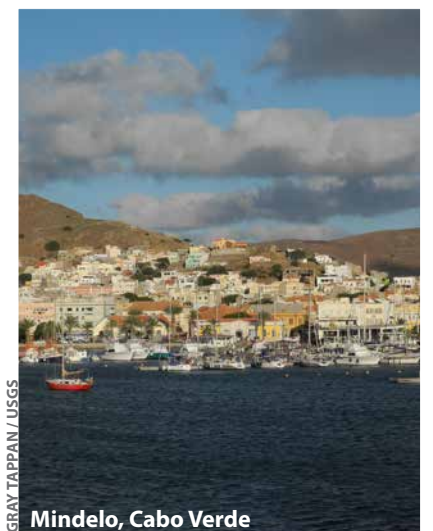


the major north-south routes, such as Maradi–Kano, and Abidjan–Ouagadougou. In the landlocked Sahel countries, large cities are sparser but new clusters and major regional hubs, such as Bamako and Ouagadougou, have emerged. Many new settlements also appeared along the major rivers in Senegal, Mali, Burkina Faso, Niger, and Chad. Because these countries have important agricultural resources to meet the growing demands of the regional market (cereals, fruits and vegetables, intensive livestock farming), the long east-west corridor from N'Djamena to Dakar constitutes a strategic area for regional trade and a very dynamic region for population flow and settlement in West Africa (Konseiga, 2005). Recent migration flows have been observed toward western Burkina Faso, a phenomenon that is accelerated by the success of cotton production and the urbanization of secondary cities, such as Bobo-Dioulasso.

Looking at each country individually, Mauritania and Burkina Faso stand out with the highest settlement growth rates, with an average of 23 and 7.7 percent per year, respectively. Mauritania's high settlement growth rate can be explained by the very rapid urbanization of

the capital Nouakchott following independence (see pages 154–155). In Burkina Faso also, the expansion of the capital Ouagadougou accounts for most of the country's growth in urban population and settlement area (see page 64). On the other hand, due to the conflicts they underwent, Sierra Leone and Liberia have the slowest average annual settlements growth rate over the past 40 years.

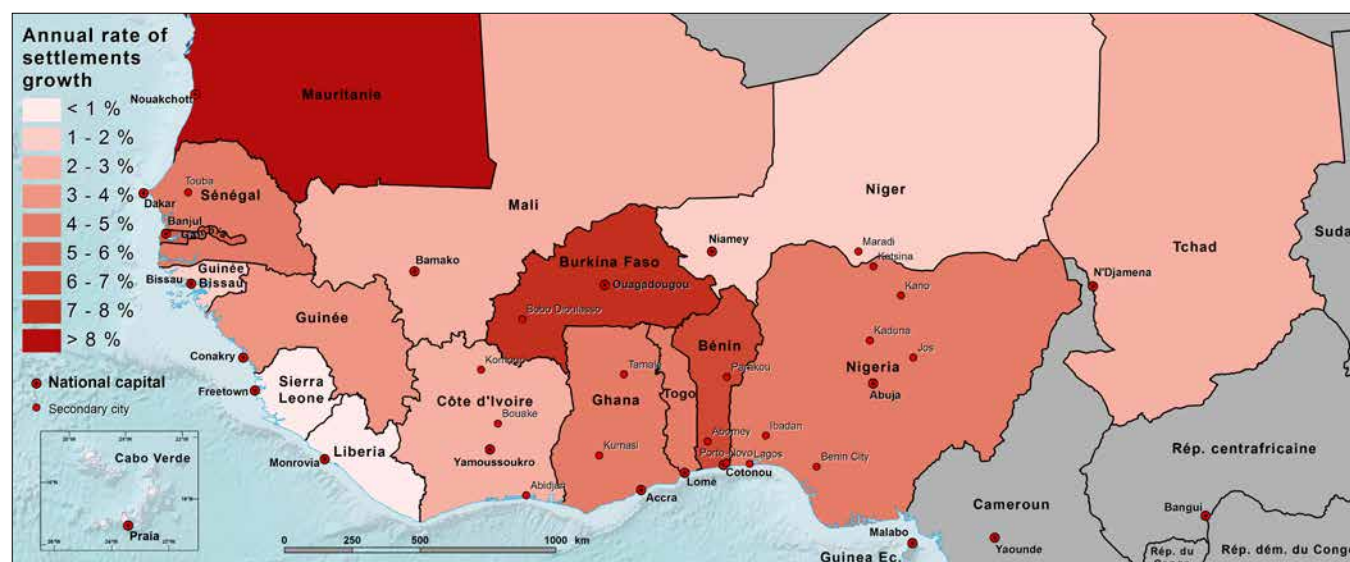
Current settlement patterns in West Africa are the result of various environmental, historical, and sociopolitical factors that have impacted each country individually and the region as a whole. West Africa will, for a long time to come, continue to experience strong population growth that will induce important intra-regional migration flows and rapid urbanization (Konseiga, 2005). However, recent (2000–2013) population growth, especially urban growth, has been slowing down. While cities are a necessity for economic development, they are not without numerous and daunting problems. Managing urban growth, including providing infrastructure and adequate services for an increasing number of citizens, must be considered a priority of public policy (Bossard, 2009).



GRAY TAPPAN/USGS

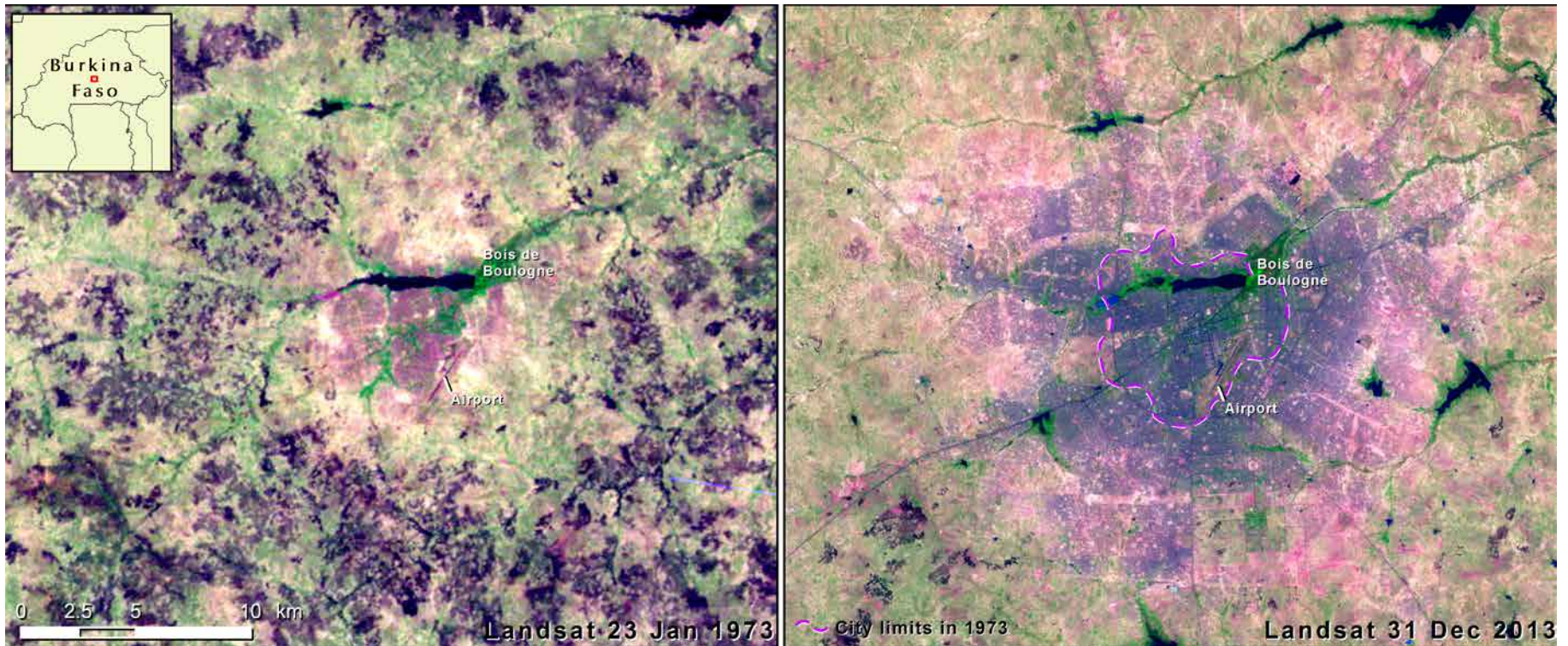
Mindelo, Cabo Verde

Average annual settlements growth rate* by country between 1975 and 2013



* The rate at which the area covered by settlements — built up areas comprising human communities in a village, town, or city — increased in each country over the 38-year period.

Top-down metropolisation: the rapid expansion of Ouagadougou, Burkina Faso



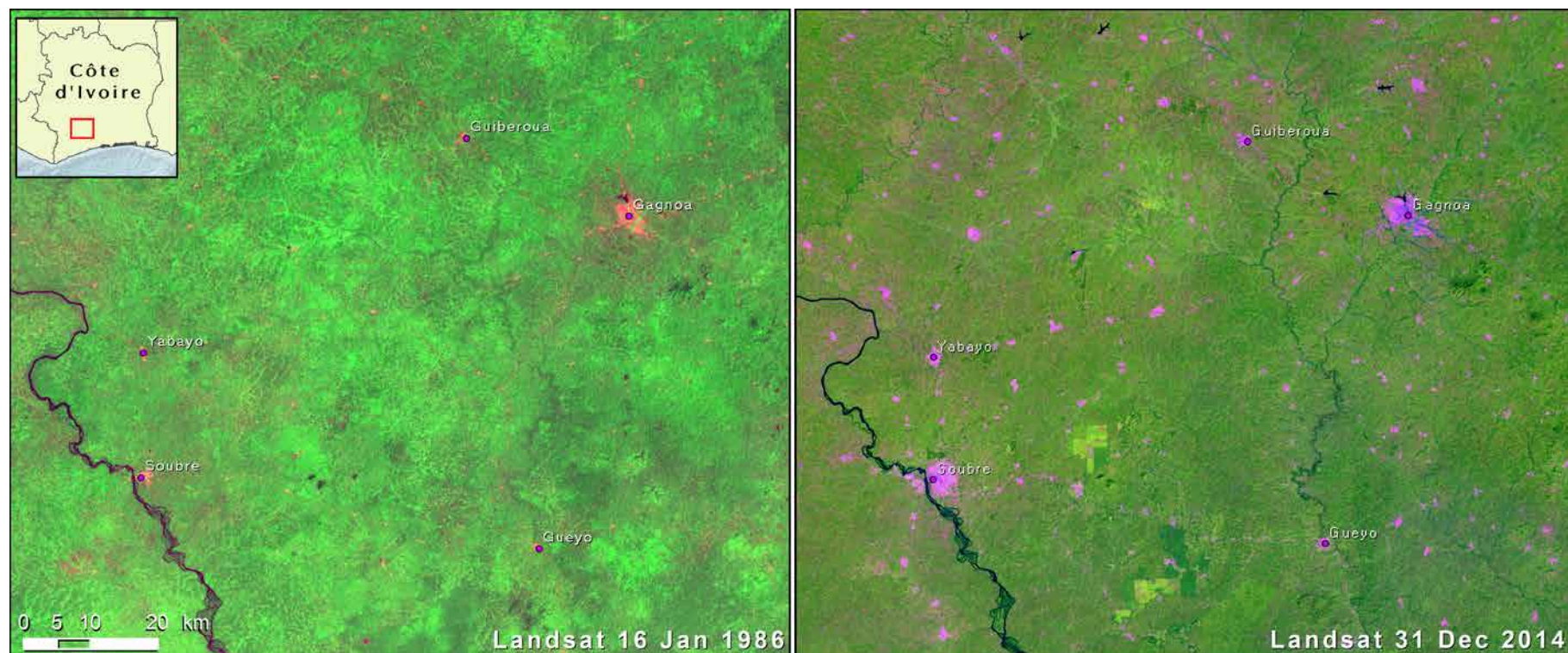
In the 1973 image (above, left), Ouagadougou (in pink) occupied only 85 sq km with most of the surrounding land covered by savanna (the dark patches are burn scars after bush fires) and cropland. The 2013 image (above, right) shows how urbanization radiated out from the city center (purple and pink in the image) displacing farms and savanna, leaving primarily cropland surrounding the expanded footprint of the city. In addition, areas of vegetation, visible within the city limits in the 1973 image have been reduced by more intense development in 2013. In 1973, the airport lies fairly close to the city's outskirts. In 2013, continued

urbanization has engulfed the airport and continues to expand mostly southward and eastward. The extensive urban growth of Ouagadougou in the last 30–35 years was mainly due to rural to urban migration following the droughts of the 1970–1980s and to the arrival of many foreign immigrants, as well as Burkinabe from the neighboring countries — especially Côte d'Ivoire — that were undergoing political unrest in the late 1990s (Kelder, 2011). These people mostly settled in Ouagadougou and its surroundings in the hope of finding work (De Jong and others, 2000).



Aerial view of Ouagadougou

Bottom-up urbanization: the multiplication of small towns in southern Côte d'Ivoire



In the 1986 image (above, left), this area of southern Côte d'Ivoire was mostly covered by savanna and degraded forest, and only a few settlements were present (pink areas). The 2014 image (above, right) shows the expansion of the existing towns but also the emergence of hundreds of small settlements and roads within the degraded forest, creating a dense settlement network. Plantations are also visible in the 2014 image (in bright green). The increase in cultivated land and the need for labor, especially for the labor-

intensive farming systems needed to grow coffee and cocoa, was the principal factor driving the dynamics of settlement and migration processes in southern Côte d'Ivoire (Adepoju, 2003). The densification of the urban network and the fast growth of secondary cities into larger urban areas reduced rural migration to the largest urban centers, like Abidjan. The same bottom-up urbanization phenomenon is also visible in Ghana and Nigeria.



Aerial view of growing rural settlements in southern Benin

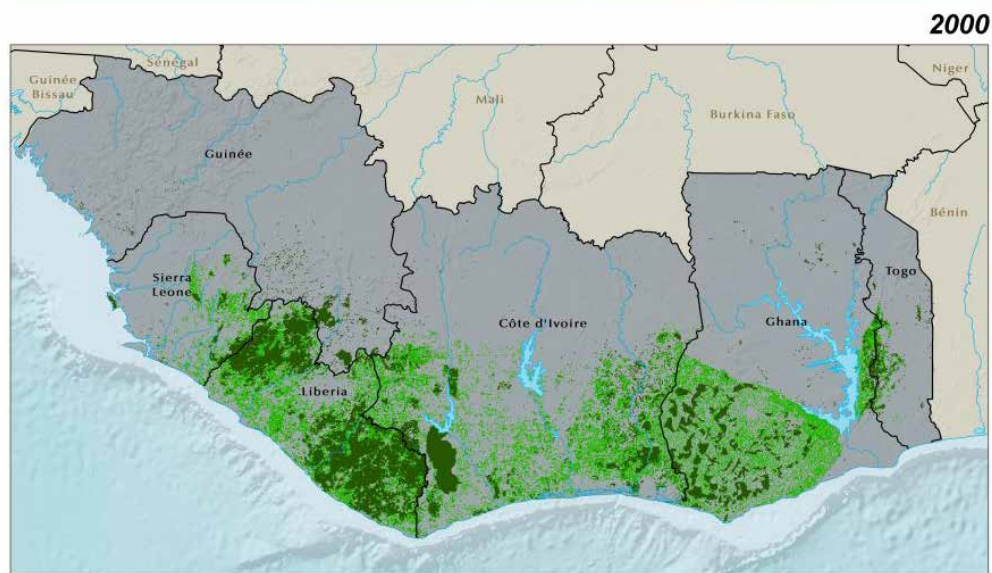
GRAY TAPPAN / USGS

The Deforestation of the Upper Guinean Forest

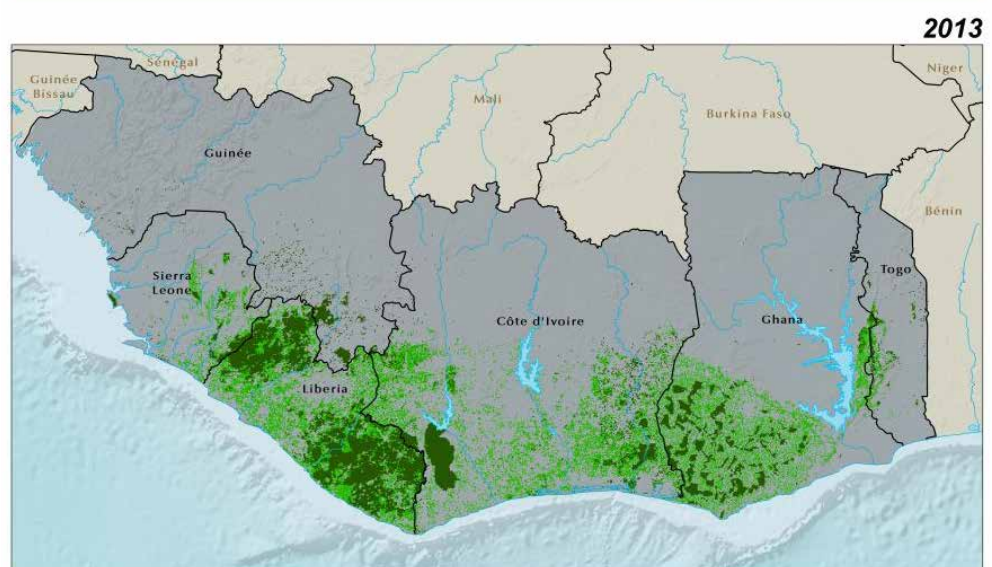
Dense and degraded forest extent in the Upper Guinean countries



1975



2000



2013

	1975 (sq km)	2000 (sq km)	2013 (sq km)
Forest / Forêt	109,000	84,000	71,000
Degraded forest / Forêt dégradée	120,100	108,000	100,500
Cloud mask / Nuages			

The Upper Guinean forest of West Africa, identified over 20 years ago as a “global biodiversity hotspot” due to its exceptional concentrations of endemic species and exceptional loss of habitats, encompasses all of the lowland forests of West Africa (Mittermeier and others, 1999; Myers and others, 2000). The forest ecosystem extends from southern Guinea into eastern Sierra Leone, through Liberia, Côte d’Ivoire, southern Ghana, and across southwestern Togo. In southeastern Ghana, a savanna corridor known as the Dahomey Gap interrupts the Upper Guinean forest ecosystem (Salzmann and Hoelzmann, 2005). One outlier in the Dahomey Gap is the forest along the Ghana-Togo border highlands.

The maps of the Upper Guinean forest show two forest stages:

- The forest class is characterized by West Africa’s dense tropical evergreen rain forest and moist deciduous forest, and a closed canopy cover (White, 1983). It occurs mainly along the coast where rainfall is higher. Of all the Upper Guinean countries, only Liberia lies entirely within the moist forest zone. About 50 percent of the remaining Upper Guinean forest is contained within Liberia.
- Degraded forests were once dense, deciduous forests, now modified and fragmented by human activity. They occur mainly in the off-reserve areas and are particularly visible in Liberia, Côte d’Ivoire, and Ghana.

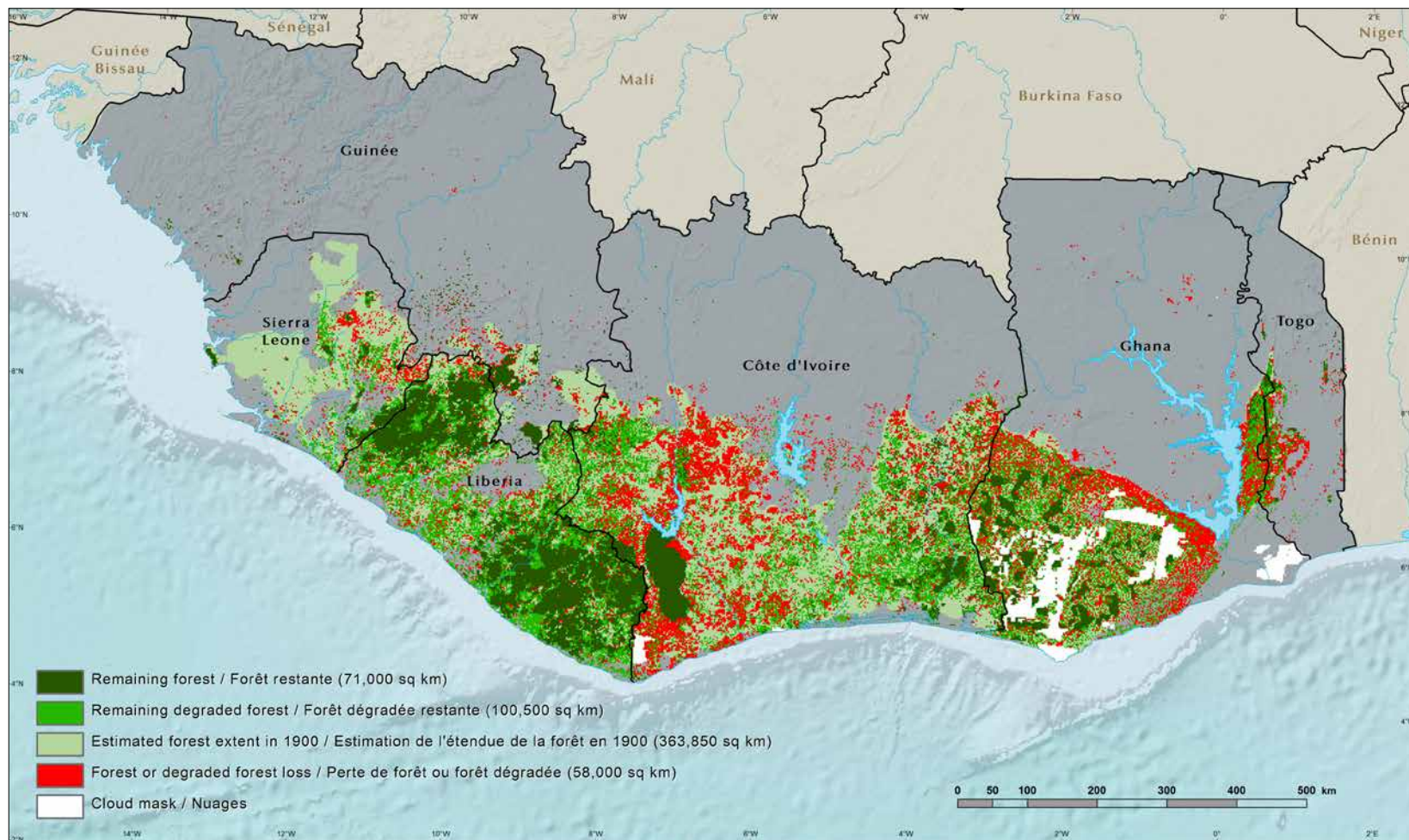
Originally, the Upper Guinean forest consisted of dense forest that covered an estimated 680,000 sq km¹ (Mittermeier and others, 1999; Myers, 2000). Using the West Africa rainfall isohyets as a general reference, as well as the extent and pattern of the forest depicted on the 1975 map, the probable limits of the Upper Guinean forest (prior to 1900) have been delineated (see map on opposite page). In 1975, many remnant or relic patches of dense forest still remained. The assumption was that the forest patches seen in 1975 were remnants of an earlier, near continuous forest. With this approach, the estimate of the forest area prior to 1900 reaches about 360,650 sq km, which still represents a conservative assessment of the original extent of the Upper Guinean forest—the actual area may have been even greater. Furthermore, according to the data collected by Unwin (1920)², the extent of forest in the Upper Guinean forest countries in 1920 was approximately 216,000 sq km, which supports the 1900 estimate.

The maps of the forest extent show that most of the forest removal seems to have occurred before 1975, with a loss of 84 percent of the original forest extent. The historical forest ecosystem has been transformed to a series of forest fragments separated by agricultural communities and degraded forested lands. Between 1975 and 2013, forest removal for wood products, plantations, farming and other uses was still ongoing, and resulted in the loss of 25 percent (58,000 sq km) of the forest (all classes considered). It is believed that Liberia is the only country in West Africa that was once entirely covered with rain forests, yet less than half remains today (Bakarr and others, 2004). Of the intact forest remaining in the Upper Guinean forest, Guinea contains 6 percent, Sierra Leone

¹ Mittermeier and others (1999) and Myers and others (2000) estimated the extent of the Guinean forest (from Guinea to Cameroon) at 1,261,970 sq km. Only Upper Guinean forest countries are considered in this analysis (from Guinea to Togo).

² Estimate calculated from the forest extent values given by Unwin for each of the Upper Guinean forest countries.

Upper Guinean forest change from 1975 to 2013

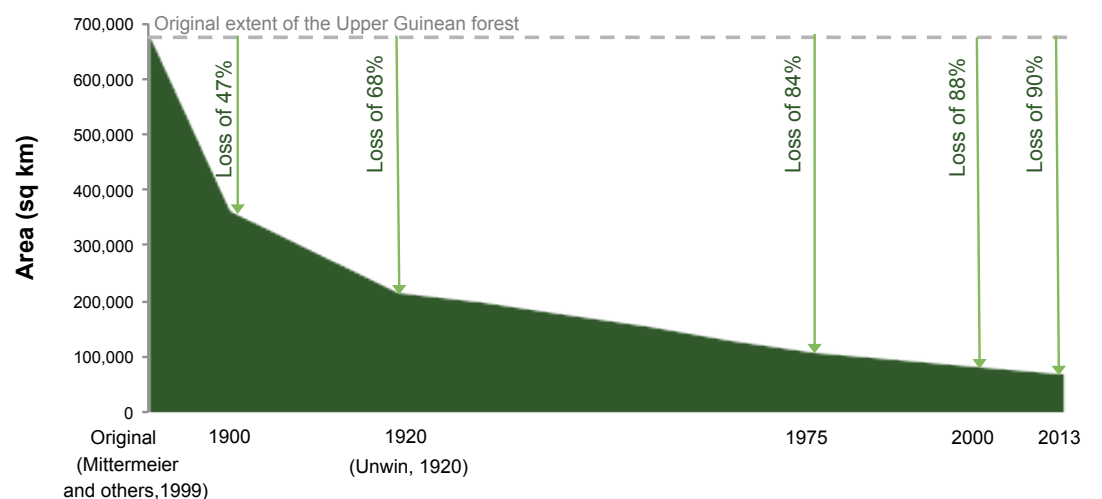


4 percent, Liberia 50 percent, Côte d'Ivoire 21 percent, Ghana 17 percent, and Togo 2 percent. In 2013, the Upper Guinean forest countries retained only about 71,000 sq km of forest cover, and only 32,000 sq km are located in national parks, classified forests, nature reserves, and wildlife sanctuaries (IUCN and UNEP-WCMC, 2016). The remaining forest cover constitutes the last testimony to the species-rich forests that used to blanket most of the southern part of the region. While the IUCN has defined six protected area management categories based on primary management objectives, in practice protected area management differs greatly from country to country. Outside of the dense forest patches, degraded forest also continues to decrease in area, dropping from 120,100 to 100,500 sq km between 1975 and 2013, a loss of 16 percent of their area. Gallery forests, which form closed canopy corridors along rivers and intermittent drainage networks, are sparse and quite rare across the Upper Guinean countries. They represent the most biologically rich habitats in the savanna zones of West Africa and are also threatened by degradation and deforestation.

Presently, the Upper Guinean forest is a highly fragmented system and remains one of the most severely threatened forest systems in the world. This region is a high global priority for biodiversity conservation, but also extractive industries, and other key global commodities such as rubber, cocoa, and oil palm. Deforestation through unregulated logging and slash-and-burn agriculture is the major threat to the forest ecosystem, and is intensified by

increasing population. By 2013, 17 percent (38,800 sq km) of the 1975 dense and degraded forest had been converted to agriculture (including conversion to plantations). Other direct threats to the forest in this area include mining, bushmeat hunting, water pollution, and coastal development. Indirect threats to these ecosystems, such as poverty, migration and urbanization, political instability, unprotected borders (both land and water), inadequate and uneven policies, and lack of regional conservation planning, contribute to the continuous pressure on the Upper Guinean forest in both unprotected and protected areas. The largest blocks of forests now protected in Liberia, Côte d'Ivoire, and Ghana are still under considerable pressure from human encroachment that is continuing to fragment and degrade the remaining blocks of this high biodiversity ecosystem.

Evolution of forest area in the Upper Guinean countries, from its probable original extent to 2013



Mangrove Changes



GRAY TAPPAN / USGS

Mangroves are coastal forests that grow where ocean water, freshwater, and land meet. They are among the planet's most productive and complex ecosystems, thriving in salty and brackish conditions that would kill most other plants (Wetlands International, 2012). Mangrove species have evolved clever mechanisms to enable them to cope with high concentrations of salt and the regular inundation of their root systems by incoming tides (Corcoran, Ravilious, and Skuja, 2007). Throughout the Sahel and West Africa, the livelihoods of coastal populations depend heavily on access to natural resources. Mangroves are integral to many of those resources, providing wood and non-wood forest products, coastal protection, conservation of biological diversity, provision of habitat, spawning grounds and nutrients for a variety of fish and shellfish, and salt production (Corcoran, Ravilious, and Skuja, 2007). Mangroves play an essential role in West Africa's coastal fisheries, which contribute \$400 million annually to the regional economy (USAID, 2014). In spite of these important roles, mangroves are experiencing deforestation and are a heavily threatened ecosystem throughout the region.

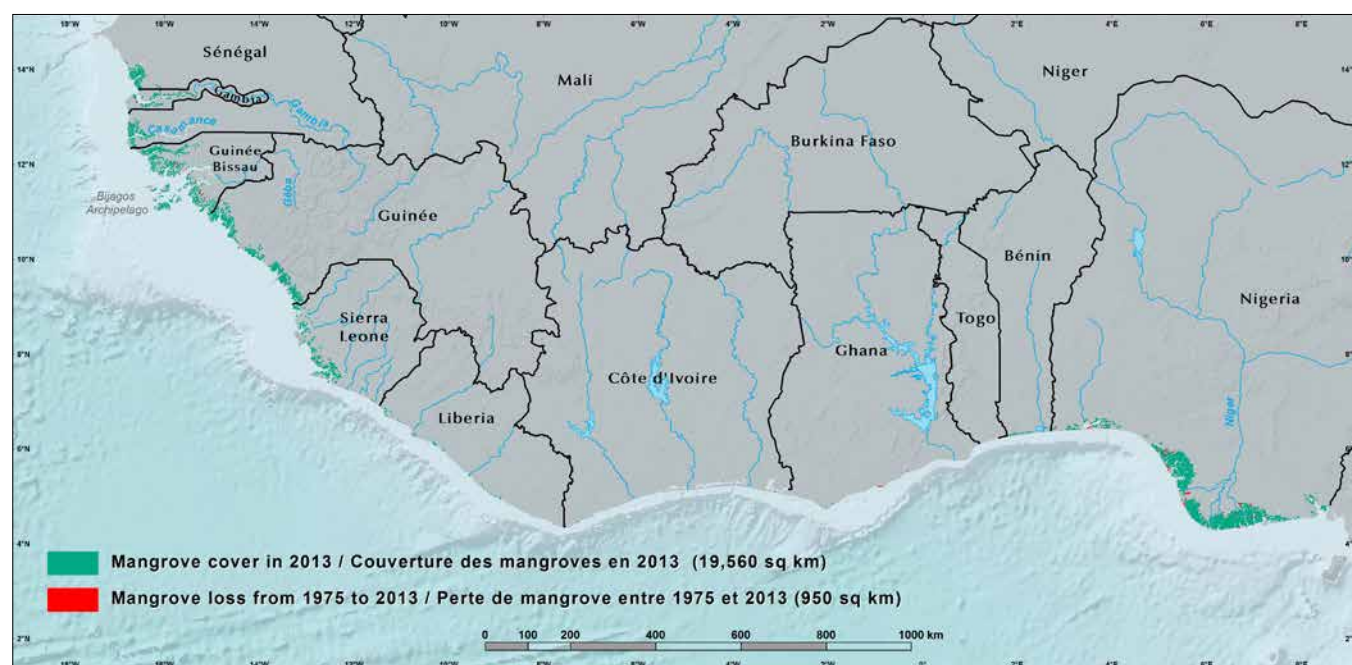
Mangroves are found in 10 of the 17 countries of West Africa, from Senegal to Nigeria. Some very small stands of mangroves can also be found in Mauritania and Togo, but their extent was too small to be mapped at the scale of this project. Nigeria contains the most extensive mangrove ecosystem of any country in West Africa, comprising nearly 50 percent of the total mangroves of the region. About 18 percent of the area identified

as mangrove falls within designated national and international protected areas. However, only a small number of the designated protected areas are actively managed (Corcoran, Ravilious, and Skuja, 2007).

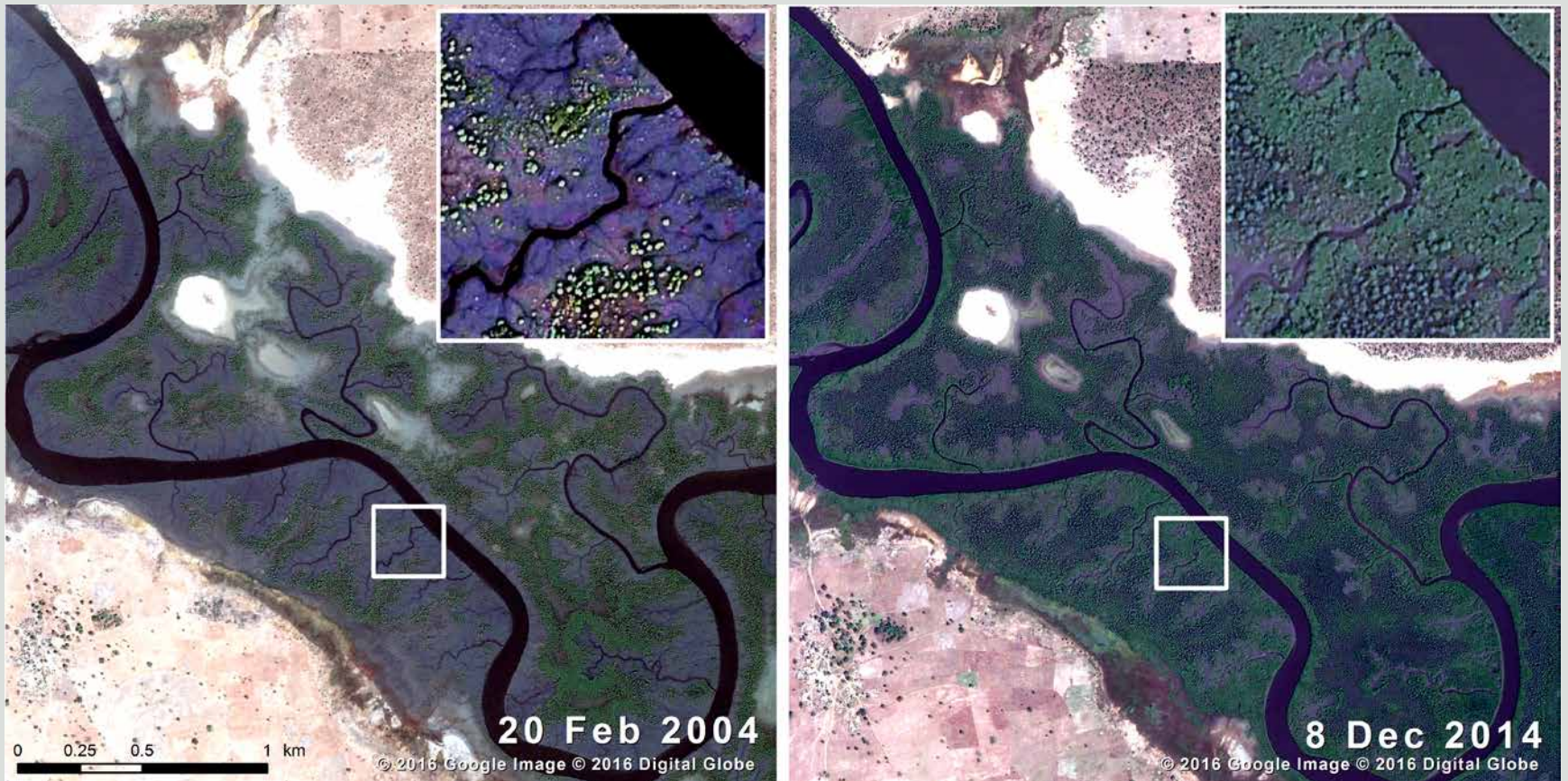
In some places, mangroves grow as far as 100 km inland, due to strong tidal influences on rivers such as The Gambia and the Casamance Rivers in Senegal, the Gêba River in Guinea-Bissau, and the Niger Delta in Nigeria (Corcoran, Ravilious, and Skuja, 2007). Similarly, where there are strong riverine influences into the ocean, islands affected by freshwater influxes provide an environment for mangrove growth, like in the Bijagos Archipelago of Guinea Bissau (AFROL, 2002). The overall regional trend from 1975 to 2013 indicates a decline in mangrove area of 4.6 percent, a net loss of 950 sq km. Nigeria had the greatest loss of mangroves between 1975 and 2013 (368 sq km), followed by Senegal and Guinea-Bissau (288 sq km and 220 sq km, respectively). Ten additional countries also show a decrease, but four countries — Ghana, Côte d'Ivoire, Liberia, and Sierra Leone — appear to have either no change or an overall increase in mangrove area over the 38-year period. Encouragingly, following reforestation efforts, Guinea, The Gambia, and Senegal show a gain of mangrove cover from 2000 to 2013.

West Africa's coastlines have some of the highest and most rapidly growing populations. Many communities rely on mangrove wood as a primary fuel source for curing fish and other purposes, and urban expansion and intensifying demands for charcoal, fuel wood, and land for agriculture are growing drivers of mangrove

Distribution and changes in mangrove area in West Africa between 1975 and 2013



Example of mangrove restoration in Senegal



Since the 2000s, large-scale reforestation campaigns have been initiated and operated by non-governmental organizations operating in Senegal (e.g., IUCN, Oceanium). Results have been spectacular: between 2006 and 2013, 140 sq km of mangrove forests were replanted, mostly in

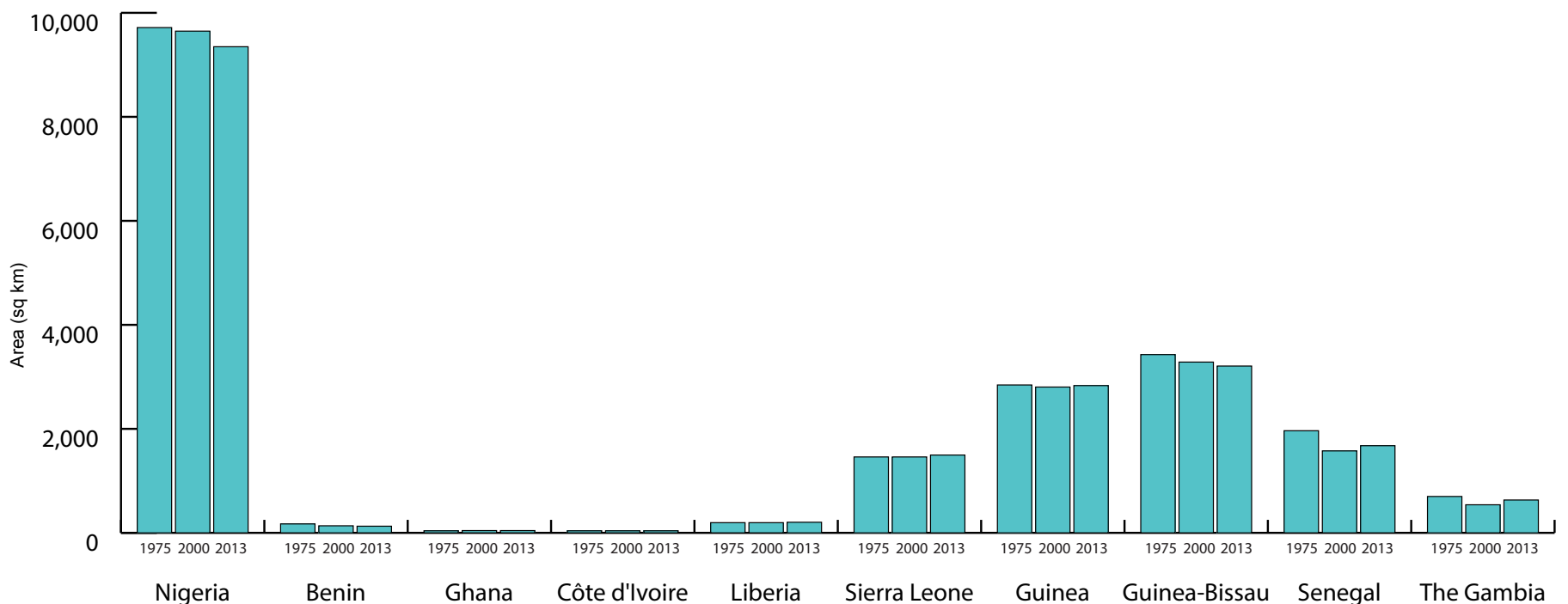
Casamance, but also along Senegal's Saloum Region (Cormier-Salem and Panfili, 2016). The pair of high-resolution images above shows successful mangrove restoration along the Koular Bolon estuary in the commune of Keur Saloum in Senegal.

deforestation and degradation (USAID, 2014). These factors — combined with rising sea levels, erosion from extreme weather, and more intense storm surges — represent significant and growing threats to mangroves (Corcoran, Ravilious, and Skuja, 2007).

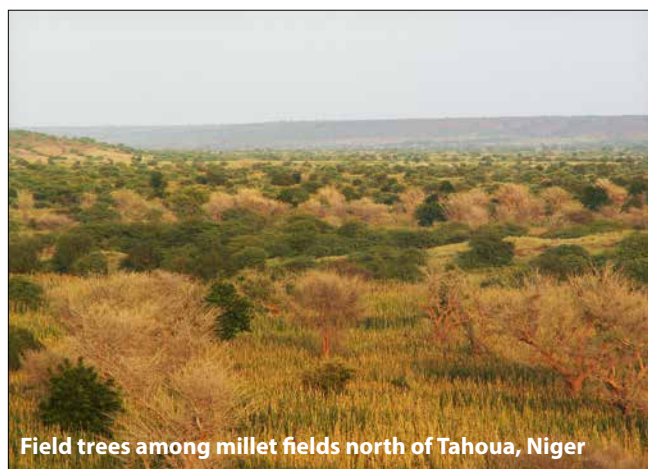
At the regional scale, efforts have increased to save mangrove forests from further destruction. Many national governments have passed legislation and signed international conventions, including the

Convention on Climate Change, the Convention on Biodiversity, the Convention on International Trade of Endangered Species, the Convention on Ozone Layer and the Ramsar Convention on the Conservation of Wetlands (Wetlands International, 2012). Mangrove restoration efforts have been conducted in almost all the coastal nations along the Gulf of Guinea to help communities restore and better manage their mangroves.

Mangrove area in West Africa by country in 1975, 2000, and 2013 (in sq km)



Landscape Restoration and Re-greening



Field trees among millet fields north of Tahoua, Niger

CHRIS REIJ / WRI



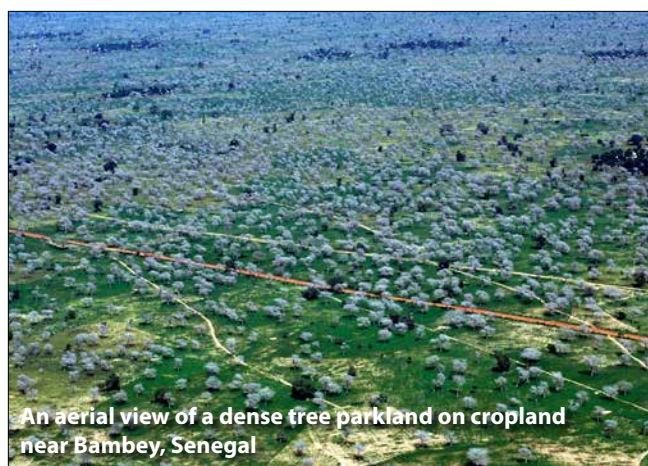
Native acacia trees planted along terraces on the Ader-Doutchi Plateau, Niger

GRAY TAPPAN / USGS



Winterthorn (*Faidherbia albida*) trees creating a parkland among peanut fields, western Senegal

JEFF POVOLNY



An aerial view of a dense tree parkland on cropland near Bambey, Senegal

GRAY TAPPAN / USGS

West Africa's population is expected to double by 2050, increasing the demands on already limited land, water, and forest resources. The region's landscapes are already affected by degradation, particularly in the fast growing agricultural lands where natural vegetation cover has been removed, and fragile soils have been exposed to wind and water erosion. Since 1975, West African forests have declined from about 131,000 sq km to just 83,000 sq km. Much of that deforestation was driven by agricultural expansion, which doubled in area between 1975 and 2013, and now extends over 1,100,000 sq km — larger than the size of Mauritania. Poor management of agricultural land contributes further to deteriorating landscapes. With so much of the natural habitat being replaced and fragmented by agriculture — and the increased degradation that is often associated with it — there is a critical need to restore degraded and deforested land at scale. While degraded savannas and other natural landscapes can be targeted for restoration, this also applies to agricultural lands where so much of the vegetation cover has been removed and biodiversity has been decimated.

Much of the 1,100,000 sq km currently in agriculture can benefit from restoration — greener landscapes with a mosaic of vegetation cover types provide benefits that boost agricultural productivity, improve food and water security, increase biodiversity, boost resilience to climate change, reduce disaster risk, and improve soil fertility.

There are reasons to be optimistic that restoration at scale can be achieved. A large area of the semiarid Sahel, centered on Niger but also including parts of Mali and Burkina Faso, has shown a remarkable transformation over the past 30 years. Landscapes that were once denuded are now home to high-density on-farm trees, which help improve soil fertility and produce fodder for livestock. Several simple techniques used by farmers in Niger have been unleashed on a large scale due to the empowerment of local groups and communities. The general term for these techniques is “re-greening” — the

transformation of degraded landscapes into productive and resilient farmland through widespread adoption of agroforestry and related sustainable land management practices (Reij and Winterbottom, 2015).

There are several techniques for integrating trees into agricultural landscapes. One of the most successful and beneficial is the practice known as farmer-managed natural regeneration (FMNR). In Niger, farmers use FMNR to regenerate and multiply valuable trees whose roots already lay underneath their land, encouraging tree growth in their fields. Niger farmers have improved about 5 million hectares (or 50,000 sq km) of land — now producing more than 500,000 additional tons of cereals per year (Reij and others, 2009). As a result of FMNR, vast areas of southern Niger are greener and more tree-covered (see pages 162–163). Agricultural income is up, and food security has been enhanced, even in drought years. The FMNR approach has increased resiliency and decreased Niger's dependency on external food aid.

In 2015, the World Resources Institute (WRI) published a report on the steps needed to scale up re-greening to a wider area, providing a practical approach to landscape restoration (Reij and Winterbottom, 2015). The report focuses primarily on re-greening of agricultural lands through a range of processes. These include the development of new agroforestry systems by farmers who manage natural regeneration of shrubs and trees, the rejuvenation of old agroforestry parklands, the management of natural regeneration on abandoned cropland and degraded land, and improved management of grazing lands by pastoralists through protection and regeneration of trees and shrubs that are sources of browsing for livestock. The WRI considers farmer-managed natural regeneration to be one of the most promising approaches to re-greening in the Sahel. Re-greening can also be applied to the Sudanian and Guinean Regions.

Contrary to first impressions, the re-greening that has occurred across parts of Burkina Faso, Mali, and Niger is not the result of massive tree-planting efforts. Rather, it has largely

The WRI report (Reij and Winterbottom, 2015) summarizes the major benefits of re-greening:

- Trees help restore, maintain, and improve soil fertility by maintaining or increasing soil organic matter.
- Trees help solve the household energy crisis by providing fuelwood, which reduces the burden on women.
- Trees provide poles for construction and manufacture of furniture and tools, as well as fences for gardens.
- Re-greening practices improve household food security, and fruit and leaves have a positive impact on nutrition.
- Trees are assets that provide “insurance and banking services,” which can be drawn on in crop-failure years and times of need.

- Many tree species in agroforestry systems produce nutritious fodder.
- Trees increase the total value produced by a farming system and help reduce rural poverty.
- Trees reduce wind speed and wind erosion.
- The shade of trees reduces soil surface temperatures and lowers evapotranspiration.
- Trees contribute to biodiversity and the restoration of ecosystem services in agricultural landscapes.
- Increasing the number of trees in the landscape helps mitigate climate change by sequestering carbon.

occurred thanks to the actions of farmers who have protected and managed the natural regeneration of trees and bushes, primarily on cultivated land. Hundreds of thousands of farmers have invested in protecting natural regeneration, increasing the number of on-farm trees. They have done so mainly for economic reasons, with the knowledge that re-greening improves soil fertility, increases crop yields, and enhances household food security (Yamba and Sambo, 2012; Reij and others, 2009; Botoni and Reij, 2009).

Re-greening delivers real economic benefits to farmers and communities. However, there are many areas across the agricultural lands of West Africa where it is not practiced, although the potential exists on most landscapes. Despite the successes we see in Niger and beyond, development practitioners need a framework for scaling up re-greening successes. The WRI report fills that void by suggesting a six-step framework for scaling up re-greening:

- Identify and analyze existing re-greening successes
- Build a grassroots movement for re-greening and mobilize partner organizations
- Address policy and legal issues and improve the enabling conditions for re-greening

- Develop and implement a communications strategy to systematically expand the use of all types of media
- Develop or strengthen agroforestry value chains to enable farmers to capitalize on the role of the market in scaling up re-greening
- Expand research activities to fill gaps in knowledge about re-greening

Scaling up re-greening requires major efforts on the part of national governments as well as farmers. National policy makers need to be informed about the existing successes and associated benefits. They need to ensure that agricultural development policies and forestry legislation induces millions of farmers to invest in on-farm trees. National and international policy makers will need to be convinced that it is economically rational to invest in re-greening — and that will require sound economic data. Farmers, too, must be convinced of the benefits of farmer-managed natural regeneration before they take it up as a farming practice. The stakes are high. Land degradation directly affects the livelihoods of millions and erodes ecosystem services that fulfill basic needs of life. There is an urgent need to work toward landscape re-greening, which can positively impact millions of rural people in just a few years, and build an environment that is more resilient to climate change.



Aerial view of winterthorn (*Faidherbia albida*) trees among rice paddies near Ziguinchor, Senegal. The trees are protected by farmers.

GRAY TAPPAN / USGS



Landscape restoration through afforestation on the Island of Santo Antão, Cabo Verde.

GRAY TAPPAN / USGS



Farmer managed natural regeneration provides farmers with fodder for their livestock; south of Zinder, Niger

CHRIS REIJ / WRI



Dense tree parklands near Tahoua, Niger allow year round browsing by livestock

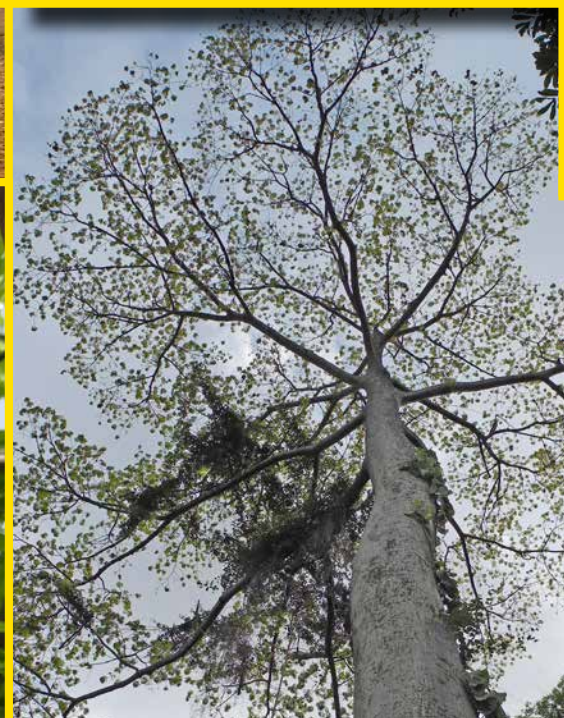
MICHAEL FITZGERALD

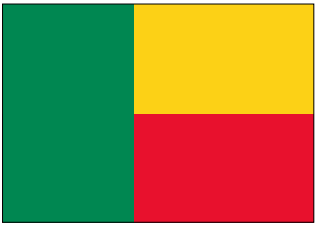


Chapter

III

Country Profiles, Land Use and Land Cover, and Trends

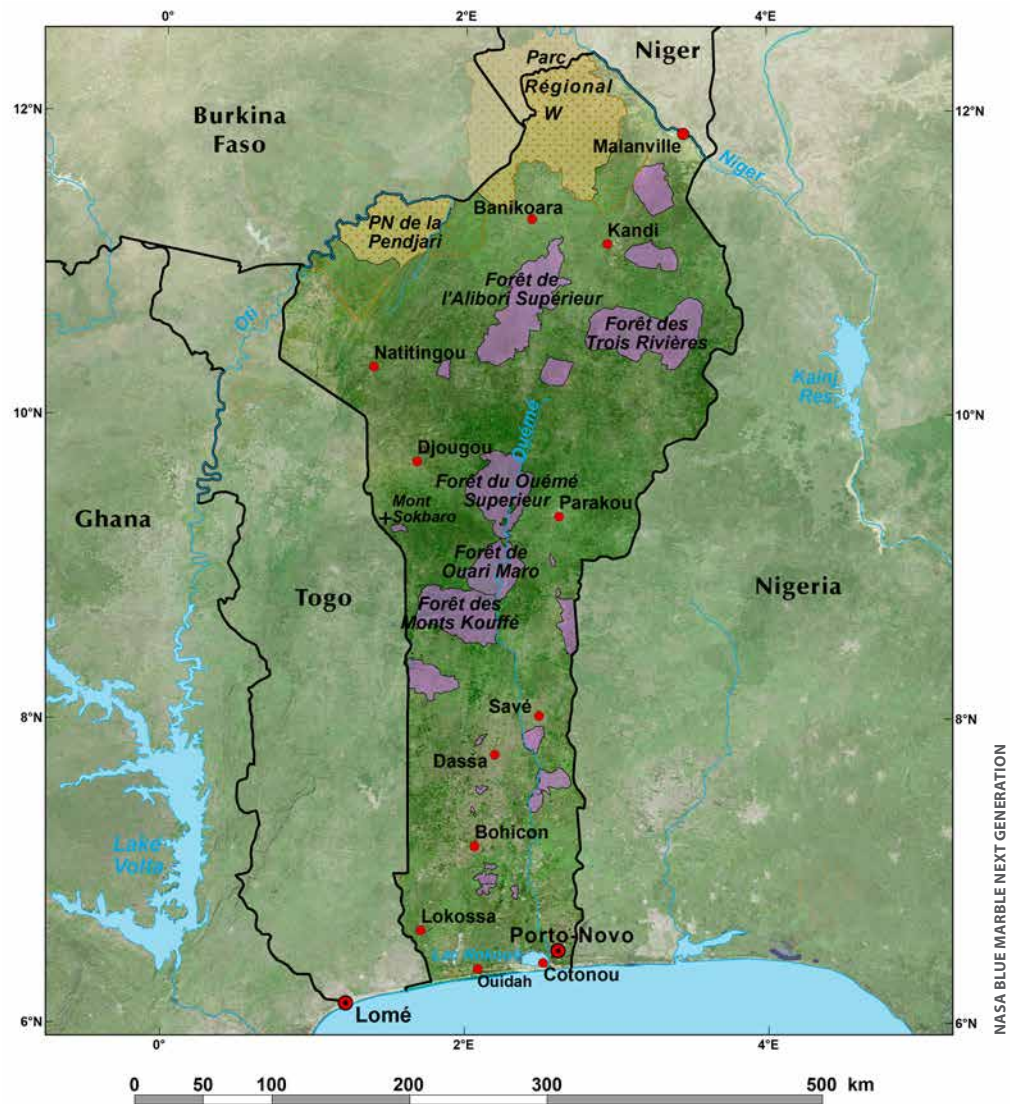




Republic of Benin

Total Surface Area: 112,622 km²
Estimated Population in 2013: 10,600,000

Benin, formerly known as Dahomey, is characterized by a great diversity of landscapes and ecosystems. Indeed, the Pendjari National Park and the W Regional Park, located in northern Benin, are two of the most protected and biodiverse semi-arid grassland ecosystems in West Africa. The mountainous region of the northwest constitutes the water reservoir for the Republics of Benin and Niger. In contrast, the central part of the country forms a large complex of plateaus covered by a mosaic of savannas, gallery forests, woodland, and cropland. Agriculture is a major part of Benin's economy, and Benin is one of Africa's largest cotton producers. In the south, the landscape is very distinct with immense palm groves scattered across the fertile plateau of the Terre de Barre. The coastal region is characterized by lagoons and marshes formed by the three main rivers of the country flowing into the coastal sandy barriers. The largest lagoon, Nokoué Lake, separates Benin's two largest cities, Cotonou and Porto-Novo. More than half of the population is concentrated in the south on only one-tenth of the country's land (BBC, 2015). As the birthplace of voodoo and home to 42 distinct ethnic groups, Benin is steeped in a rich cultural diversity and a complex history.



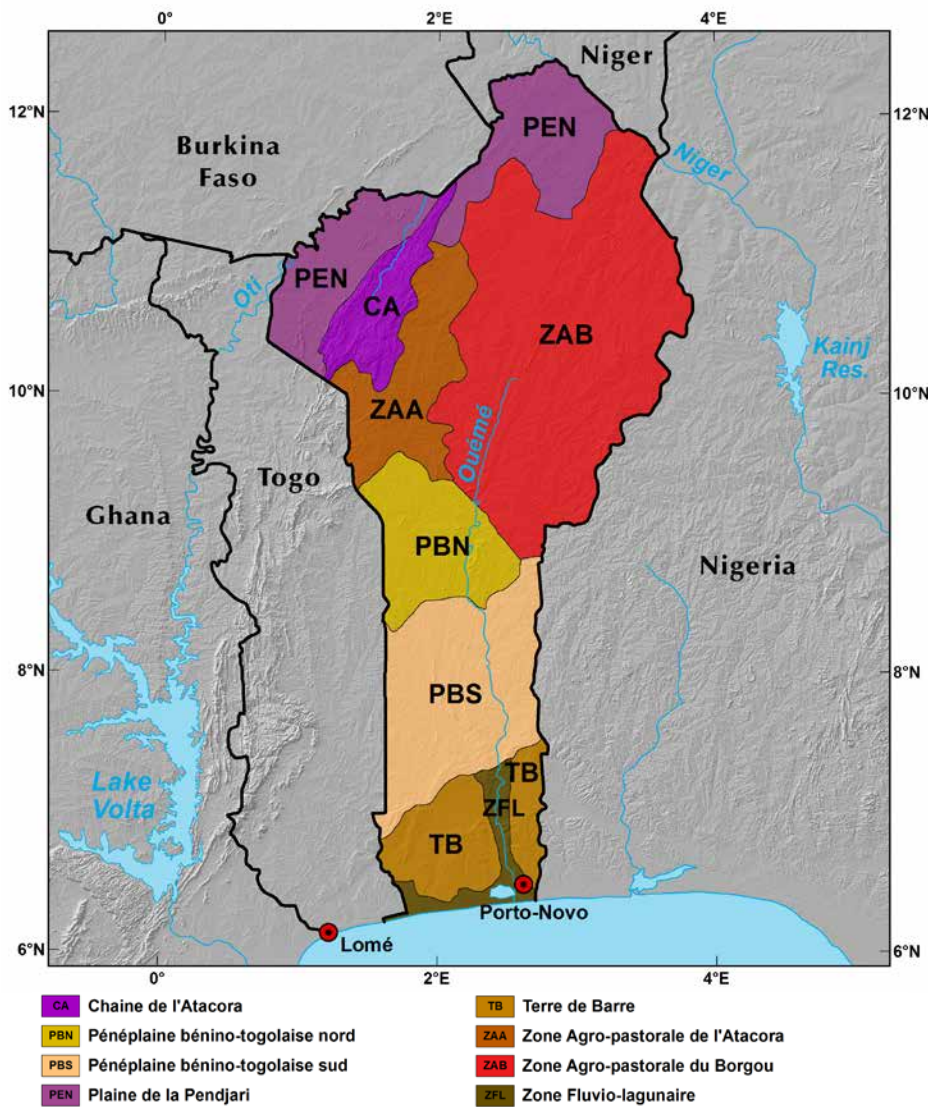
- Réserve de Biosphère / Biosphere Reserve
- Parc National / National Park
- Forêt Classée / Forest Reserve
- Capitale Nationale / National Capital
- Autre Ville / Other City

Environmental Highlights:

- Deforestation
- Susceptible to drought in the north
- Land degradation
- Stability of the protected areas
- High biodiversity

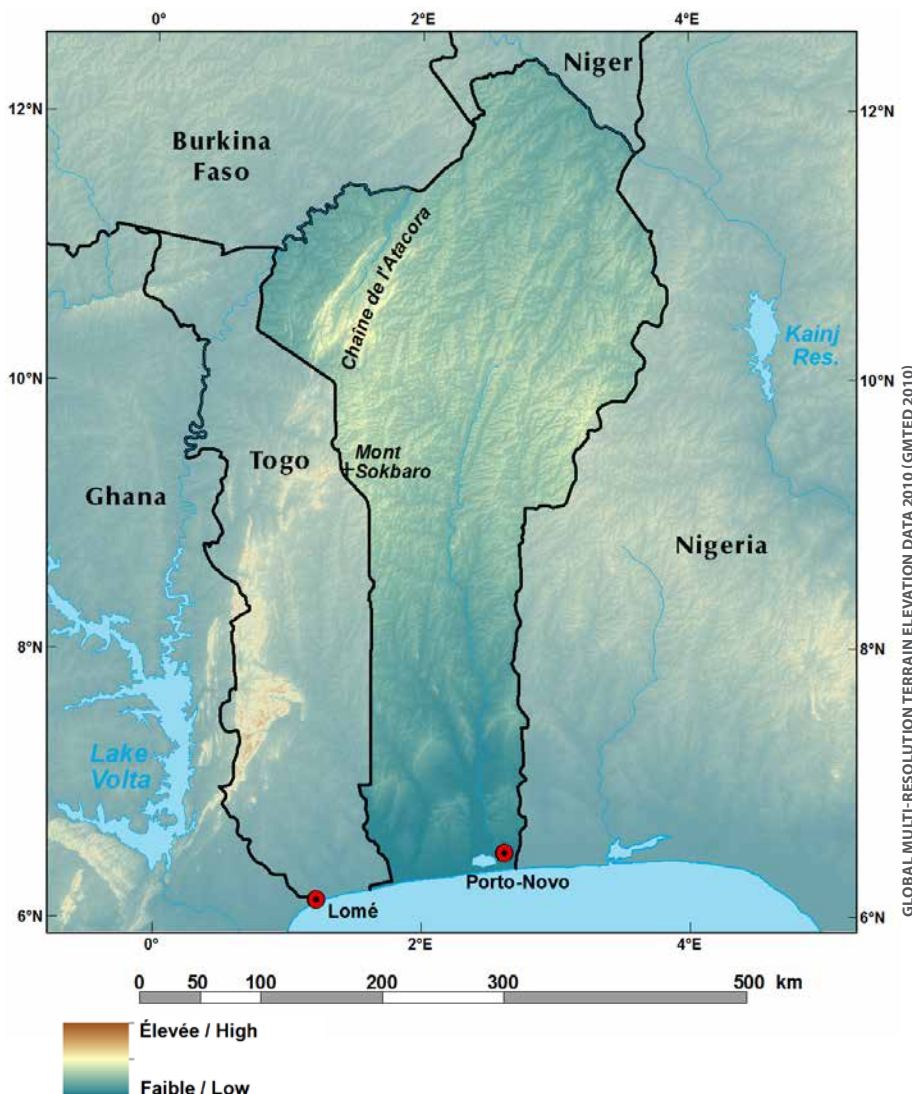
Gallery forest in a savanna landscape

Ecoregions



The southern part of Benin is characterized by the coastal Zone Fluvio-lagunaire (ZFL), made of lagoons and marshes and surrounded by the Terre de Barre (TB), a fertile plateau made of iron clay cut with depressions and often covered by immense palm groves. This plateau is endowed with moisture from the surrounding lagoons and has a high bioproductivity. Central Benin, however, consists of the large Pénéplaine bénino-togolaise (PBS and PBN). The agropastoral regions of northern Benin (ZAA and ZAB) form a heavily populated agricultural landscape. The Pendjari Plain (PEN), which spreads north into Burkina Faso and Niger, is isolated from the central plains by the mountainous Chaîne de l'Atacora (CA).

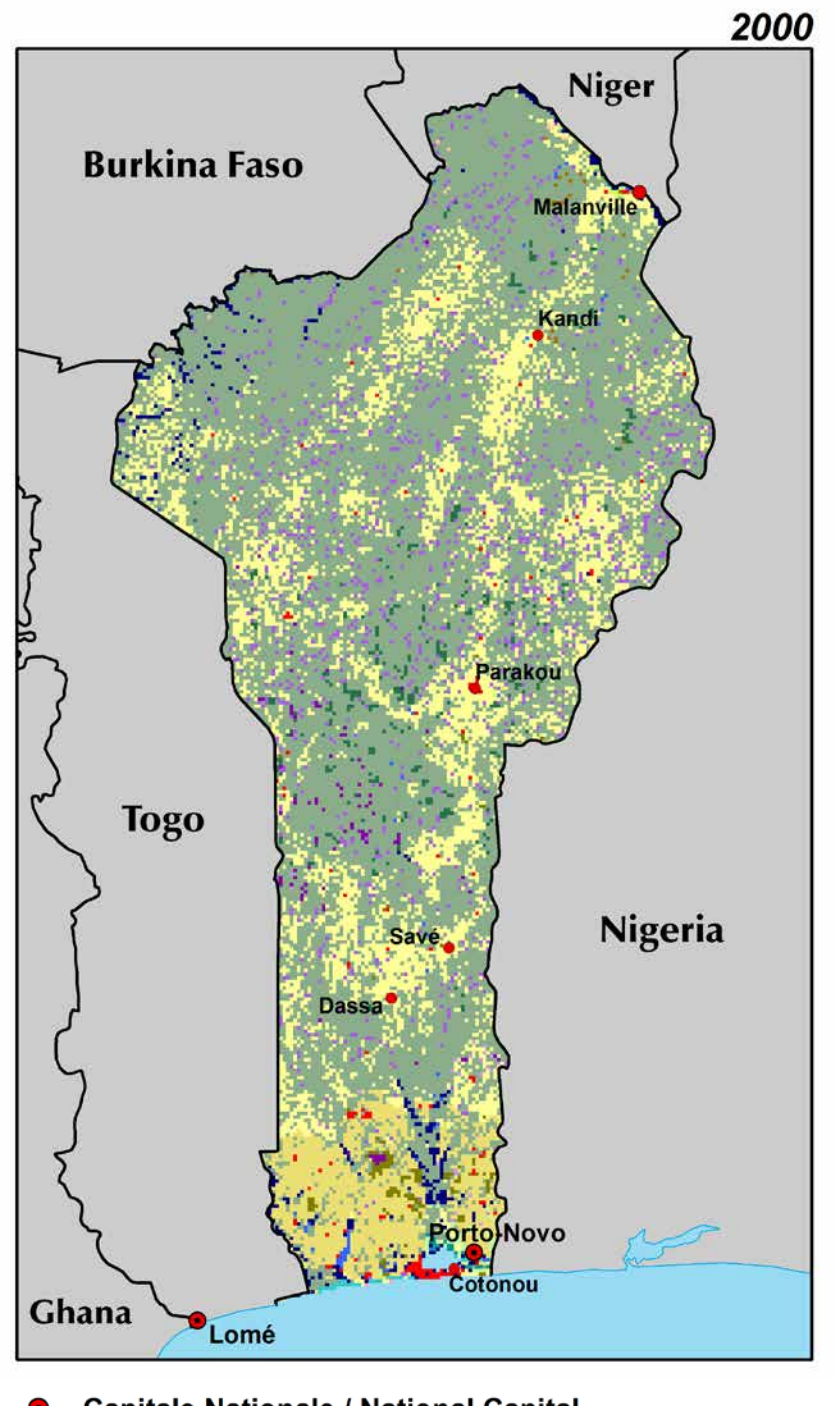
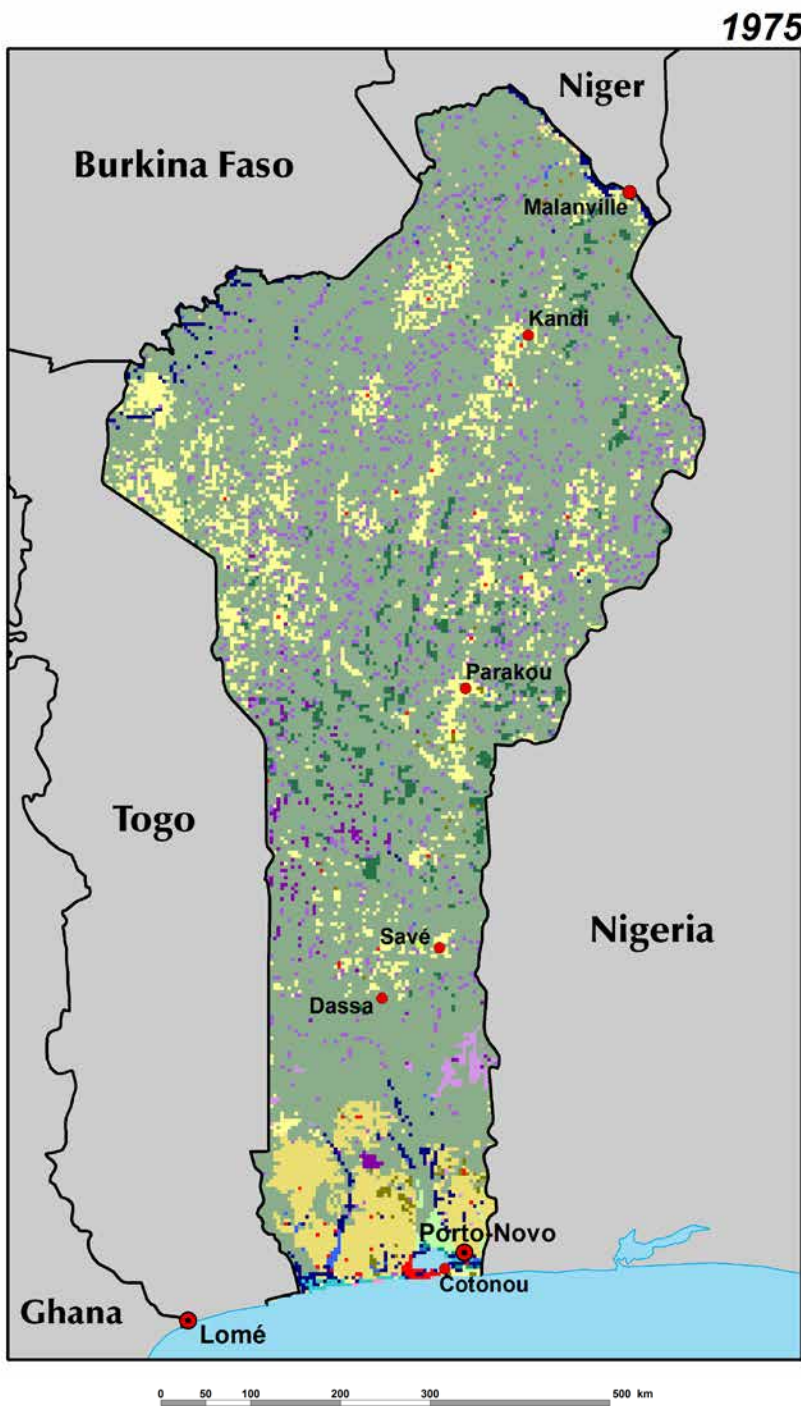
Shaded Relief



A village in northern Benin at the base of the Atacora mountain range.

ROBERT WATREL/SDSU

Land Use, Land Cover and Trends



● Capitale Nationale / National Capital



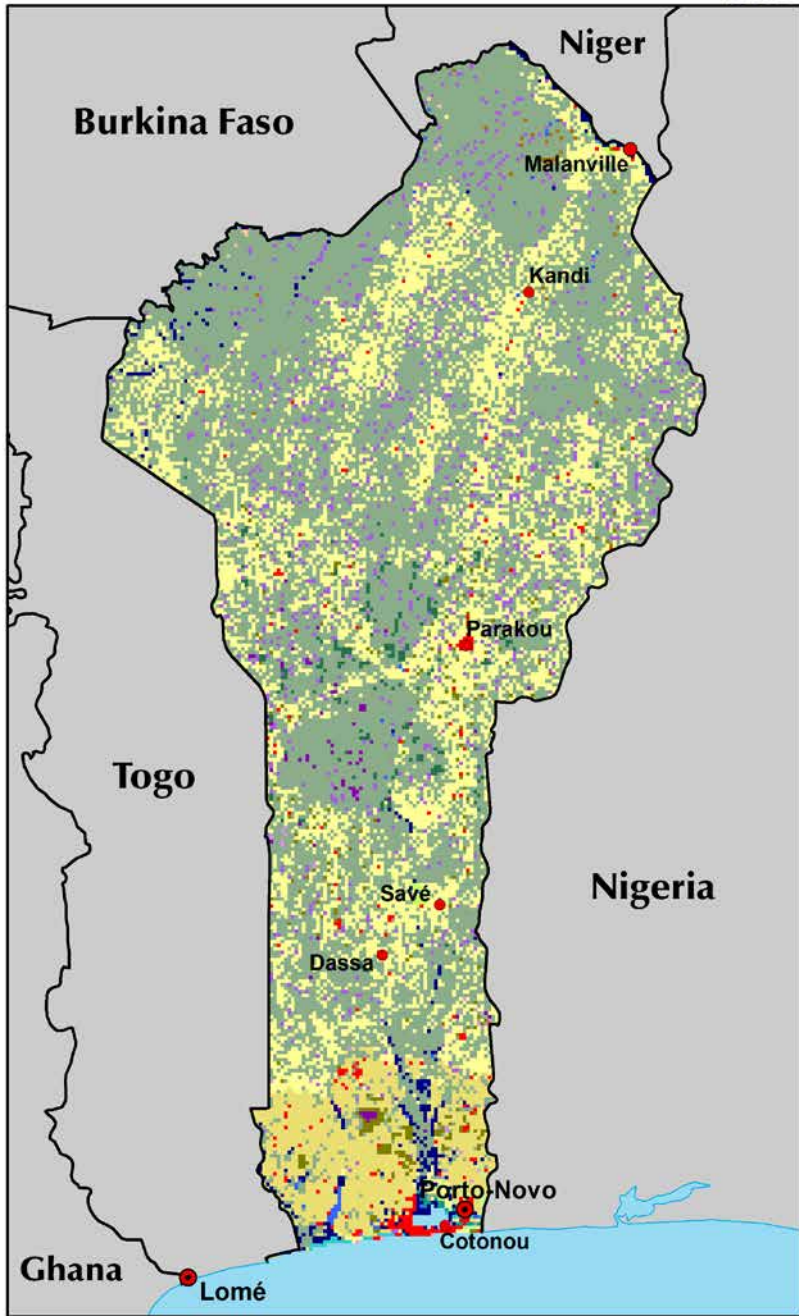
Wooded savanna being cleared for agriculture

GRAY TAPPAN / USGS

The most obvious change in land cover is the major expansion of agricultural land across most regions of Benin. Agricultural areas (including plantations and irrigated agriculture) progressed from 9.2 to 27.1 percent of the total country area, or an increase of over 5 percent (about 600 sq km) per year between 1975 and 2013. In northern Benin, much of the Pendjari Plain (PEN) and the Northern Pénéplaine bénino-togolaise Plain (PBN) has been spared from these landscape transformations owing to the complex of protected areas in that ecoregion. Rainfed agriculture expansion tends to follow the main transportation arteries. One major axis of development has been the north-south highway from Parakou to Kandi to Malanville. The highest levels of agricultural progression occurred farther south in the Pénéplaine Bénino-togolaise Sud (PBS), along the Dassa-Savé axis. Furthermore, Benin's agriculture is characterized by cropland associated with oil palm trees. Although they already covered most of the Terre de Barre (TB) plateau by 1975, oil palms farmland increased by about 28 percent over the 38-year period. Associated with agricultural expansion is the considerable fragmentation of Benin's diverse remaining savannas that range from open tree savannas in the north to wooded savannas in the south. Even though savanna area decreased by 23 percent since 1975, it remains the dominant land cover type in Benin and still covers more than half of the country.

A century or more ago, much of southern Benin was still covered in dense, biologically diverse forest. Since then, Benin has lost nearly all of that forest cover with only about 700 sq km remaining in 1975. By 2013, 58 percent of the 1975 forest cover had been lost, leaving only 0.2 percent of the country covered in dense forest. Similarly, degraded forest nearly vanished and

2013



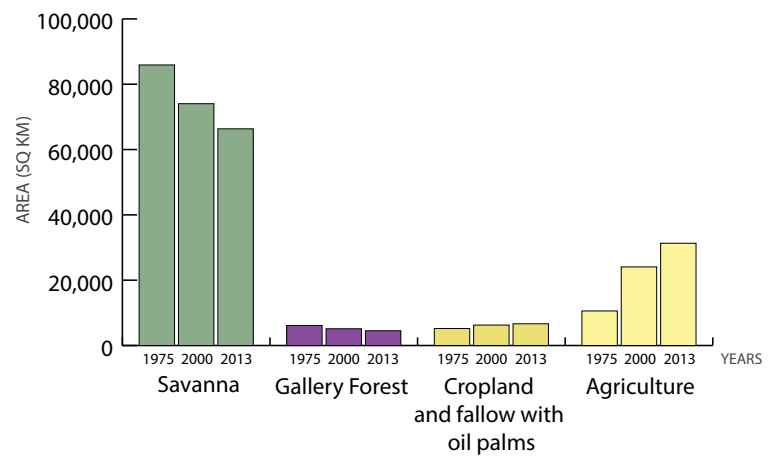
Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Savane / Savanna
- Savane sahélienne / Sahelian short grass savanna
- Steppe
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Surfaces sableuses / Sandy area
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

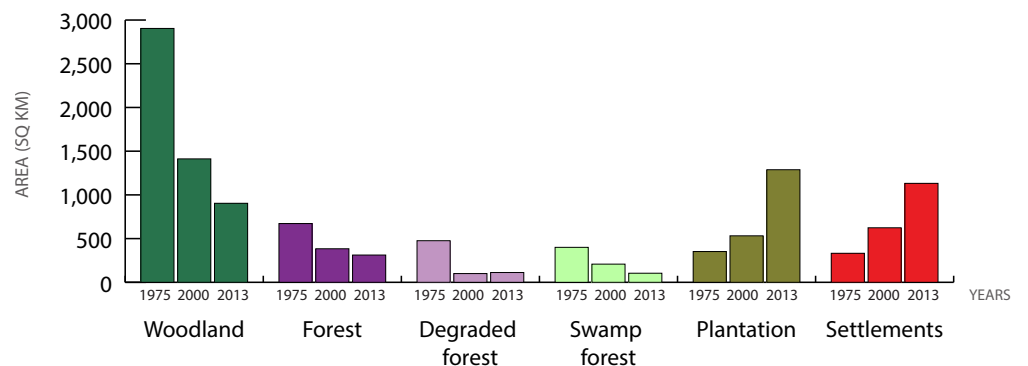
woodland regressed by 70 percent. Another important forest class found in Benin is the gallery forest, which is the most biologically rich habitat in the savanna zones of the central and northern plains. While gallery forests are limited to a narrow strip of dense canopy trees along the river systems, their total area greatly exceeds that of the few remaining dense forests. In 1975, the gallery forests covered about 6,200 sq km, but they decreased to 4,500 sq km in 2013, a decline of 27 percent.

In a country where most people obtain their subsistence from land resources, population growth is a driving factor of land cover change. Benin's population tripled between 1975 and 2013, increasing from 3,263,000 to 10,600,000. As a result, the surface area of villages, towns and cities has expanded by 241 percent. Urban and agricultural landscapes have extended to the detriment of Benin's natural ecosystems, such as savannas, forests, and woodland, which have drastically decreased over the years. Agriculture, the first form of economic activity occupying a majority of the active population, constitutes an essential factor in land degradation and can have major impacts on environmental sustainability.

Large area classes



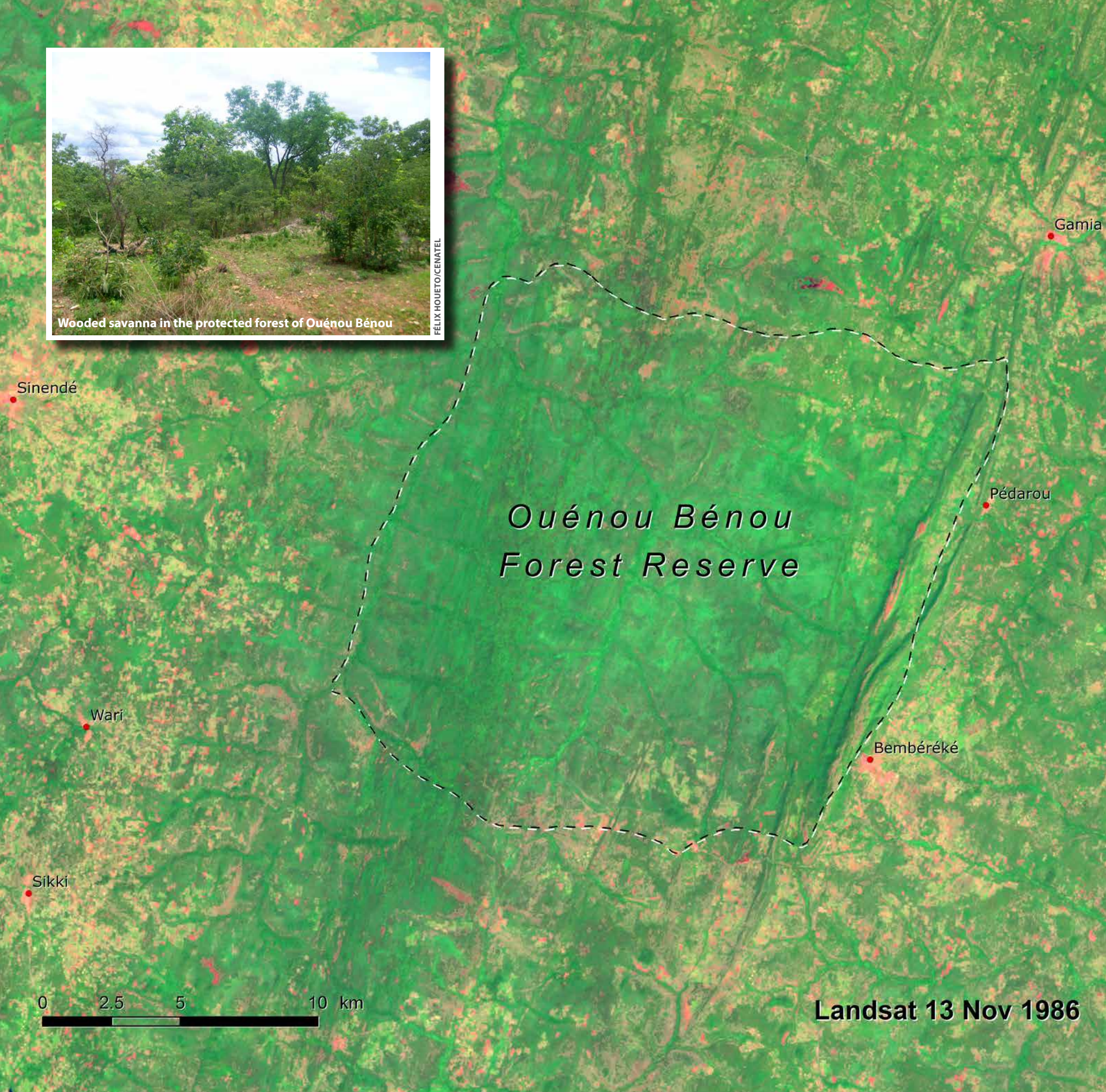
Small area classes





FÉLIX HOUEYO/CENATEL

Wooded savanna in the protected forest of Ouénou Bénou



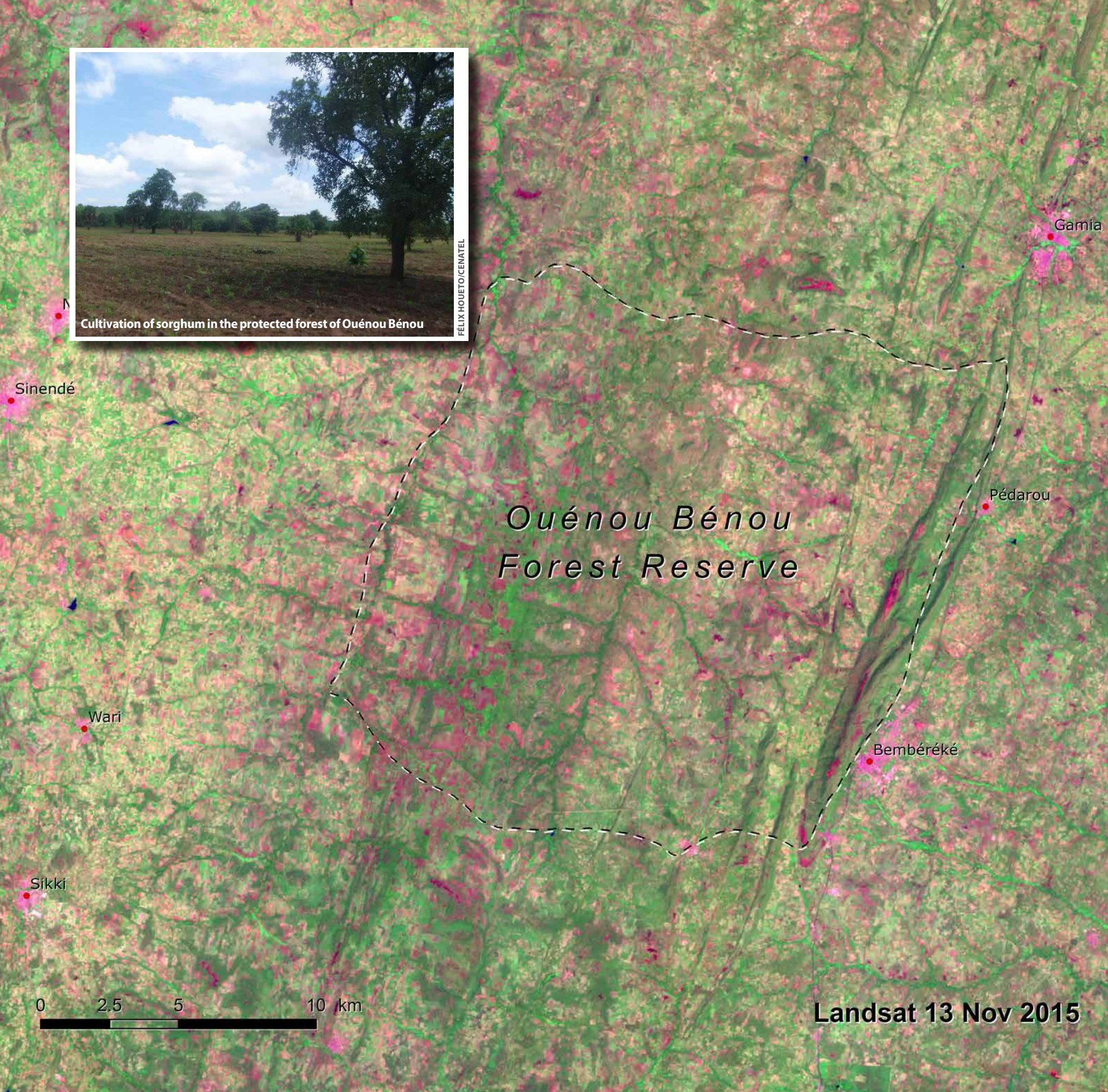
Ouénou Bénou Forest Reserve

Landsat 13 Nov 1986



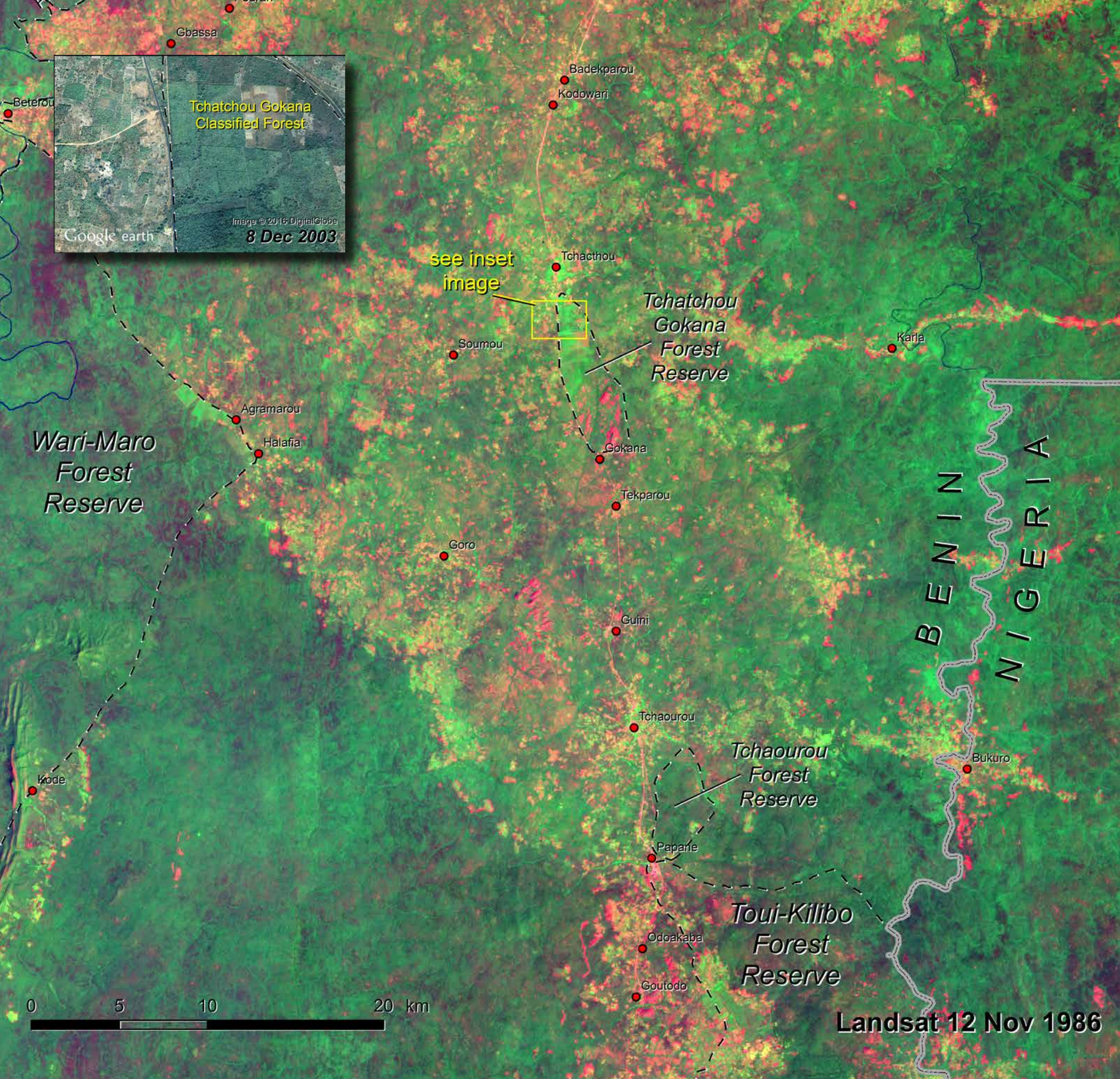
Agricultural encroachment on the protected forest of Ouénou Bénou

Fears about irreversible deforestation and fuel wood shortages prompted the colonial and later national governments of West Africa to set up protected forests across the region. The Ouénou Bénou Forest Reserve is one such example from the woody savanna zone of northern Benin. An area of 300 sq km was set aside in 1943, in which land use rights were restricted to the collection of dead wood and wild fruits. Strict measures of forest protection were enforced initially; however, under the pressure of a fast growing population, linking environmental conservation with ensuring people’s livelihoods has become a challenge. Shortcomings in the implementation of forestry laws have been exacerbated by an underfunded forestry department and a lack of qualified staff and surveillance personnel. As a result, protected forests have been subject to uncontrolled bush fires, illegal exploitation of wood, and clearing for agriculture.



Landsat imagery from 1986 and 2015 shows the encroachment of farmers' fields (light colored patches) both outside and inside of the protected forest of Ouénou Bénou. Inside the forest reserve, virtually no agriculture (less than 5 percent) was visible in 1986. By 2015, the protected forest had been massively encroached, with more than 50 percent of its area cleared for farming. This land cover transformation affected gallery forests located along the drainage network as well as wooded savannas. It has largely been driven by an agricultural policy aimed at increasing agricultural production at any price, and a lack of coordination between the agriculture and forestry departments. Incoming migrant farmers were encouraged to cultivate in the forest reserve, where soils were still fertile.

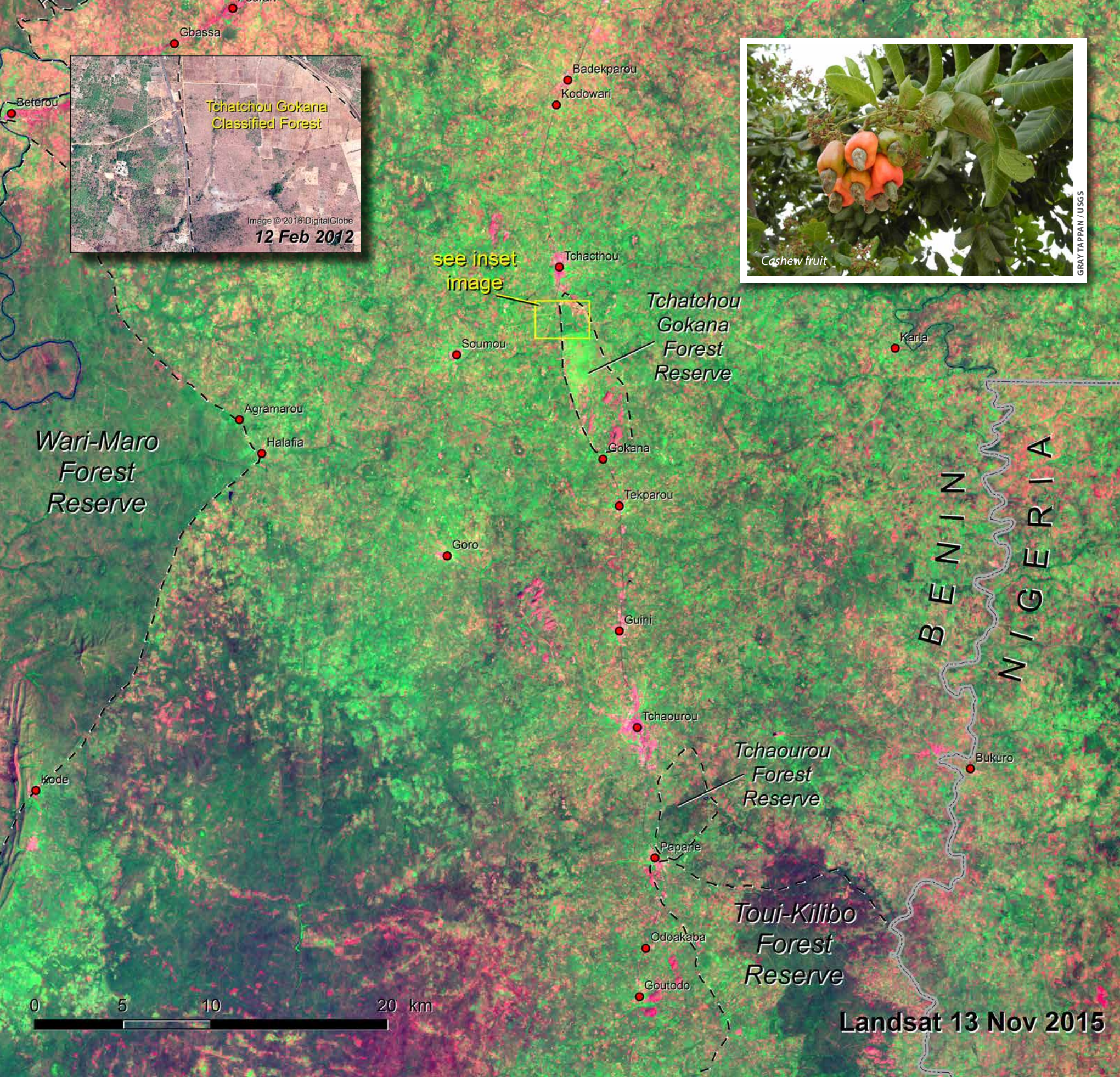
The population of the rural communities of Bembèrèké and Sinendé, the majority of which practice subsistence agriculture, are aware of the environmental cost of the deforestation: a loss of certain woody species that are used in traditional medicine, increased soil erosion, and progressive impoverishment of soils. On the other hand, they also draw some benefits from the agricultural expansion. The increased agricultural production has positively impacted food security, and the cultivation of export crops, in particular cotton, created income opportunities for some. In order to allow for a more sustainable exploitation of the lands, which support livelihoods without depleting tree and forestry resources, a new forest management approach is needed.



The expansion of cashew plantations in the commune of Tchaourou

Benin's population has more than tripled since the 1950s (UN, 2015). In Central Benin this steep population growth has been caused by both high birth rates and an influx of migrants who have been drawn to the area ever since the French colonial regime introduced labor-intensive cash crops, such as tobacco, cotton, and groundnut. The migrants have contributed to the economic development of the area by providing a steady supply of labor, but at the same time their presence has added to the pressure on the savanna ecosystem. Deforestation from clearing the natural woodlands for farming has been common throughout this region.

A comparison of Landsat imagery from 1986 and 2015 shows a dramatic decrease in natural savanna and woodlands (darker greens) surrounding Tchaourou. Even inside the protected forests of Tchatchou, Tchaourou and Toui-Kilibo, which had already experienced some minor clearing, the area of wooded savanna has been decimated. The land cover maps (see pages 76–77) measure a decline in savanna from 72 percent of the study area in the 1970s to less

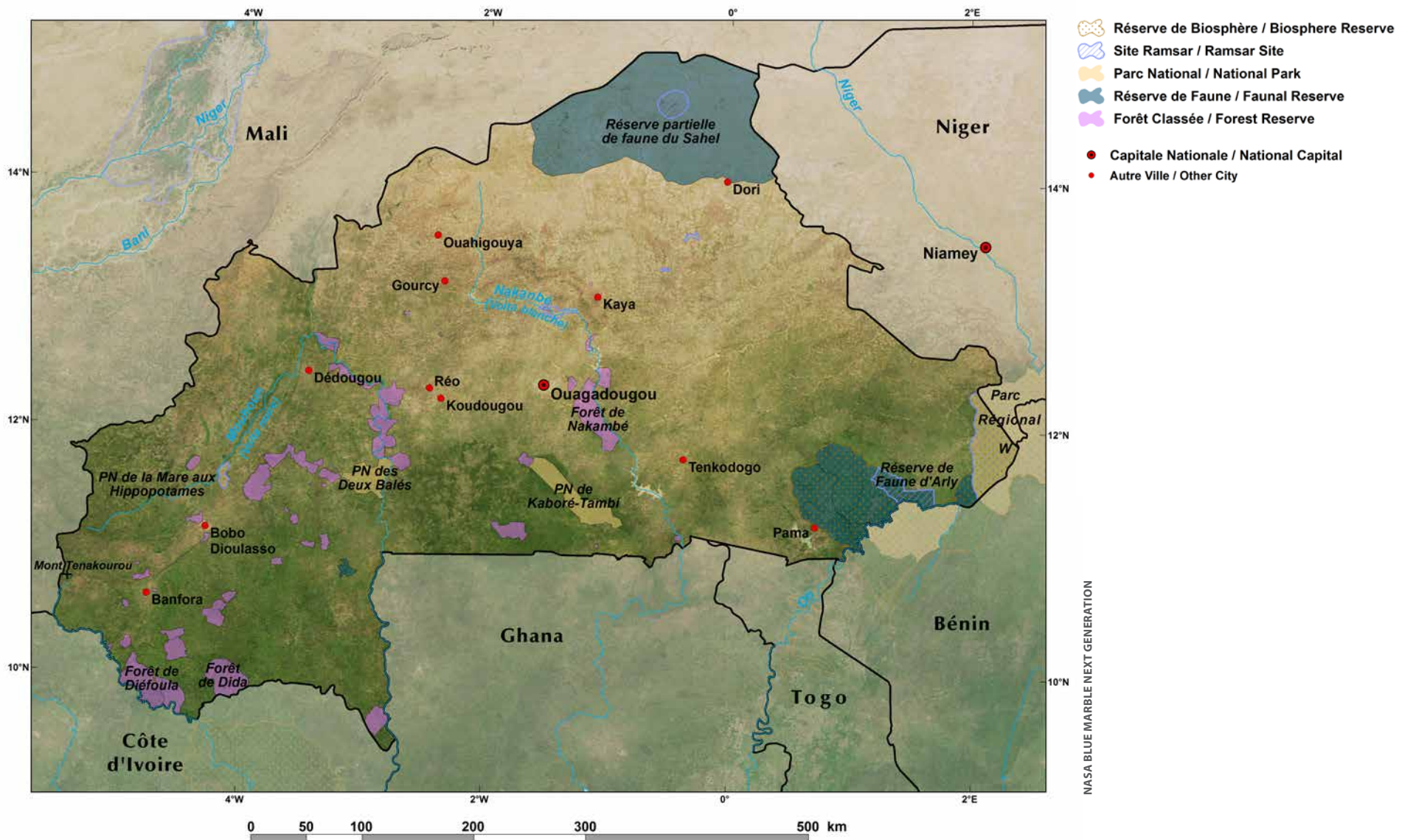


than 45 percent by 2015. During the same period agriculture has grown by four times to cover over 44 percent of the study area. Agricultural landscapes, including rainfed cropland and plantations, now dominate. Within the agriculture areas, however, the expansion of cashew plantations has helped to mitigate the loss of woody cover and biomass, somewhat offsetting the loss of trees from deforestation. The right half of the 2003 inset image (top of left page) shows some remaining forest cover within the Tchatchou Gokana Forest Reserve. In contrast, by the time of the 2012 inset image (top of right page) there are more cashew trees outside the reserve than natural tree cover within it. The proportion of cashew plantations has risen greatly as a percent of the land area in 2013. Like other afforestation activities, cashew plantations protect against soil erosion, contribute to increasing soil fertility, and create a cooler microclimate.

Several factors have contributed to the success of the cashew economy. Many small producers received monetary support to invest in cashew cultivation as part of the national development strategy of promoting export-oriented economic sectors. The large and growing rural population provides a continuous supply of labor. Cashew nuts are in high demand on the global market, and Benin's market shares have increased to make it the 5th largest producer worldwide (US Department of State, 2015). The cashew tree is well adapted to the environment in Central Benin. It requires very little input and can thrive even on poor soils. Hence, it is very well suited for the rehabilitation of degraded lands.



Burkina Faso



Total Surface Area: 274,400 km²
Estimated Population in 2013: 17,085,000

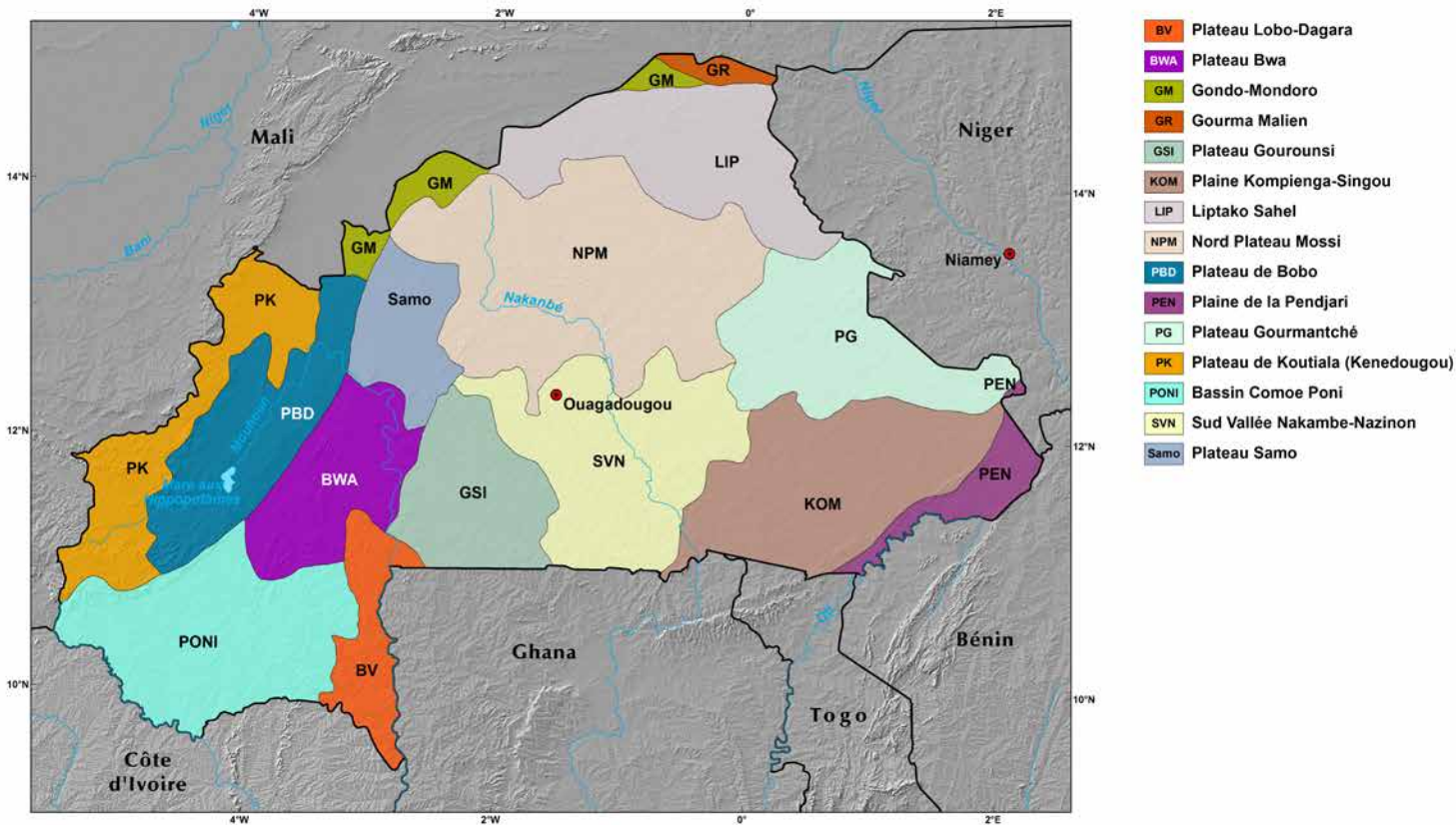
Burkina Faso, (named Upper Volta until 1984) is a landlocked country that spans across the semiarid Sahel and the more humid Sudan bioclimatic zone. Burkina Faso is culturally rich, but limited in its endowment of natural resources. As in many other countries in the region, rural-to-urban migration has spurred the growth of urban areas. However, agriculture still accounts for 32 percent of the country's gross domestic product (GDP) and employs about 80 percent of the population. In the north, where rainfall averages 300–400 mm per year and is limited to a short wet season, animal husbandry is the main livelihood. Rainfall is somewhat higher across the Central Plateau, where agriculture has been the dominant activity for centuries. Cotton is the main cash crop; however, livestock production is also an important source of income. In order to reduce its vulnerability to droughts and water shortages, Burkina Faso has built many dams and levees along major rivers and their tributaries. These reservoirs meet the water needs of the urban population and provide for irrigation of horticultural crops during the dry season, contributing to the country's agricultural diversity. In addition, Burkina Faso has successfully attracted foreign investments and has experienced a rise in gold prospecting and production. With

Environmental Highlights:

- Deforestation due to agricultural expansion
- Fragmentation of natural habitats
- Large number of reservoirs
- Agricultural production diversification
- Widespread adoption of soil and water conservation practices

rapid population growth (over 3 percent per year), Burkina Faso faces major challenges in reaching a balance between preserving its natural resources and feeding its growing population. Despite explosive cropland expansion into remaining natural landscapes, recent successes in land management and increased agricultural productivity are encouraging.

Ecoregions

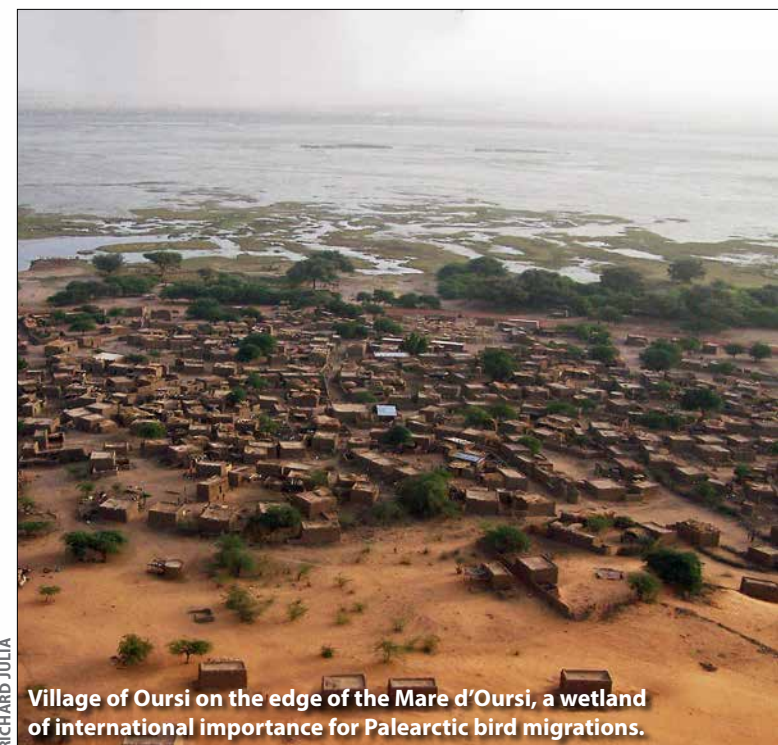


Burkina Faso is fairly flat, with an extensive penneplain that covers about three quarters of the country; elevations range from 250 to 400 m. The Koutiala Plateau (PK), a sandstone block situated in the country's southwest, is the highest and most rugged part of the country. Several rivers cross Burkina Faso; all are tributaries of one of three major rivers: the Volta, the Comoé, and the Niger.

The large northern ecoregions, Liptako Sahel (LIP), Gondo-Mondoro (GM), and Gourma Malien (GR), belong to the Sahelian Region and are dominated by shrub savanna and steppe. Moving south, the Plateaus of Samo, Gourmantché (PG), and the Nord Plateau Mossi (NPM – North

Mossi Plateau) dominate the north-central part of the country, where population density is high. The Mossi people have been farming here for generations, almost exclusively planting millet and sorghum, particularly in the numerous valleys and low-lying areas (Marchal, 1977; Dugué, 1993). The southern ecoregions, from the Pendjari plains (PEN) in the east, to the Bwa Plateau and Comoé Poni Basin (PONI) in the southwest, cover a wide bioclimatic gradient. With rainfall varying from 650 mm to over 1,000 mm, these ecoregions extend over the more humid Sudanian Region. The more favorable climate and permanent rivers make most of Burkina Faso quite suitable to agriculture, with cash crops becoming increasingly important.

Shaded Relief

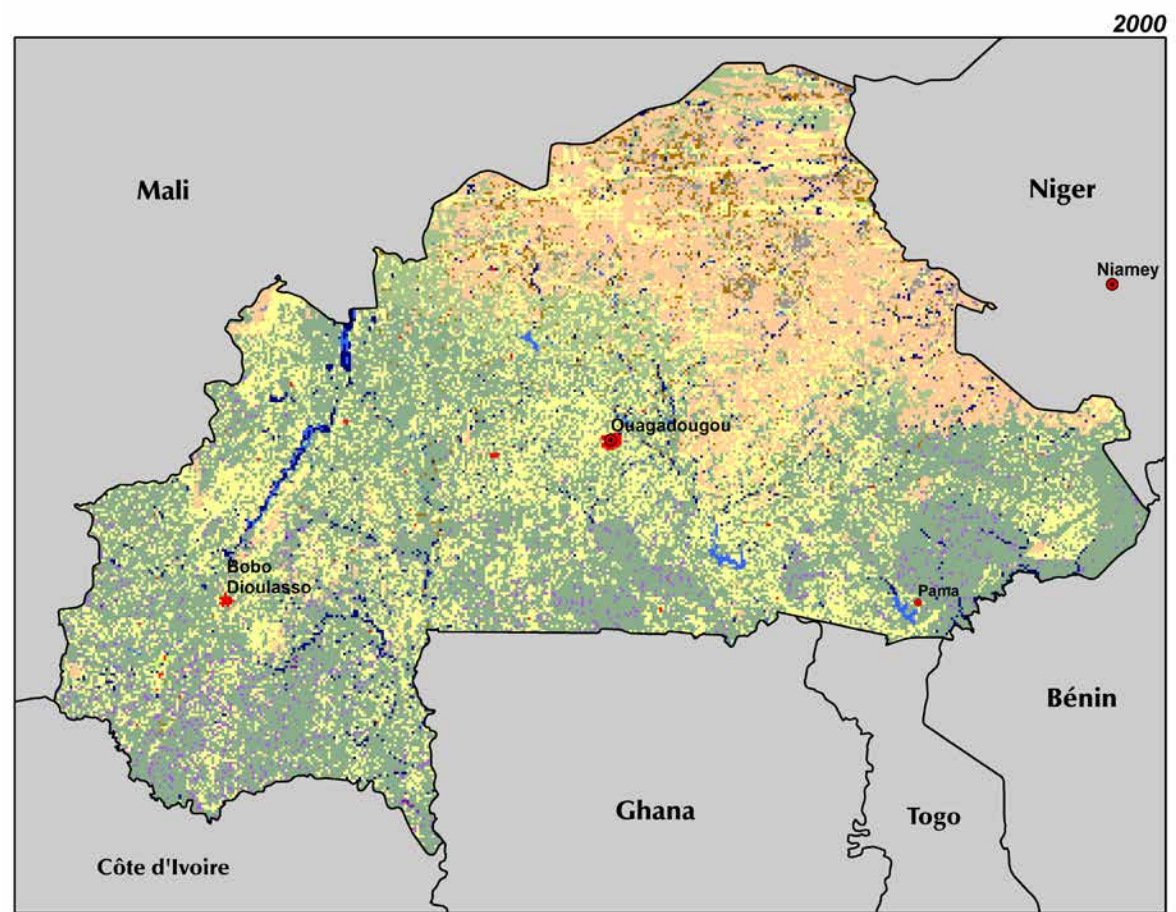
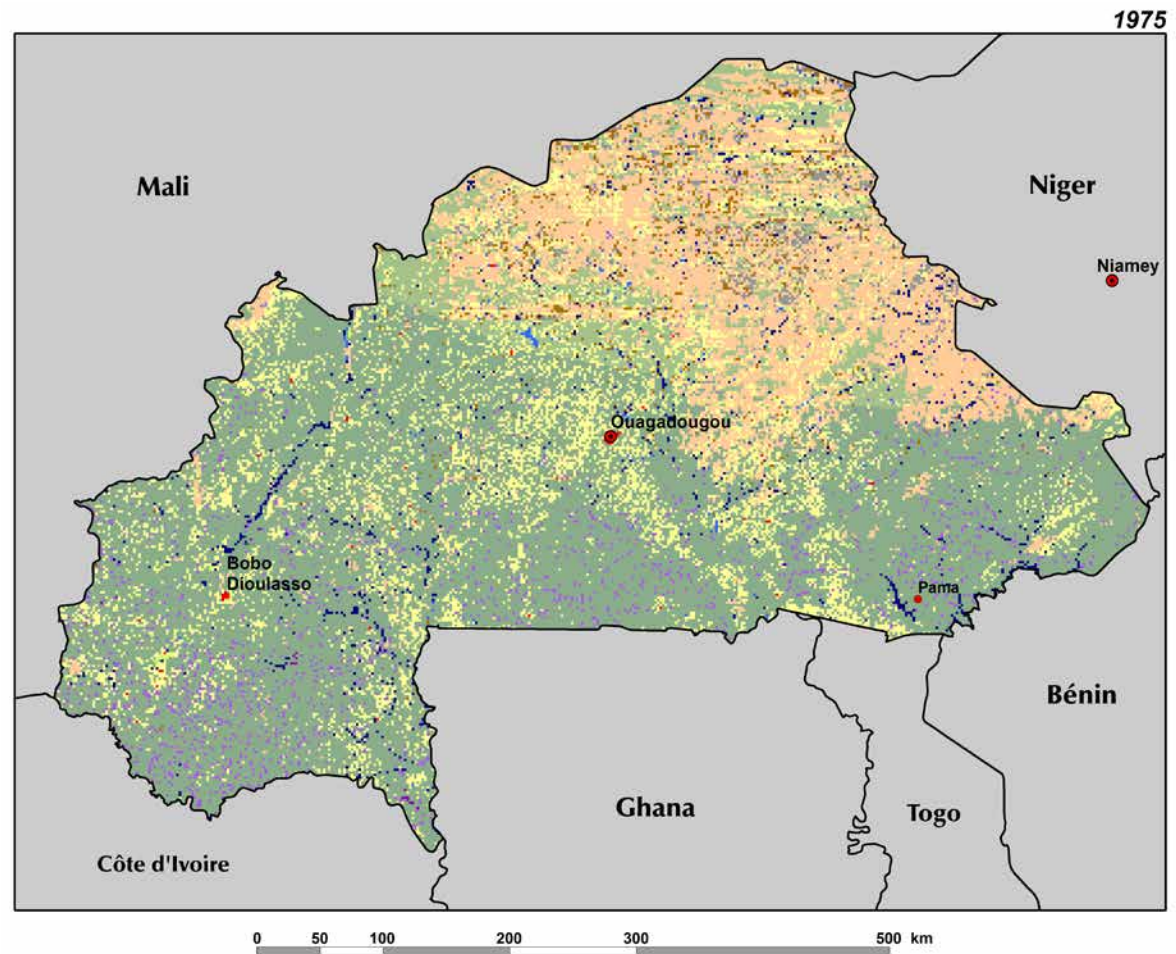


Land Use, Land Cover and Trends

The most obvious change in Burkina Faso's land cover is the major expansion of croplands. In 1975, when the population was just over 6.1 million, savannas were still the dominant landscape. Even then, agricultural development was beginning to fragment the wooded savannas in central areas of the country. Agricultural expansion started along the main roadways. Similarly, agriculture was increasing along the Ouagadougou-Pama corridor in the southeast, and small isolated patches of cropland were appearing among extensive natural areas. However, a large portion of the country's southern ecoregions remained relatively untouched. The majority of protected areas could not yet be distinguished from the surrounding natural savanna landscapes.

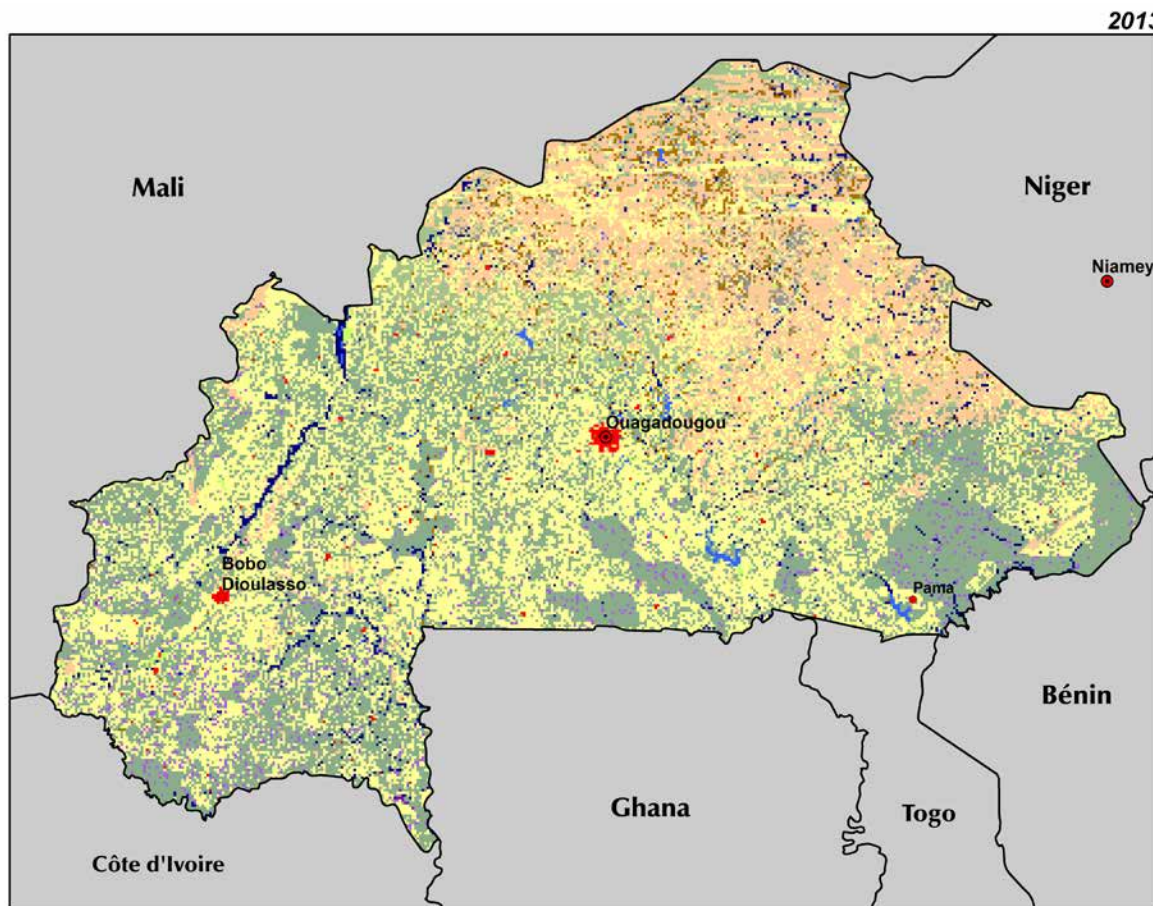
In 2013, the population of Burkina Faso reached 17 million and changes in land cover shown by the maps are striking. Burkina Faso's natural landscapes have been rapidly altered by human activity. Conversion into croplands represents a major transformation, leaving few remnants of the former vegetation structure and diversity. In the north, steppe areas have remained fairly stable because this land cover class occurs in the more arid Sahel, where more marginal soils and lower rainfall severely limit crop cultivation. In 1975, 82.5 percent of Burkina Faso's land was still covered by natural land cover classes (forest, gallery forest, savanna, steppe, or rocky land). In 2013, only 57.4 percent of the country's land was occupied by these land cover classes. Between 1975 and 2013, savannas (Sahelian and Sudanian) shrank by 39 percent. The country's land area covered by rainfed agriculture increased from only 15 percent in 1975 to 39 percent in 2013, an overall increase of 160 percent. This agricultural expansion exceeds 4 percent per year on average, which corresponds to 1,720 sq km of cropland added each year.

Agricultural areas increased only slightly in the north and central plateau, where unfavorable rainfall and rocky soils have kept agricultural expansion to a minimum, but the other two-thirds of the country has experienced considerable agricultural development. Tree and wooded savannas and the gallery forests of the Sudanian zone have been heavily altered



● Capitale Nationale / National Capital





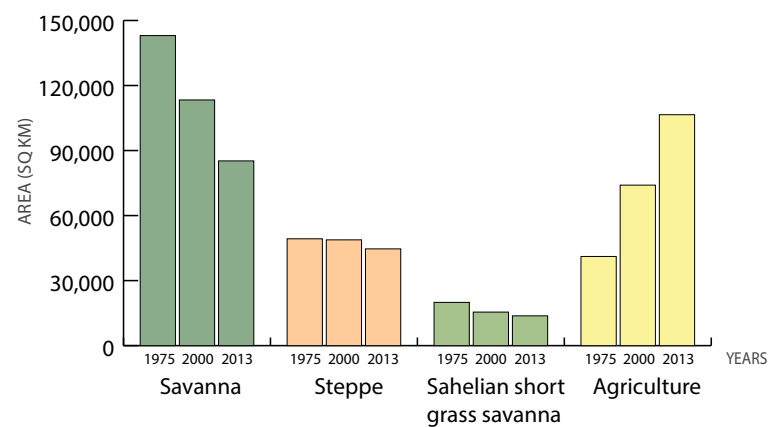
Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Savane / Savanna
- Savane sahélienne / Sahelian short grass savanna
- Steppe
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Surfaces sableuses / Sandy area
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

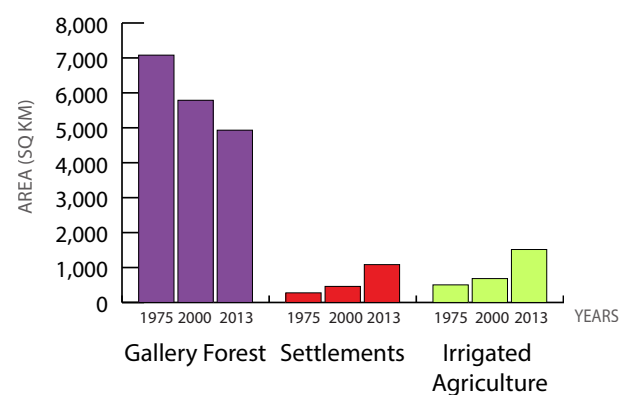
to make room for rainfed crops. The progression of croplands across Burkina Faso during the last four decades has replaced natural landscapes with crop fields and fallows. The only natural landscapes of significant size are restricted to protected areas, and these now stand in sharp contrast against the dominant surrounding agricultural landscape. In 2013, Burkina Faso ranked second in West Africa behind Nigeria as the most agricultural country (in percent of land covered by crops). Burkina Faso is close to reaching the point where human-shaped landscapes cover over half of the country. It seems possible that, in the near future, savannas, woodlands, and forests may only exist in isolated, protected areas that will no longer be connected by natural corridors.

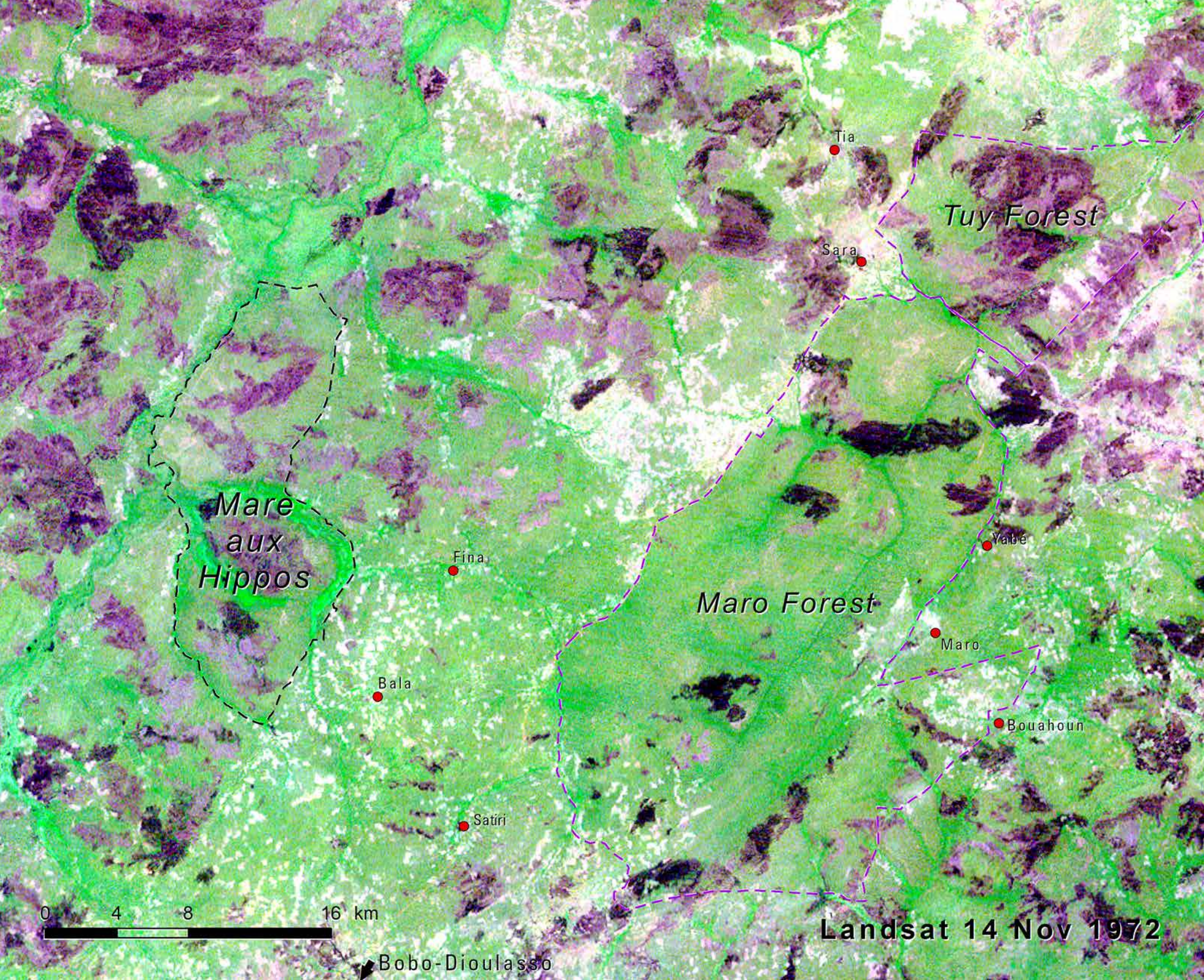
Another critical land cover class is gallery forest. Gallery forests are easily spotted because they stand out from the surrounding savanna vegetation. Although gallery forests are limited to a narrow strip of dense tree cover along streams, their overall area widely exceeds the few remnants of forest (only 48 sq km in 2013). In 1975, gallery forest occupied 7,000 sq km, or about 2.6 percent of the Burkinabe land area. Agricultural expansion decreased this to about 5,000 sq km in 2013, which corresponds to a 30 percent reduction within 38 years. Gallery forests host a wide variety of plant and animal species, making them a conservation priority.

Large area classes



Small area classes



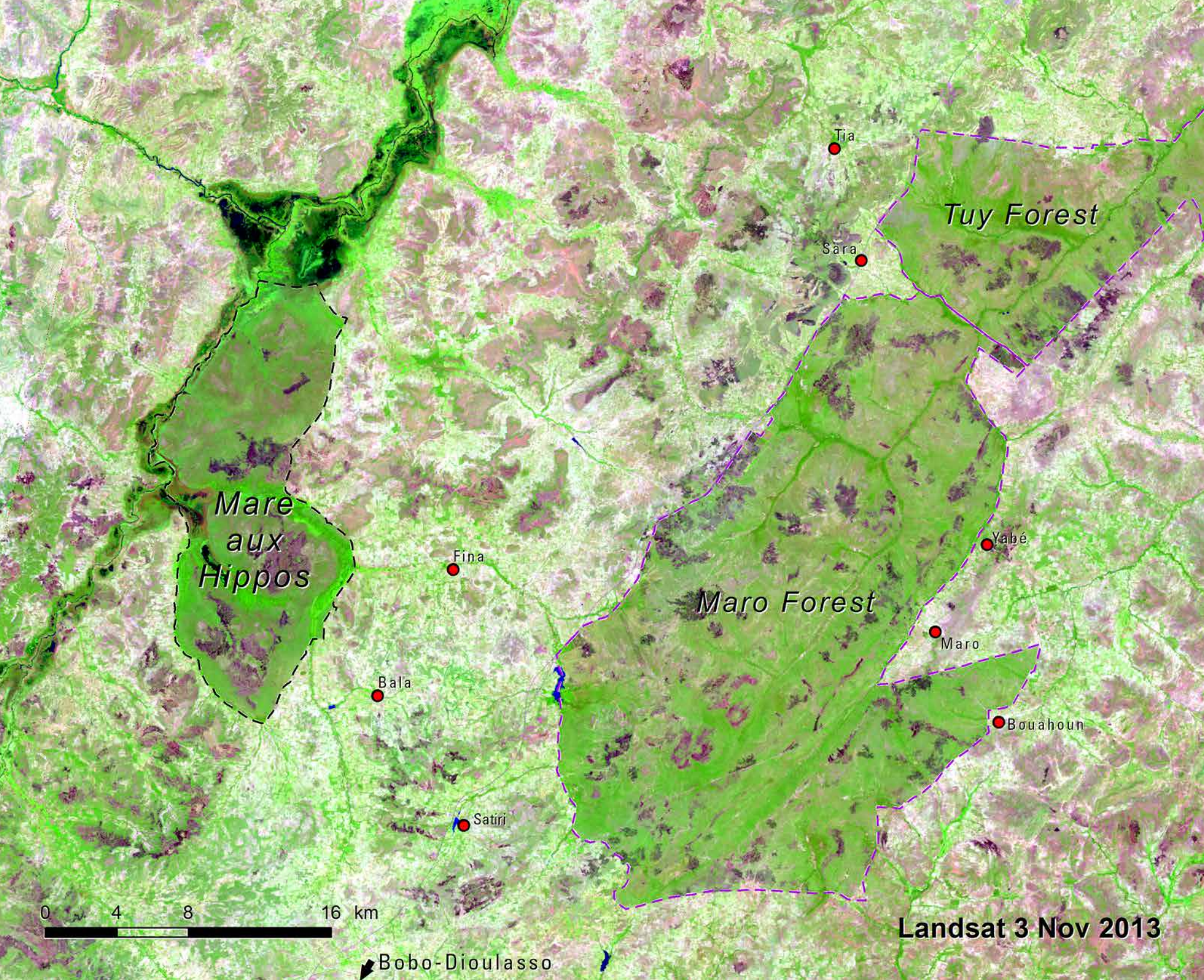


The Mare aux Hippopotames National Park and Biosphere Reserve

The Mare aux Hippopotames National Park was designated as a Biosphere Reserve by UNESCO in 1987 and a Ramsar site in 1990. It is a natural habitat that has remained fairly intact thanks to community protection efforts. This park is a crucial ecosystem for the preservation of regional biodiversity and for local people who rely on its resources. Yet the reserve faces increasing pressure due to a growing population and resulting agricultural expansion, which together threaten its ecological integrity.

Located in the Houet province about 60 km north of Bobo-Dioulasso, the Mare aux Hippopotames is in the Sudanian bioclimatic region, with annual rainfall approaching 1,000 mm. Overall, the reserve encompasses 192 sq km, of which 1.40 sq km is covered by a permanent water body that can reach 6.60 sq km during flooding periods. The reserve is well known for its freshwater lake ("mare" in French), linked to a network of swamps and floodplains and fed by the Volta Noire River.

This complex of wetlands has high ecological value. In addition to its importance as a wintering ground for migrating birds, the Mare aux Hippopotames helps to recharge the water table, prevent or control floods, control erosion, and maintain a more moderate climate. The lake's diverse habitats abound in wildlife unique to the region, including the famous hippopotamuses that inhabit the lake. Protection efforts have increased the number of hippopotamuses



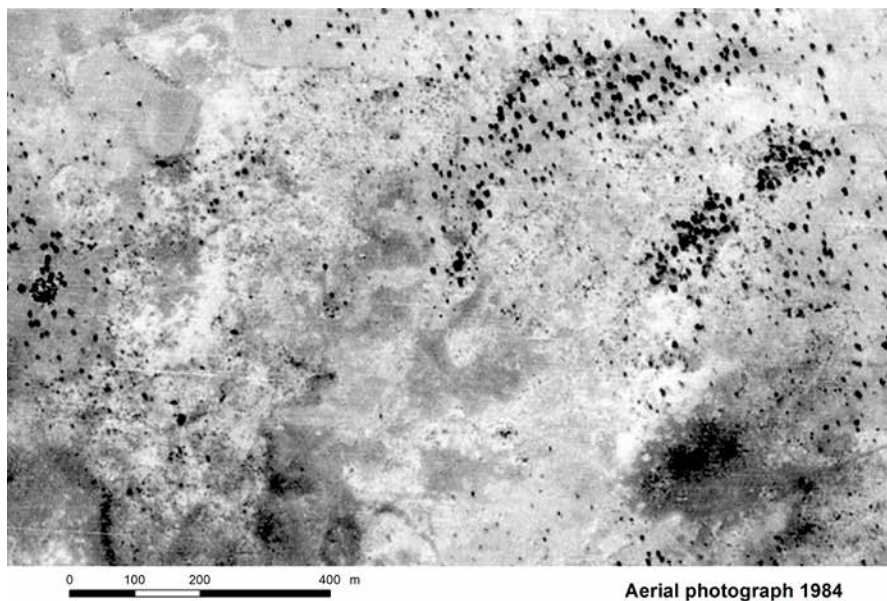
from about 30 animals in 2006 to about 100 in 2010 (SP/CONEDD, 2012). Other mammals also live in the reserve, especially elephant, bushbuck, and roan antelope. The reserve also contains 17 sq km of gallery forest and 110 sq km of tree and shrub savannas.

For local people, the reserve serves as a fishery and provides critical resources, such as fruits, honey, wood fuel and ecotourism (about 1,000 visitors per year) (Pagen, 2006). The satellite image from 1972 shows the beginning of agriculture encroachment into savannas. Croplands appear as light patches; the dark spots are burn scars from natural bush fires. In 1972, the reserve boundaries are hardly discernable within the surrounding savanna. By 2013, the Mare aux Hippopotames reserve's natural savannas sharply contrast with the widespread transformation to agriculture. At least for now, the reserve boundaries are being respected by farmers. However, careful management and monitoring will be needed to preserve this ecosystem into the future.

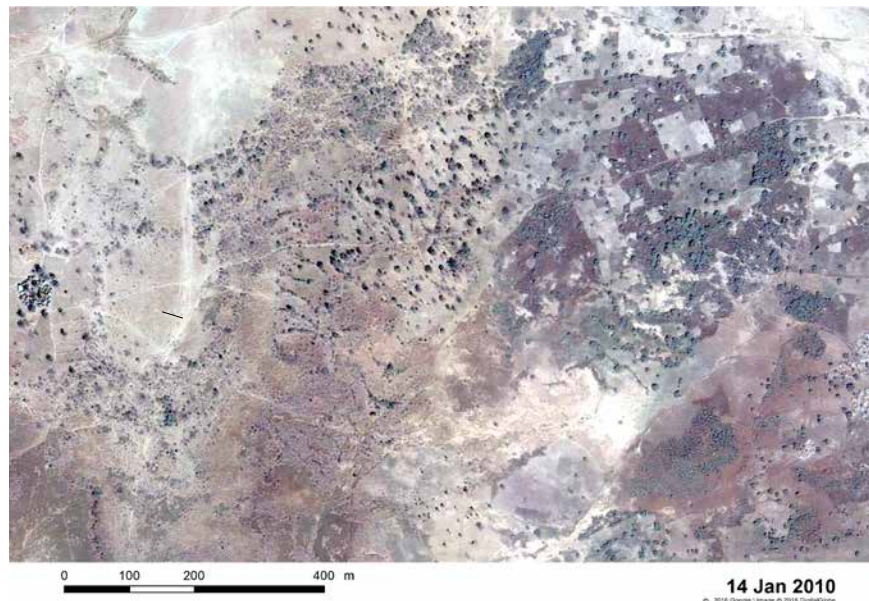


JAMES ROWLAND/USGS

Aerial view of the Mare aux Hippopotames area



Aerial photograph 1984



14 Jan 2010

A comparison of a 1984 aerial photograph (left) and a 2010 satellite image (right) showing the dramatic rehabilitation of barren land by farmer innovator Ali Ouédraogo.



Land rehabilitation and community forests on Burkina Faso's Central Plateau

The landscapes of the northern Central Plateau are known for their harshness, dominated by rocky plateaus and unproductive soils. Despite this, approximately 50 percent of Burkina Faso's rural population lives here, coping with unreliable rainfall. The major droughts of the 1970s and 1980s exacerbated the difficult living conditions of rural people across this region, compelling many farm families to leave their villages and to settle in regions of higher rainfall to the south.

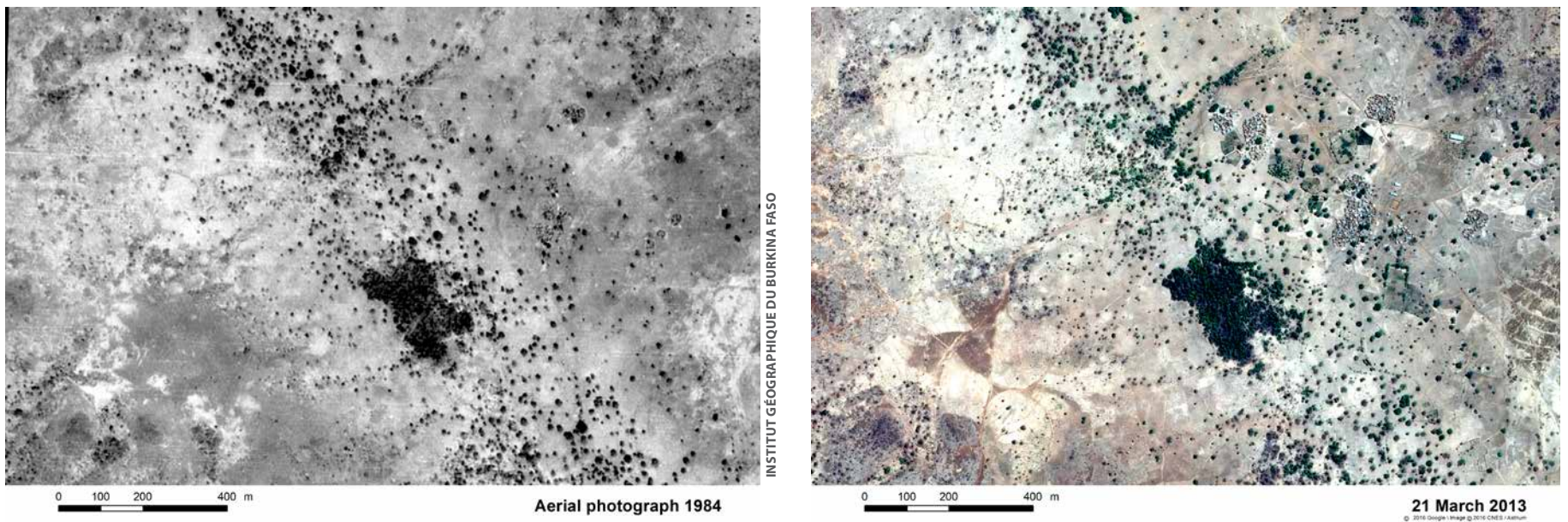
Faced with this situation, many villagers took initiatives to fight against environmental degradation and to improve rural living conditions. Few would have predicted that nearly 30 years after the last great drought, with a population density roughly double what it was then, that we would see many examples of land rehabilitation, including productive farming on formerly barren plateaus. Surprisingly, we also see scattered community-managed forests that show the potential of what can be done across the Sahel. Here, we present two examples of the many successes in land management on the Central Plateau.

The first site is an example of a farmer innovator, Ali Ouédraogo, who in 1983 began rehabilitating degraded, barren land west of Gourcy (see image pair above). The comparison of a 1984 aerial photograph and a 2010 satellite image clearly shows the dramatic results of Ali's work. The barren, laterite landscape (at the center and left of center of the photo) is the site of Ali's future fields. His efforts to rehabilitate this barren land had only just begun. Ali was trained in the layout and construction of contour stone bunds by the Oxfam-funded Agroforestry Project (Reij and Waters-Bayer, 2001). He soon discovered that trees started growing alongside the bunds in his fields because their seeds were deposited there by the runoff water. He protected this natural regeneration, and from 1986 onwards he decided to stimulate the establishment of trees. To grow his crops, he placed seeds in

Two recent views of Ali Ouédraogo's fields with tree regeneration along the rock lines he constructed beginning in 1983.



GRAY TAPPAN / USGS



Comparison of a 1984 aerial photograph (left) with a 2013 satellite image (right) showing the village of Pouima (right center), its community forest, and its agricultural parklands.

thousands of planting pits (also known as “zai”) — the revival of an old practice which also contributed to obtaining good yields of millet, sorghum and cowpea. In 2010, 26 years after Ali’s initial efforts, the barren land had been transformed into productive cropland accompanied by a diverse tree parkland. Ali’s fields and trees dominate the central part of the image, completely rehabilitating the laterite surfaces (top right, opposite page). The zebra stripe pattern is a testament to the vigorous regeneration of trees that take advantage of the favorable micro-environment created by his rock lines, which trap soil and seeds, and enhance water infiltration. Practices such as these have helped rehabilitate between 2,000 and 3,000 sq km of land and produce an additional 80,000 tons of food per year (Reij, Tappan and Smale, 2009).

The second site is one of dozens of community-managed forests widely scattered across the dry landscapes of northern Burkina Faso (see image pair above). These forests provide much inspiration, for they prove that forests can and do thrive in the harsh Sahelian environment. One of these community forests is associated with the village of Pouima, near Gourcy. The forest covers about 4.6 hectares, forming a dense woodland of indigenous trees and shrubs characteristic of the Sahel. The forest is quite old, and has been protected and managed by the villagers for at least several generations. A comparison of an aerial photograph taken in 1984 with a satellite image acquired in 2013 shows that the forest has increased in area.

The villagers of Pouima say that the forest continues to benefit from the protection placed upon it by their ancestors. They inherited the forest, and they feel that they must preserve it for future generations. It continues to serve the community in many ways. Fruit and firewood can be collected only by the older women in the village. However, anyone from the village may harvest fruit when it is ripe. No cutting of wood is allowed. The forest also serves as a site for sacrificial ceremonies, which explains the respect people have for it.



Recent views of the interior of the Pouima community forest.

GRAY TAPPAN / USGS

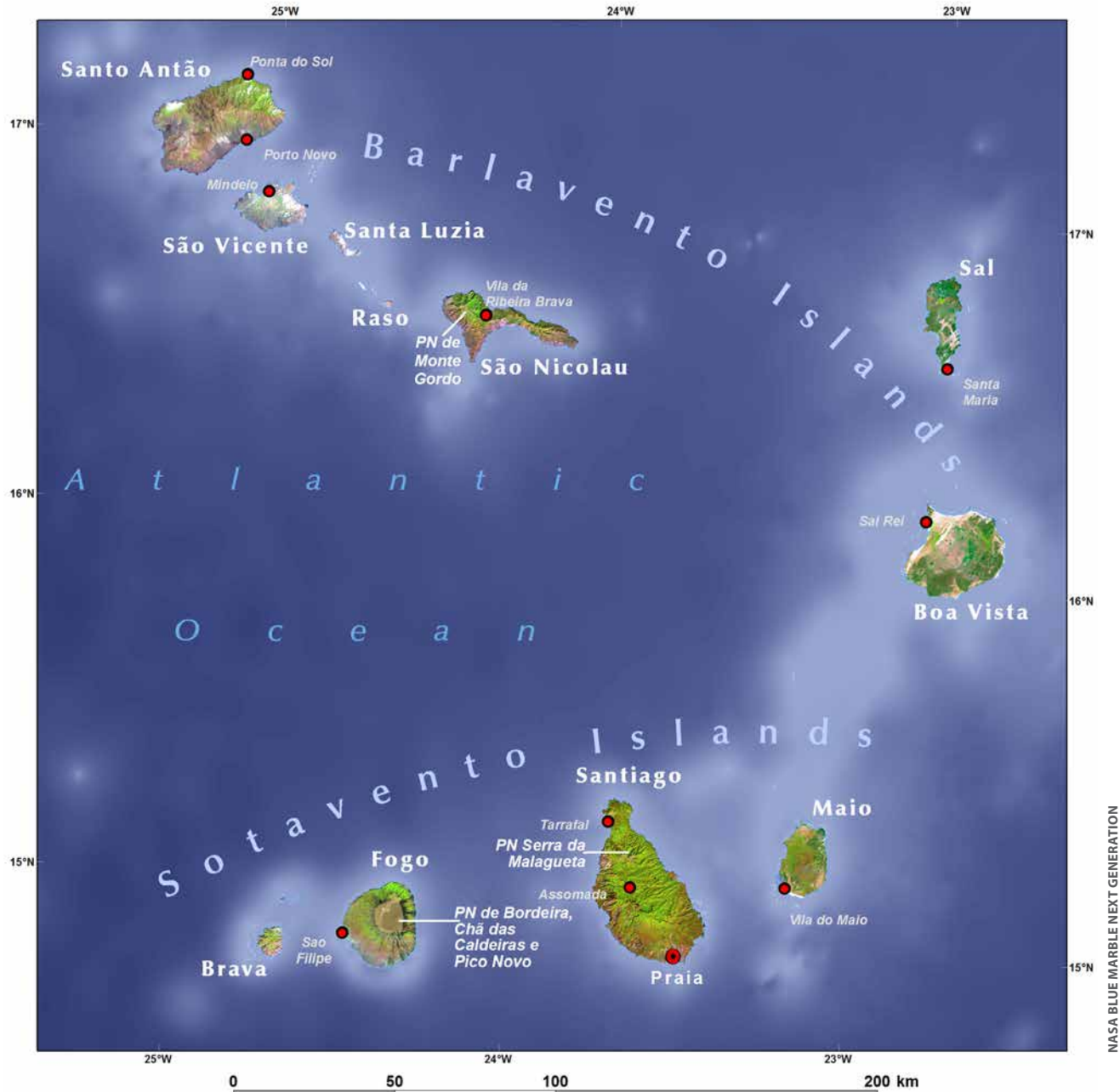


Republic of

Cabo Verde

Total Surface Area: 4,033 km²
Estimated Population in 2013:
507,000

Located approximately 600 km from the West African mainland, Cabo Verde is a volcanic archipelago that consists of 10 larger islands and several uninhabited islets, divided into two ensembles: the leeward islands (Sotavento) in the south and the windward islands (Barlavento) in the north, depending on whether the islands are more or less affected by the trade winds from the northeast (Eklund and Kronhamn, 2002). Before being discovered by the Portuguese in 1456, the Cabo Verde islands were uninhabited. Today, a majority of inhabitants are of mixed Portuguese and African ancestry, and Cabo Verde is known for its Creole Portuguese-African culture and morna music. The climate is tropical dry and rainfall is limited and quite erratic, with an average of less than 300 mm per year. The landscapes of this archipelago are very diverse, formed by volcanic activity 8 million to 20 million years ago. In the mid-20th century, major afforestation and soil and water conservation efforts were undertaken to restore degraded land. The land of the western mountainous islands has undergone extensive conversion that transformed the dry steppe habitat to a heavily human-influenced landscape. Dense forest now covers some of the highest elevations and the more humid windward-facing slopes, while woodlands have been established on some of the drier areas. The potential for agriculture is extremely varied, hampered by aridity, extreme topography, and unequal land ownership.



- Site Ramsar / Ramsar Site
- Parc National / National Park
- Capitale Nationale / National Capital
- Autre Ville / Other City

Environmental Highlights:

- Soil erosion
- Desertification
- Successful afforestation
- Extensive use of agroforestry
- Thriving and expanding tourist trade

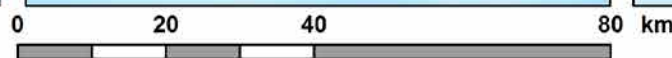
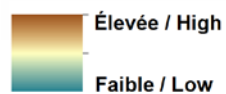
Arid landscape in Cabo Verde

Shaded Relief

Îles de Barlavento / Barlavento islands



Îles de Sotavento / Sotavento islands



The mountainous islands of Brava, Santiago, Fogo, Santo Antão and São Nicolau — all with peaks over 1,000 m — are rocky, with relatively productive volcanic soils in deep valleys that support various kinds of agriculture. These islands have the longest histories of human habitation and densest populations in the archipelago. The rugged landscapes consist of high peaks, ridges, plateaus and valleys. The elevations are high enough (the highest point is Mount Fogo at 2,829 m) to produce a strong orographic effect with few, but intense, precipitation events (Mannaerts and Gabriels, 2000). The mountains catch enough moisture to support grassland as well as intensive agriculture in a succession of altitudinal zones. In contrast, Maio, Boa Vista, and Sal, lying to the east, are flat, highly eroded desert islands with an arid climate marked by year-round exposure to dry winds blowing off the Sahara. Open steppe, bare soil, and long sandy beaches are the predominant land cover types. Their economy is primarily based on salt extraction and animal husbandry.



GRAY TAPPAN / USGS

Forest on the mountain slopes of Santo Antão

Land Use, Land Cover and Trends

Centuries of land alteration to expand agricultural production has created a highly engineered, complex mosaic of land use in Cabo Verde. A few early records describe the original vegetation of the islands. Grasses and shrubs likely constituted the vegetative communities of the arid lowlands. The more humid highlands probably consisted of woody shrubs interspersed with herbaceous species, and a handful of tree species colonizing the most favorable waterways. Closed-canopy forests likely never existed (Benton, 2013). After the Portuguese colonization, the land underwent vast land use changes. Intensive agricultural practices, livestock (primarily goats), and other introduced plant and animal species greatly altered the native vegetation and decimated the native tree populations. The reduction of natural vegetation in many areas also contributed to soil erosion. By the early 20th century many parts of the islands were heavily degraded.

Afforestation and soil and water conservation efforts to restore degraded land were begun in earnest in the mid-20th century by the Portuguese (Benton, 2013). From 1928 to 1975, Cabo Verde gained about 30 sq km of afforested areas, mostly in Santo Antão, Fogo, and São Nicolau (WOCAT, 2015; Lopes and Santos, 2010). Both the mountainous parts of the islands and the arid and semiarid zones benefited from the afforestation programs. After Cabo Verde's independence in 1975, critical forest regulations were established and the expansion of forests continued. These afforestation efforts were already highly visible on the landscape in 2000. The earliest plantations (*Pinus spp.*, *Cupressus spp.*, and *Eucalyptus spp.*) on the highlands of Santo Antão and São Vicente have become dense forests and woodlands on the highest slopes, where cultivation is not possible. These forests are still expanding. Forest area increased by 21 percent (6 sq km), and woodland by 24 percent (34 sq km), between 2000 and 2013. The more recent afforestation projects of the last two decades have focused mainly on the drier lands of the Sotavento islands (i.e. Santiago, Maio, and Brava). The main species being planted were *Prosopis juliflora*, *Acacia spp.* and *Ziziphus mauritiana*, all well adapted to the arid climate. A total of 248 sq km of plantations were mapped in 2000, decreasing



The land use and land cover maps characterize the landscapes at a resolution of 500 m. They are based on visual interpretation of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and high-

resolution images, from 2000 and 2013. No comparable sources of imagery were available to complete a map for the 1975 period.



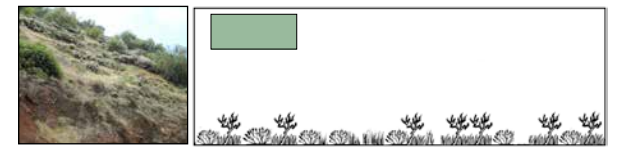
2013



Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Forêt claire / Woodland
- Zone arbustive / Shrubland
- Savane herbacée / Herbaceous savanna
- Steppe
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Surfaces sableuses / Sandy area
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

Cabo Verde has a semi-arid shrubland land cover class that is unique to these islands. It is characterized by shrubs and bushes scattered on discontinuous grassland cover (shrubs and bush cover between 25 and 50 percent). Shrublands are mostly located on the more humid northern slopes of the mountainous islands or along the ribeiras.

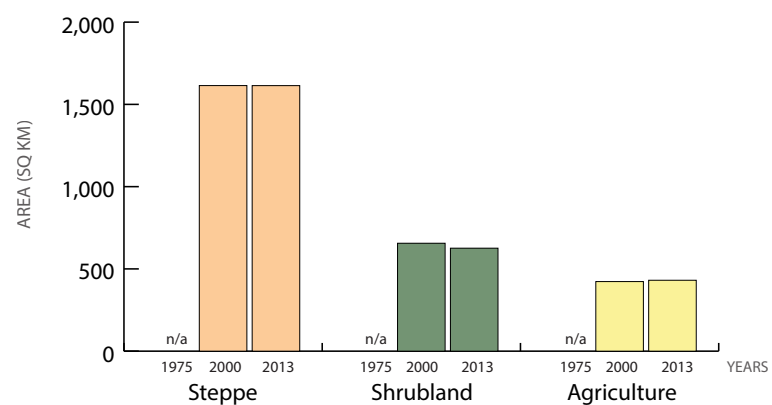


slightly to 243 sq km in 2013. As the young trees matured and their canopies coalesced, the plantations take on a woodland appearance. The succession of some plantations into woodlands accounts for the decrease in plantation area.

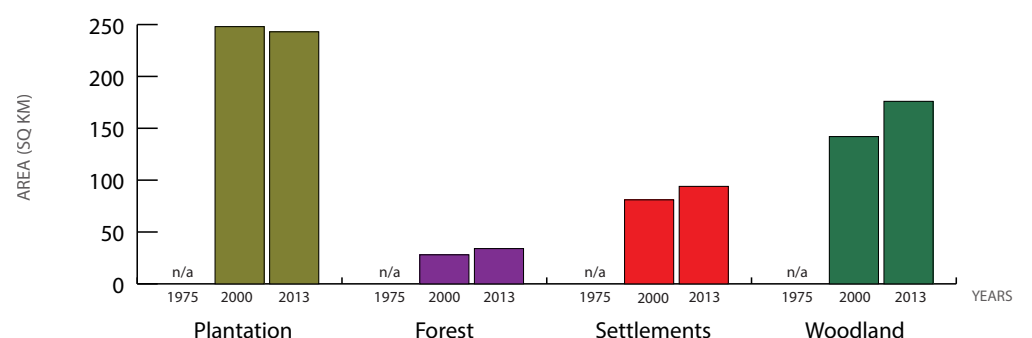
The arid zones of the lower elevations — all the flat islands such as Sal, Boa Vista, and Maio, and the pediments of the mountainous islands — account for over half the Cabo Verde's land area. These areas, predominantly bare, steppe, or shrubland, remained largely stable from 2000 to 2013. Suitability for agriculture is very low but better suited to pastoral or silvo-pastoral use. However, steppe and shrubland areas decreased 2 and 5 percent, respectively, between 2000 and 2013, mostly because of restoration projects that converted certain areas to plantation or woodland.

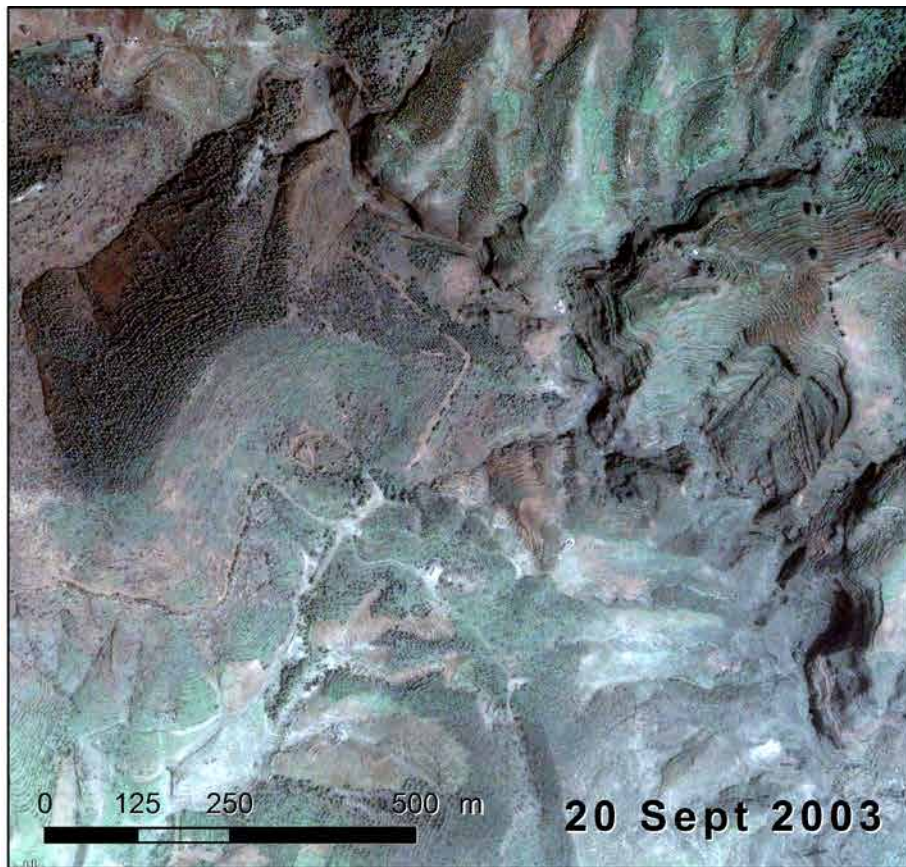
In 2000, agriculture covered 423 sq km over the whole archipelago, about 10 percent of the country area. Cropland increased by only 8 sq km from 2000 to 2013. Cultivated areas, however, are not evenly distributed among the islands. Santo Antão and Santiago are the most cultivated islands, with more than 70 percent of the total farmed land of Cabo Verde. Irrigated agriculture was mostly found on Santiago island in the *ribeiras* — valleys where ephemeral streams have created steep hillsides, at times with nearly vertical walls. In spite of climatic hazards and rugged terrain, agriculture is the main activity in the archipelago, occupying more than half of the workforce.

Large area classes



Small area classes





A comparison of two satellite images showing the dramatic afforestation on the slopes of Santo Antão Island.



The successful large-scale afforestation of Santo Antão and Santiago Islands

Santo Antão and Santiago are the two largest islands of the archipelago of Cabo Verde (991 sq km and 754 sq km, respectively). Following the colonization of the islands in the late 1400s, the fragile environment of these relatively recent volcanic mountains, associated with the arid and semiarid sahelian climate, underwent severe deterioration (Spaak, 1990). The land degradation problems led to large afforestation programs after independence in 1975, which restored more than 800 sq km of land and drastically changed the landscape of Cabo Verde.

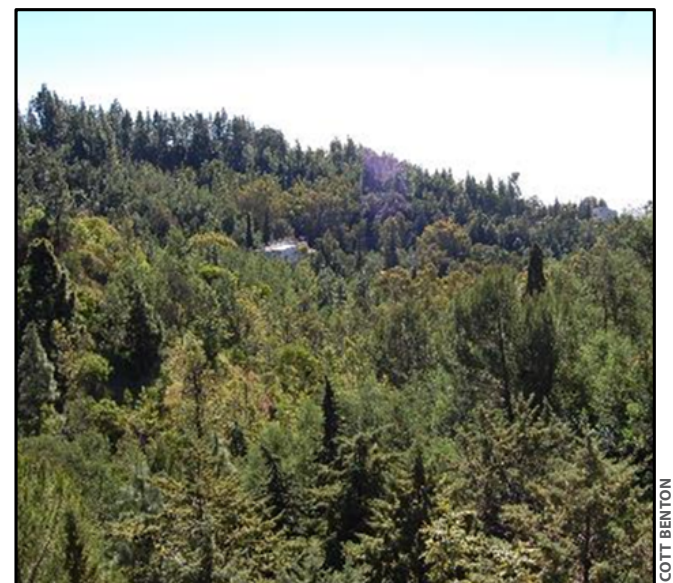
Santo Antão and Santiago islands are characterized by a dramatic landscape with steep slopes, associated with a strong orographic effect. Their soils are generally young, shallow, and very susceptible to erosion. The climate varies from humid to arid, with a short rainy season from August to October and periodic multi-year droughts. Rainfall varies widely from place to place and year to year, ranging anywhere from 50 to 1400 mm (Eklund and Kronhamn, 2002).

Since the 1980s, afforestation has focused mainly on the arid zones of Santiago and Santo Antão, where the annual rate of afforestation was 57 sq km (Santiago received about 80 percent, or 45 sq km). This was a big step toward land restoration (Eklund and Kronhamn, 2002). The goals of all afforestation efforts were to 1) provide soil erosion control by mechanical and vegetative methods; 2) increase infiltration, fog capture, and water availability; 3) increase biodiversity and vegetative cover; and 4) increase economic aspects of forests such as firewood, employment,

Ground pictures showing the afforestation on Santo Antão island between 1950 (left) and 2012 (right) (Agua das Caldeiras).



ANONYMOUS, 1960



SCOTT BENTON



A comparison of two satellite images showing the afforestation on the drylands of Santiago Island.

or timber (Benton, 2013). Over the past 40 years, this afforestation has contributed to a general rehabilitation of vegetation cover, combating desertification, meeting energy needs, forage production and development of agrosilvopastoral systems, while at the same time contributing to a significant increase in the diversity of the landscape in Cabo Verde (Lopes and Santos, 2010). The former degraded areas of Santiago and Santo Antão islands are now covered by a dense forest in the mountainous parts, and woodland in the drier areas.

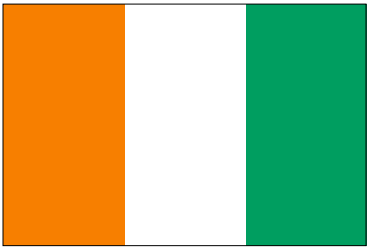
The first image pair (see opposite page) shows an example of afforestation on a humid highland in Santo Antão. In 2003 (left), forest and woodland already existed on some of the slopes and highland areas, resulting from earlier afforestation projects in the 1970–1980s. In the early 2000s, new plantations were implemented on slopes but the trees were not visible yet in 2003. In 2014, however, the forest became denser and new woodland and growing plantations appeared on the lower slopes. Afforestation continues and several programs have been implemented in the late 2000s, especially in Santiago and Maio, but not to the same extent as before.

In the second image pair (above), high-resolution images show the afforestation on arid land in Santiago (8 km northwest of Praia). In 2002, an afforestation project had just started to restore the degraded steppe. The trees might have been planted but are not visible in the imagery. In 2014, the whole area was covered by dense plantations. Today, 67 percent of the total reforested area in Cabo Verde is located in Santo Antão or Santiago, and represents 7 percent¹ of the country area (about 300 sq km). The afforestation also had a great impact on the local population. Forests are perceived to provide numerous benefits to communities, especially to the poorer rural interior of the island. Since the beginning of the afforestation program, major positive changes in vegetation, land use, and infrastructure can be observed.

Afforestation is one of the key technologies to address the fragility of ecosystems. It provides better protection against erosion and makes better use of rainfall in order to maintain the sustainability of agricultural systems (WOCAT, 2015). The forests of Cabo Verde present an enduring example of positive land use change in West Africa. They are heavily utilized by the local population to meet many needs and are viewed favorably. Simple changes in forest management practices can improve biodiversity conservation and increase economic activity. Many valuable lessons learned in Santo Antão and Santiago can be applied in other West African afforestation projects.



¹ This number represents the area that successfully was reforested and is now covered by forest, woodland, or new plantations. It does not take into account the agroforestry plantations in areas of agricultural potential.



Republic of

Côte d'Ivoire

Total Surface Area: 322,463 sq km
Estimated Population in 2013: 21,622,000

Côte d'Ivoire borders the Gulf of Guinea with 515 km of coastline fringed by a network of large lagoons. The northern and southern halves of Côte d'Ivoire present two distinct landscapes: a seasonally wet-and-dry savanna landscape typical of the Sudanian zone in the north, and in the south, humid tropical Guinean and Guineo-Congolian landscapes with a variety of evergreen vegetation types. The southern part of the country was once entirely covered by dense tropical forest, but is now dominated by a mosaic of plantations, degraded forest, and cropland, along with patches of remaining dense forest. Until recent decades, there were greater stands of useful timber in Côte d'Ivoire than in any other West African country. The area covered by rain forest was halved between 1900 and 1960, and that trend has continued — most of the forest has now disappeared. The Taï National Park, in southwestern Côte d'Ivoire, constitutes the largest intact relic of old tropical forest in West Africa and was listed as a World Heritage Site in 1982.

Côte d'Ivoire has a climate system that is common to all the Gulf of Guinea countries, with two clear rainfall seasons on the coast, transitioning to one rainy season in the north. Soils are particularly fertile and agriculturally productive, even in the northern semiarid savanna. Côte d'Ivoire is one of the world's largest producers of cocoa and coffee. The richness of this country is not only based on the land but also on the people — Côte d'Ivoire is home to 68 ethnic groups, contributing to a wide diversity of customs and art.



- Réserve de Biosphère / Biosphere Reserve
- Site Ramsar / Ramsar Site
- Parc National / National Park
- Réserve Naturelle / Nature Reserve
- Réserve de Faune / Faunal Reserve
- Forêt Classée / Forest Reserve
- Capitale Nationale / National Capital
- Autre Ville / Other City

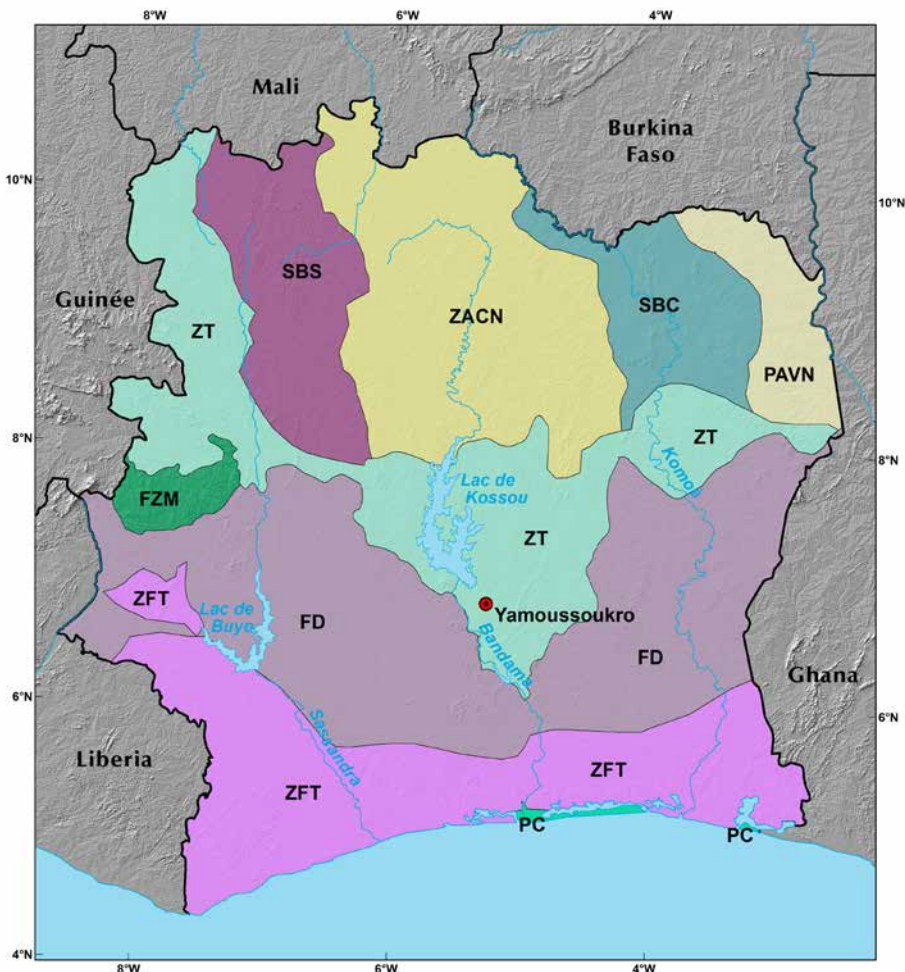
Environmental Highlights:

- Deforestation
- Land degradation
- Largest intact tract of primary forest
- Second highest number of chimpanzees among West African countries



Cropland at the bottom of a forested hills in southern Côte d'Ivoire

Ecoregions



- FD Forêt Dégradée
- FZM Forêt Montagnarde
- PAVN Plateau Agricole de la Volta Noire
- PC Plaines Côtières
- SBC Savanes du Bassin de la Comoé
- SBS Savanes du Bassin de la Sassandra
- ZACN Zone Agricole du Centre-Nord
- ZFT Zone Forestière Tropicale
- ZT Zone de Transition

The southern part of Côte d'Ivoire is characterized by broad plains, dissected by three main rivers, the Sassandra, the Bandama, and the Komoé (also spelled Comoé). These plains and their productive soils were once forested, but are now heavily used for agriculture and plantations. The center of the country is a transition zone between forest and savanna. Most of the savannas are being encroached upon by rainfed agriculture, especially in the north, along the borders with Mali and Burkina Faso. In northwestern Côte d'Ivoire, several highlands rise from the surrounding plateau. This mountainous region is part of the Guinean Highlands that extend from the southern Fouta Djallon through southeastern Guinea, northern Sierra Leone and Liberia, and adjacent areas of Côte d'Ivoire.

Shaded Relief



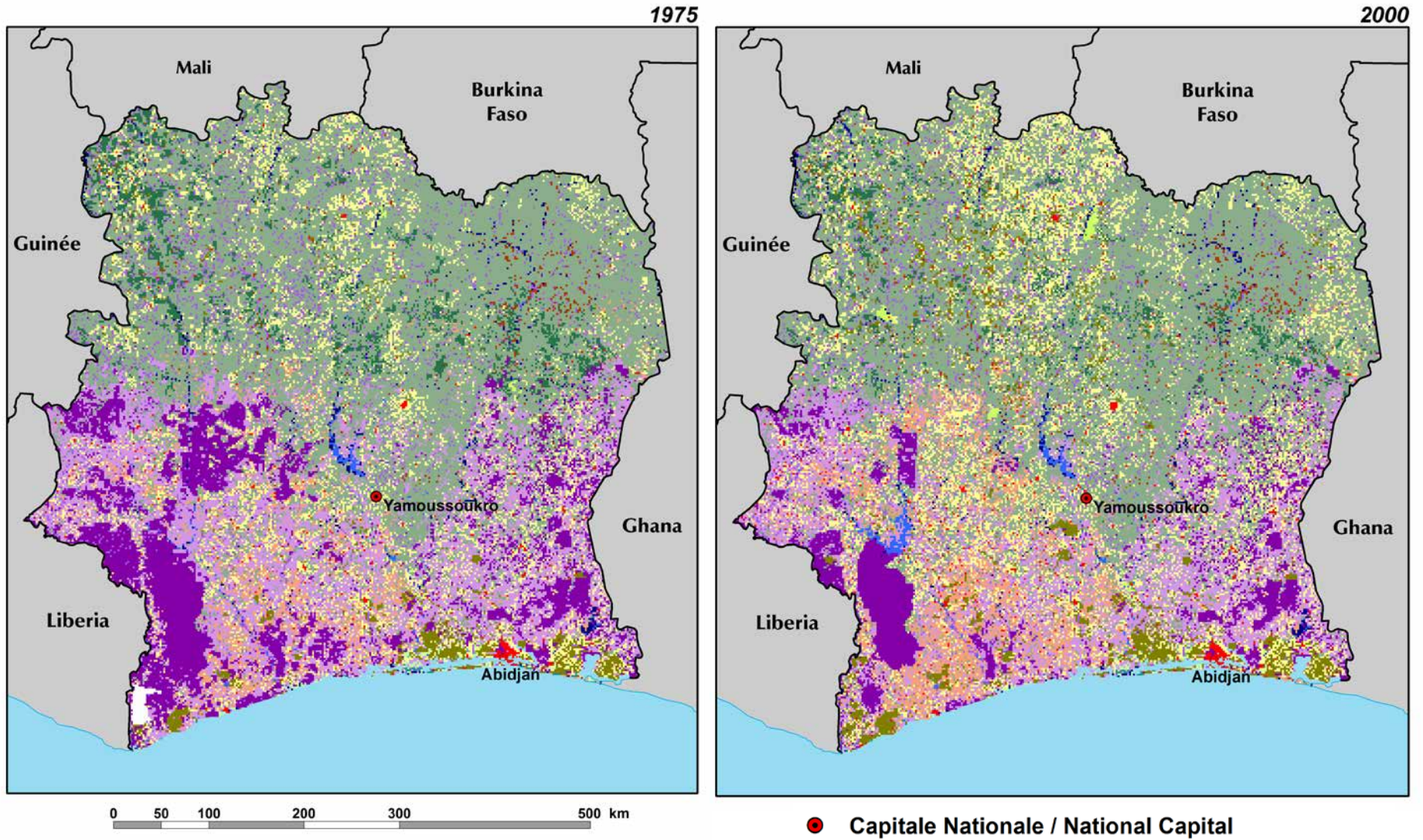
- Élevée / High
- Faible / Low



GRAY TAPPAN / USGS

Dense forest in southern Côte d'Ivoire

Land Use, Land Cover and Trends



Pineapple crop in Côte d'Ivoire

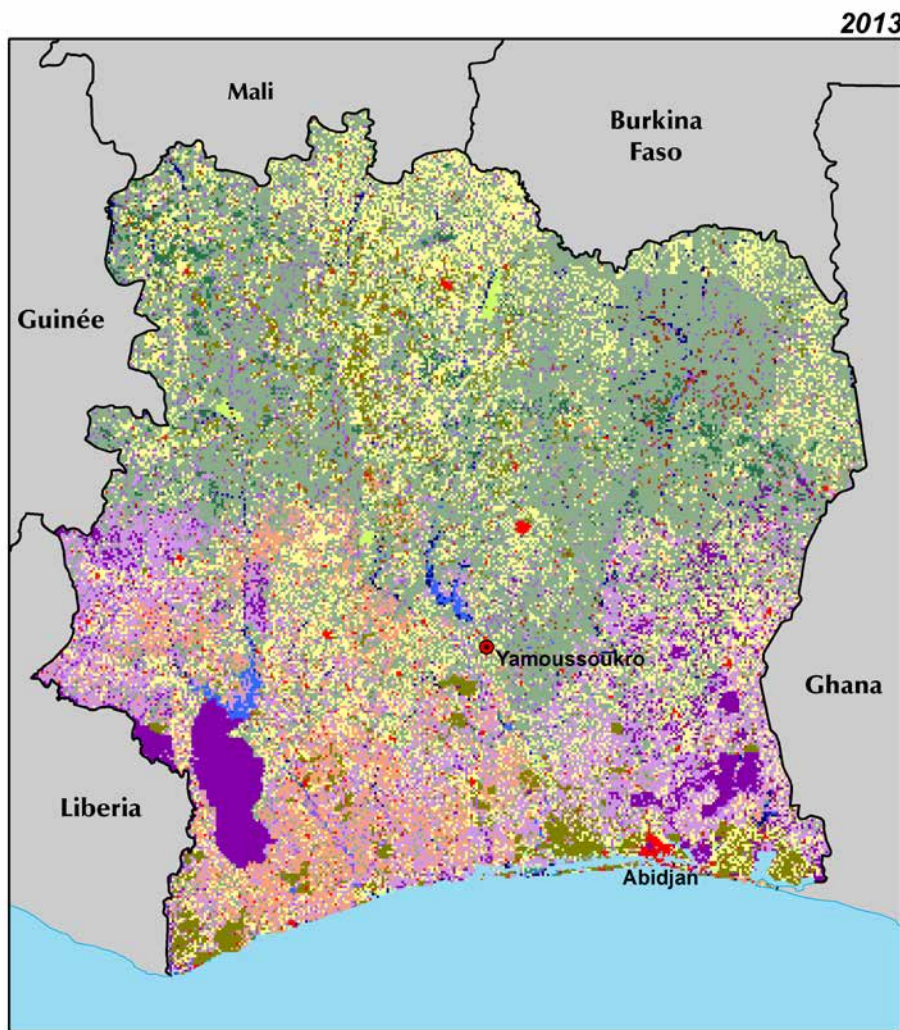
GRAY TAPPAN / USGS

Land use and land cover in Côte d'Ivoire have changed dramatically over the 38-year period between 1975 and 2013. Most striking has been the expansion of agriculture, with a net increase of 84 percent (31,600 sq km). Agriculture spread almost everywhere in Côte d'Ivoire, with the exception of the northeast, where the boundary of Comoé National Park is well respected and the savanna protected.

In the southern half of the country, rainfall is higher and the soils more productive, making it the center of production for most of the export crops, such as coffee and cocoa. Palm, coconut trees, and rubber tree plantations increased by 160 percent (10,420 sq km), mostly in the southern and central parts of the country. In the northern half of Côte d'Ivoire, subsistence and cash crops such as cotton, sugar, starches, and rice greatly increased, fragmenting the large expanses of woodland and savannas.

Because a large part of the population in Côte d'Ivoire obtains its subsistence from farming, agricultural expansion was mostly driven by population growth. Population increased steadily from 6.6 million in 1975 to 21.6 million in 2013, a rise of 227 percent. On the land cover maps, the area occupied by settlements — towns and cities — doubled from 1975 to 2013. This national average, however, masks an uneven distribution, with much of the population concentrated in the farm-and-forest patchwork region in the south.

Expansion of agricultural lands was not without consequences on the forested landscape. Indeed, the continuous deforestation to clear for cultivation is one of the most dramatic and possibly irreversible events in Côte d'Ivoire. In the past, most of the timber harvest occurred



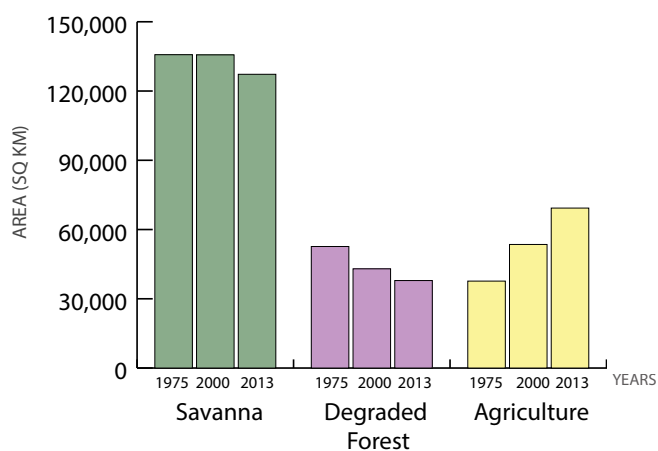
Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Forêt dégradée / Degraded forest
- Forêt claire / Woodland
- Forêt marécageuse / Swamp forest
- Mangrove
- Savane / Savanna
- Fourré / Thicket
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Surfaces sableuses / Sandy area
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

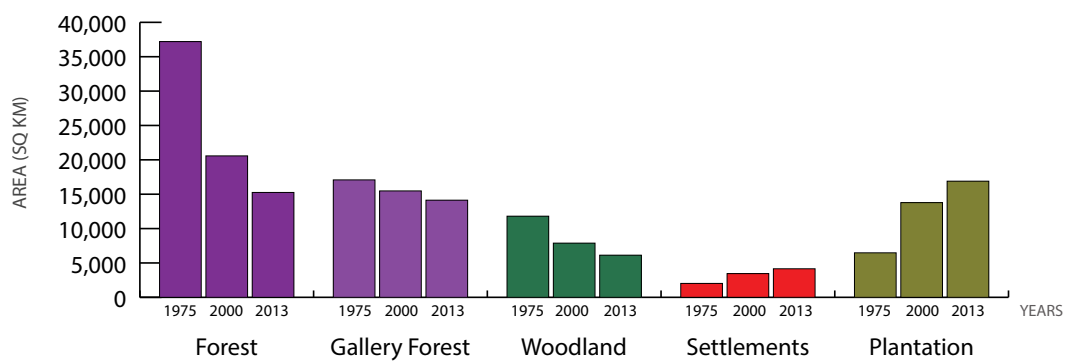
within the reserved forests that counted for 40 percent of the total forest of the country (14,500 sq km). However, excessive extraction over the past 38 years has led to their depletion, and reserved forests lost almost 70 percent of their forest coverage. In addition, timber theft and illegal logging are widespread and are the primary reasons for the degradation of natural forests. Forests and gallery forests, as well as woodland outside protected areas, are all heavily degraded. By 2013, Côte d'Ivoire had lost nearly 60 percent of the 37,300 sq km of dense tropical forests that existed in 1975. Similarly, degraded forest decreased by 28 percent and woodland area declined by 48 percent. Another important forest class is the gallery forest — dense ribbons of biologically rich forest that follow watercourses and river systems up into the Sudanian zone savannas in the north. While they are limited to narrow strips of dense forest, their total area covers almost 5 percent of the country. In 1975, the gallery forests represented 17,100 sq km. This figure decreased to 14,130 sq km in 2013.

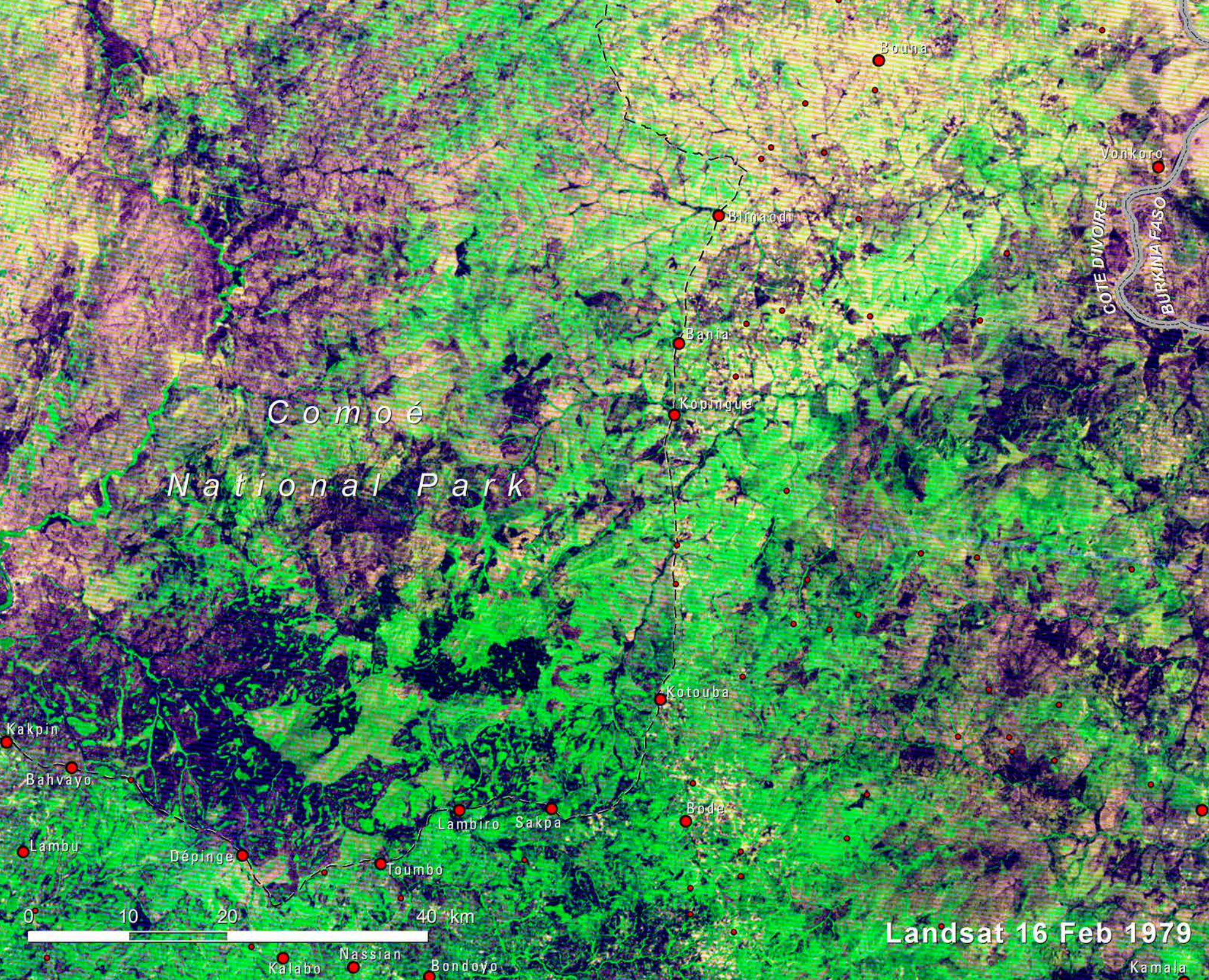
Despite recent forest management efforts taken by the government, such as halting illicit harvesting, promoting reforestation, reformation of logging activities, increasing the protected areas, and encouraging private investments in forestry, expansion of agricultural lands driven by an increasing population remains the key driver to deforestation in Côte d'Ivoire (Ehuitché, 2015).

Large area classes



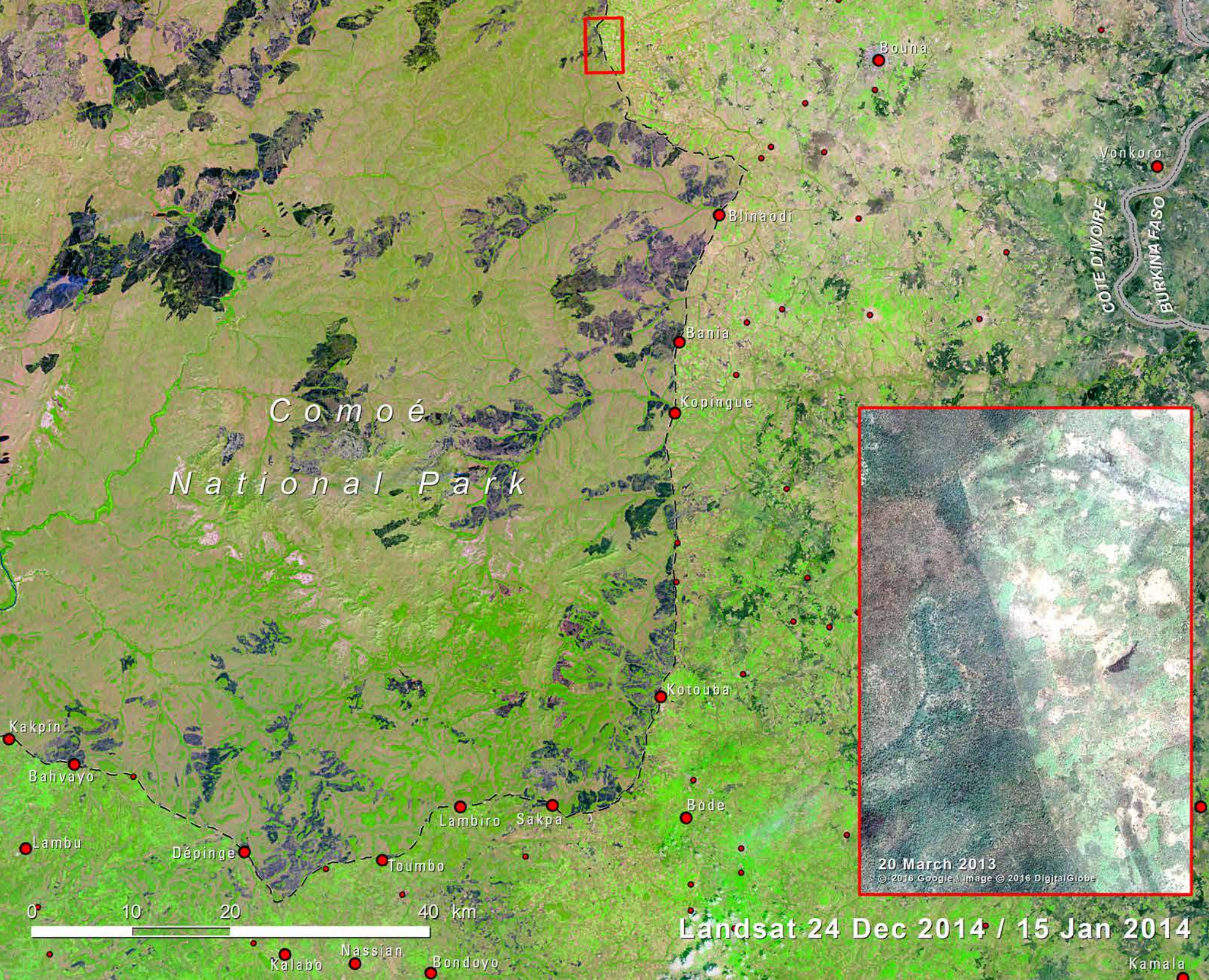
Small area classes



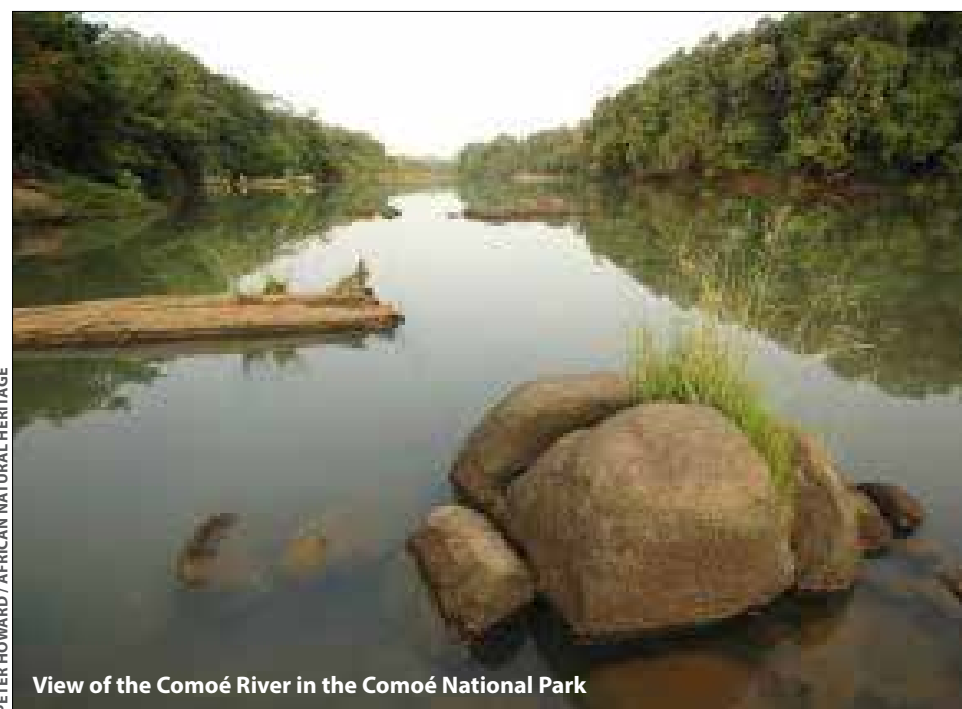


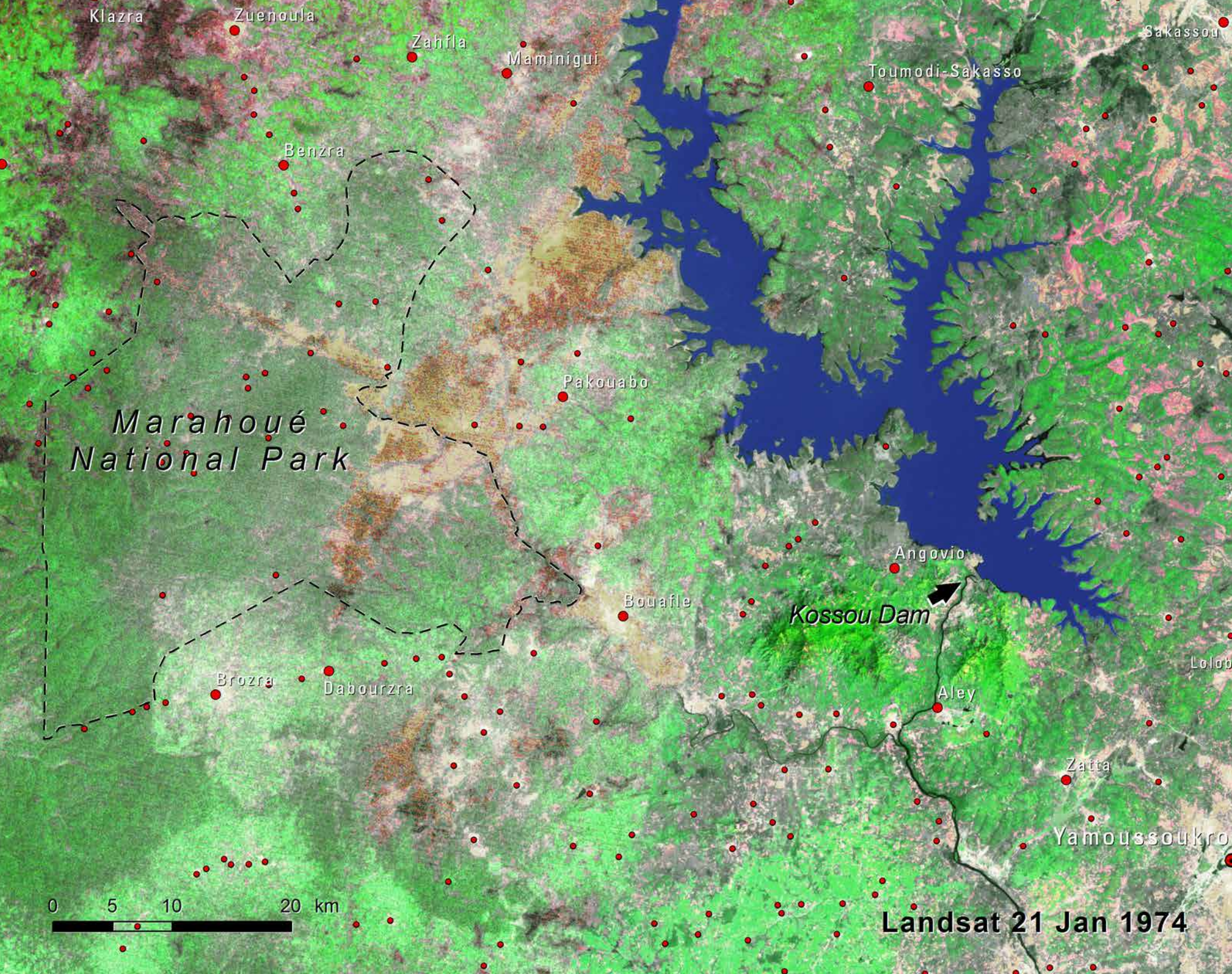
Protecting the ecological integrity of Comoé National Park

Located in northeastern Côte d'Ivoire, 30 km south of the Burkina Faso border, Comoé National Park covers about 11,500 sq km. Comoé National Park was established in 1968 and designated a UNESCO World Heritage Site in 1983. Due to its location and vast area dedicated to the conservation of natural resources, this park is an ecological unit of particular importance. Comoé National Park contains a remarkable variety of habitats, ranging from open savannas and woodland to wetland and gallery forests, normally only found much farther south (UNESCO, 2015). In the 1970s, the Park's natural landscapes could hardly be distinguished from the surrounding savannas and woodlands, with the exception of the northeast boundary where agriculture had already started to expand between the park and the Burkina Faso border (UNEP-WCMC, 2014). By 2014, the park boundary clearly stands out from the growing agricultural landscapes around it. Despite increasing pressure from agriculture expansion and urbanization, the park's natural habitats have remained relatively intact. However, in 2003, Comoé National Park was added to the list of World Heritage Sites in Danger due to poaching, overgrazing by cattle, and breakdown of management owing to civil conflict (UNEP-WCMC, 2014). To reduce these problems, checkpoints and patrol posts were implemented



around the park boundary, and only two zones are open for tourism. An evaluation by UNESCO recommended an efficient surveillance system throughout the park and the establishment of participatory management with local communities to diminish the pressures and impacts associated with the management of areas located on the periphery (UNESCO, 2015). Currently, Comoé National Park is a rare sanctuary for a variety of West African species, including the western chimpanzee, the African wild dog, and the African elephant. It is also one of the few remaining natural areas in the region that is large enough to ensure the ecological integrity of the species that live there. Despite the clearly established and defined boundaries, additional management measures will be needed to protect the unique park ecosystems in their entirety in the long term.



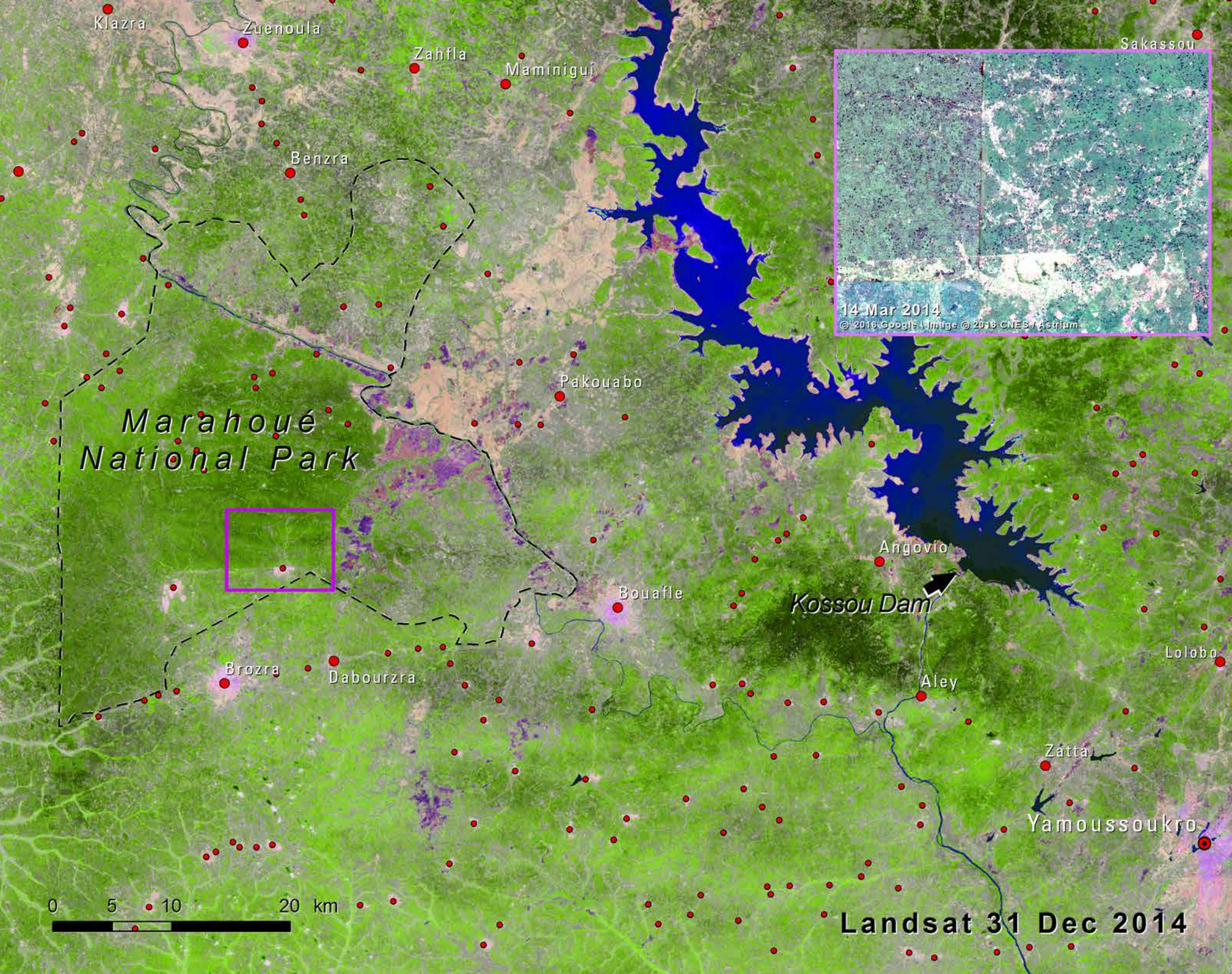


Marahoué National Park: a protected area on the edge of existence

Marahoué was designated as a national park in 1968, after being previously established as a wildlife reserve in 1956. The park covers 1,010 sq km in central Côte d'Ivoire. Marahoué lies on the northern edge of West Africa's Upper Guinean forest and was especially unique for its range of habitat types and great diversity of fauna (Schulenberg and others, 1999).

As a transition zone between the savannas and the tropical rain forest, the park was an important center of biodiversity due to the presence of species from both savanna and forest-type habitats. The variety of environments in Marahoué also provided refuge for several rare and endangered species, including forest elephants, primates, and a wide variety of birds (Schulenberg and others, 1999). Prior to its establishment as a national park, several cacao plantations and cropland had already encroached within its boundary, covering about 3 percent of the park area by 1975. The remaining vegetation of Marahoué National Park was composed of approximately 60 percent forest, 15 percent degraded forest, 5 percent gallery forest, and 17 percent mosaic of savannas and thickets.

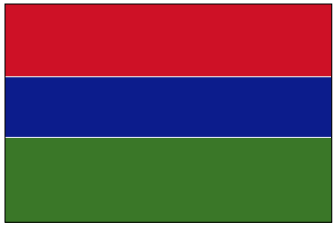
In recent decades, Côte d'Ivoire has experienced some of the highest rates of deforestation seen anywhere in Africa. The non-eviction of farmers within the national park exacerbated human pressure on its resources, especially near the eastern and northern boundary. This human pressure is also related to the proximity of the city of Yamoussoukro and the Kossou dam (Denis, 2015). Wildlife and other park resources were subject to exploitation by human populations from adjacent villages and towns, mainly for game meat, wood and land for agriculture. Many people continue to cultivate and extend large cocoa plantations within the park boundaries,



even though it is illegal (Schulenberg and others, 1999). By 2014, the forest had totally disappeared and only few vestiges of degraded forest and gallery forest remained (12 percent and 4 percent of the park area, respectively). Agriculture and plantations had replaced natural habitats and covered about 15 percent of the park area. Although the land cover appears green and lush in the 2014 Landsat image, intensive deforestation had converted most of the forested habitats to savanna and thicket that now represent 67 percent of the Marahoué National Park area (see inset above).

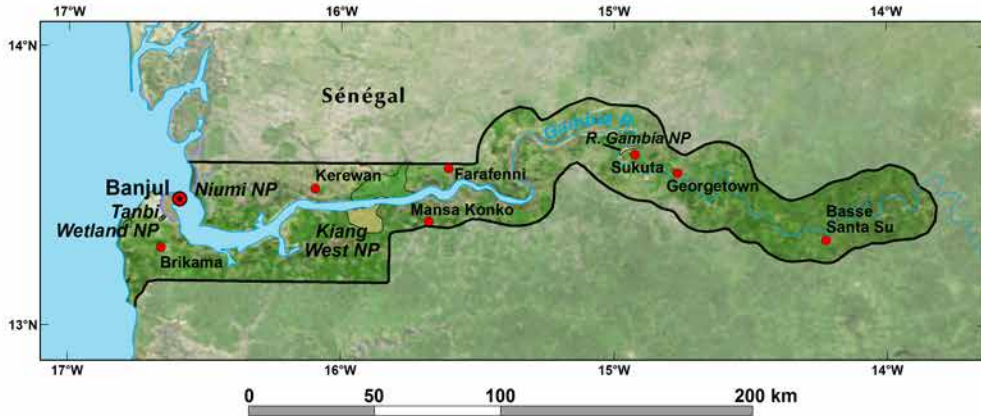
Human pressure has left wide swaths of land inhospitable to most park wildlife, and today Marahoué National Park is characterized by a sharp deterioration in its natural resources. Human pressures, years of continuous poaching and the development of plantations have significantly reduced the number of animals within the park boundary (Denis, 2015). As habitat shrinks, species such as the chimpanzee (*Pan troglodytes verus*) were almost totally eradicated, and others, such as the elephants, had to be relocated to avoid conflicts with farmers (AFP, 2014).





Republic of

The Gambia



-  Ramsar Site / Site Ramsar
-  National Park / Parc National
-  Nature Reserve / Réserve Naturelle
-  Faunal Reserve / Réserve de Faune
-  Capitale Nationale / National Capital
-  Autre Ville / Other City

NASA BLUE MARBLE NEXT GENERATION

Total Surface Area: 11,295 km²
Estimated Population in 2013: 1,867,000

The Gambia is the smallest country on mainland Africa, with an extent of about 330 km east to west, and less than 50 km north to south. It is a former British colony, forming an enclave within Senegal, a former French colony. The Gambia is one of the most densely populated countries in West Africa. The highest concentration of people is around the increasingly urbanized landscape spreading outward from The Gambia's capital, Banjul. The city is built on a small peninsula tucked between mangrove-lined estuaries and the broad mouth of the Gambia River, which rises out of the Fouta Djallon Highlands of Guinea. With its natural port, Banjul is an important trading post between West Africa and the world. The main ethnic groups are the Mandinka, the Wolof and the Fula.

The Gambia's economy is dominated by agriculture. About two-thirds of the population is engaged in raising livestock or growing crops, such as rice, maize, millet, sorghum, and cassava. Small-scale manufacturing includes processing peanuts, fish, and hides. The country lies within the Sudanian climatic region, with a distinct short rainy season and a long dry season. The Gambia has also found a niche in tourism, taking advantage of its beautiful beaches, warm water, and nature retreats. It is well known for bird watching, with over 540 species of birds recorded (Barlow and Wacher, 1997).

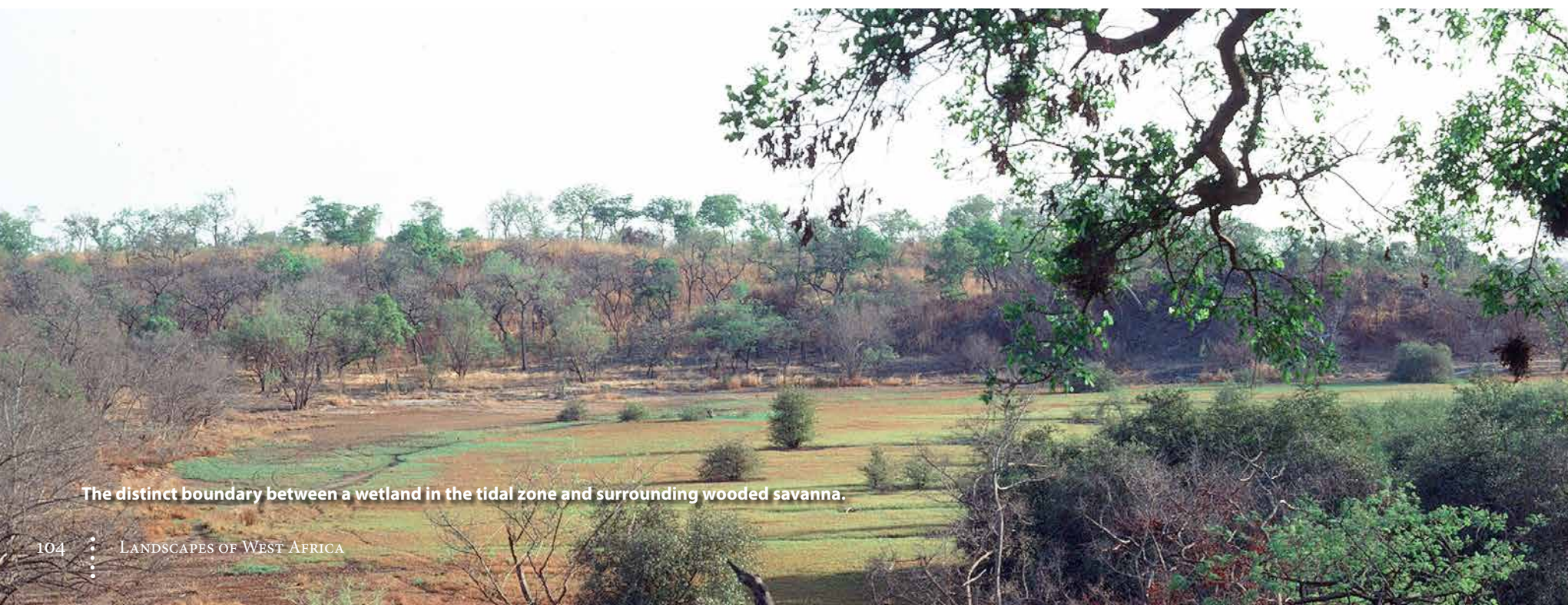
Environmental Highlights:

- Overfishing
- Coastal erosion
- Deforestation
- Rapid urbanization
- Tourism, bird watching



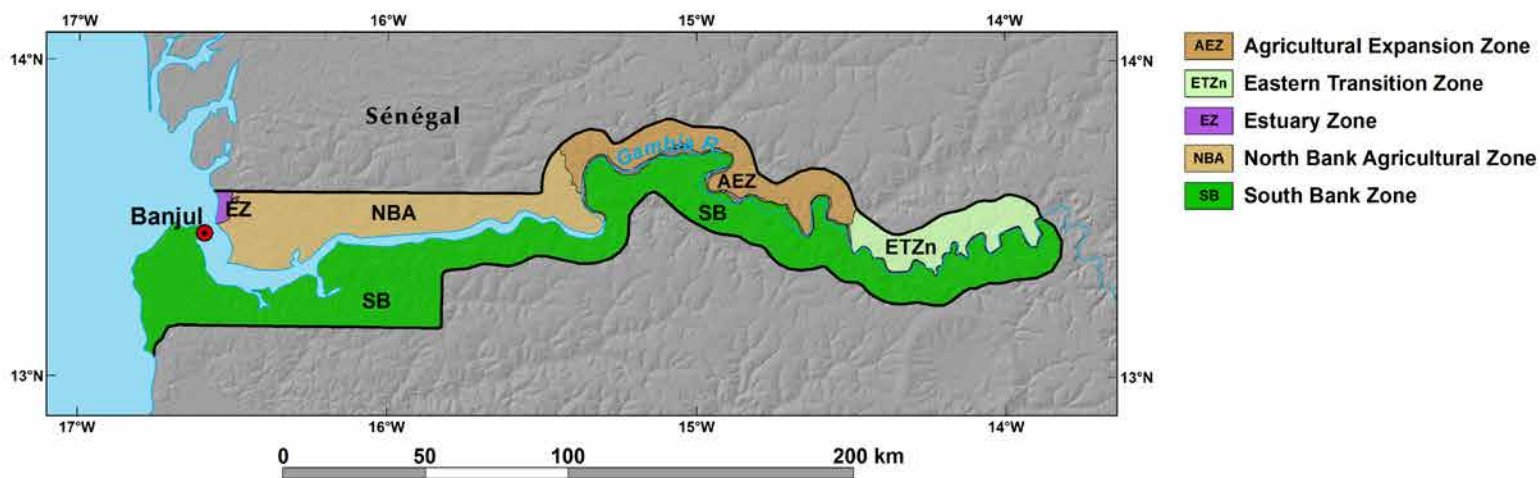
Malachite kingfisher

MELISSA MATHIS/SGT



The distinct boundary between a wetland in the tidal zone and surrounding wooded savanna.

Ecoregions



The Gambia lies entirely within the drainage basin of the Gambia River, a basin that extends well into Senegal and Guinea. The river’s channel only descends 10 m as it flows from The Gambia’s eastern border to its mouth at Banjul. The river’s flow is very seasonal, and sea water intrudes some 200 km upriver during the dry season. The land is also flat, especially in the western half. In the eastern part of The Gambia, the river carves a meandering path through laterite-capped plateaus; terraces and shallow valleys characterize the terrain. The highest point is Red Rock, at only 53 m above sea level.

The Gambia’s five ecoregions are all transboundary areas that have their counterparts in Senegal. The Gambia River forms a natural boundary between the northern ecoregions and the one in the south — the South Bank Zone (SB). Over a century ago, most of the country was blanketed by Sudanian woodlands, wooded savannas, and gallery forests. Today, most of the more wooded landscapes are found on the south side of

the river, where the South Bank Zone extends seamlessly into Senegal’s Casamance (CAS) ecoregion. The woodlands nearer the coast are denser and have much higher biodiversity than those in the east.

Major systems of mangroves and mudflats are found along the coast near the mouth of the river, extending nearly half way up the length of the country. These constitute the Estuary Zone (EZ), an ecoregion that extends well into the Saloum River complex in Senegal. North of the Gambia River, three ecoregions reflect the varying degrees of human transformation of natural landscapes into agricultural ones. The North Bank Agricultural Zone (NBA) is almost entirely devoted to groundnut, millet, and maize cultivation on sandy soils. The Agricultural Expansion Zone (AEZ) is a mix of broad cultivated valleys among laterite plateaus with shrub and tree savannas. In the east, the Eastern Transition Zone (ETZ) is more sparsely populated, and the predominance of lateritic plateaus has spared the region from the more intensive human pressures of the western regions.

Shaded Relief

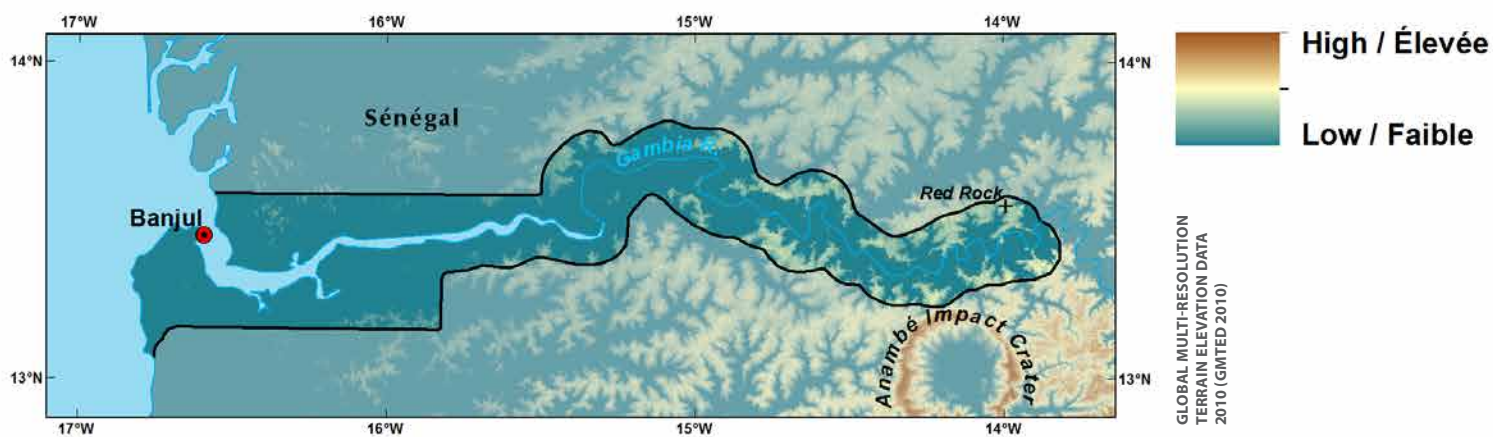
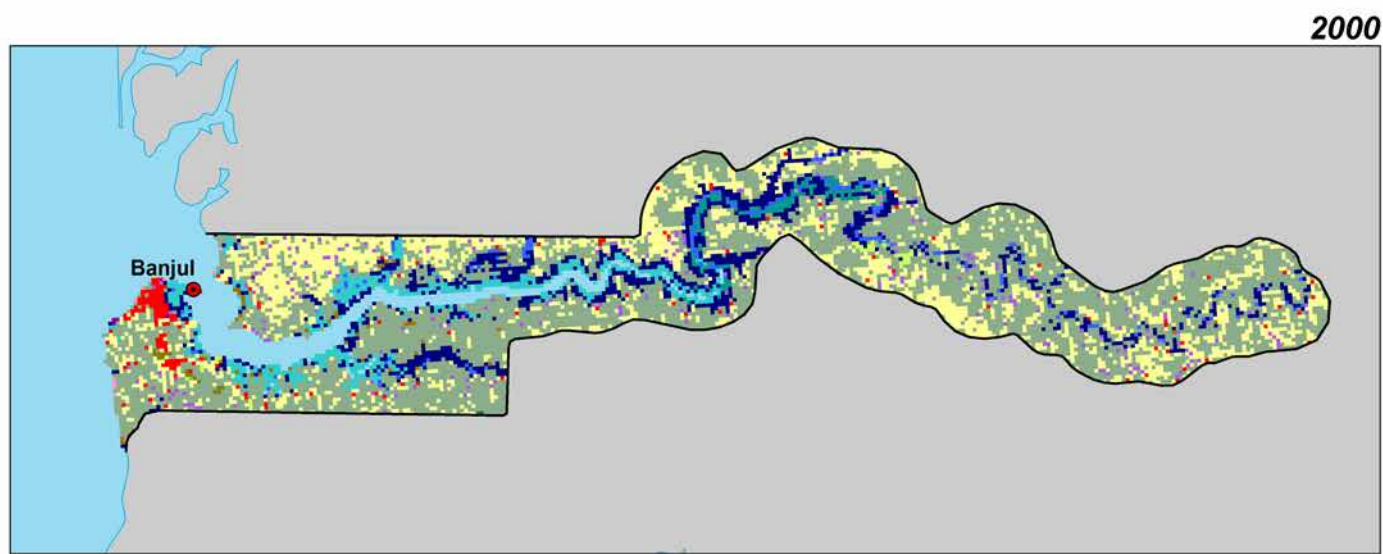
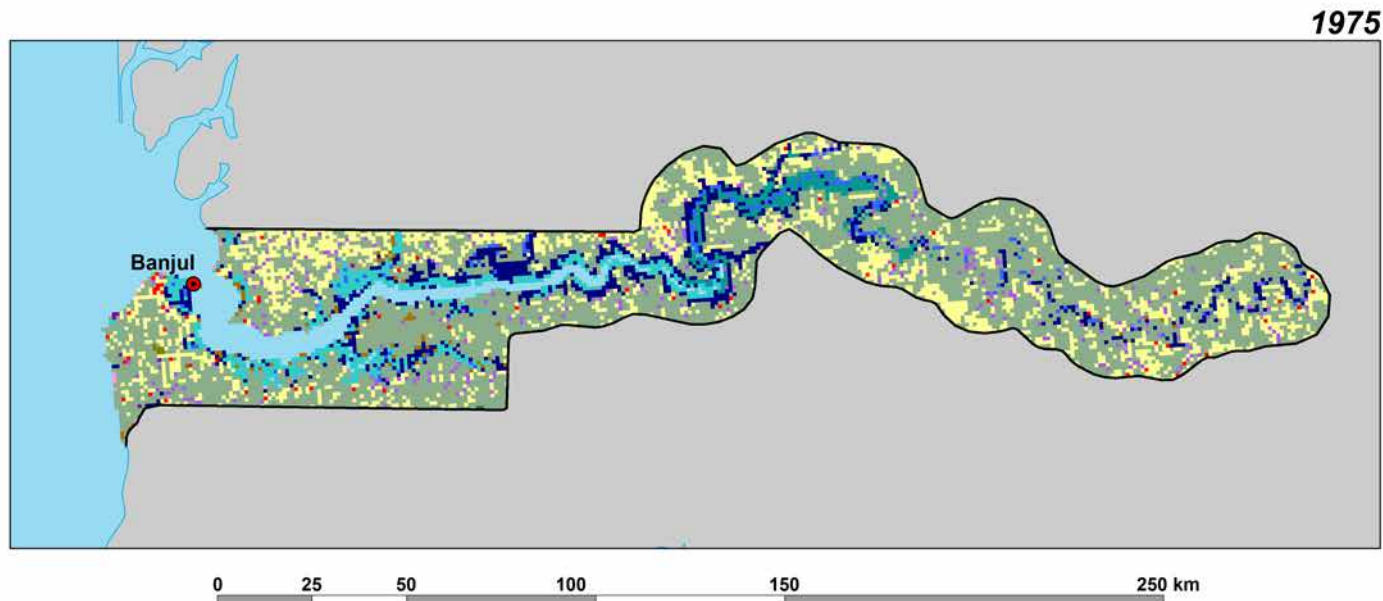


PHOTO (OPPOSITE PAGE): GRAY TAPPAN / USGS

Land Use, Land Cover and Trends



● Capitale Nationale / National Capital



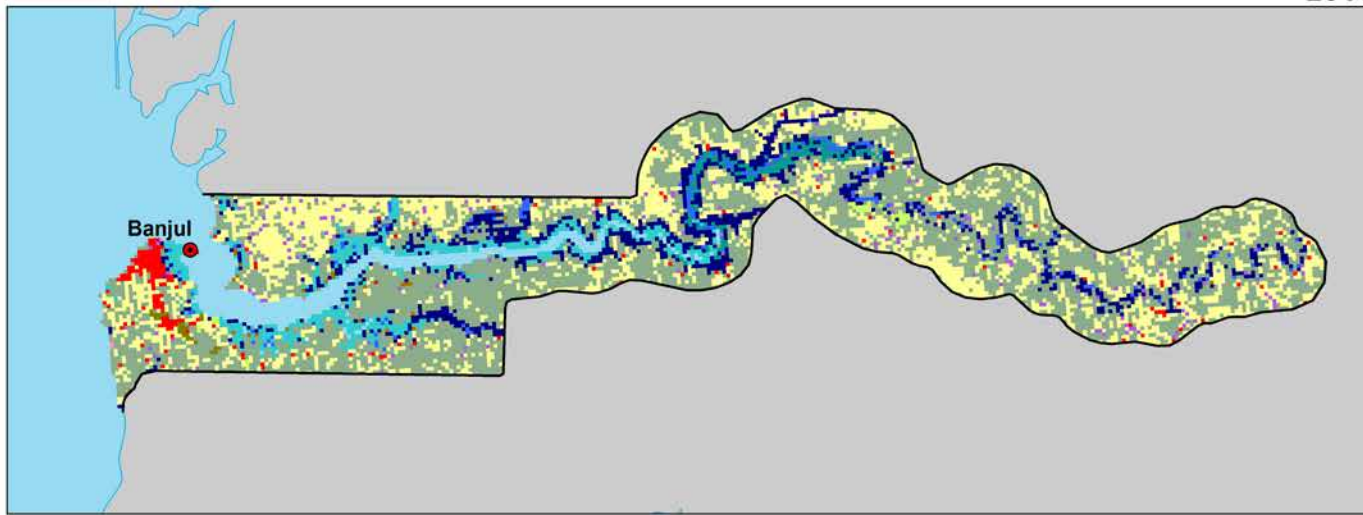
Aerial view of a village on the bank of the upper Gambia River

Until the middle of the 20th century, The Gambia's landscapes were extensively wooded, as part of the broad Sudanian wooded savannas that sweep across this latitude of West Africa. Today, vegetation density and diversity increases from east to west, as well as from the relatively drier north to the moister south. The Gambia's land cover has changed dramatically. The first change is the expansion of agriculture as the savannas are cleared for farming. The second is the rapid urban sprawl of Greater Banjul and beyond.

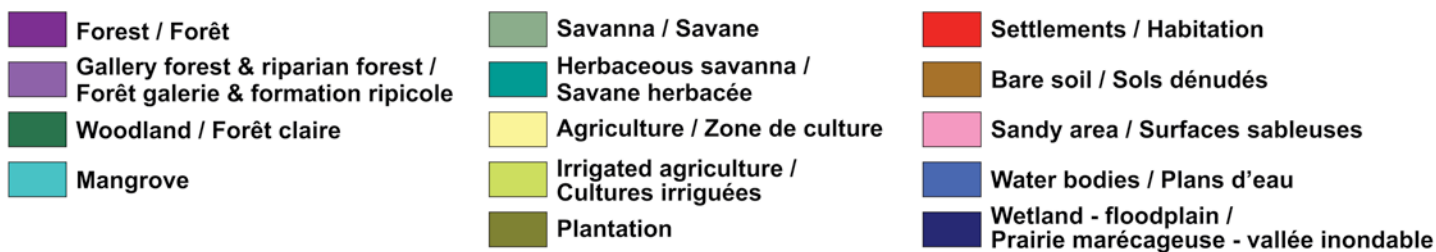
Among The Gambia's semi-natural landscapes, savanna — which ranges from open shrub and tree savanna to dense wooded savanna — is still the predominant class by area. However, the maps show that it is giving way to agriculture. In 1975, savanna occupied 51.3 percent of the total land area, whereas in 2013 it occupied 43.4 percent. In the eastern and southern regions of the country,

GRAY TAPPAN / USGS

2013



Land Cover / Occupation des Terres

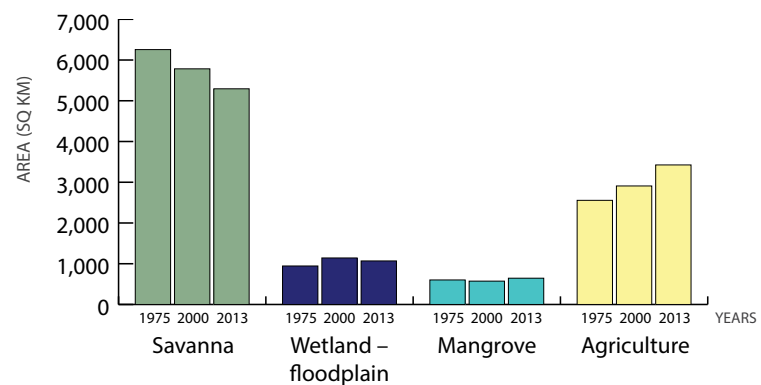


the savanna land cover is also becoming more fragmented as village lands devoted to agriculture coalesce.

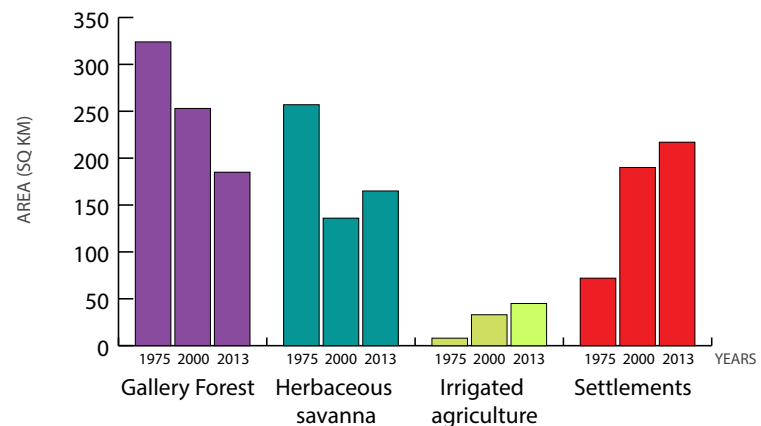
The Gambia's forests offer a more mixed picture of change. Majestic gallery forests (and fringing riparian forests along humid bottomlands) once lined most of the streams and drainage ways. They often occur on deeper soils with shallow water tables. These areas are also favored for rice cultivation and other uses. As a result, gallery forests are being seriously depleted by clearing, or degraded by selective logging of large trees for high value wood. In 1975, 324 sq km of gallery forest were mapped. By 2013, only 185 sq km remained, a loss of over 42 percent. In contrast, The Gambia's mangrove forests have been fairly stable, with a slight increase in area from 602 sq km in 1975 to 654 sq km in 2013 (see mangrove regeneration story, page 69).

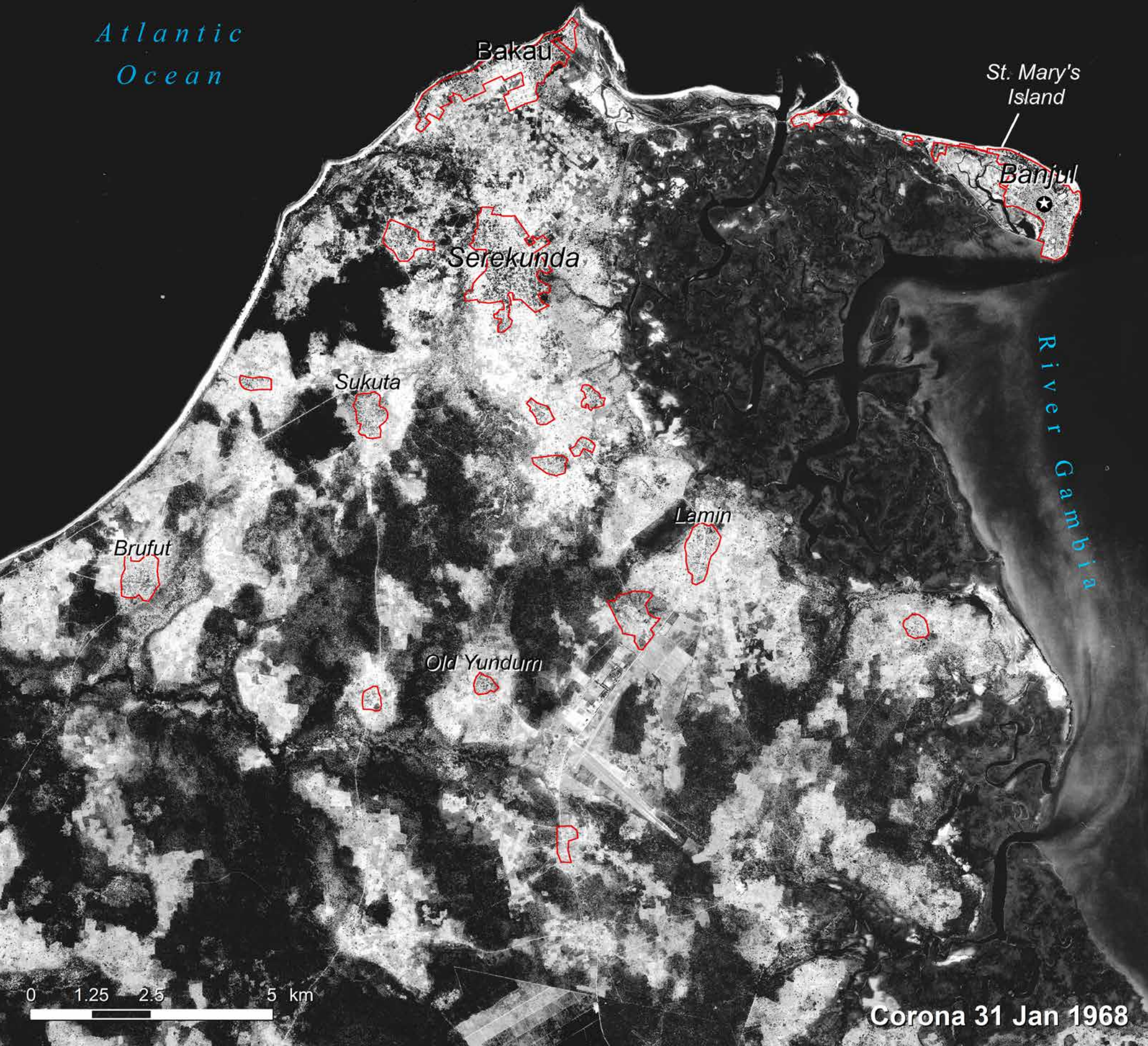
With the French introduction of groundnuts as a cash crop in Senegal in the 1800s, the production of groundnuts gradually spread across the border into western The Gambia. The northern half of The Gambia was the first to embrace large-scale groundnut cultivation because of its proximity to the major groundnut producing region of Senegal. By the 1930s, this area had become The Gambia's main agricultural region. Patches of savanna used for grazing and forest resources were still present, as seen in the 1975 map. By 2013, The Gambia's western portion, north of the river, had become almost continuously cultivated, and the traditional system of bush fallow largely abandoned. Agricultural expansion continues in all regions. In the east, where it was once found mainly on deeper soils in valleys, rainfed cultivation has now expanded into the terraces and plateaus. At the national level, agriculture in 1975 was found on 21 percent of The Gambia's land area. The area increased to 23.9 percent in 2000, and 28.1 percent in 2013.

Large area classes



Small area classes

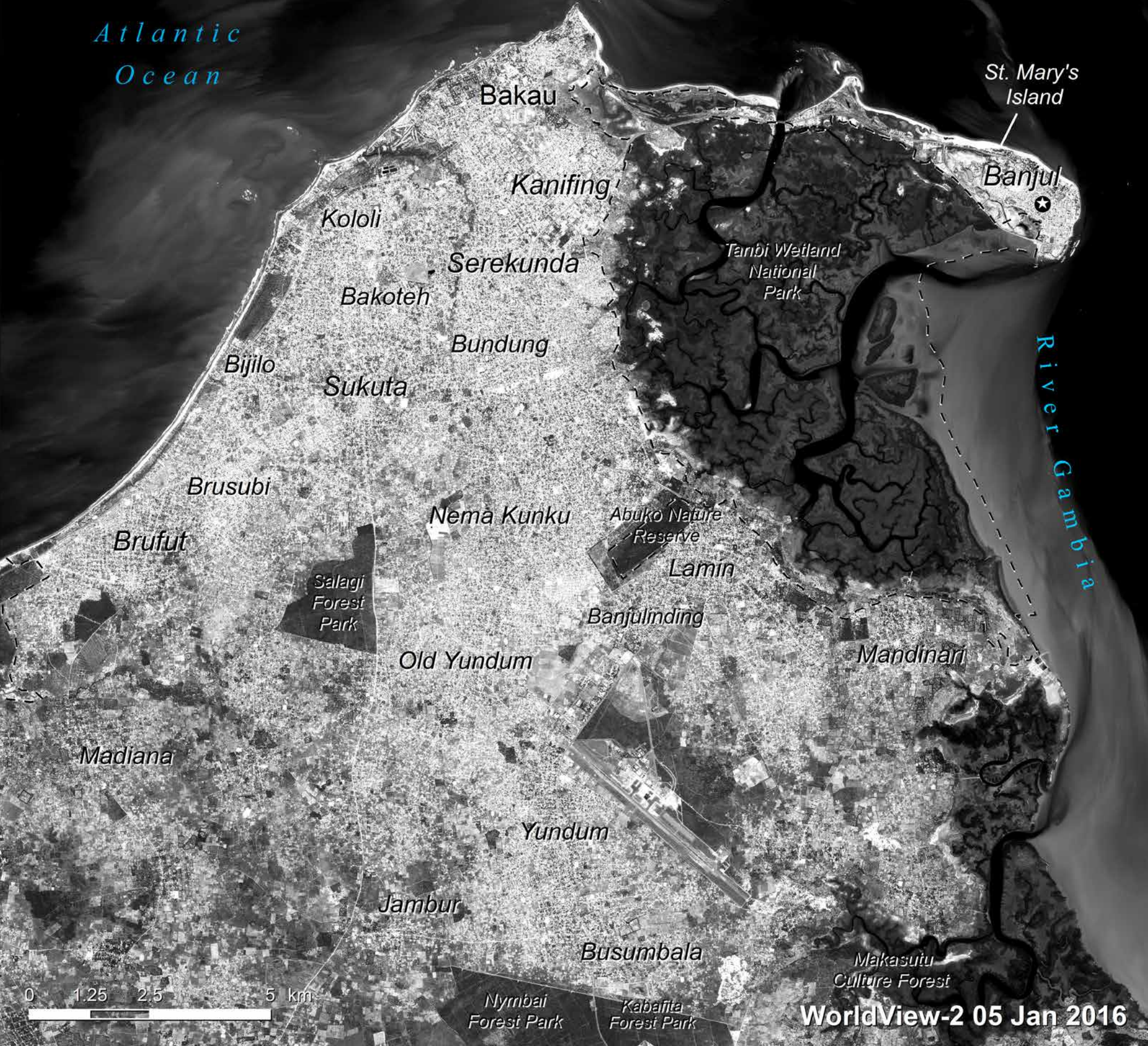




The urban sprawl of Greater Banjul

Banjul is the capital and the largest city in The Gambia. In the 1960s the built up area of the city and surrounding towns covered only St. Mary's Island and a small part of the north end of the cape area. The villages that would later grow and be absorbed into the Greater Banjul metropolitan area (many outlined in red) across the rest of the cape were separated by areas of farming and savanna woodland in the 1968 Corona image. Over the next four decades the urban development spread west and south across the cape, swallowing up villages, farms and woodlands as it grew. By 1990 the population had reached roughly half a million for the area shown in the images above. By the time of the 2016 image, it had grown to an estimated 1.39 million (CIESIN, 2005).

The rapidly growing population presents a serious challenge to sustainable use of The Gambia's land resources (FAO, 2010). The sprawling urban growth (seen as brighter areas in the images) between 1968 and 2016 is needed to house Greater Banjul's rapidly growing population, but displaces other essential land uses. Demand for agricultural products grows with the population and drives conversion of natural landscapes to farm fields. Roughly 97 percent



of The Gambia's household energy is from fuel wood (UNDP, 2012). In addition to loss of wooded areas, the pressure on remaining forests has led to their serious degradation (UNDP, 2012).

The land use and land cover maps (see pages 106–107) show that the settled areas have grown from less than 8 percent of the image area in 1975 to about 29 percent of that area in 2013. During the same time, the area of savanna has been cut in half, going from about 43 percent of the image in 1975 to just over 18 percent in 2013. Some agricultural areas were lost to the expanding urban footprint as well, but because some of the savanna was converted to agriculture the overall area being farmed in the images shown above was slightly greater in 2013 than in 1975.

The remaining patches of wooded savanna are clearly visible in the 2016 image (dark patches in the inland areas) as are the mangroves

of Tanbi Wetland National Park and the Makasutu Culture Forest. The Gambian Forestry Department has emphasized community management of forests for over two decades as a way to build stronger buy-in from local communities to meet goals, which include a long-term target of maintaining a minimum of 30 percent permanent forest cover (Thoma and Camara, 2005). The Gambia has an established ecotourism trade that depends on healthy natural areas for its survival and growth, giving them a stake in preserving the remaining forested areas and mangroves as well (Wally, 2001). Balancing the pressure to meet short-term needs of a growing population against the long-term goals of sustainable land use will challenge The Gambia over the decades ahead.



Republic of Ghana

Total Surface Area: 238,533 km²
Estimated Population in 2013: 26,164,000

Ghana is situated in the center of the Gold Coast of Africa and has a 535-km-long shoreline that includes lagoons and mangrove forests. The country's tropical climate varies from a Sudanian type climate in the north with a short rainy season, to the high rainfall regime of the forested Guinean and Guineo-Congolian Regions in the southwest. The export of cocoa has traditionally dominated the economy of Ghana, and today it is one of the world's largest exporters of cocoa. Agriculture remains a major economic sector, providing income for nearly half of Ghanaians. The country is endowed with rich natural resources. Timber, gold, diamonds, bauxite, manganese, and oil contribute to making Ghana among the wealthier nations in West Africa. While its economy is one of the most successful in the region, it remains heavily dependent on international finance. Ghana, like most West African countries, has daunting environmental challenges since its economic development depends directly on natural resources. Large tracts of forest have been cleared to support increasing cocoa production. Mining is causing localized land degradation and water pollution. A quarter of its people are concentrated along the narrow coastal zone.



-  **Biosphere Reserve / Réserve de Biosphère**
-  **National Park / Parc National**
-  **Nature Reserve / Réserve Naturelle**
-  **Faunal Reserve / Réserve de Faune**
-  **Wildlife Sanctuary / Sanctuaire de Faune**
-  **Forest Reserve / Forêt Classée**
-  **National Capital / Capitale Nationale**
-  **Other City / Autre Ville**

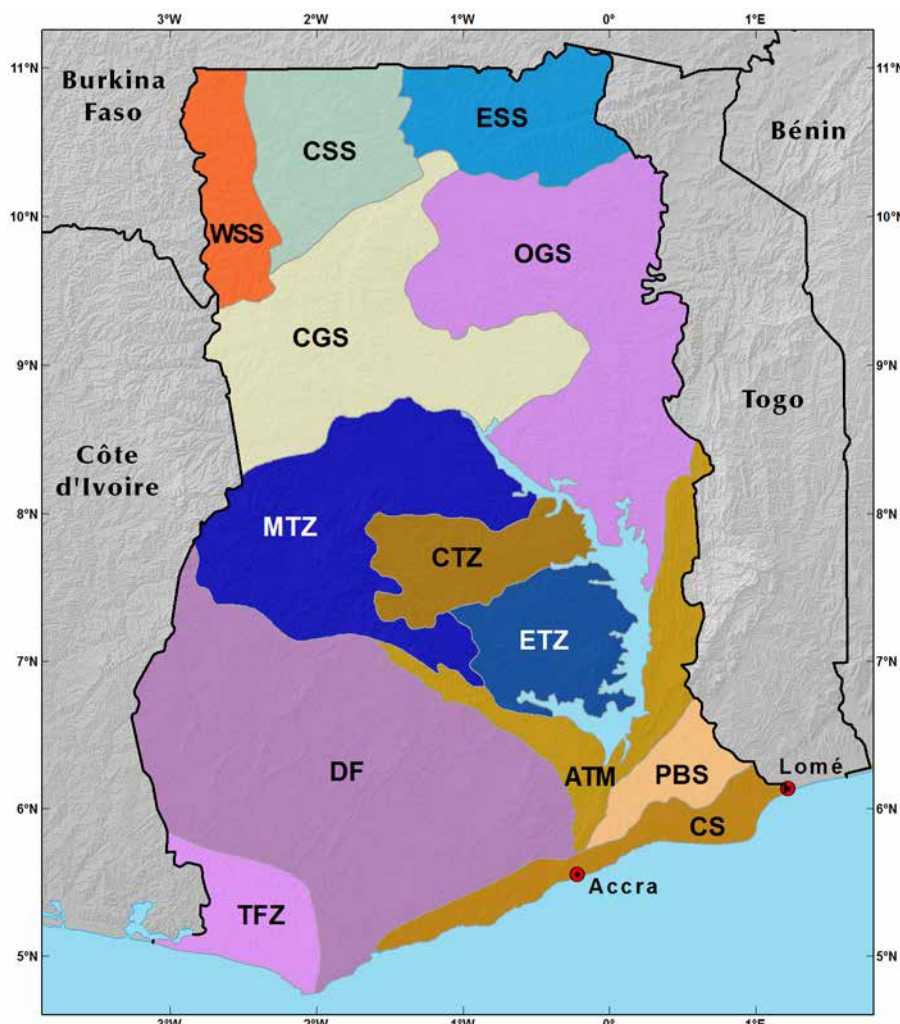
Environmental Highlights:

- Significant inventory of Upper Guinean biodiversity
- Largest artificial lake (by area) in the world
- Ecotourism
- Deforestation
- Pollution from mining



Grassy coastal plain in the western region, Ghana

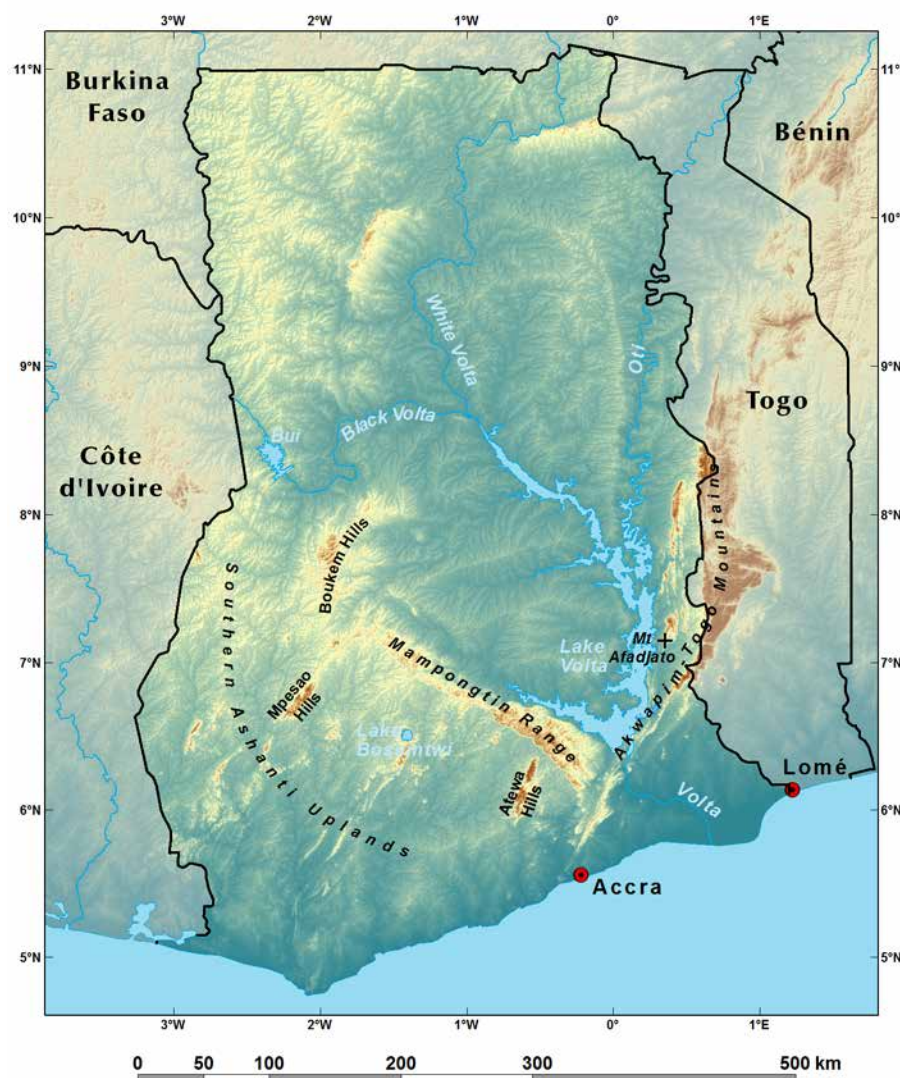
Ecoregions



- ATM Akwapim Togo Mountains
- CGS Closed Guinea Savanna
- CS Coastal Savanna
- CSS Central Sudan Savanna
- CTZ Central Transitional Zone
- DF Deciduous Forest
- ESS Eastern Sudan Savanna
- ETZ Eastern Transitional Zone
- MTZ Main Transitional Zone
- OGS Open Guinea Savanna
- PBS Pénéplaine bénino-togolaise sud
- TFZ Tropical Forest Zone
- WSS Western Sudan Savanna

With elevations that range from sea level to 885 m on Mount Afadjato, Ghana's physical terrain is composed primarily of low plains, punctuated with several uplands and a major plateau in the south-central part of the country. Ghana is home to Lake Volta, the world's largest artificial lake by area (8,482 sq km). In the north, the three Sudan Savanna ecoregions (WSS, CSS, and ESS) characterize the relatively dry northern climate with its single rainy season, open tree savannas, and scattered rainfed croplands. Moving south, the Closed Guinea Savanna (CGS) has extensive wooded savannas characteristic of the Guinean Region. In the adjacent Open Guinea Savanna (OGS) ecoregion, farmlands are expanding rapidly into the wooded savannas. In central Ghana, the Main, Eastern, and Central Transitional Zones (MTZ, CTZ, and ETZ) share common elements of a transitional climate with two rainy seasons and transitional forest-savanna vegetation. To the southeast, the Akwapim Togo Mountains (ATM) make up Ghana's highland ecoregion. It derives its main character from the rugged mountain chain and lush forested vegetation cover. This region still harbors much wildlife and offers great potential for ecotourism. The Deciduous Forest (DF) ecoregion in the southwest is Ghana's largest ecoregion, with deciduous tropical forests scattered among a number of biological reserves. In the south, the Tropical Forest Zone (TFZ) is Ghana's wettest ecoregion, with remnants of its biologically diverse evergreen rain forest. Finally, the Coastal Savanna (CS) ecoregion is highly distinguished by its relatively low rainfall in two seasons, high population density, grassland savanna vegetation, and coastal geomorphology that includes tidal flats and lagoons.

Shaded Relief



- Élevée / High
- Faible / Low

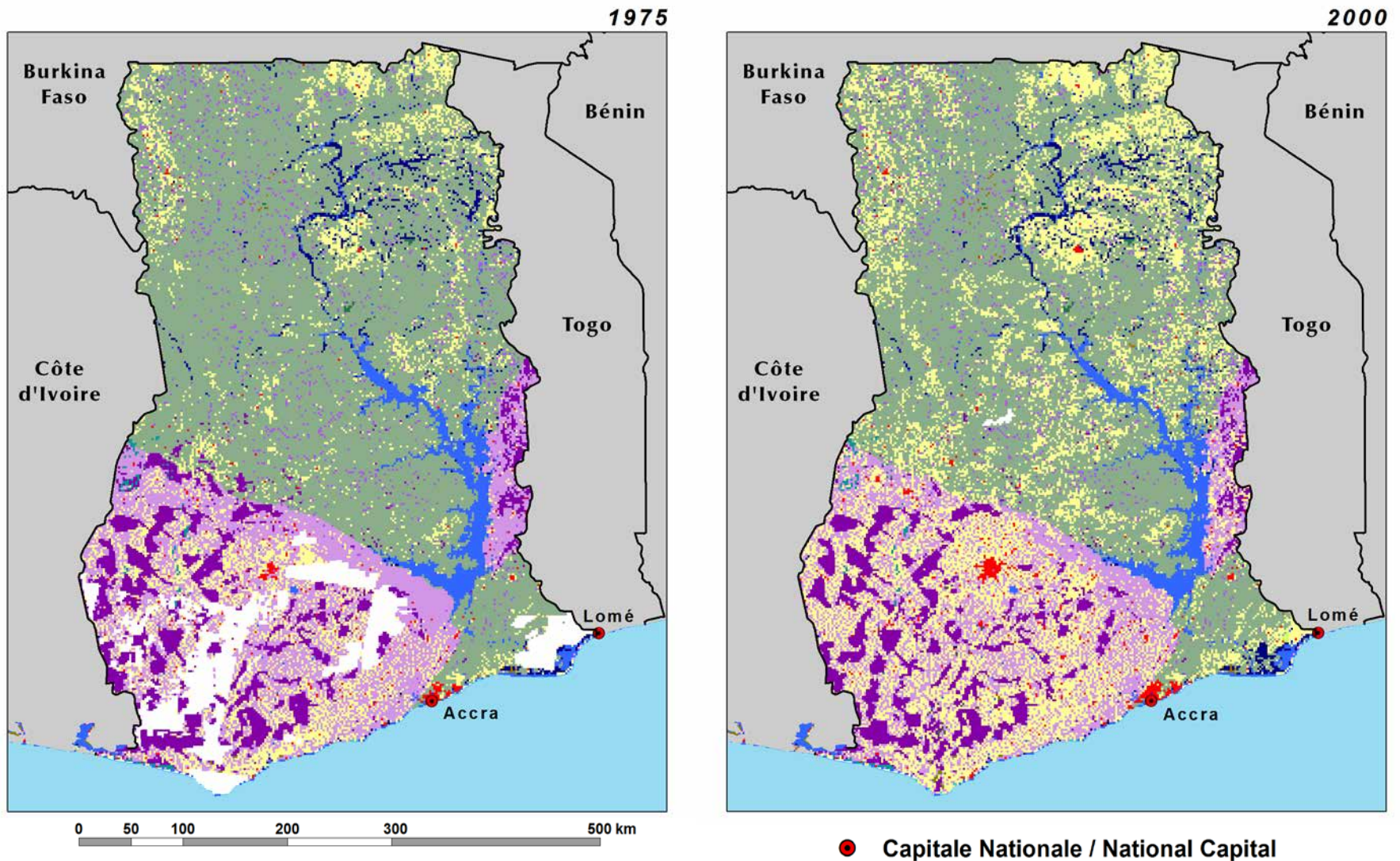


Canopy walk at Kakum National Park

GLOBAL MULTI-RESOLUTION TERRAIN ELEVATION DATA 2010 (GMTED 2010)

ERIC LANDWEHR/SDSU

Land Use, Land Cover and Trends



White areas in the 1975 map represent data gaps caused by persistent cloud cover.

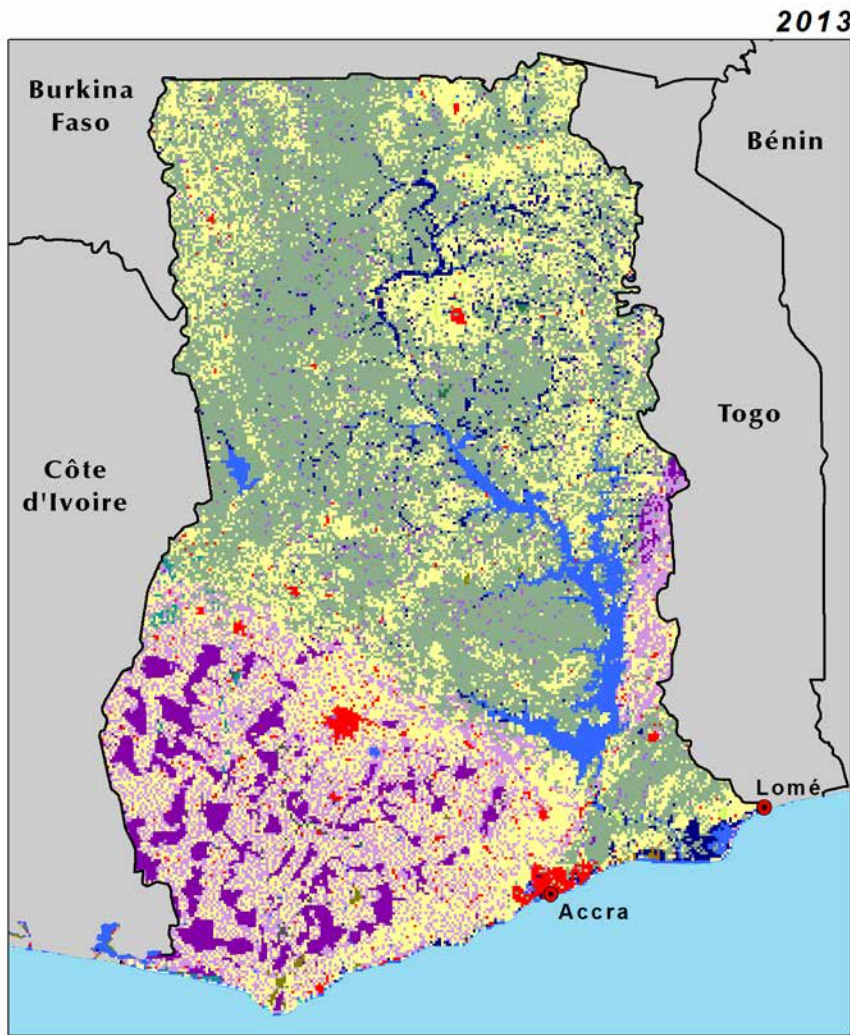


Fishermen boats on the beach

ROBERT WATREL/SDSU

The most obvious land cover change in Ghana is the major increase in agricultural land in all regions of the country. However, the largest increases can be seen in the northeast, east-central, and southwestern regions of Ghana. This rate of agricultural expansion is unprecedented in the country's history, overrunning many of the other land cover types, including Ghana's savannas, woodlands, and forests. From 1975 to 2000, agricultural lands expanded from 13 to 28 percent of Ghana's total area and continued to extend rapidly, reaching 32 percent of Ghana's land area in 2013. This expansion has significance beyond the simple area numbers. Agricultural lands often represent a radical transformation from a diverse variety of vegetation types and natural habitats to crop-dominated landscapes. In Ghana, savannas experienced a large loss, from about 51 to 40 percent of the total land area from 1975 to 2013. The formerly uninterrupted savanna landscapes of the Central Sudan Savanna, Main Transitional Zone, and Central Transitional Zone are now highly fragmented, with large tracts of natural habitat broken into myriad patches of farmland, reducing habitat suitability for many types of wildlife.

Another important land cover change in Ghana is the degradation of forest. The forest class (represented primarily by Ghana's dense evergreen rain forest and moist deciduous forest) shows a small decline in area from about 16,400 sq km in 1975 to 15,500 sq km in 2000, a reduction of 5 percent. This decline accelerated rapidly between 2000 and 2013, as forests were reduced by an additional 20 percent, to 12,400 sq km in 2013. The degraded forest, which occurs mainly in the off-reserve areas, represents a vegetation type that was derived from the dense and deciduous forests, modified by human activity. The traditional slash-and-burn method of agriculture, logging, annual wildfires, and recently commissioned open cast mining are the major disturbing factors that have diminished vegetation extent and composition in the southern ecoregions. Degraded forests continued to decrease in area, losing 17 percent of their cover between 1975 and 2013. The expansion of cocoa farms,



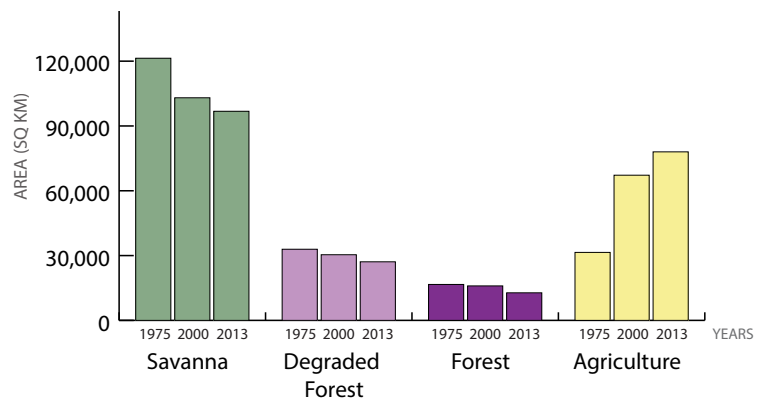
Land Cover / Occupation des Terres

- Forest / Forêt
- Gallery forest & riparian forest / Forêt galerie & formation ripicole
- Degraded forest / Forêt dégradée
- Woodland / Forêt claire
- Mangrove
- Savanna / Savane
- Herbaceous savanna / Savane herbacée
- Agriculture / Zone de culture
- Irrigated agriculture / Cultures irriguées
- Plantation
- Settlements / Habitation
- Bare soil / Sols dénudés
- Rocky land / Terrains rocheux
- Open mine / Carrière
- Water bodies / Plans d'eau
- Wetland - floodplain / Prairie marécageuse - vallée inondable
- Cloud / Nuage

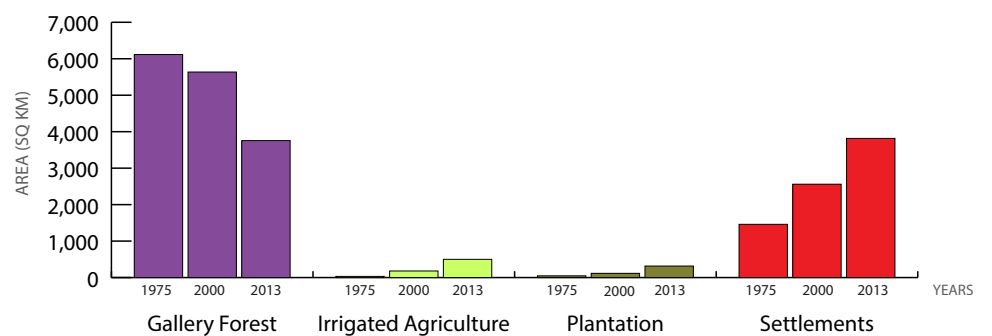
other crops, and fallow lands was the primary driver of the decline in degraded forest area. The gallery forest, which represents the most biologically rich habitat in the savanna zones of central and northern Ghana, also experienced a decline that has accelerated, mainly because of clear-cutting for agriculture, from 6,200 sq km in 1975 to 3,750 sq km in 2013. If we add all forest classes together, we see a significant decline of 25 percent of forests over the 38-year period. However, historical imagery confirms that a much larger loss of forest occurred during the 1960s. What remains today is primarily contained in the biological reserves. Ghana continues to lose its forest resources at an unsustainable rate.

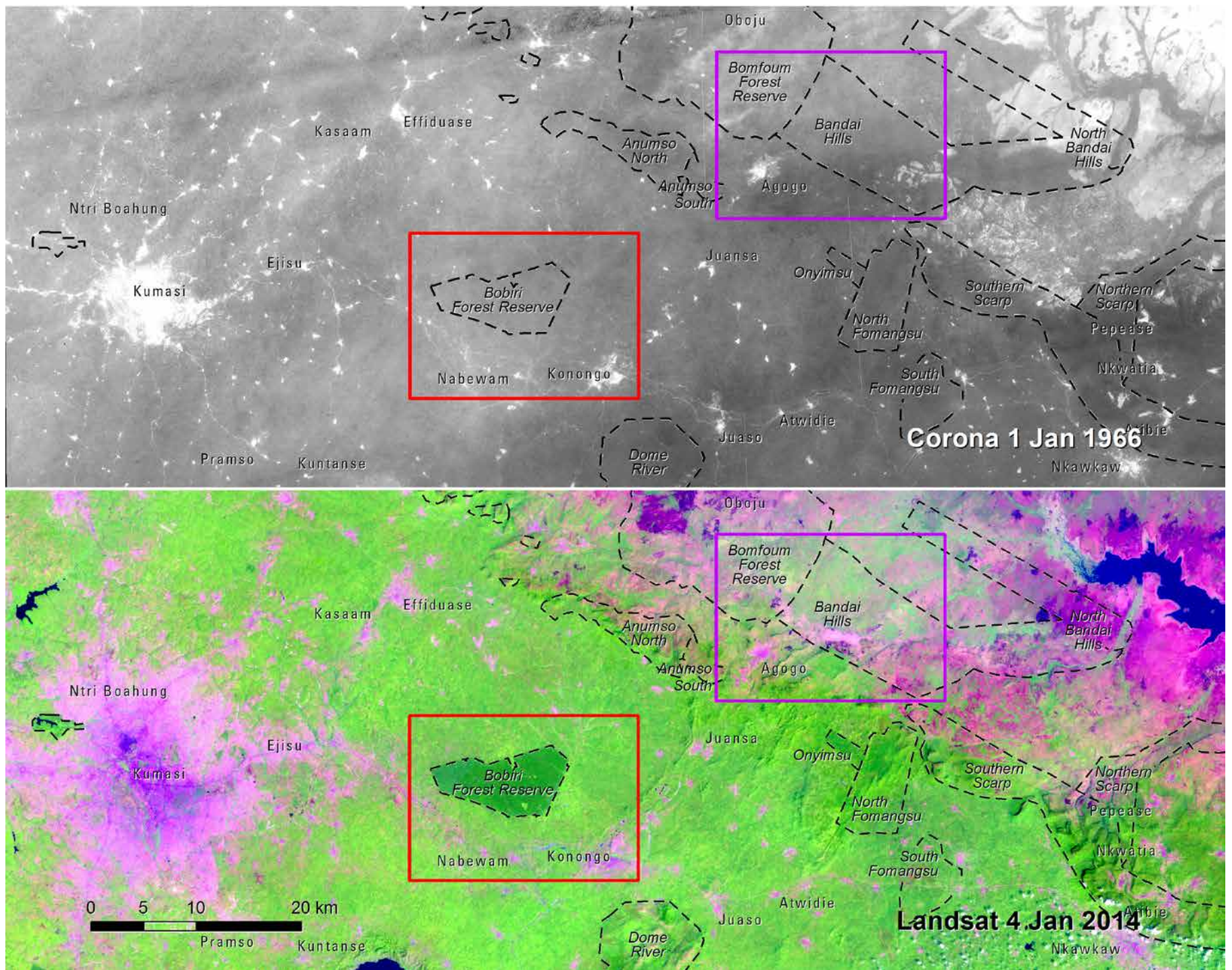
Ghana's rapid population growth is reflected in the rapid expansion of the Settlements land cover class. From 1,460 sq km in 1975, urban areas expanded to 2,560 sq km in 2000 and 3,830 sq km in 2013, a 161 percent increase over 38 years. The greater Accra metropolitan area has about 4 million people, Kumasi just over 2 million, and Tamale about 370,000 (GSS, 2013).

Large area classes



Small area classes





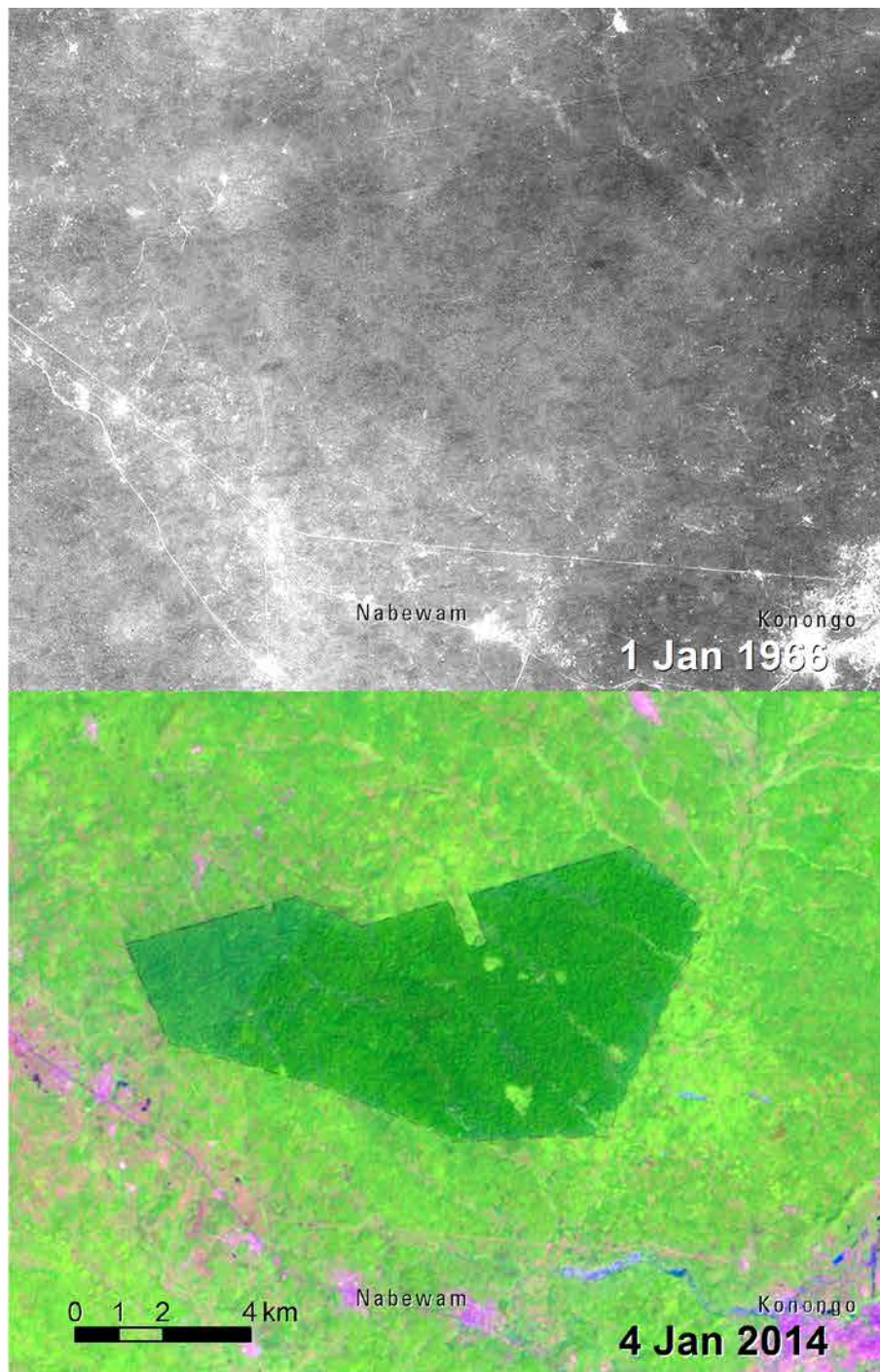
Urbanization and deforestation in the Greater Kumasi area

Kumasi is the second largest city in Ghana, after the capital Accra, and functions as the administrative, commercial, industrial, and cultural center of the Ashanti region. Owing to considerable rural-urban migration driven by the growth of industries and commercial activities in and around the city, the population of Kumasi has increased sharply over the past four decades. The census of 1970 reported 346,000 inhabitants, surpassing 1 million by 2000 and over 2 million in 2013 (GSS, 2013).

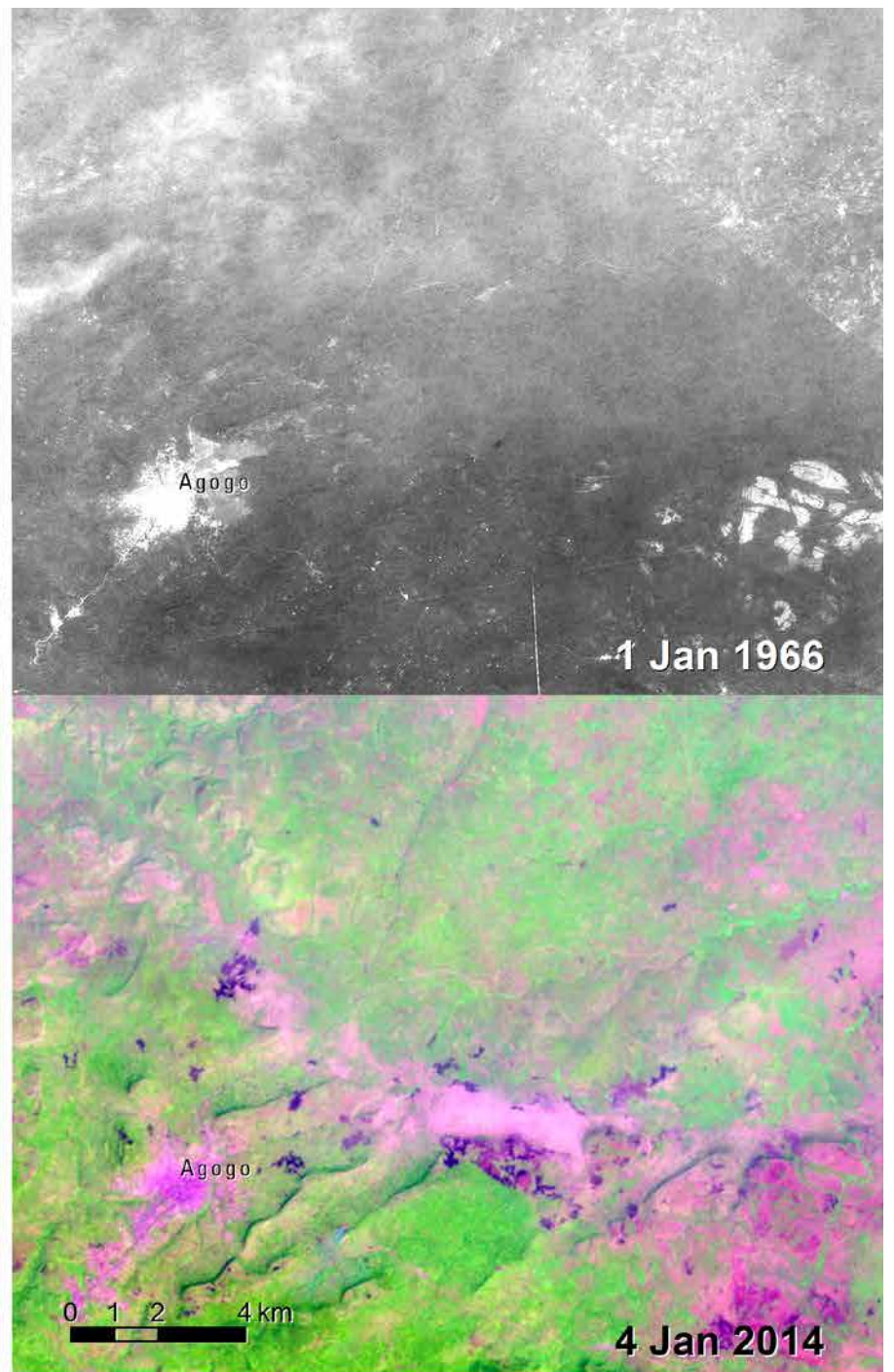
The comparison of a Corona satellite image from 1966 with a Landsat image from 2014 shows the expansion of built-up area from 60 sq km in 1966 to over 400 sq km in 2014, in parallel with the population growth in the Kumasi metropolis. The influence of the city on land cover change reaches far beyond the immediate peri-urban area. While agriculture, mostly in the form of shifting cultivation, was certainly present in greater Kumasi in 1966, by 2014 the forest and woody savanna has become considerably more fragmented within a radius of at least 50 km of the urban fringe, creating a fine mosaic of cultivated land and degraded forest.

The Bobiri Forest Reserve, 20 km east of Kumasi, illustrates the contrast between this mosaic and a continuous forest canopy. In 1966, the forest reserve completely blended in with its surroundings. Although it contains nearly 50 sq km of forest, the reserve is far from pristine. It has already been actively exploited for timber, and its more accessible parts are known to be moderately to severely degraded. By 2014, fairly large clearings for cultivation

Bobiri Forest Reserve



Bandai Hills



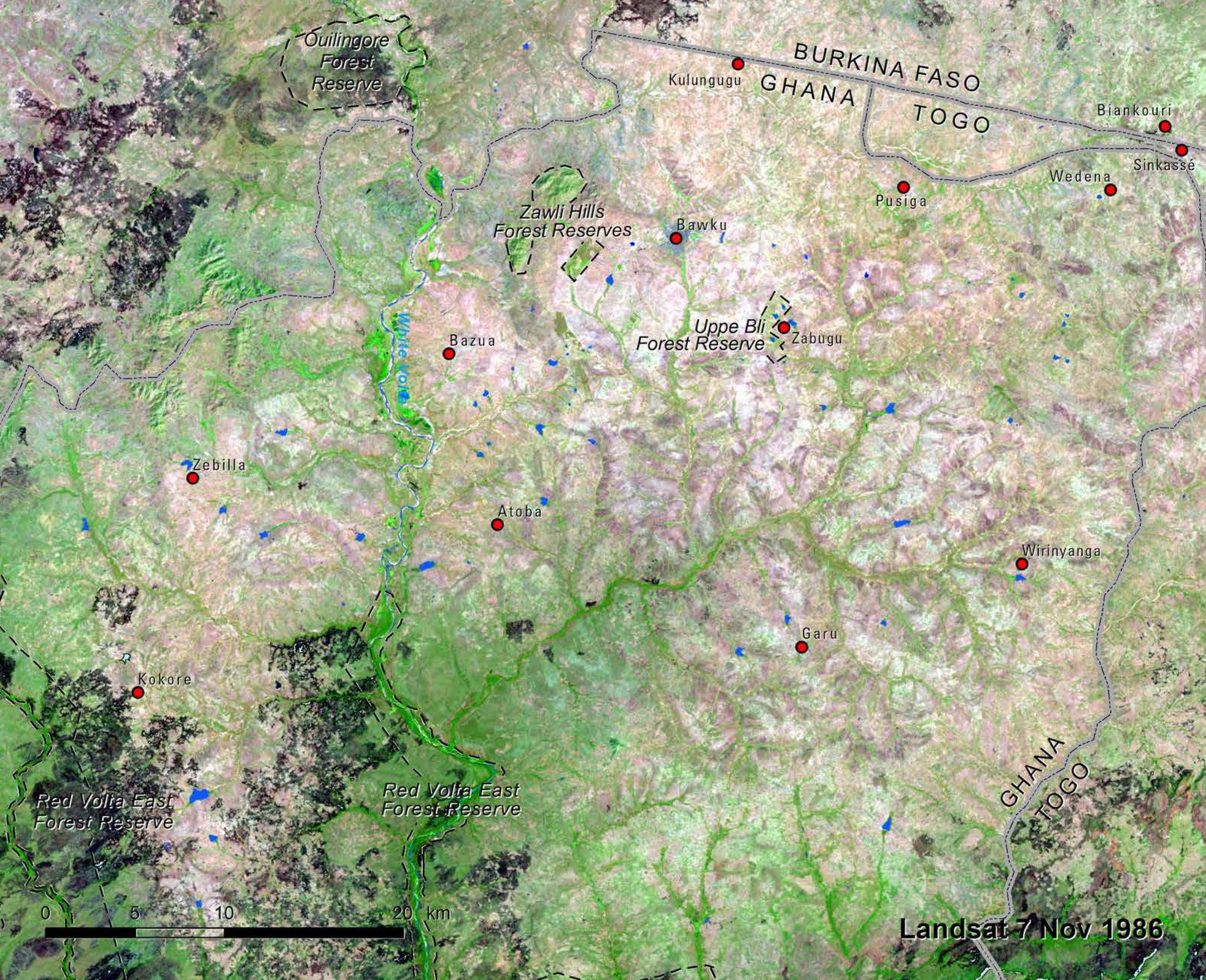
and palm wine tapper camps are visible inside the reserve. Locals collect firewood, and the felling of small trees is not uncommon. On the positive side, the reserve also includes significant sections of intact high canopy forest and hosts a forest arboretum with about 100 indigenous tree species. The reserve also has a butterfly sanctuary with 340 butterfly species, which is managed according to an ecotourism plan for the benefit of local communities.

Between 1966 and 2014 in the Bandai Hills, a contiguous area of degraded forest of 130 sq km has been cleared for cultivation to the northeast of the town of Agogo, leaving a visible footprint in the 2014 Landsat image. However, deforestation is not a new phenomenon in Ghana. Encroachment of agriculture into forest has accelerated dramatically in recent years, but historical research has shown that much of the forest inside and outside of reserves is not primary, but regenerated secondary forest on previously cultivated and depopulated lands.



ROBERT WATREL/SDSU

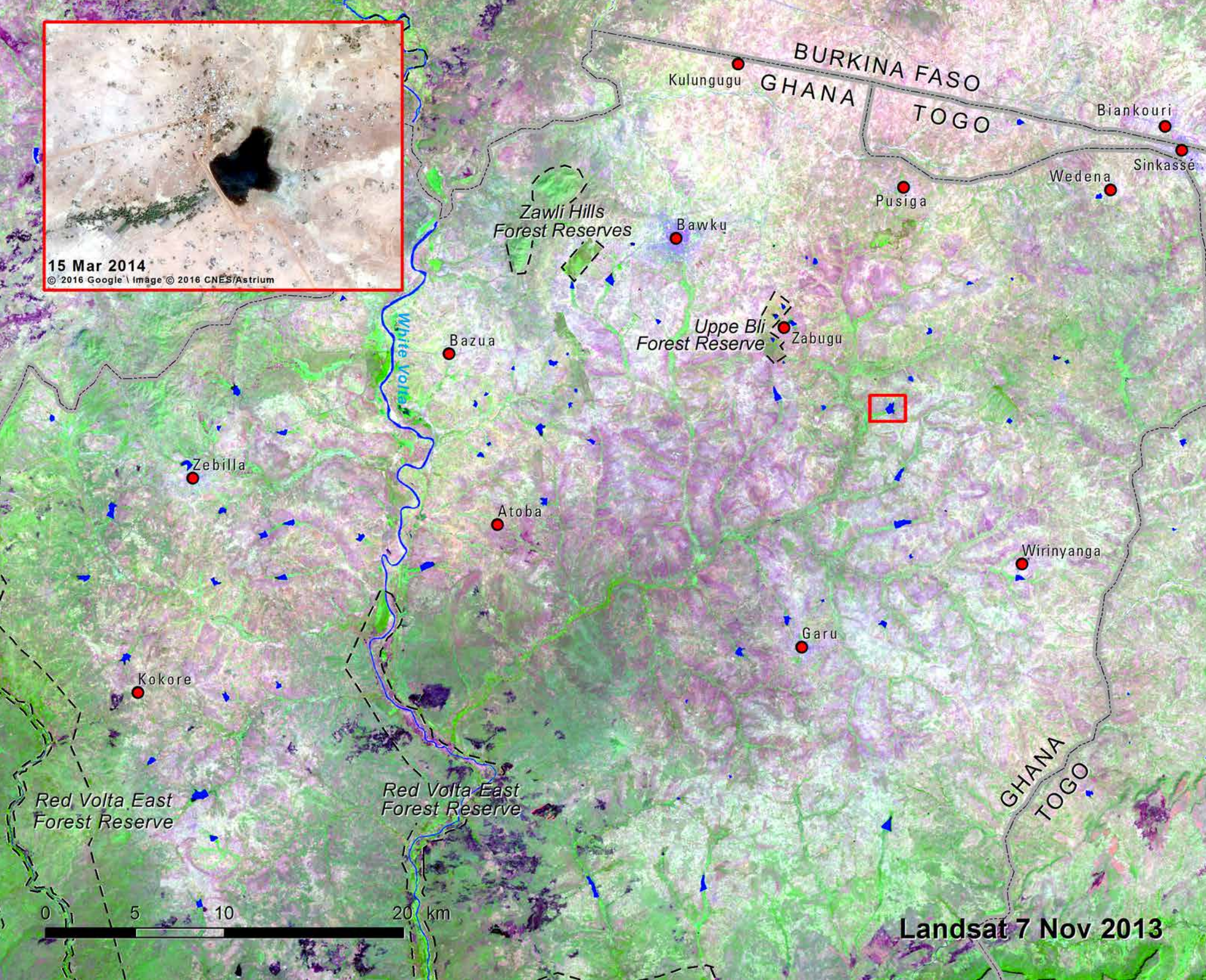
Central Kumasi



Small reservoirs as engines for local development in the Upper East region of Ghana

Northern Ghana trails the rest of the country in terms of wealth, not least because of its environmental challenges — low mean annual rainfall (about 900 mm per year), frequent droughts, and shallow soils susceptible to erosion. Given its dry climate and a high incidence of rural poverty, it is also considered the part of Ghana most vulnerable to climate change. Nonetheless, population densities are relatively high and growing, particularly in the Upper East region, where most people work in agriculture. While rates of out-migration are among the highest in Ghana at over 20 percent, birth rates are also above the national average. At the same time, northern savanna regions have served as receiving areas for Fulani migrants from Burkina Faso, Mali, and Niger. Thus, the population of the Upper East region has more than doubled from almost 500,000 in 1960 to over a million in 2010.

Due to the precarious environmental situation and high pressure on resources, the Upper East region has long been a focus of development interventions in natural resource management. Already in colonial times, protected areas had been set aside and timber plantations of local tree species established, in particular *Ceiba* and *Anogeissus*. Several small-scale water reservoirs also date from that period, when they were created to help meet the dry season water needs of the rural population. Since then, donor-funded projects have rehabilitated the old reservoirs and constructed new ones (Snyder and others, 2013). Today, 149 small reservoirs and 129 dugouts can be counted in the Upper East region. They provide a source of water for livestock, domestic use, dry season irrigation, and



fish production. A total area of nearly 9 sq km is irrigated by these systems. The water surfaces appear as small blue patches in the images, and an increase in number and size can be observed between 1986 and 2013. They are not to be confused with the larger irregular dark surfaces, which are temporary and represent areas recently burned and charred by grass fires.

A close-up view at higher resolution of the community of Bugri shows land use around the reservoir, which has a surface area of almost 10 ha and is one of the more important reservoirs (see inset). Downstream from the dam, reservoir water benefits fruit trees and allows for dry season cultivation of a variety of garden crops (onions, peppers, tomatoes). A portion of the dry season crops are sold on the market, whereas wet season crops such as maize, millet, beans and rice are mainly grown for household consumption. The ability to have two or three growing seasons per year, to keep more livestock and to sell produce on the market has made the communities with access to reservoirs more food secure and better off than neighboring communities without reservoirs (Namara, Nyamadi, and Barry, 2011). Tree densities were found to be higher and tree species more diverse in communities with reservoirs, since the availability of alternative and more sustainable sources of income has lessened the pressure on tree resources. An additional benefit that appears to have arisen from the presence of reservoirs is a strengthening of local governance and institutions, as these communal structures require collective management and have hence encouraged community organization.



STEFANIE HERRMANN / U. OF ARIZONA

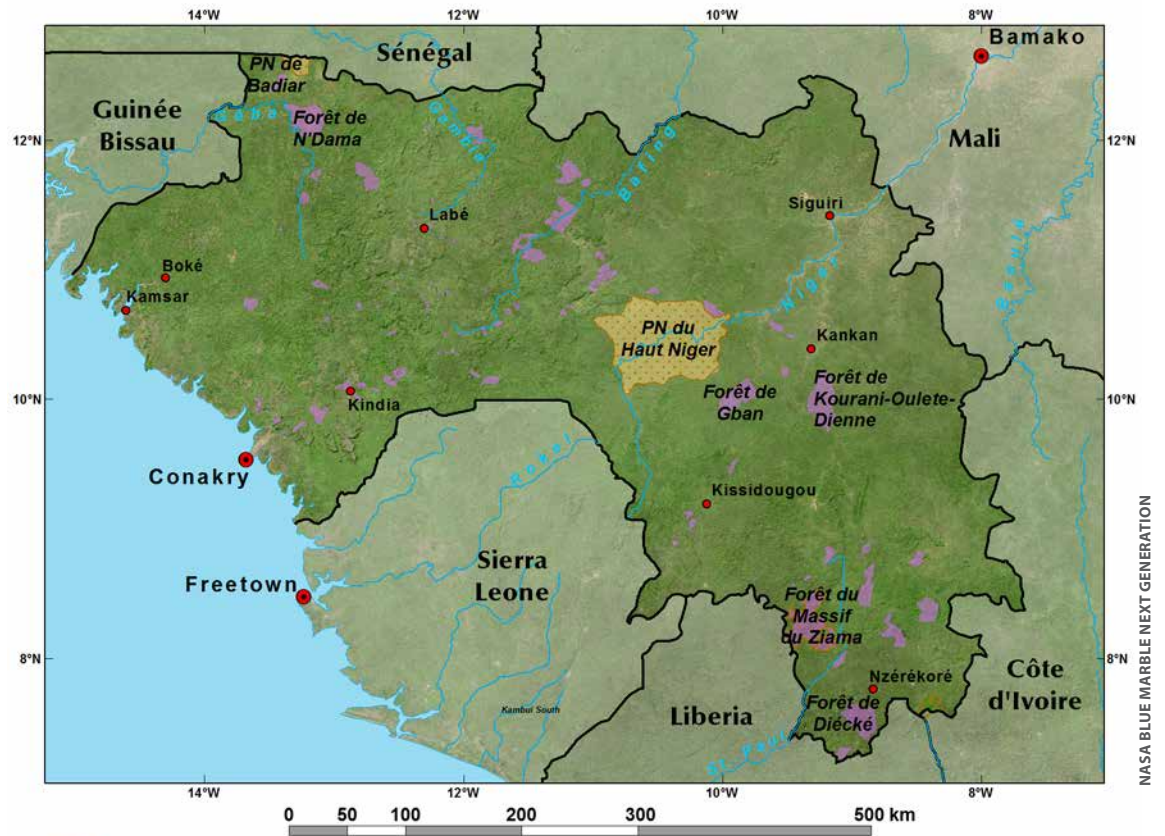
Farmer watering onions and leafy winter crops using calabashes.



Republic of Guinea

Total Surface Area: 245,857 km²
Estimated population in 2013: 11,949,000

Guinea extends southeast in a crescent from the Atlantic coast of West Africa. Its topography varies from coastal plains to inland mountains that account for about 60 percent of the land area. Several of the region's major rivers, in particular the Niger, Senegal, and Gambia, all originate from these highlands, making Guinea the "water tower" of West Africa. These rivers drain vast arable plains, and upstream offer important potential for hydroelectric energy. Guinea's forests are now mostly limited to a few mountainous areas in the south (Ziama and Nimba), and to gallery forests along watercourses. Guinean landscapes also have the largest extent of lateritic plateaus, called bowé, creating natural clearings of treeless meadows. They are a common feature in the north and west of the country. In addition, Guinea is endowed with huge deposits of mineral resources. It has the largest deposits of bauxite and iron ore in the world and is a gold and diamond producer. Thanks to these mineral resources, Guinea has the potential of being one of Africa's richest countries. Its Atlantic shoreline supports a large-scale fishing industry and has developed large commercial harbors, such as Conakry and Kamsar.



-  **Réserve de Biosphère / Biosphere Reserve**
-  **Parc National / National Park**
-  **Réserve Naturelle / Nature Reserve**
-  **Forêt Classée / Forest Reserve**
-  **Capitale nationale / National capital**
-  **Autre Ville / Other City**

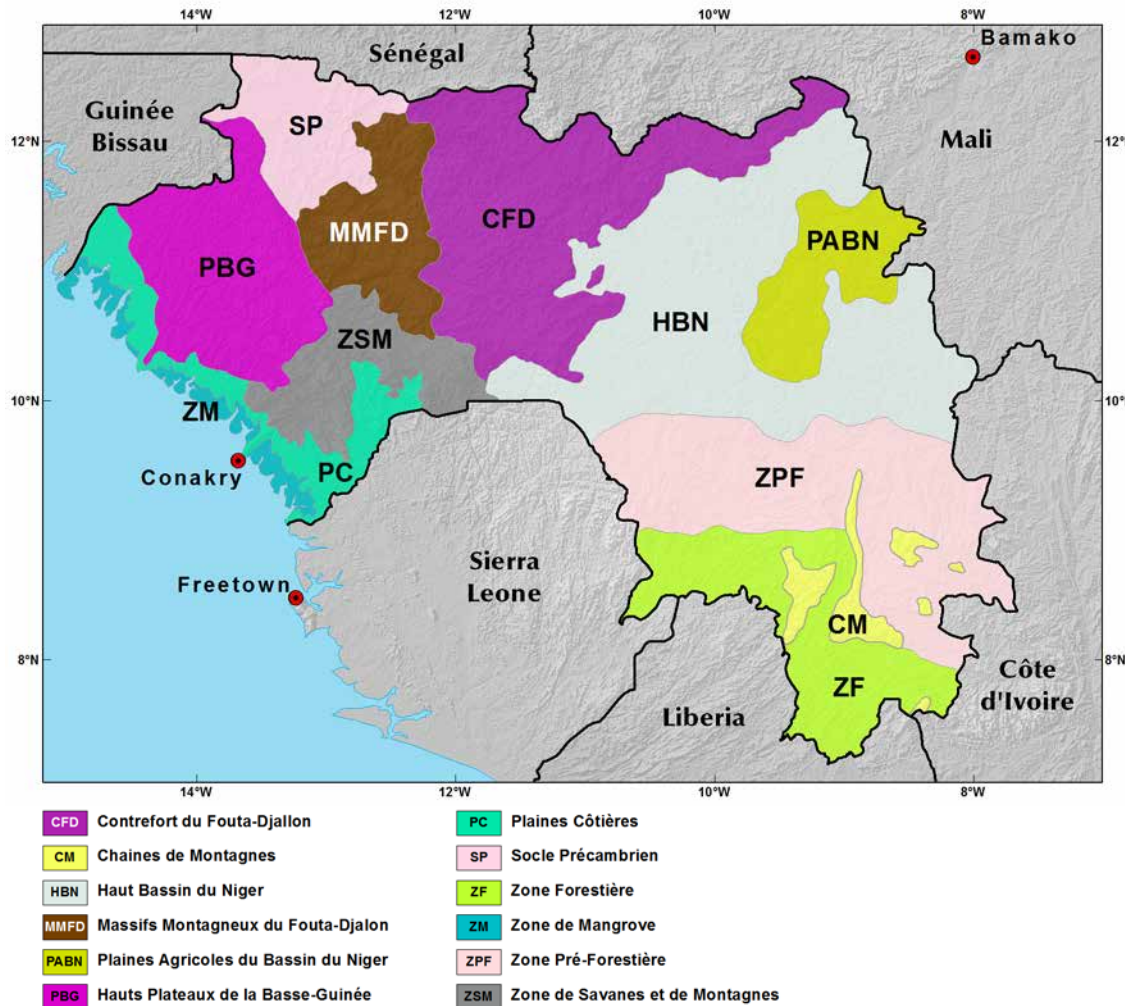
Environmental Highlights:

- Deforestation
- Soil erosion
- Forest remnants
- West African "water tower"
- Wealth in minerals, precious metals, and diamonds

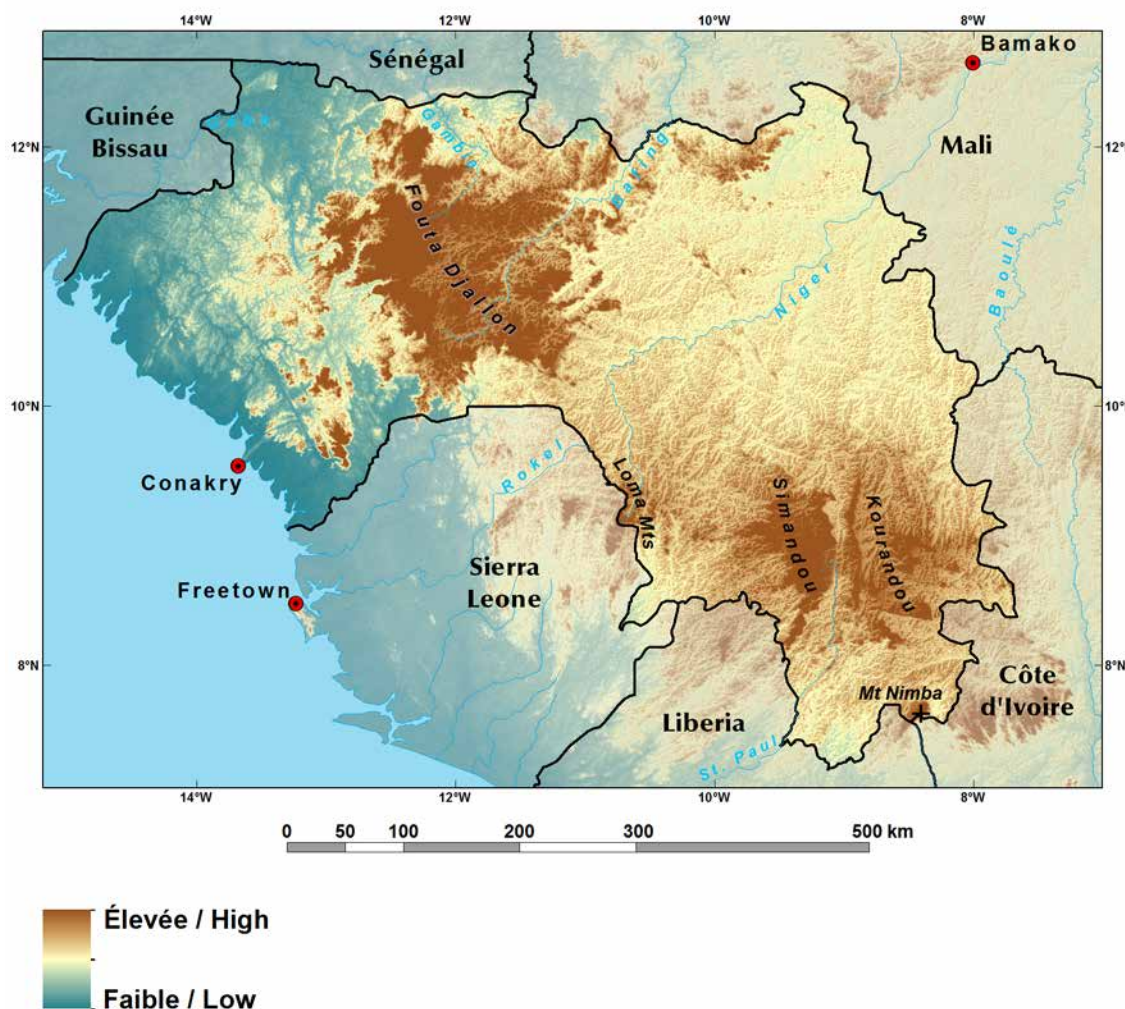


High plateaus bordering the coastal plain of western Guinea

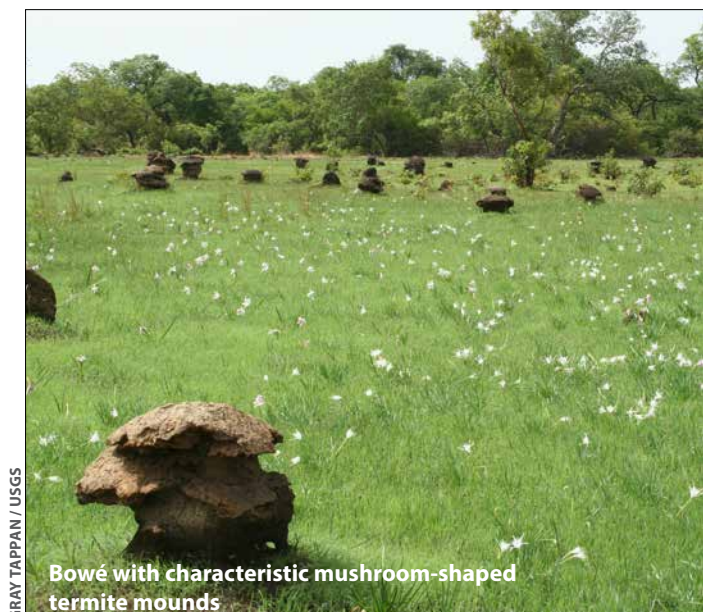
Ecoregions



Shaded Relief



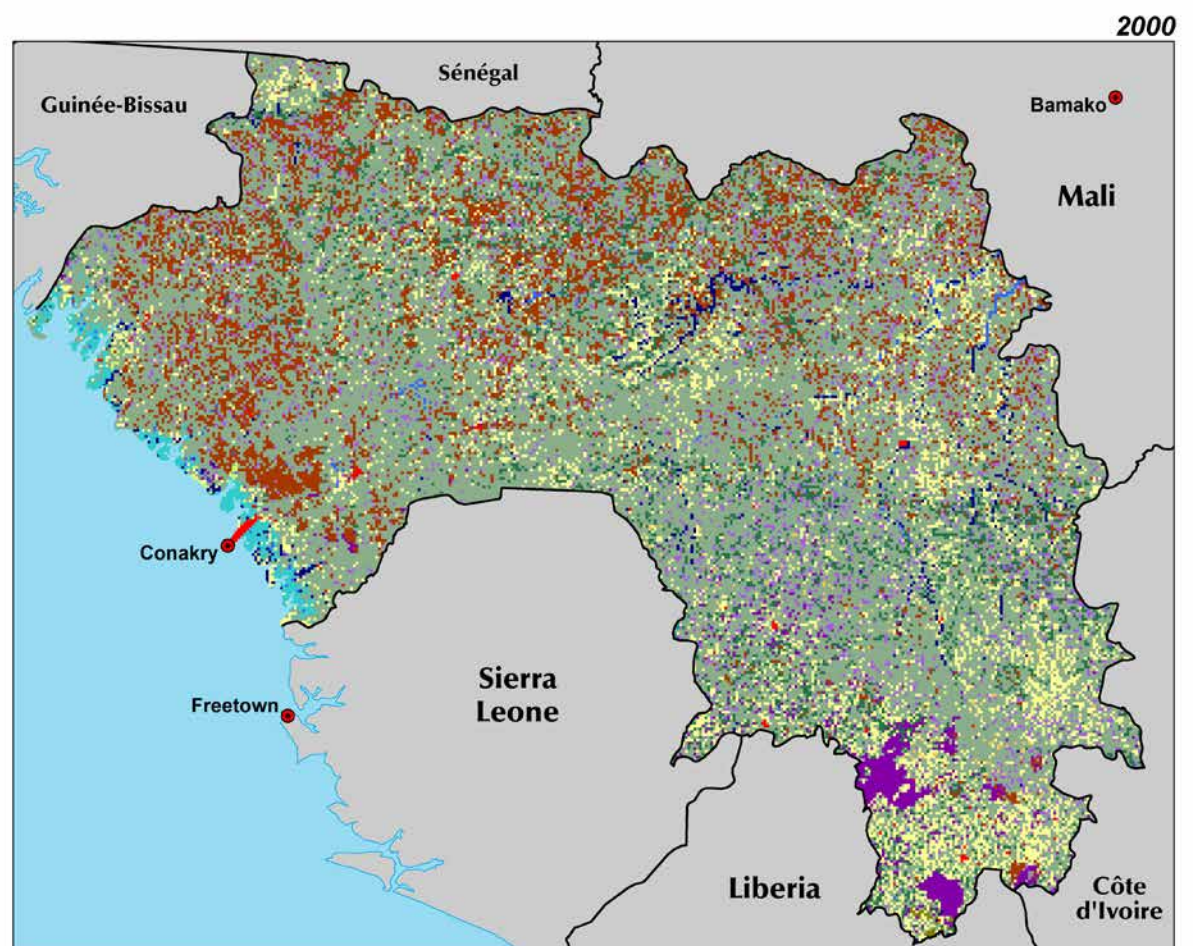
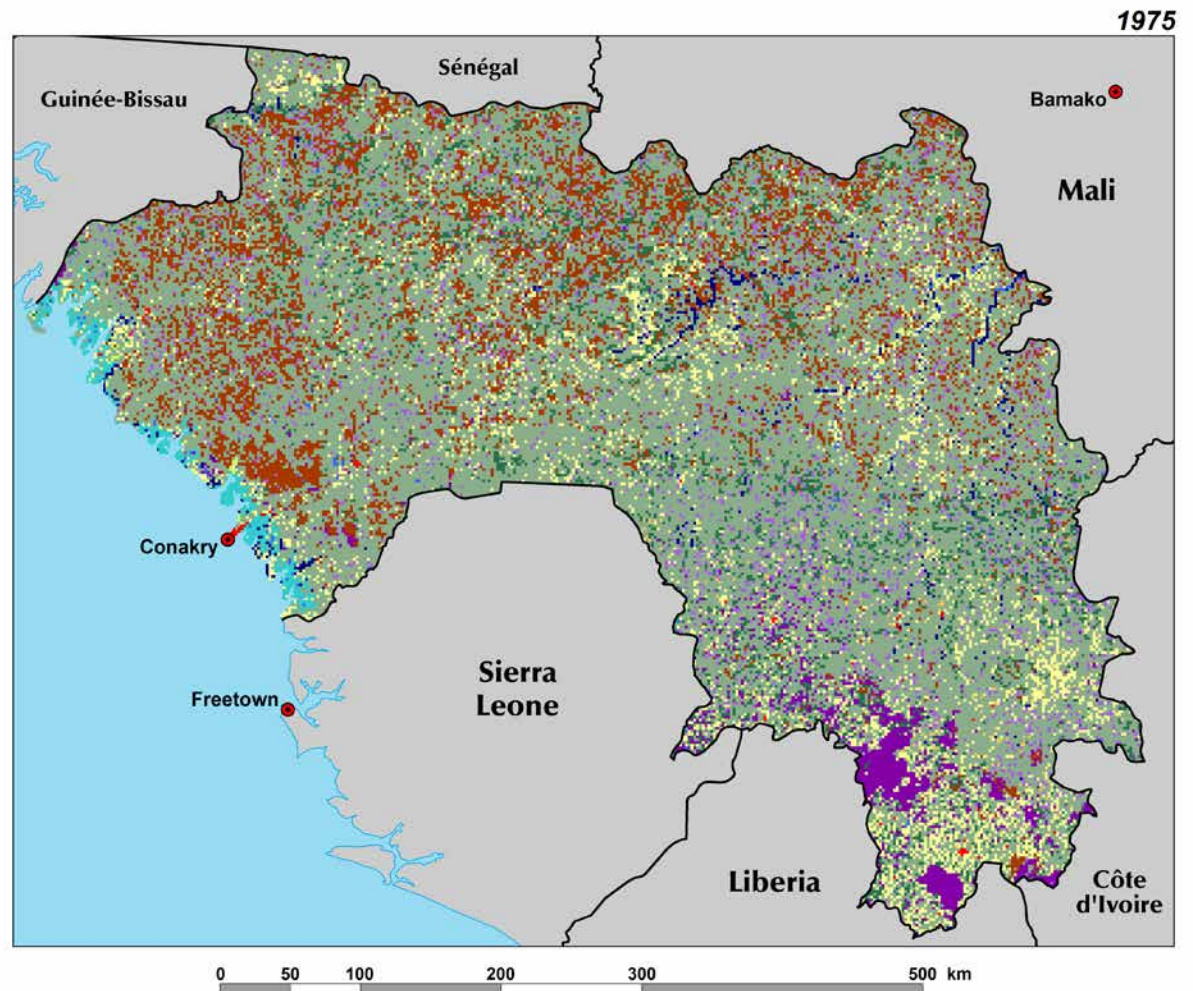
In western Guinea, two ecoregions characterize some 300 km of Atlantic coastline and coastal plains — the *Plaines Côtières* (PC – Coastal Plains) and *Zones de mangroves* (ZM – Mangrove Zones). Eastward of the coastal lowlands the land rises, at times in the form of spectacular escarpments, into two major ecoregions, the *Plateaux de Basse Guinée* (PBG – Lower Guinea Plateaus) and the *Zone de Savane et de Montagne* (ZSM – Savanna and Mountain Zone). Guinea’s famous interior highlands are captured in two ecoregions, the scenic *Massifs Montagneux du Fouta Djallon* (MMFD – Mountainous Blocks of Fouta Djallon) and the *Contrefort du Fouta Djallon* (CFD – the Foothills of the Fouta Djallon). Both the MMFD and the CFD are made of rugged high plateaus, often capped by laterite (bowé), and dissected by deep valleys. Most of Guinea’s rivers originate here, fed by the abundant rainfall of the highlands. Descending to the east, the Niger River and its tributaries have fashioned the low, rolling landscapes of the *Haut Bassin du Niger* (HBN – Upper Niger Basin) with its broad plateaus and alluvial plains once covered by extensive savannas and gallery forests. This relatively dry part of Guinea falls into the Sudanian climate zone. The south part of the country is home to Guinea’s forest zone (ZPF – Zone Pré-Forestière and ZF – Zone Forestière), whose ecoregion names derive from the Upper Guinean forest that formerly covered large swaths of this region. The Zone Forestière is made of a ridge, which is a spur of the Fouta Djallon highland, extending as far south as Mount Nimba (1,752 m). The forest is now limited to the high valleys and eastern flanks of these mountainous zones (CM). Although prone to erosion on steeper slopes, the soils of the Zone Forestière are highly fertile, supporting cultivation of food and cash crops, such as coffee, tea, cocoa and rubber.



Land Use, Land Cover and Trends

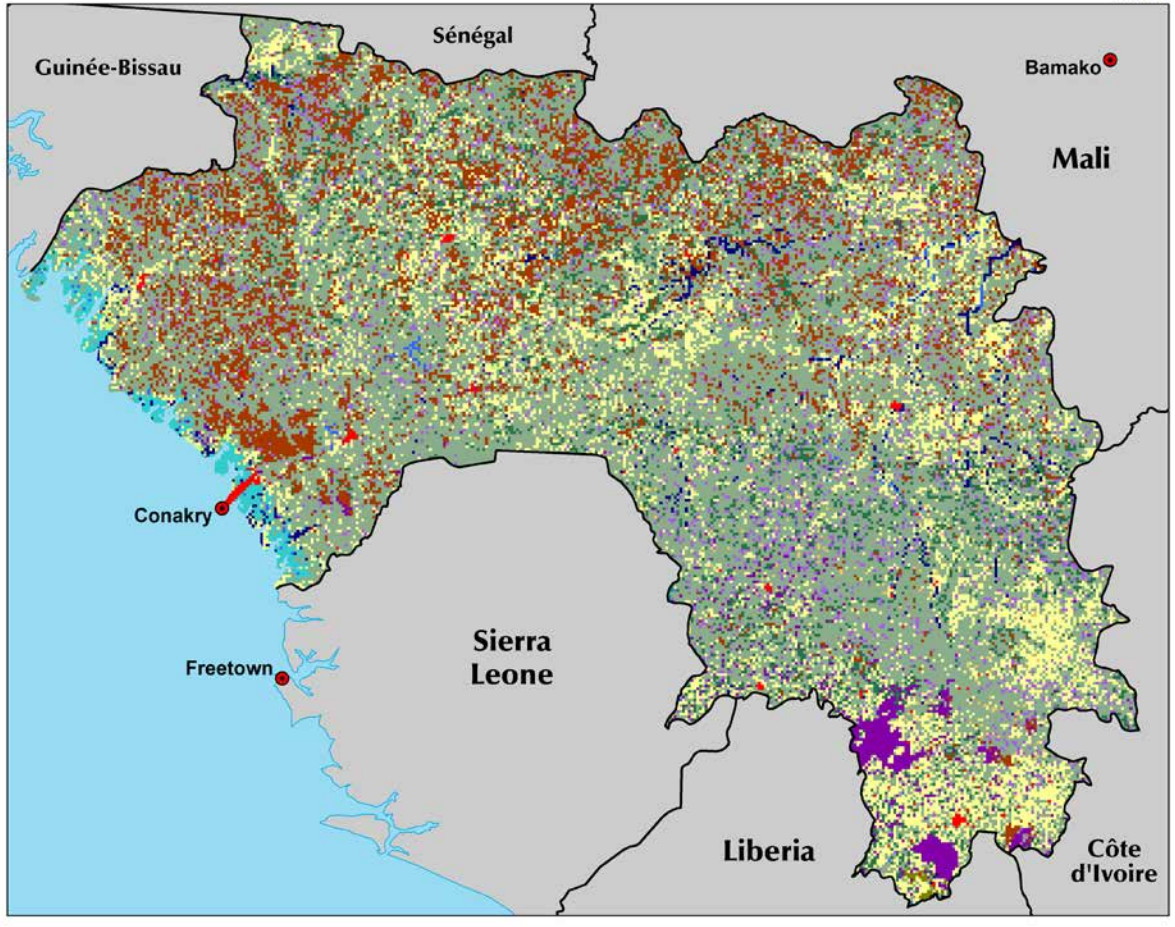
Despite a significant reduction in land area since 1975, savannas still dominate the Guinean landscape, accounting for 54 percent of the national land surface. Savanna loss is mainly due to agricultural expansion, with cropland area having doubled over 38 years. Driven by population growth, the mean rate of agricultural expansion rose dramatically from 1.3 percent per year during the 1975–2000 period to 4.7 percent per year between 2000 and 2013. However, agriculture expansion was not equal throughout the country. Southern ecoregions, especially the Zone Forestière (ZF – Forest Zone), the eastern Zone Pré-Forestière (ZPF – pre-forest Zone), and the Fouta Djallon massif have experienced the greatest expansion. In these zones, the practice of slash-and-burn on steep slopes increases their vulnerability to erosion. However, agricultural practices, such as terrace cropping and rock lines have helped to mitigate soil erosion. Farther westward, on the Plateaux de Basse-Guinée (PBG – Lower Guinea Plateaus), in the Zone de Savanes et de Montagnes (ZMS – Savana and Mountain Zone), and in the ecoregion of the Socle Précambrien (SP – Precambrian Shield) where soils are rocky, non-productive, and relatively unsuitable to cultivation, agricultural development is limited to alluvial valleys and low plateaus. Irrigated agriculture has also doubled since 1975, especially in the Plaines Agricoles du Bassin du Niger (PABN – Agricultural Plains of the Niger Basin), which lend themselves to rice cultivation.

Between 1975 and 2013, forest areas decreased by about 33 percent to only 4,440 sq km, found mainly in the Zone Forestière (ZF – Forest Zone). One major cause of this reduction is the significant population growth resulting from a heavy migration from the north and from a huge influx of refugees from Sierra Leone, Liberia, and Côte d'Ivoire. Non-protected forest areas have been severely degraded by uncontrolled logging for both local and commercial uses, and by slash-and-burn cultivation. While Guinea's national forests are receding, there is remarkable stability among Guinea's forest "islands" (Fairhead and Leach, 1994). Many hundreds of forest islands — areas of high forest around villages — have been encouraged and managed by villagers for centuries. Several ethnic groups in the forest-savanna transition



● Capitale Nationale / National Capital

2013



Occupation des Terres / Land Cover

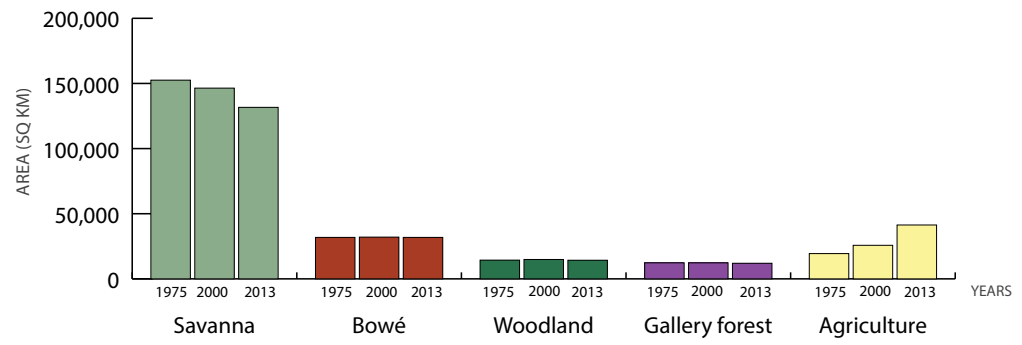
- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Forêt dégradée / Degraded forest
- Forêt claire / Woodland
- Mangrove
- Savane / Savanna
- Bowé
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

zone maintain these multi-purpose forest islands (see page 57). Woodlands and gallery forests, with a land surface three times higher than that of dense forests, have not experienced the same high level of deforestation as Guinea's dense forests. Woodlands and gallery forests are found in all regions of Guinea and their surface area has only decreased by 0.5 and 2.7 percent, respectively, over the 38 years.

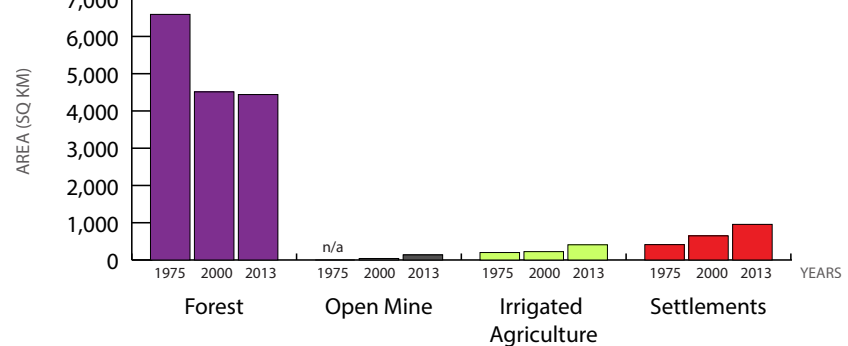
Bowé — laterite-capped plateaus that characterize much of Guinea's landscapes — accounts for 13 percent of Guinea's land surface. Naturally, bowé are very stable over time. While unsuited to cultivation, these treeless grasslands serve as important water catchment areas and as pasture for livestock.

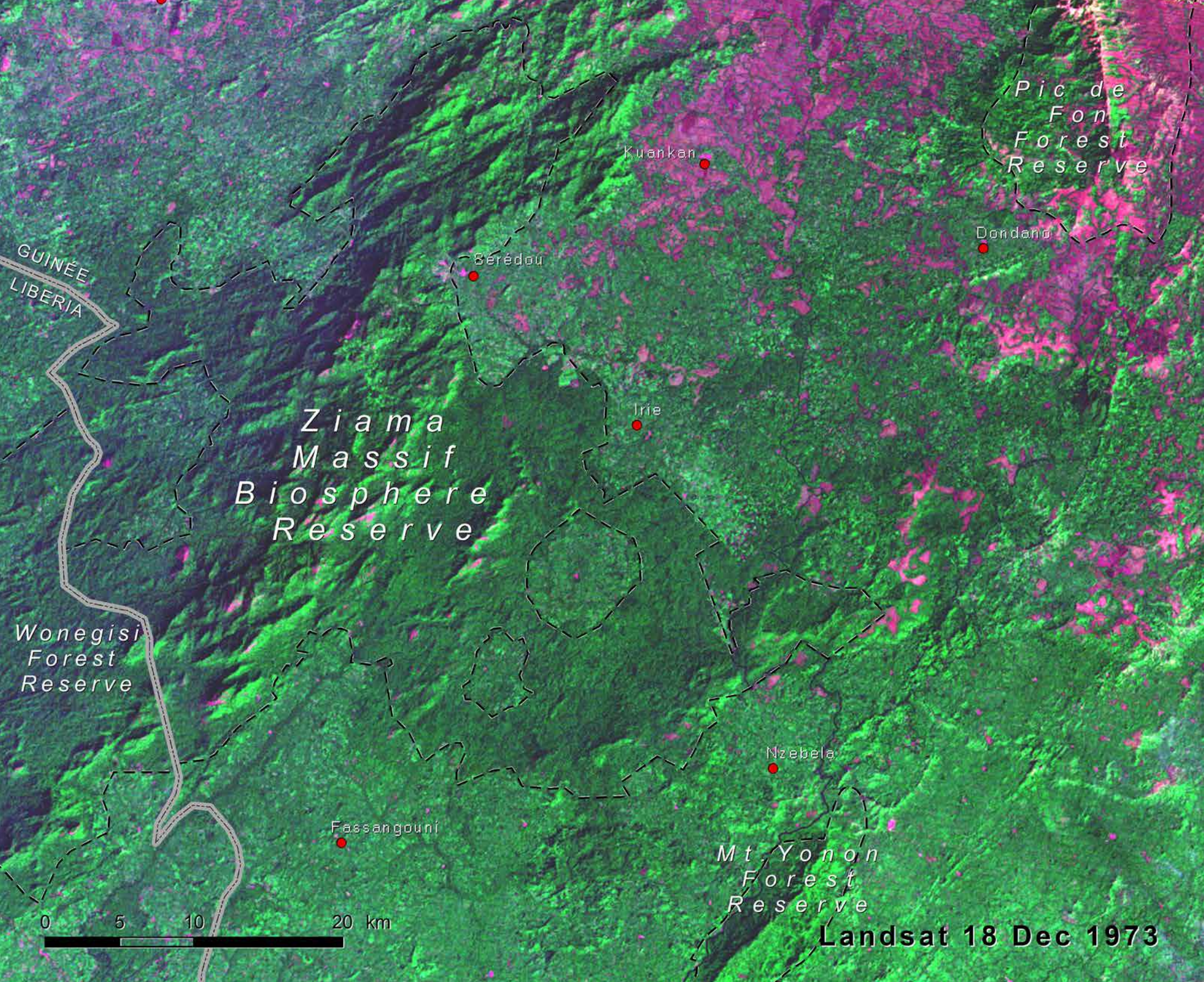
The land area of large industrial mines has tripled between 2000 and 2013, increasing from 40 sq km to 130 sq km. They are testimony to the development of Guinea's growing industrial mining sector. Although local-scale artisanal mining is difficult to map at a national scale, it has also intensified as the price of gold has risen, and has a significant impact on the environment.

Large area classes



Small area classes

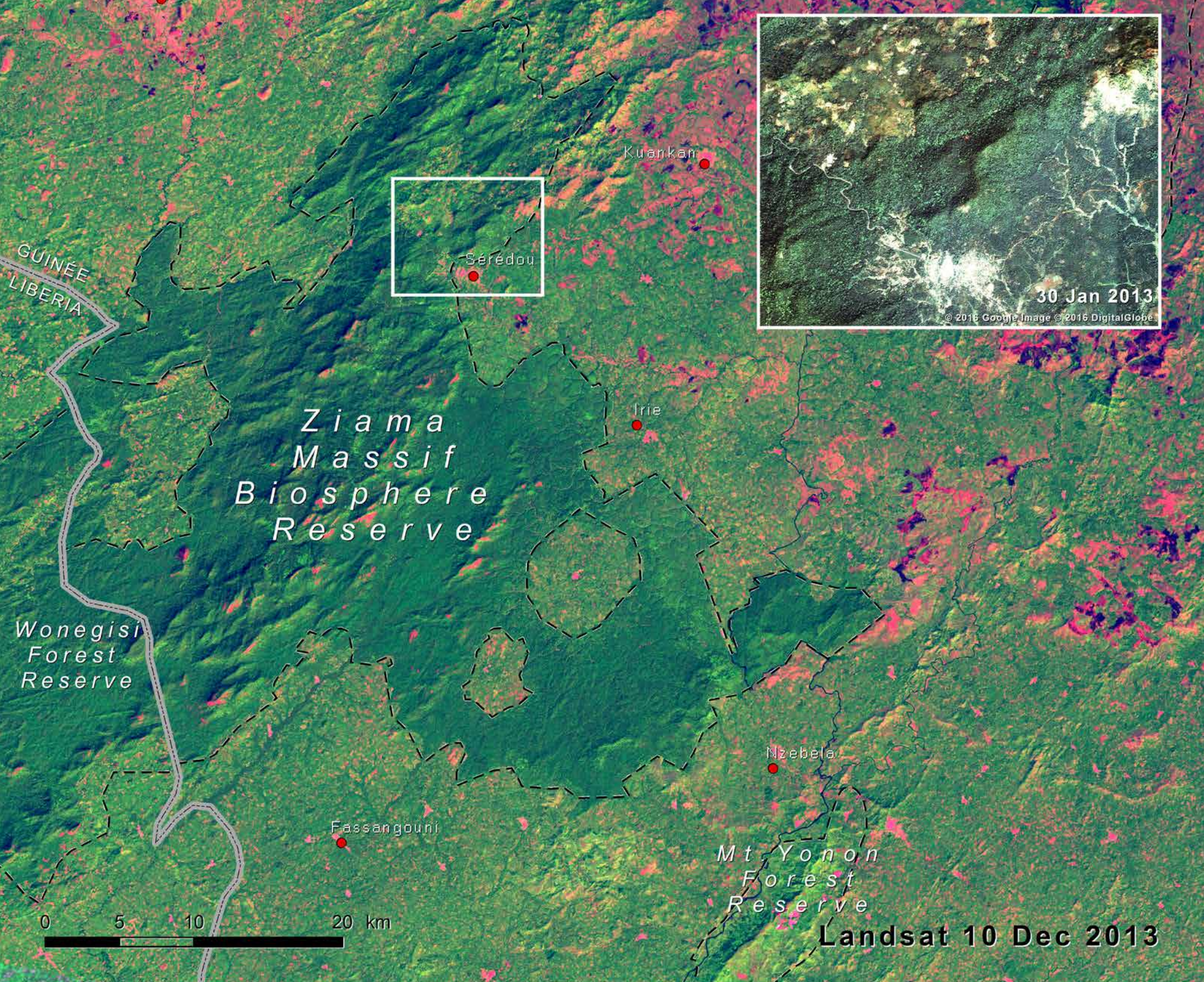




The Zياما Massif: A relic of the diminishing Upper Guinean forest ecosystem

The Zياما Massif is part of the Guinean Highlands region; elevations rise nearly 1,400 m above sea level. This mountain range is characterized by rugged terrain with valleys, plateaus, rocky peaks, cliffs, and granite outcrops. Mean annual precipitation varies from 1,700 mm to 2,000 mm. The vegetation communities on the massif include savanna, primary dense mountain forest, secondary mountain forest, as well as woodland in the northern valleys, plains and swamps. The massif supports a great diversity of Guinean zone tree species.

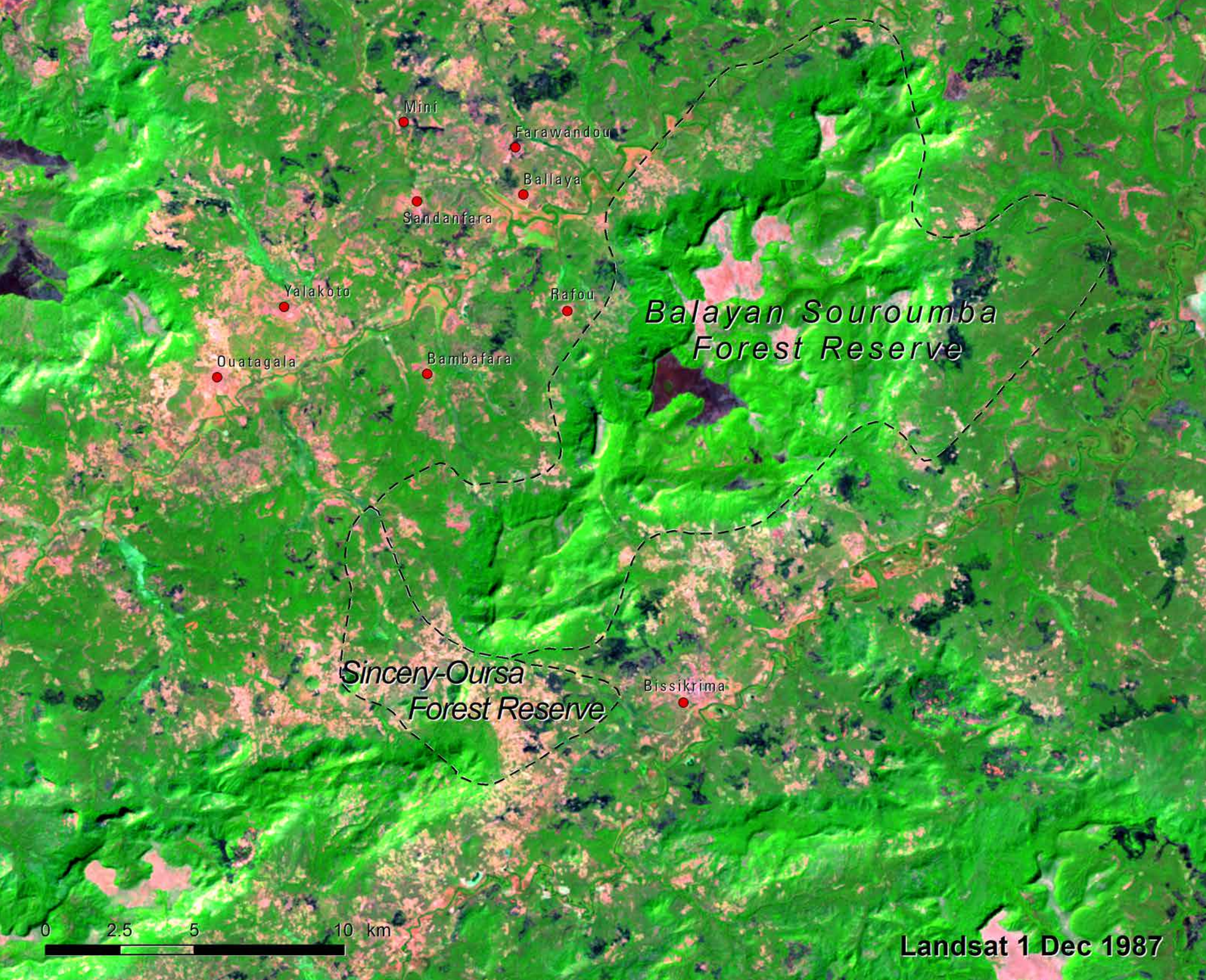
This highly biodiverse area, with a great number of threatened mammal species (chimpanzee, Diana monkey, pygmy hippopotamus, elephant) and a large diversity of plant species, is one of only four biosphere reserves in Guinea. The Zياما Massif was designated a forest reserve under French colonial rule in 1932, in an effort to stop "savannization," the perceived advance of the savanna from the north. After independence, however, the new state-run economy put major emphasis on agricultural development, with biodiversity conservation given very low priority. As a result, farmers cultivated many of the protected areas established in the colonial period. In 1981, the Zياما Massif was made a Biosphere Reserve. In order to better engage local support, conservation is enforced with decreasing intensity outward from the core and allows increasing rural development activity in the buffer and transition areas (Fairhead and Leach, 1994).



As in the case of the Kangari Hills in Sierra Leone (see pages 188–189), the conservationists’ view of a supposedly “pristine” forest stands in contradiction to evidence of abandoned village sites and detailed written and oral accounts of a prosperous agricultural landscape in the mid-19th century, accounts that have shaped local perceptions. Clashes between subsistence needs of a growing population — 29,000 people in 23 villages in and at the margins of the reserve, and in the town of Sérédou — and long-term conservation interests have been exacerbated by the slow start of promised rural development activities in the buffer zone (Fairhead and Leach, 1994). It is unknown to what extent the management plan for timber extraction and agroforestry in the buffer zone is being followed, or to what extent shifting agriculturalists and refugees are exploiting and encroaching the reserve (Brugiere and Kormos, 2009). The Landsat images of the Ziama Massif and surrounding area from 1973 and 2013 show relatively stable forest cover inside the Biosphere Reserve. In 1973, agriculture was already present around the reserve, but the surrounding landscape was still wooded and dominated by natural habitats. By 2013, farmland replaced most of the savanna and woodland outside of the reserve boundary. Agriculture started to encroach on the outskirts of the Ziama Massif, especially in the northern part around Sérédou (see inset). With rates of population growth of 2.6 percent per year, an influx of refugees from neighboring countries, and the predominance of itinerant agriculture, there is a need for careful planning and multi-stakeholder management in order to preserve this hotspot of biodiversity.



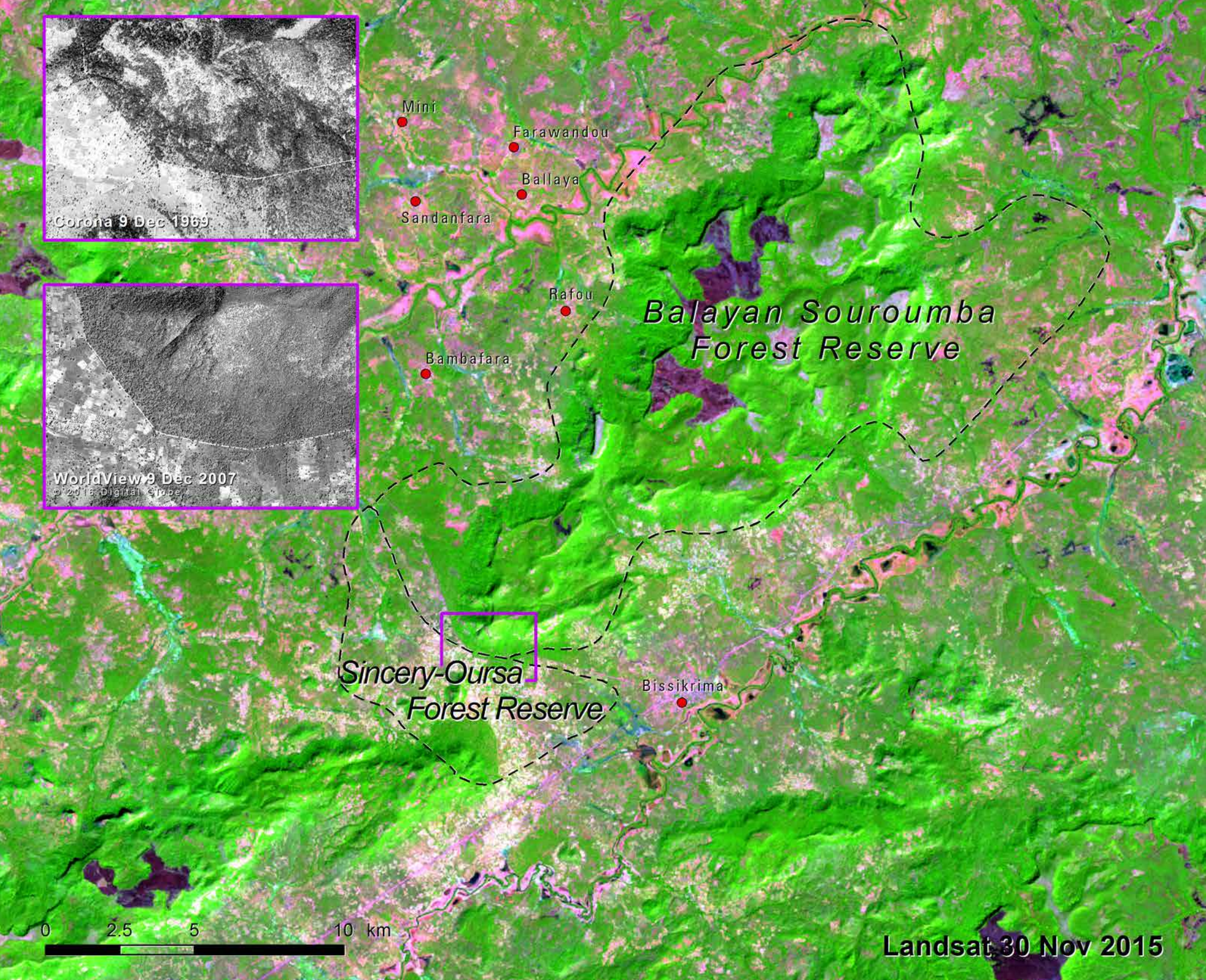
GRAYTAPPAN / USGS



Sustainable forest management in Guinea

The remaining forests and woodlands of Guinea play a critical role in preserving biodiversity in West Africa. A number of these forests are found in Guinea's highlands, known as the "water tower" of West Africa because they provide a source of water to many of the region's rivers, including the Niger, Senegal, and Gambia Rivers. Many of Guinea's forest reserves have become degraded as a result of population pressure, slash-and-burn agriculture, and uncontrolled burning. To combat forest degradation, Guinea has adopted a new, more effective approach to forest management. Since 1993, the U.S. Agency for International Development (USAID) and the Direction Nationale des Eaux et Forêts de la République de Guinée (DNEF—Water and Forest National Office of Guinea) have worked together on co-forest management in four forest reserves within the Fouta Djallon highlands of central and northern Guinea. Under this decentralized approach, the DNEF and communities adjacent to these forests enter into a legal contract for the management of the reserves by the local communities. The premise is that if local communities are provided with the authority (and associated benefits) to manage a forest, then the forest will be managed more sustainably. In each case, DNEF forestry agents assisted forest communities in developing a management plan. Consistent with this plan, villagers are often allowed to use sections of the forest for agricultural production or other limited uses. In some cases, both the DNEF forestry agents and the forest communities have worked together to prevent the illegal cutting of forests. One of the DNEF forest agents interviewed said, "We are now educators, not policemen."

But what has been the real impact of over two decades of co-forest management on these forests? To help answer this question, USAID and the DNEF teamed up with the USGS to look at actual forest conditions on the ground

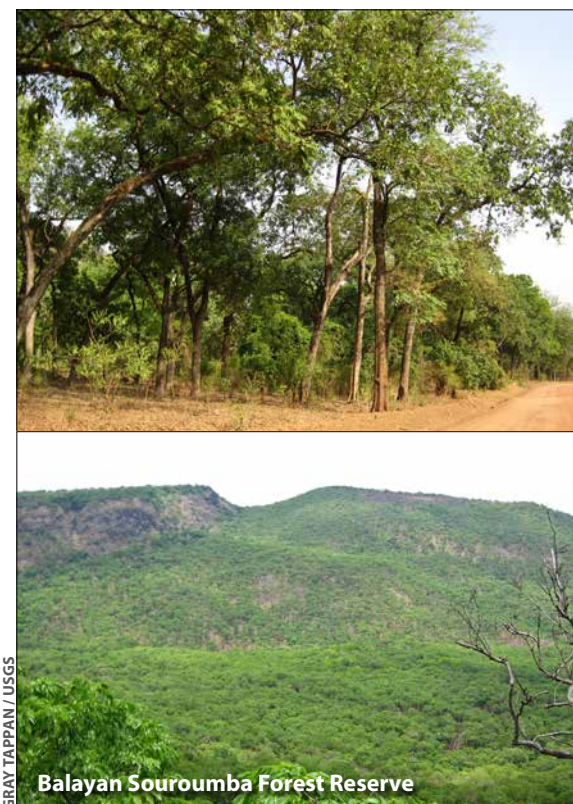


and use satellite images to see how they've changed over time. USGS used a nearly 50-year historical record of satellite images to assess the extent of forest cover and its biophysical condition within the four forests reserves in which USAID and the DNEF have been working. Two of those reserves — Balayan Souroumba and Sincery Oursa — are shown in the images above (the others were Nyalama and Souti-Yanfou).

The scientists analyzed satellite imagery from 1969, 1987, 2007, and 2015 to assess forest resource trends over time. No one necessarily expected to see positive changes in the forest, but the results from the USGS time-series image analysis were surprising and encouraging. The extent and condition of all four of the forest reserves have remained quite stable, and in some areas have improved over the past two decades.

Both forest reserves show a significant increase in tree density over the years. Indeed, tree cover is much denser now than in 1967 (see insets). Local forest agents attribute this to the benefits of co-forest management, particularly to improved fire management through early prescribed burning. They also credit relocation of villages and fields from the interior to the periphery of the reserve, tree planting, and the development of a plan for the sustainable management and regeneration of timber.

The local DNEF forestry agents speak positively regarding the benefits of Guinea's co-forest management approach: "We are proud of the interventions of the projects. We can increase the forests of Guinea — we see a way forward. Our victory is if the experiences of co-management are shared and used elsewhere." The Guinea government is doing just that. The Guinean government's forestry and decentralization policies now favor a co-management approach for all of the nation's forest reserves.



GRAY TAPPAN / USGS

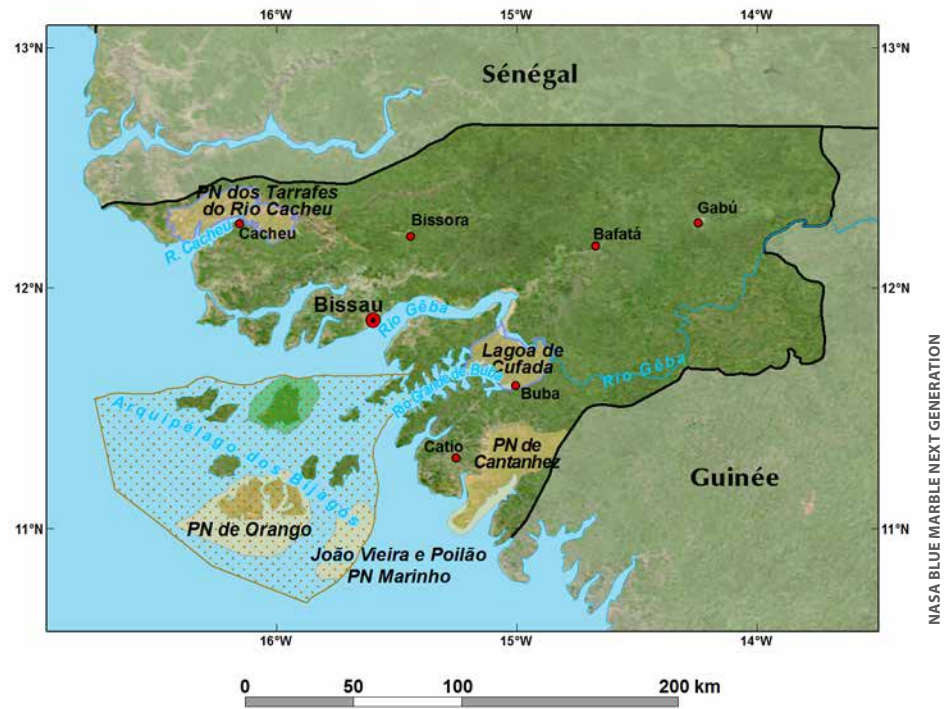


Republic of

Guinea-Bissau

Total Surface Area: 36,120 km²
Estimated Population in 2013: 1,757,000

At just over 36,000 sq km in area, Guinea-Bissau is one of the smallest West African countries. Most of its generally flat terrain averages just 20 to 30 m above sea level, with low-lying plateaus in the east rising to 150 m. Guinea Bissau has an intricate shoreline on the Atlantic Ocean, with numerous estuaries that penetrate inland. Coastal valleys flood regularly, making them conducive to rice cultivation. Half of the population of this former Portuguese colony is found in the coastal zone and has been living for centuries in a tight relationship with the mangrove ecosystem and its rich fisheries. Not far offshore, the Bijagos Archipelago, which includes 18 islands and numerous islets, is regarded as one of the world's most beautiful island groups. Listed in 1966 by UNESCO as a biosphere reserve, the Bijagos Archipelago provides a refuge for abundant marine flora and fauna, including sea turtles and sea hippopotamuses. Some of the islands are also protected as a National Park and as a Community Marine Protected Area. The Bijagos Archipelago is economically important for tourism, fishing, and exploitation of native palm trees. Guinea-Bissau's economy also depends on farming and agro-pastoral activities, as well as on logging for timber. The country ranks fourth in Africa for cashew nut production, with exports from cashews accounting for 60 percent of the national income (FAOstat, 2015).



-  **Biosphere Reserve / Réserve de Biosphère**
-  **Ramsar Site / Site Ramsar**
-  **Parc National / National Park**
-  **Réserve Naturelle / Nature Reserve**
-  **Capitale nationale / National capital**
-  **Autre Ville / Other City**

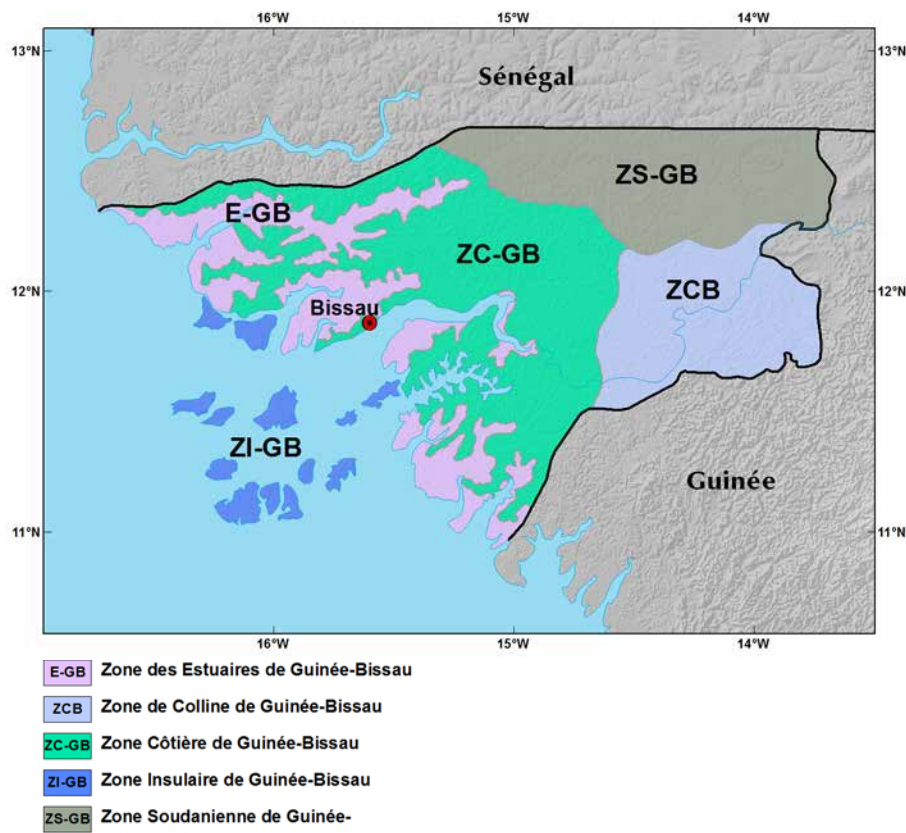
Environmental Highlights:

- Deforestation
- Overfishing
- Diverse mangrove ecosystem
- Ecological richness of the Bijagos Archipelago



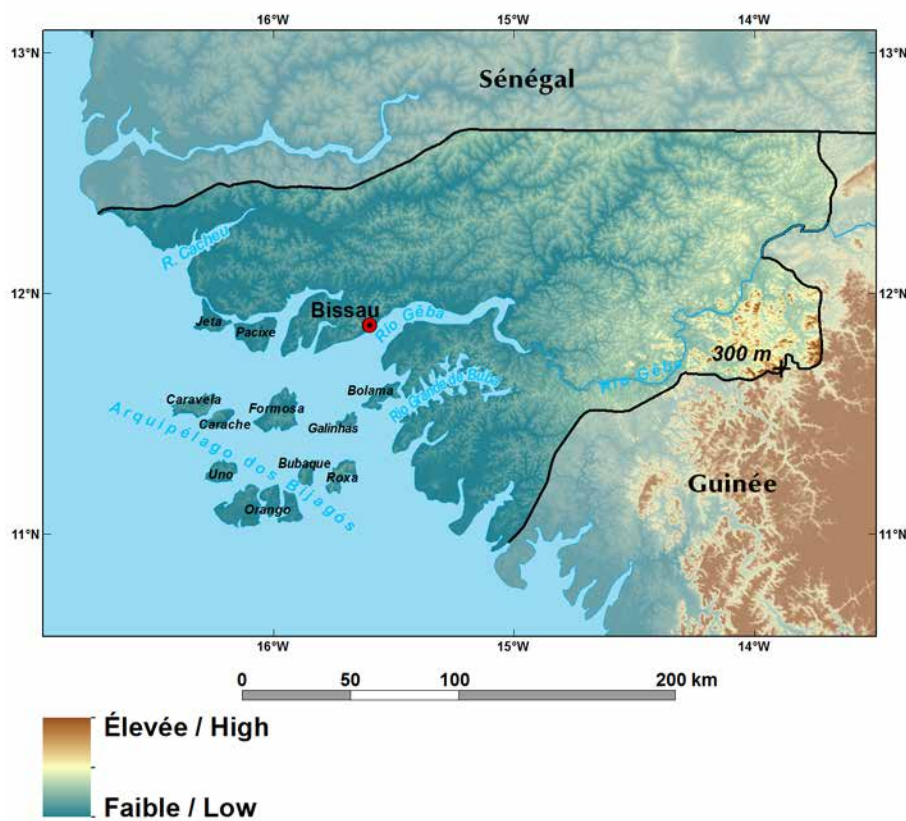
Rice fields and fringing forest

Ecoregions



The Bijagos Archipelago constitutes the first of five ecoregions — the Zone Insulaire de Guinée-Bissau (ZI-GB – Guinea-Bissau Island Zone). On the mainland, two distinctive ecoregions make up the coastal area. The first is the Zone des Estuaires de Guinée-Bissau (E-GB – Estuaries of Guinea-Bissau) where the narrow land-water interface presents a complex system of estuaries, lined with mangrove forests, tidal flats, and herbaceous savanna fringed with palm groves. Just inland is the Zone Côtière de Guinée-Bissau (ZC-GB – Guinea-Bissau Coastal Zone), a low, rolling plain and broad valleys devoted in large part to agriculture, carved out of remnants of Sudanian and Guinean Zone woodlands. In the northeast is the Zone Soudanienne de Guinée-Bissau (ZS-GB – Guinea-Bissau Sudanian Zone), a transition zone of wooded savannas on ancient bedrock between the high Fouta Djallon in Guinea and the coastal lowlands. In the southeast lies the relatively remote Zone de Colline de Boé (ZCB – Boé Hill or Upland Zone), a dissected upland capped by extensive laterite soils and herbaceous bowé formations.

Shaded Relief



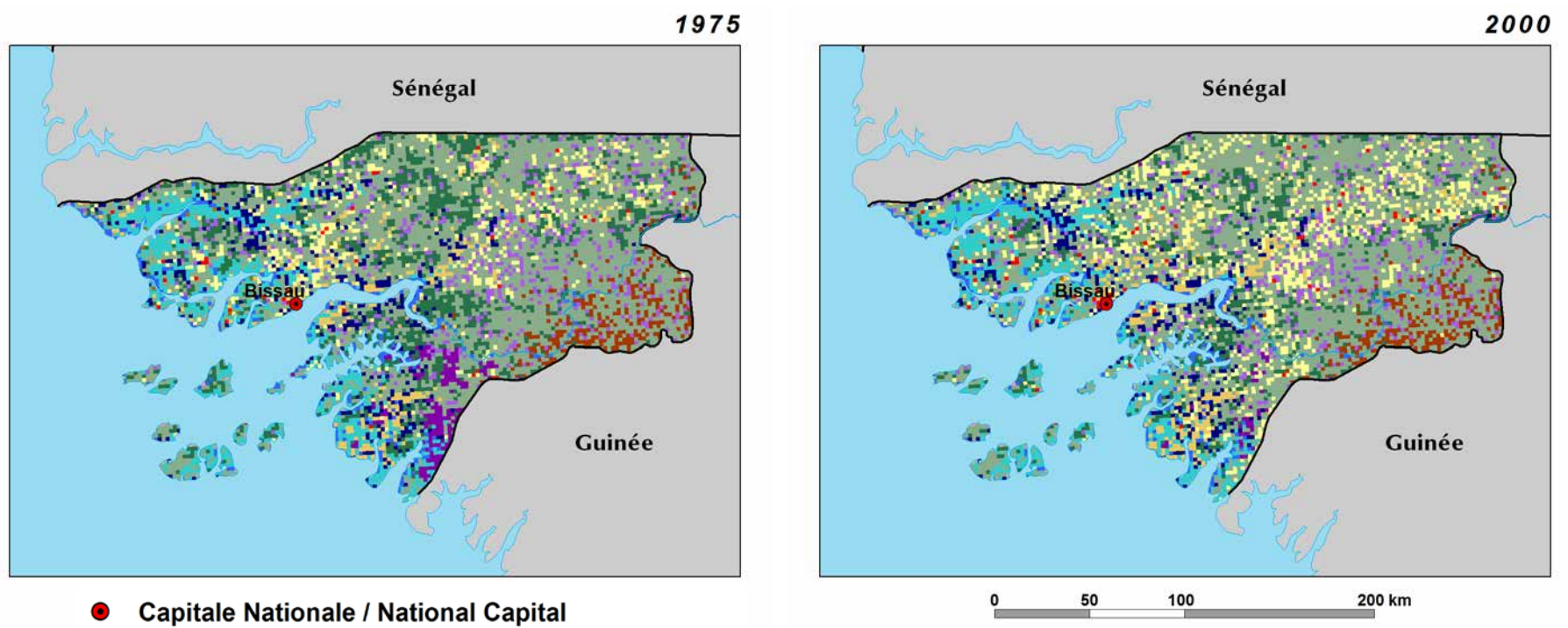
GLOBAL MULTI-RESOLUTION TERRAIN ELEVATION DATA 2010 (GMTED 2010)



JBDODANE / CC BY-NC 2.0

Wetland and mangrove forest in Guinea-Bissau

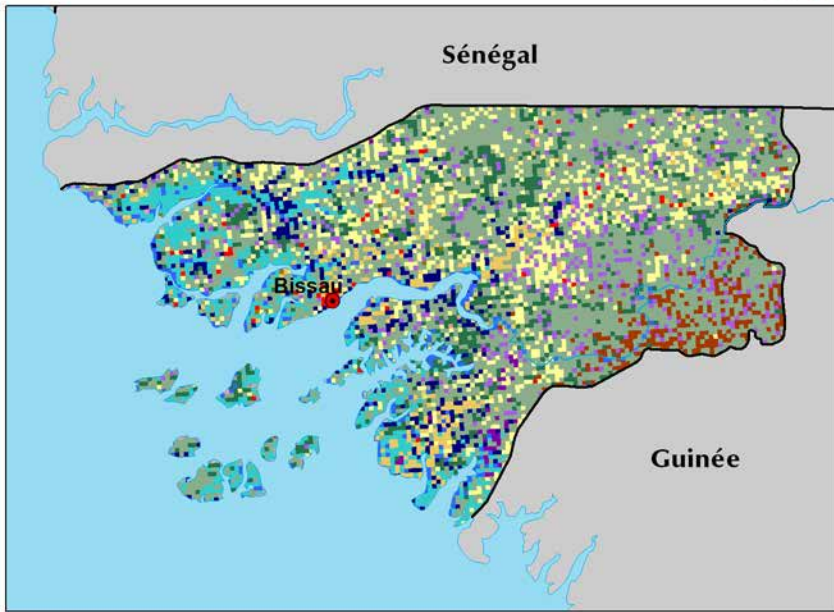
Land Use, Land Cover and Trends



In Guinea-Bissau, savannas dominate the land cover, accounting for about 45 percent of the country's land surface. Although the total savanna land surface has remained nearly unchanged, the underlying dynamic is not so simple. Agricultural areas have doubled since 1975. Covering 13 percent of the national land surface in 2013, agriculture has become the second most extensive land cover class. Clearing for cultivation has encroached into natural habitats in all of Guinea-Bissau's ecoregions except the Zone de Colline de Boé (ZCB – Boé Hill or Upland Zone). Whereas agricultural

expansion explains the loss of about 2,500 sq km of savannas (or 16 percent of their 1975 total land surface), the degradation of woodlands and forests from logging and clearing has produced open landscapes that take on the characteristics of tree and wooded savannas, increasing the area mapped as savanna in the same period. Deforestation for wood production is responsible for 65 percent of forest habitat losses (forests, woodlands, gallery forests), or 1,700 sq km of forest that have become savannas in 2013.

2013



Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Forêt claire / Woodland
- Mangrove
- Savane / Savanna
- Bowé
- Fourré / Thicket
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures des bas-fonds et de décrue / Agriculture in shallows and recession
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Surfaces sableuses / Sandy area
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

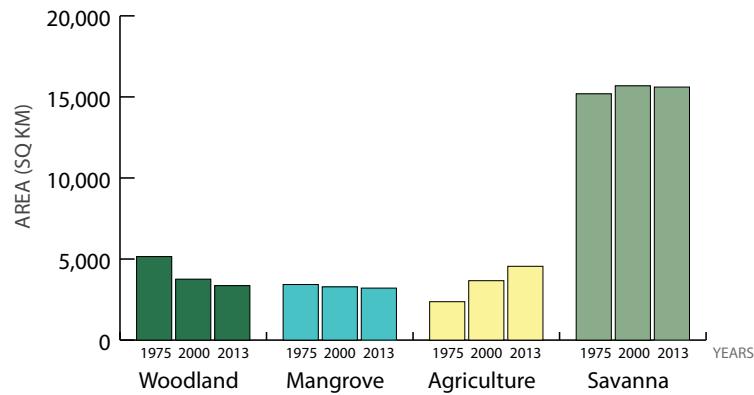
Agriculture in shallows and recession, in particular rice cultivation, colonizes alluvial floodplains in the Zone des Estuaires (E-GB – Estuary Zone) and the Zone Côtière (ZC-GB – Coastal Zone). Rice cultivated areas have slightly increased in Guinea-Bissau since 1975, encroaching into wetlands, gallery forest and mangroves.

Whether from clearing for cultivation, local harvesting of wood, or for external commercial markets, the forest resources have been heavily degraded by rapid exploitation. The rate of deforestation has increased from about 2 percent per year between 1975 and 2000 to 3.9 percent over the 2000 to 2013 period. Overall, Guinea-Bissau lost about 77 percent of its forests between 1975 and 2013; only 180 sq km remain, mainly in the south near the Guinea border. Likewise, woodlands regressed by 35 percent over the 38 years, a loss of 1,750 sq km.

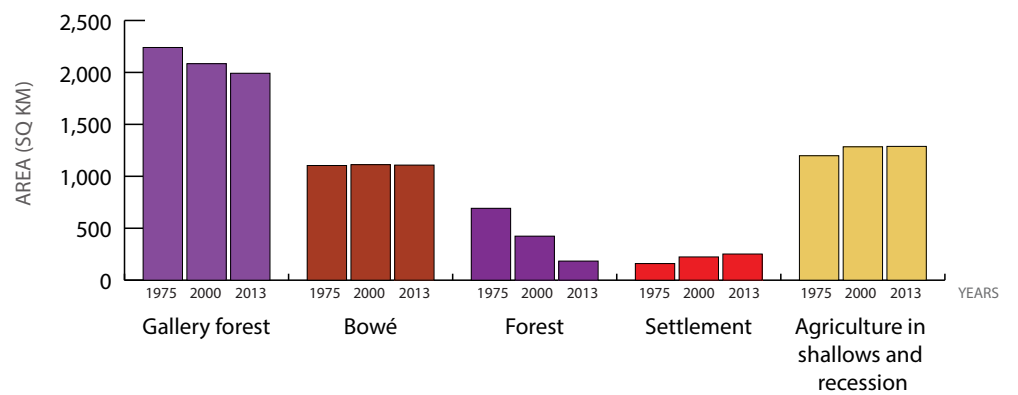
Mangroves are one of the major land cover classes in Guinea-Bissau, accounting for over 9 percent of the country's land surface. This fragile ecosystem is critical to coastal people who take advantage of its rich fisheries and wood resources. They also use the tidal flats for traditional rice cultivation (Corcoran, Ravilious, and Skuja, 2007). Between 1975 and 2013, mangroves decreased by 6.4 percent, or 220 sq km.

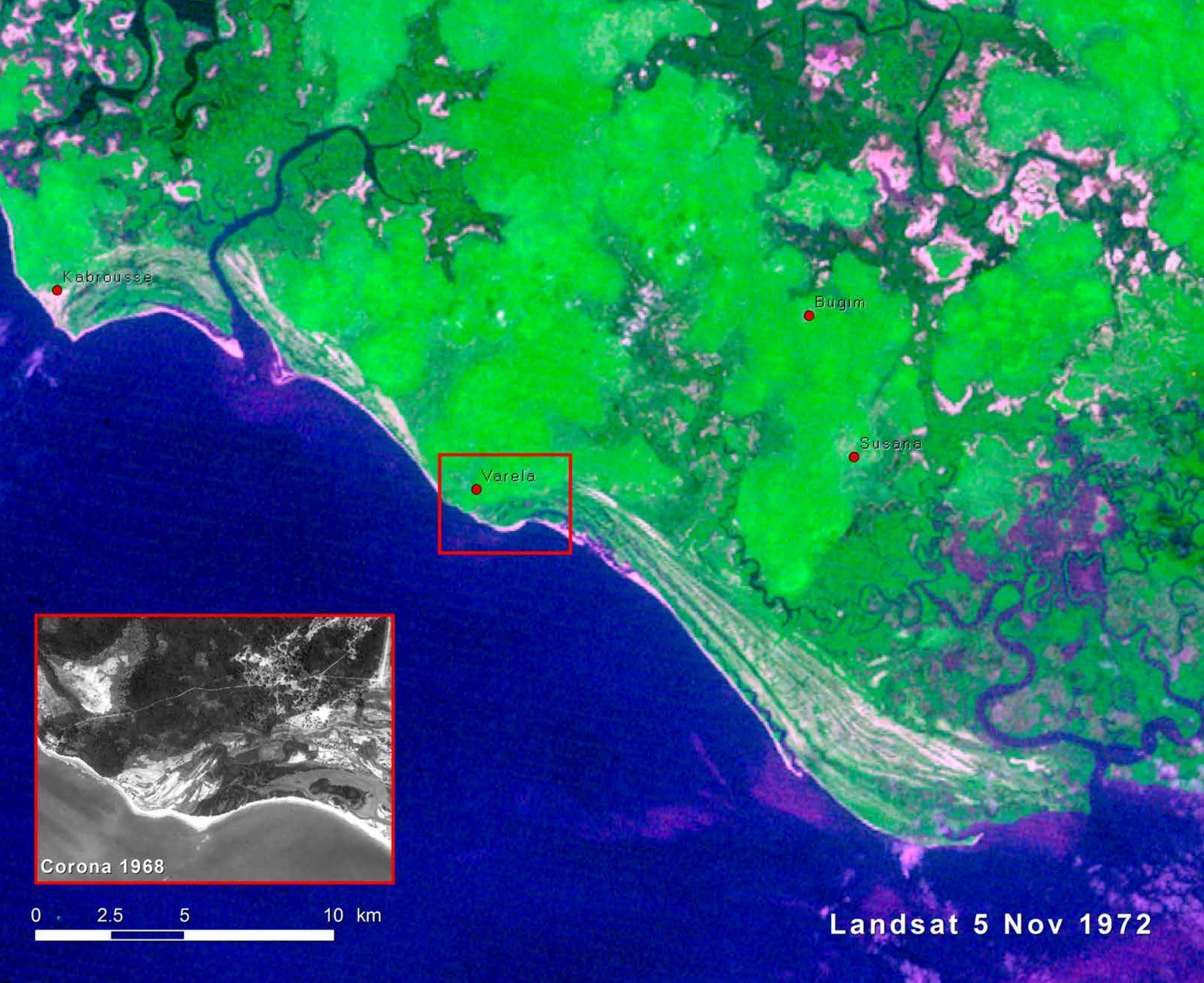
Bowé, lateritic landscapes that characterize Guinean plateaus, cover 3.2 percent of the country's land surface and are mainly found in the Colline de Boé (ZCB – Boé Hill or Upland Zone) ecoregions. These rocky, impenetrable soils are usually devoid of woody vegetation but support a herbaceous cover during the rainy season. As a result, bowé is one of the most stable landscapes in Guinea-Bissau. Bowé is ill-suited to agriculture but conducive to grazing.

Large area classes



Small area classes





0 2.5 5 10 km

Landsat 5 Nov 1972



Coastal erosion in northwestern Guinea-Bissau

Coastal erosion is a major environmental problem throughout West Africa, but some stretches of the coastline are more severely affected than others. In northwestern Guinea Bissau, coastal zones have eroded rapidly over the past few decades. In Varela, the shoreline has retreated by up to 700 m inland in the past 40 years (see inset above). Both rising sea levels and the destruction of mangrove forests, which act as natural barriers, have been blamed for the loss of land. The loss of mangrove forests is especially visible around Kabrousse and along the coast south of Varela; mangroves have been harvested as fuel wood for smoking fish and for other household needs.

As a result of coastal erosion, trees and infrastructure have been disappearing gradually. Towns and villages located close to the shoreline, where most of the economic activity takes place, are likewise threatened. The ruins of a tourist resort, built in the 1980s, stand as a poignant reminder of the forces of the rising



ALEXANDRE CABRAL

Trees uprooted by the action of the waves, further destabilizing the coastline.



tides (see adjacent pictures). Biodiversity of the coastal ecosystem is also at risk. The habitats of marine turtles and the African manatee, both of whom depend on mangrove forests and sea grass beds, have been shrinking. Saltwater intrusions associated with sea level rise present another threat to the coastal ecosystem.

Due to the severity of coastal erosion in this location, Varela beach was selected as a pilot site for the United Nations' Adaptation to Climate Change in Coastal Zones of West Africa project (UNESCO, 2012). In the course of the project, afforestation and rehabilitation of tourism potential were carried out with the help of the local population, and a biodiversity library was established in the Varela Environmental Audit School. Studies were also conducted of Varela's coastal biodiversity and ecological and economic vulnerability to erosion.

Coastal erosion in Varela is expected to increase due to the sea level rise of over 10 cm since 1950. Hence, preparedness — protection of existing natural barriers, monitoring of the coastline, and creation of alternative income opportunities is paramount (Nicholls and Cazenave, 2010).



Crumbling foundations of a tourist resort on the beach.



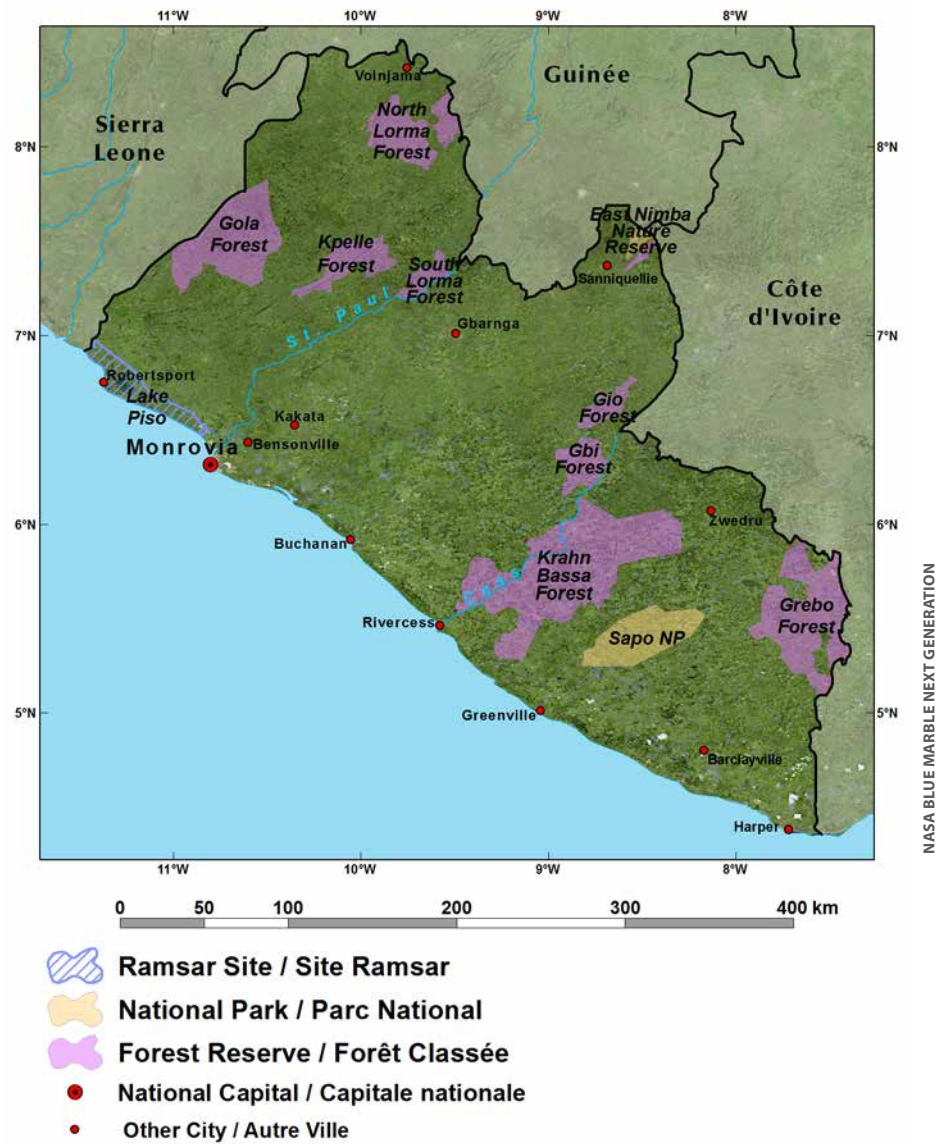
Republic of Liberia

Total Surface Area: 111,369 km²
Estimated Population in 2013: 4,294,000

Liberia, the “Land of the Free”, was established as a homeland for freed African-American slaves in the 19th century and was the first African country to gain independence. The coastal country is characterized by humid, tropical climate with mean rainfall ranging from 2,000 mm farthest inland to over 5,000 mm at the coast. Liberia contains the largest part (50 percent) of the remaining Upper Guinean rain forest in West Africa, which is an important hotspot of global biodiversity. Liberia’s forests contain approximately 225 timber species and are home to a rich diversity of mammals, birds, reptiles and insects (CIFOR, 2005). According to recent assessments (FAO, 2014), less than 5 percent of Liberia’s forests are considered primary forests (no clearly visible indications of human activity); the vast majority are regenerated forests (native species, but with indication of human activity). While Liberia’s forests are recognized as a top conservation priority in the entire region, there are currently only two actively protected areas —Sapo National Park and the East Nimba Nature Reserve —and eight forest reserves. This conservation goal, however, competes with extractive economic activities, such as mining and logging, which account for large portions of Liberia’s export income.

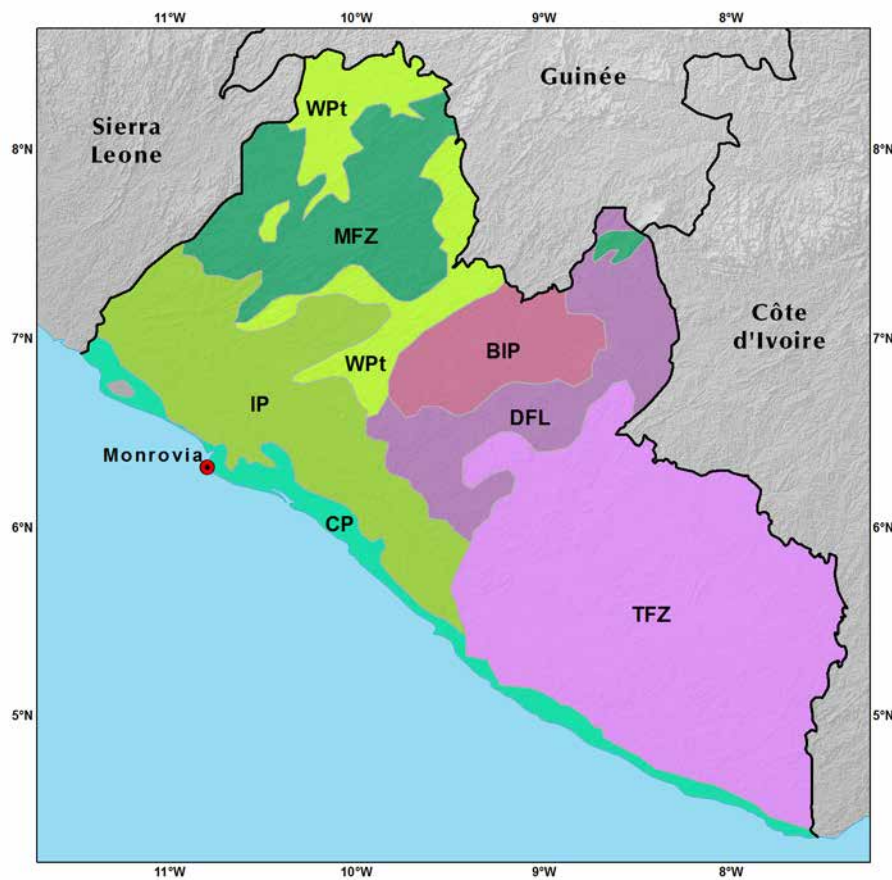
Environmental Highlights:

- Most forested country in West Africa
- Significant reservoir of biodiversity
- Endangered species hunted for bush meat (poaching)
- Deforestation
- Pollution and waste management



View of the Mount Nimba foothills and the railway used to transport the iron ore

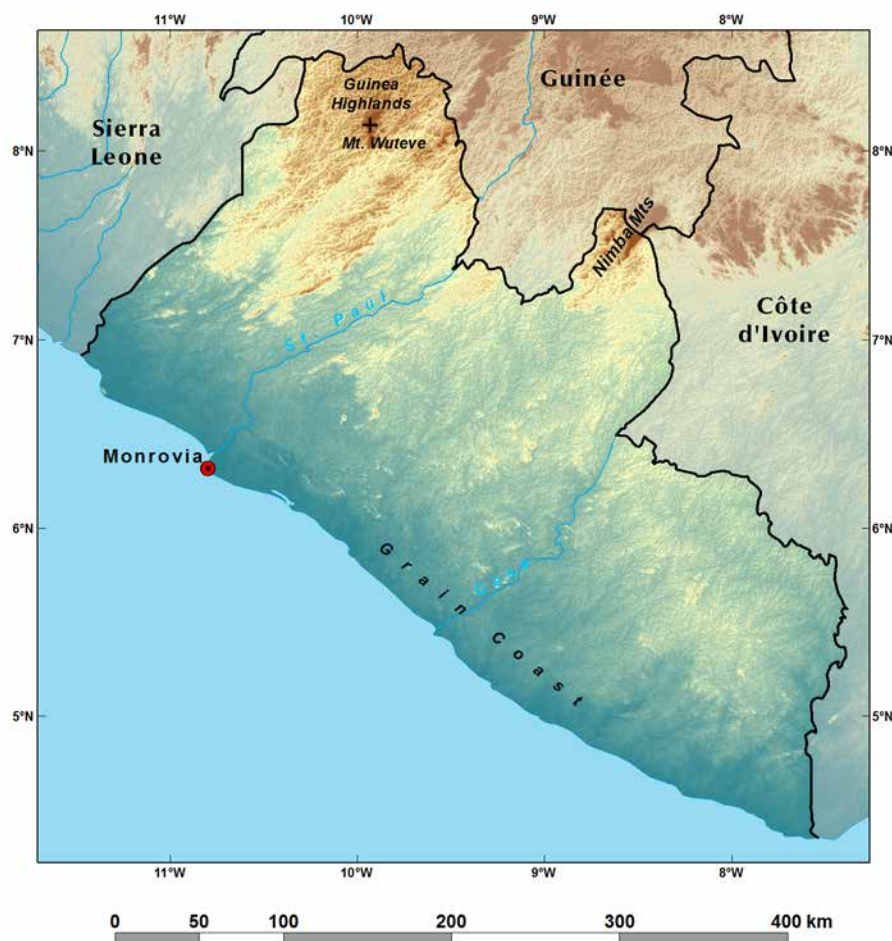
Ecoregions



- BIP Bong Interior Plateau
- CP Coastal Plains
- DFL Degraded Forest
- IP Interior Plains
- MFZ Montane Forest Zone
- TFZ Tropical Forest Zone
- WPt Wooded Plateaus

Liberia’s landscapes range from flat coastal lowlands with mangroves and swamps, to rolling hills and plateaus further inland, and low mountains in the northeast. The Nimba Mountain range, partially protected as a Nature Reserve, stretches along the Guinea border. The Coastal Plains (CP) are covered by a mosaic of savannas, degraded forest and agriculture. In contrast, the hills of the Montane Forest Zone (MFZ) and Tropical Forest (TF) ecoregions are mostly covered by dense rain forests. Within the Montane Forest Zone (MFZ), Mount Wuteve reaches a maximum of 1,380 m, the nation’s highest point. This mountain range is surrounded by the less densely forested Wooded Plateaus (WPt), where woodland and degraded forest dominate. The Bong Interior Plateau (BIP) encompasses most of Liberia’s arable land.

Shaded Relief



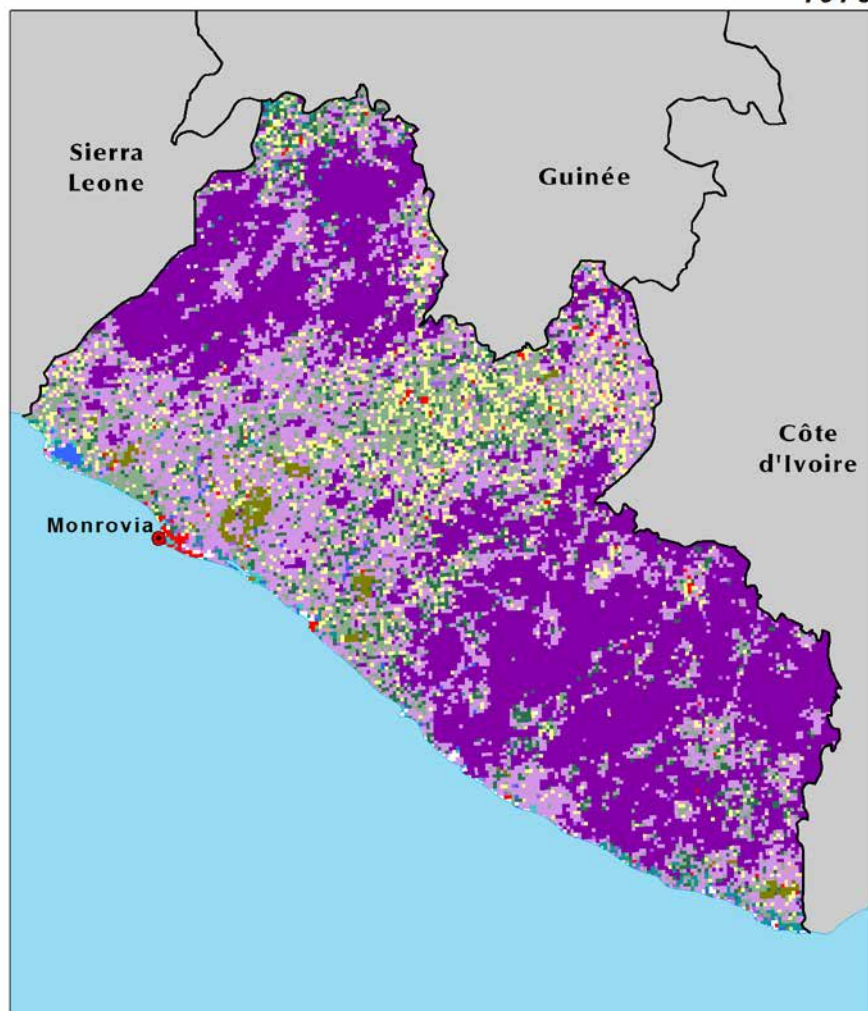
- Élevée / High
- Faible / Low



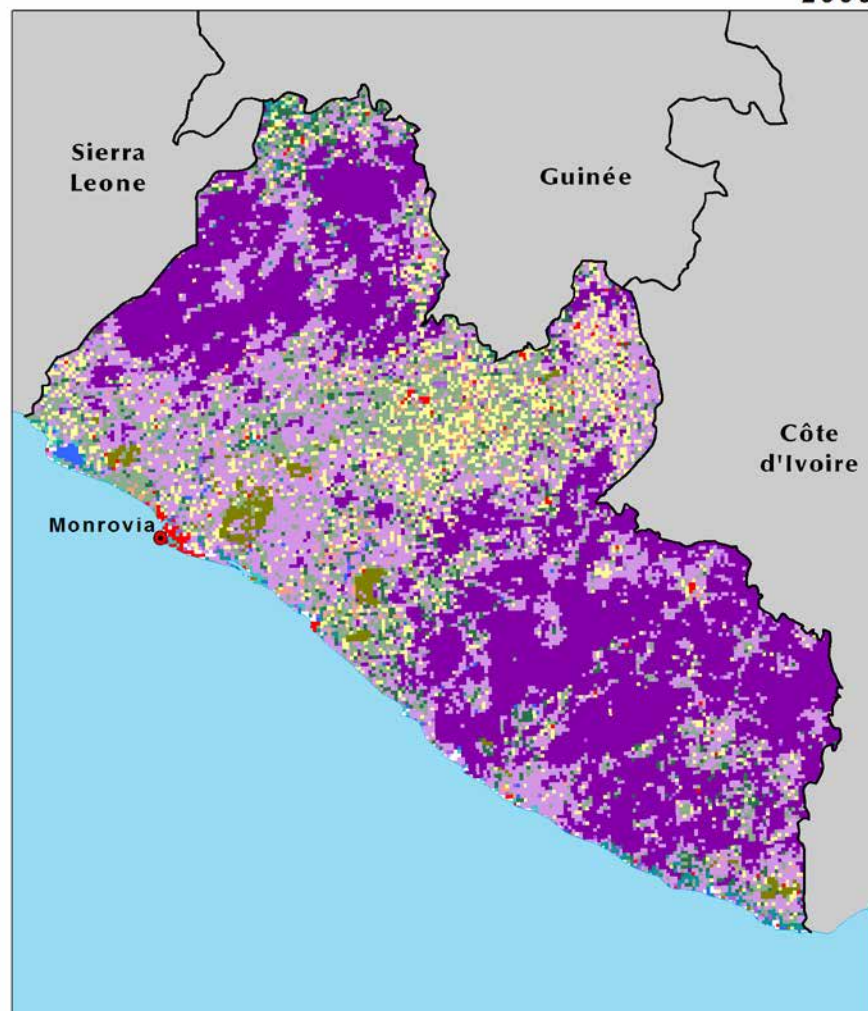
Village in Liberia

Land Use, Land Cover and Trends

1975



2000



● Capitale Nationale / National Capital



Rubber plantation, Liberia

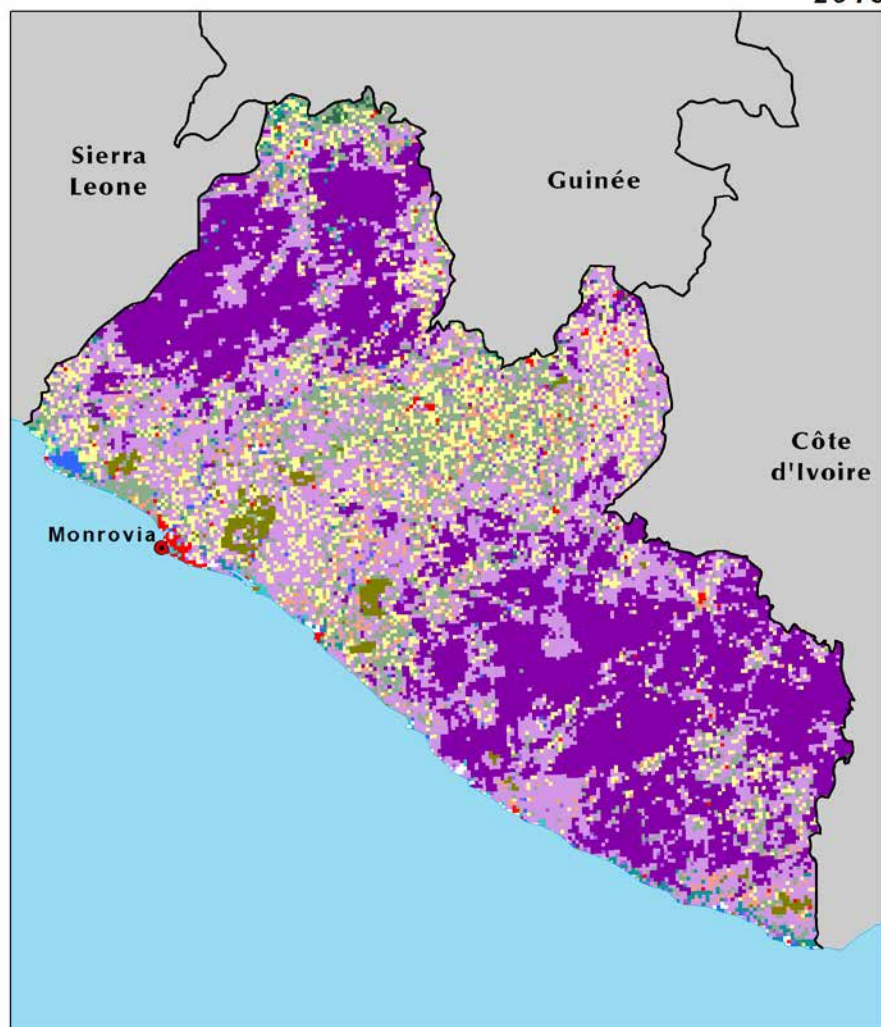
JBDODANE / FLICKR.COM / CC BY-NC 2.0

Liberia stands out as the most forested country in West Africa. In 2013, forest covered two-thirds of Liberia's land surface, of which less than half (44 percent) was mapped as degraded forest, followed by agriculture (13 percent of the land surface) and savanna (11 percent). Smaller land cover classes include thicket (3 percent), gallery forest (2 percent) and plantations (1.5 percent). The remaining land cover classes each occupy less than 1 percent of Liberia's land surface.

The overall rate of change in land use and land cover has accelerated from 0.5 percent per year between 1975 and 2000—slightly below regional average—to 1.3 percent per year between 2000 and 2013, which is above the regional average for this time period. While the civil wars (1989–1996 and 1999–2003) slowed down development and as a result land use change, the post-conflict years have seen a surge in land cover transformation.

The most important trajectories of land use and land cover change have been associated with loss of forest cover: 3,000 sq km of forest were lost between 1975 and 2000, and another 3,500 sq km between 2000 and 2013,

2013



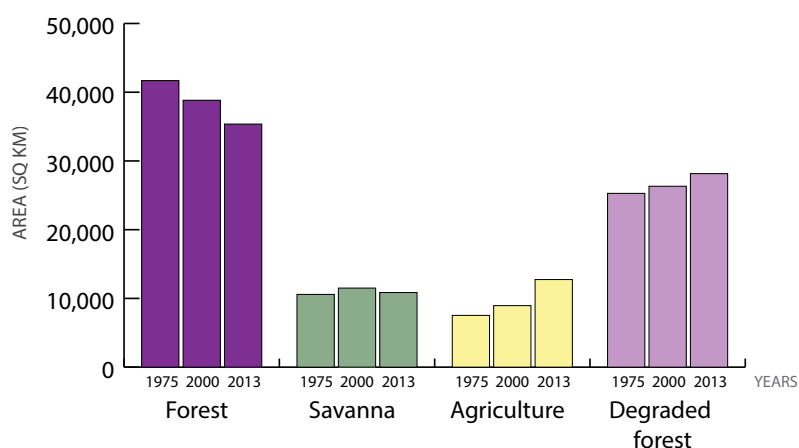
Land Cover / Occupation des Terres

- Forest / Forêt
- Gallery forest & riparian forest / Forêt galerie & formation ripicole
- Degraded forest / Forêt dégradée
- Woodland / Forêt claire
- Swamp forest / Forêt marécageuse
- Mangrove
- Savanna / Savane
- Herbaceous savanna / Savane herbacée
- Thicket / Fourré
- Agriculture / Zone de culture
- Irrigated agriculture / Cultures irriguées
- Agriculture in shallows and recession / Cultures des bas-fonds et de décrue
- Plantation
- Settlements / Habitation
- Bare soil / Sols dénudés
- Rocky land / Terrains rocheux
- Open mine / Carrière
- Water bodies / Plans d'eau
- Wetland - floodplain / Prairie marécageuse - vallée inondable

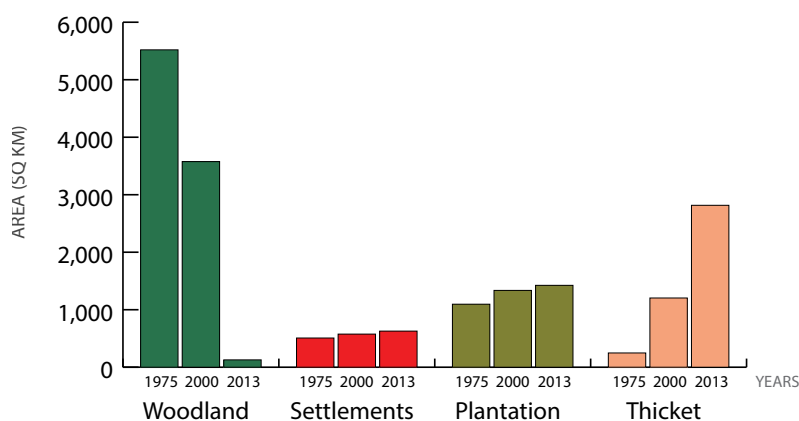
which represents an overall loss of 15 percent of the 1975 forest coverage. Most of the forest loss occurred in the eastern part of the country, in the Tropical Forest Zone (TFZ). Dense forest was mostly converted into degraded forest, savanna, agriculture and thicket, as a result of selective logging and slash-and-burn agriculture. Due to the highly dynamic nature of these land use strategies and the rapid re-growth of vegetation after clearing in this humid tropical environment, the land cover classes of agriculture, degraded forest and savanna show both gains and losses. On the other hand, dense forest, which takes the longest time to fully regenerate, has seen almost exclusively losses.

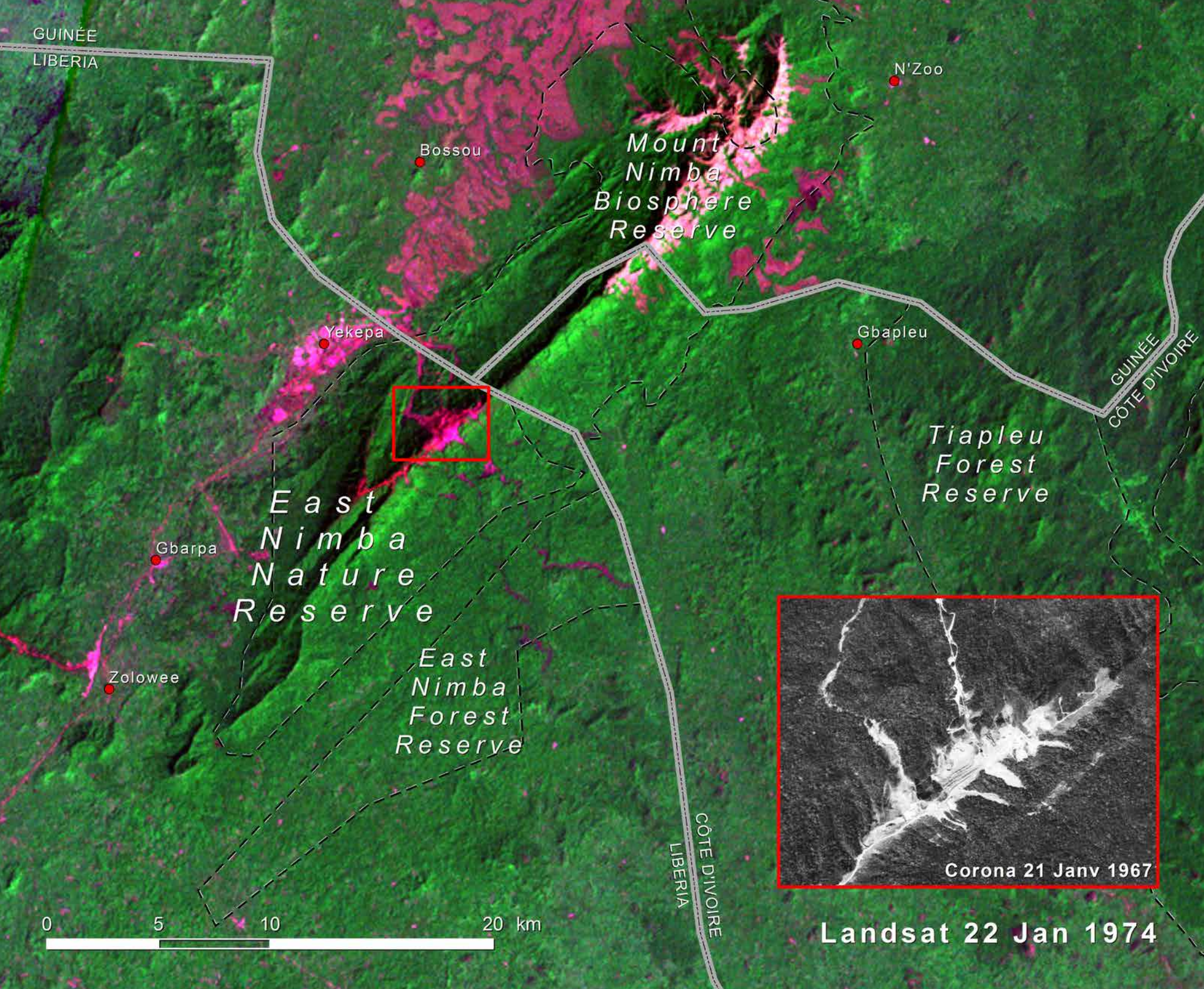
While several of the smaller land cover classes have seen higher losses as a percentage of their 1975 coverage, the 15 percent loss of forest is by far the largest in terms of actual area lost (6,600 sq km) and is the most significant because of the importance of this remnant of Upper Guinean rain forest. Loss of woodlands has been even more dramatic, with a 98 percent loss since 1975, mostly replaced by thickets whose area has grown tenfold during the same time period. Since 2000, agriculture and irrigated agriculture have also expanded rapidly, along with agroforestry (plantations) and mining, all experiencing a revival since the end of Liberia's civil war in 2003.

Large area classes



Small area classes

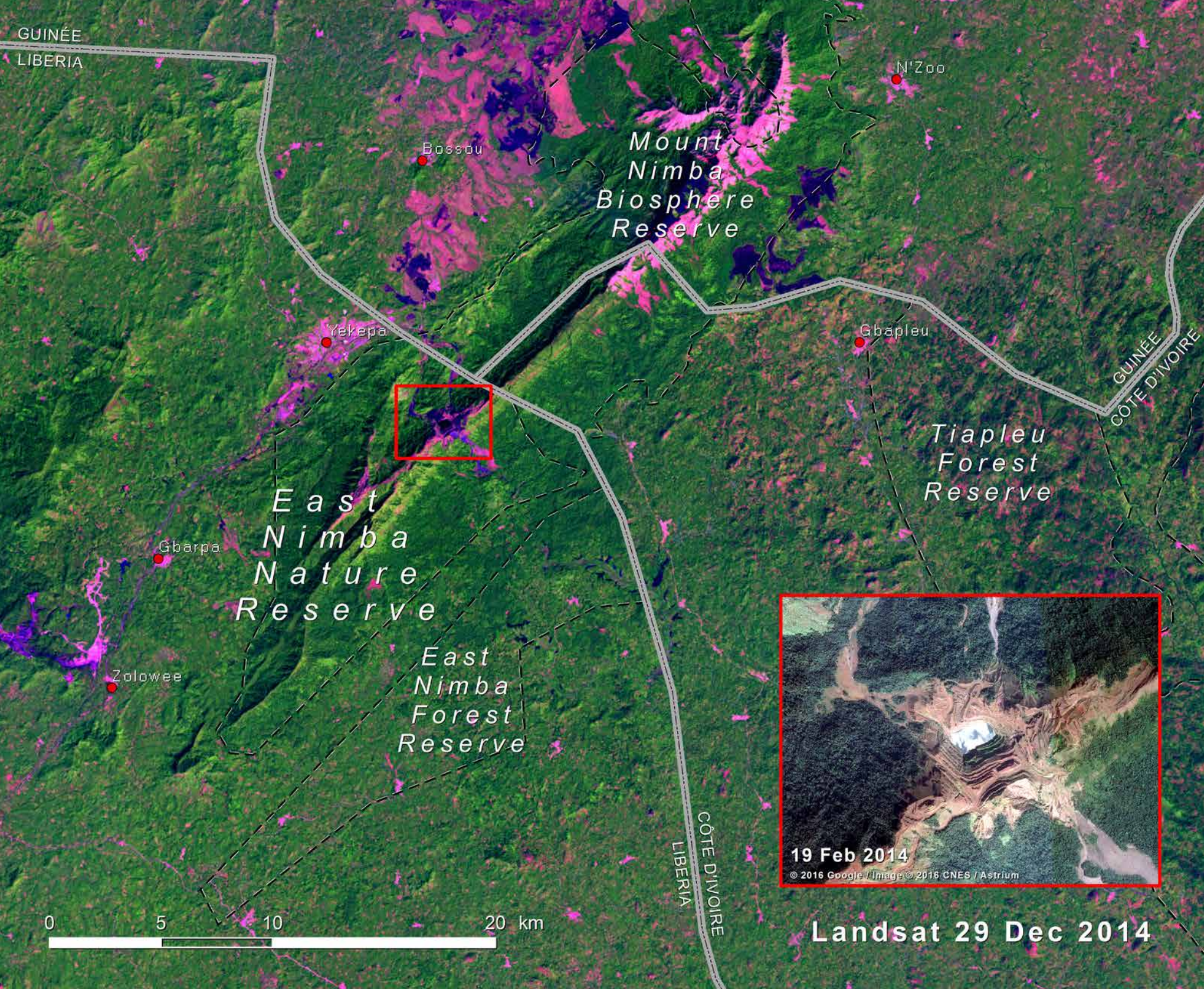




The forest ecosystem of the East Nimba Nature Reserve threatened by human impacts

The Mount Nimba range is a transboundary forested massif which extends from northeastern Liberia into southeastern Guinea and western Côte d'Ivoire. Rising to a maximum altitude of 1,752 m, Mount Nimba is one of the highest elevation forest ecosystems in West Africa. The mountain range encompasses striking landscapes of steep valleys, plateaus, sharp cliffs, and exposed rocks. The Mount Nimba range remained a forest refugium during past glacial periods, when surrounding landscapes became covered by savanna, giving the range biodiversity unparalleled on the continent. It contains original and diverse species of the most remarkable animal and plant populations, notably threatened species such as the *Micropotamogale* of Mount Nimba, the viviparous toad of Mount Nimba and western chimpanzees. As the source of several important rivers, including the Cavalla and St. John, the mountain range also plays an important role in the regional water cycle.

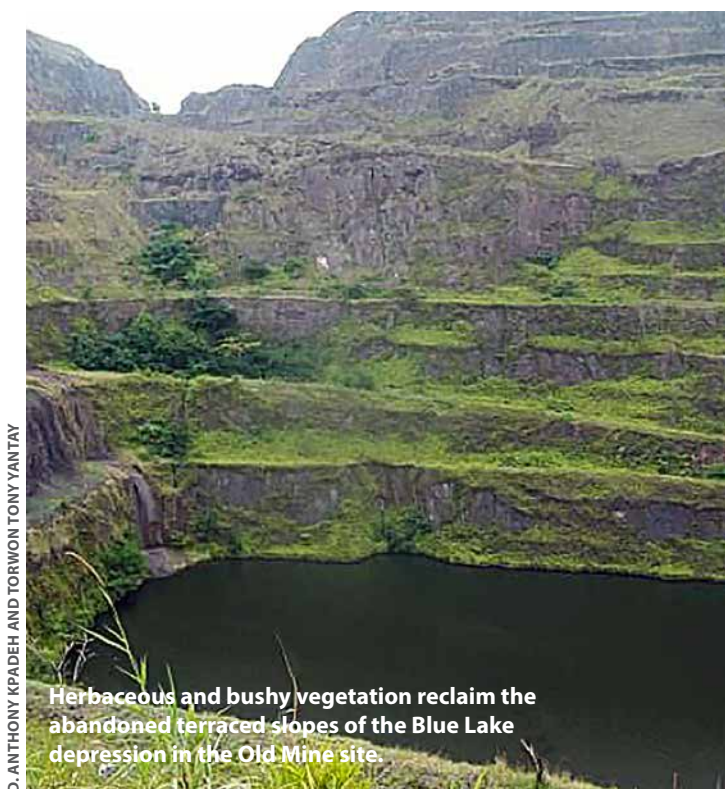
The part of the massif located in Liberia, however, has been greatly degraded by mining. The satellite images from 1974 and 2014 show the impacts of iron ore mining that occurred in Mount Nimba between 1962 and 1989. In 1967, mountaintop mining had already begun (see inset above). Although dense forest still covered most of the East Nimba area in 1974, mining activities also stimulated the development of local and national road infrastructure, further impacting the habitat in the surrounding lowland. The footprints of mining camps and roads in construction are visible along the western boundary of the nature reserve. During the civil wars, the



Mount Nimba region saw an influx of people fleeing the areas of unrest. During that time, in the absence of forestry law enforcement, major logging activities were carried out in the forest, bush meat was hunted on a large-scale, and slash-and-burn agriculture expanded.

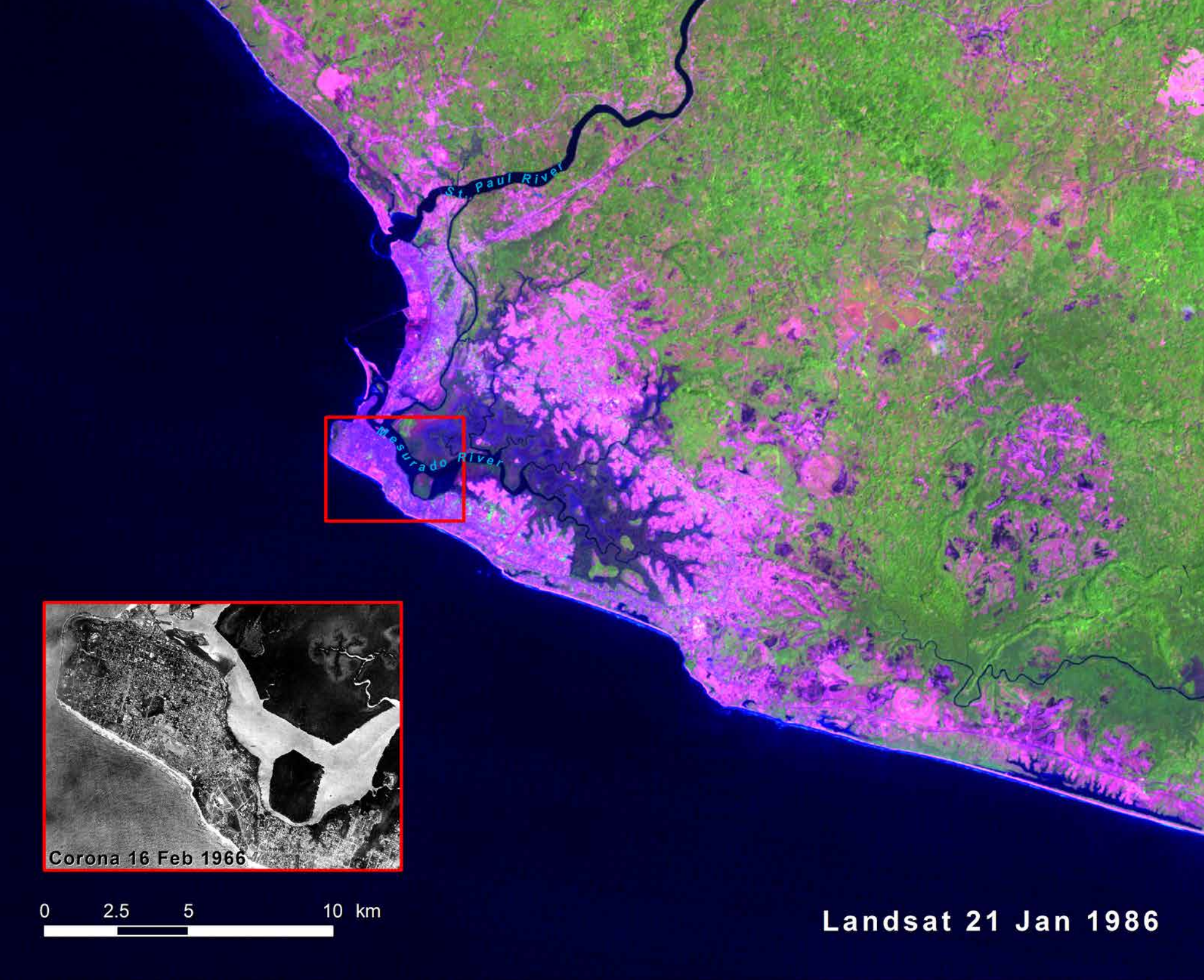
By 2014, forest cover had been greatly reduced in the Mount Nimba area. The East Nimba Forest Reserve had lost about half of its 1974 forest cover to encroachment by agriculture and settlements. The slopes of Mount Nimba had been deforested, causing soils and mineral waste to wash downhill and silt the rivers. The legacies of former mining activities, such as the carved terraces and the open pit depression called the Blue Lake, are still visible on the land and altered the landscape of the mountain ridge (see inset above and adjacent picture).

In response to concerns about the pressures from mining operations and population growth, the East Nimba Nature Reserve of Liberia was established in 2003 with the primary conservation objective of preserving Mount Nimba's high and unique biodiversity. Covering over 135 sq km of mostly montane tropical forest, the reserve follows earlier conservation efforts in Côte d'Ivoire and Guinea — Mount Nimba Strict Nature Reserve in 1944 and Mount Nimba Biosphere Reserve in 1980. Field reports indicate a slight recovery of the vegetation cover since the establishment of the reserve.



D. ANTHONY KPADEH AND TORWON TONYANTAY

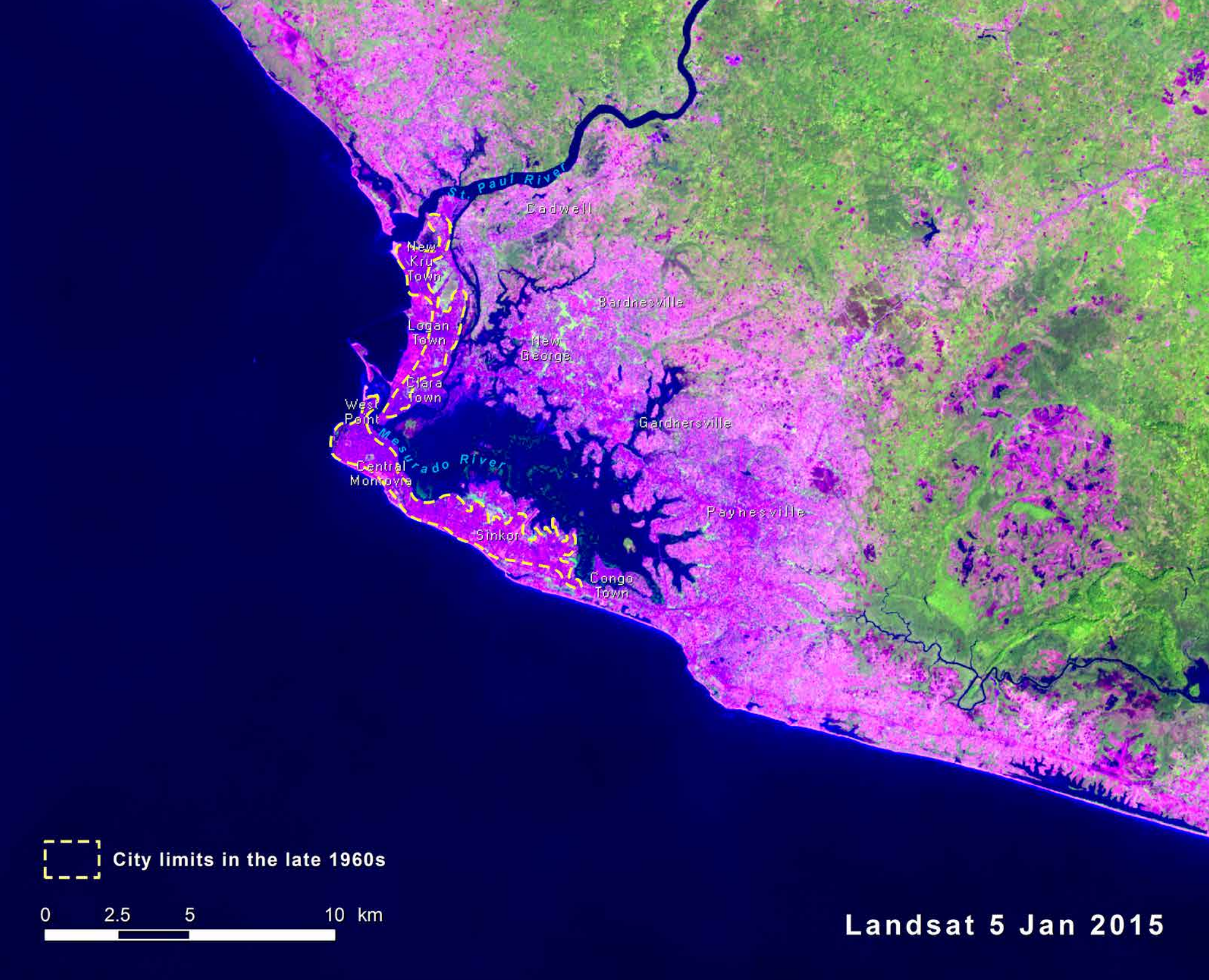
Herbaceous and bushy vegetation reclaim the abandoned terraced slopes of the Blue Lake depression in the Old Mine site.



Urban growth in Liberia's only metropolis: Monrovia

Liberia was founded in 1822 as a place to resettle freed American slaves, with Monrovia as its capital. Originally divided into two parts — Monrovia proper, south of the Mesurado River with the city's Americo-Liberian population, and Krutown, north of the river, mainly inhabited by ethnic Krus and other local tribes. Old Krutown was demolished in 1945 for construction of new port facilities and its residents resettled. The expanded port remains important to the economic development of Liberia.

In Monrovia's humid tropical climate, obtaining a cloud-free view of the city from satellites is quite rare. The Corona mission returned a partially clear photo of the city in February 1966 (see inset). At that time, the city's growth was limited by an extensive mangrove swamp along the Mesurado River and Monrovia did not expand beyond the peninsula. Monrovia's dramatic growth from 1986 to 2015 is shown in Landsat satellite images of the city. The 1986 image shows that the city grew first around the mangrove swamp and then along the southern coast. By 2015, the city had expanded even farther inland and along the west side of the St. Paul River, outside of the Greater Monrovia district. In the past four decades, the population of Monrovia increased 13-fold, from about 80,000 in the early 1960s to over 1,100,000 in 2015. The land cover maps (see pages 134–135) indicate that its built-up area increased from 100 sq km in 1975 to 176 sq km in 2013. Highest housing densities are found in the historical center of the city; from there, housing density gradually decreases toward the outskirts.



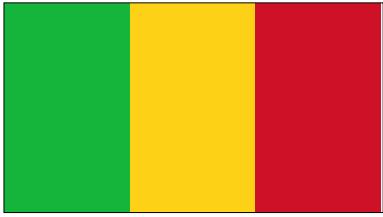
Landsat 5 Jan 2015

The reasons for Monrovia’s population growth include an upsurge in both rural-to-urban migration and inter-urban migration. The present economy of Liberia is very Monrovia-centric, and there are large disparities between Monrovia and other parts of the country in terms of wealth, infrastructure, and possibilities for participation in the political process. Part of this is due to Monrovia’s huge population; Liberia’s second largest city, Gbarnga, has only 60,000 people. During the civil wars when Monrovia was under control of peacekeeping forces and governed by interim governments, many rural Liberians fled to Monrovia for safety. After the wars ended, many of those internally displaced people chose to remain in the city. As in many other fast-growing African cities, the development of infrastructure and social services can hardly keep pace with rapid population growth, leaving many of Monrovia’s poorer neighborhoods in slum-like conditions. Combined with extensive war damage, Monrovia faces the daunting challenge of rebuilding at the same time as extending its urban infrastructure (Ngafuan, 2010).

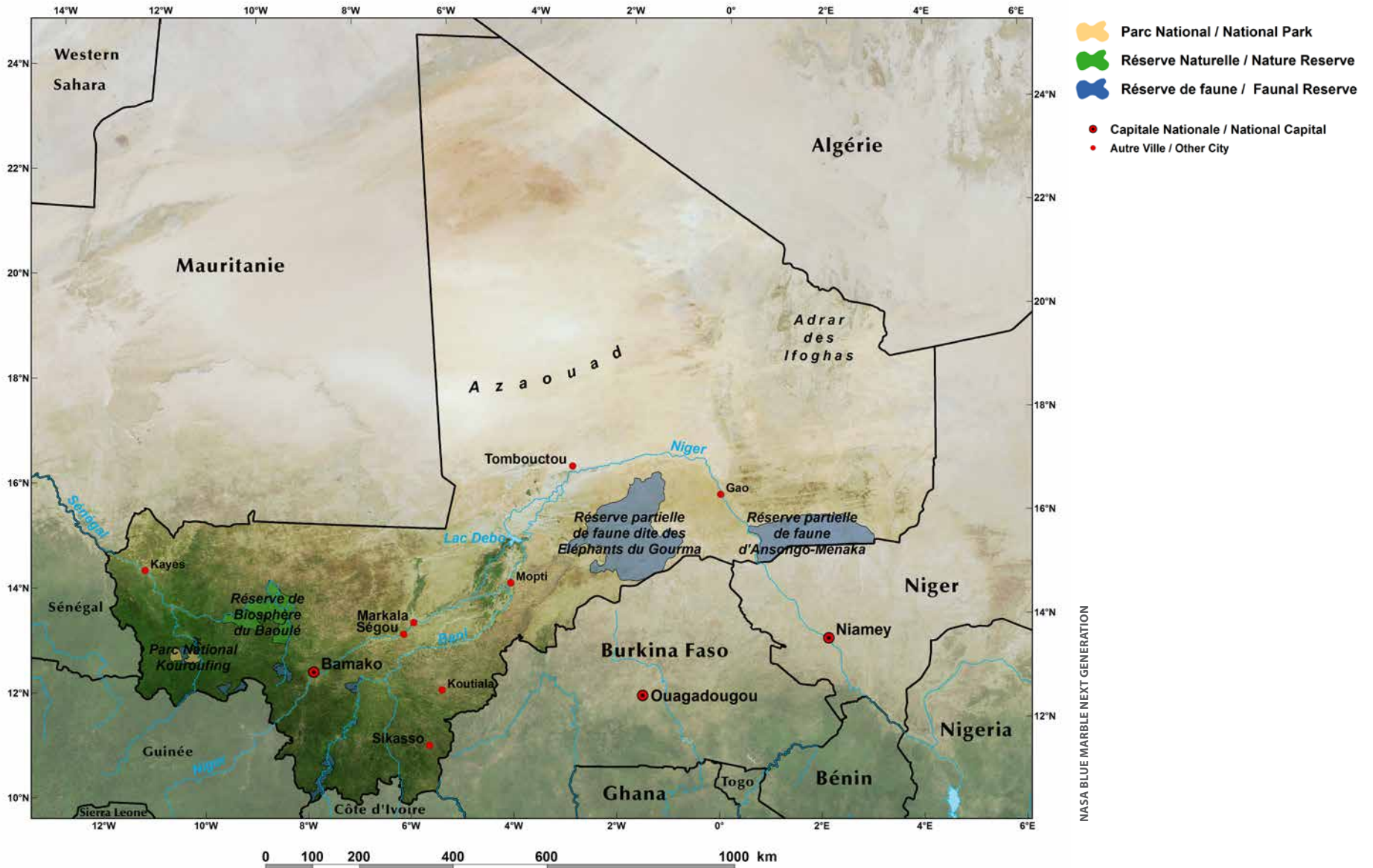


JBDODANE / FLICKR / CC BY-NC 2.0

West Point, Monrovia



Republic of Mali



Total Surface Area: 1,241,200 km²
Estimated Population in 2013: 16,592,000

The area occupied by Mali was once home to the Manding Empire (c. 1230 to c. 1600), the largest empire known to exist in Sub-Saharan Africa. In the 1300s, the Manding Empire extended from the Atlantic coast to west of the Niger River, bordered by the Sahara Desert in the North and the equatorial rain forest in the South.

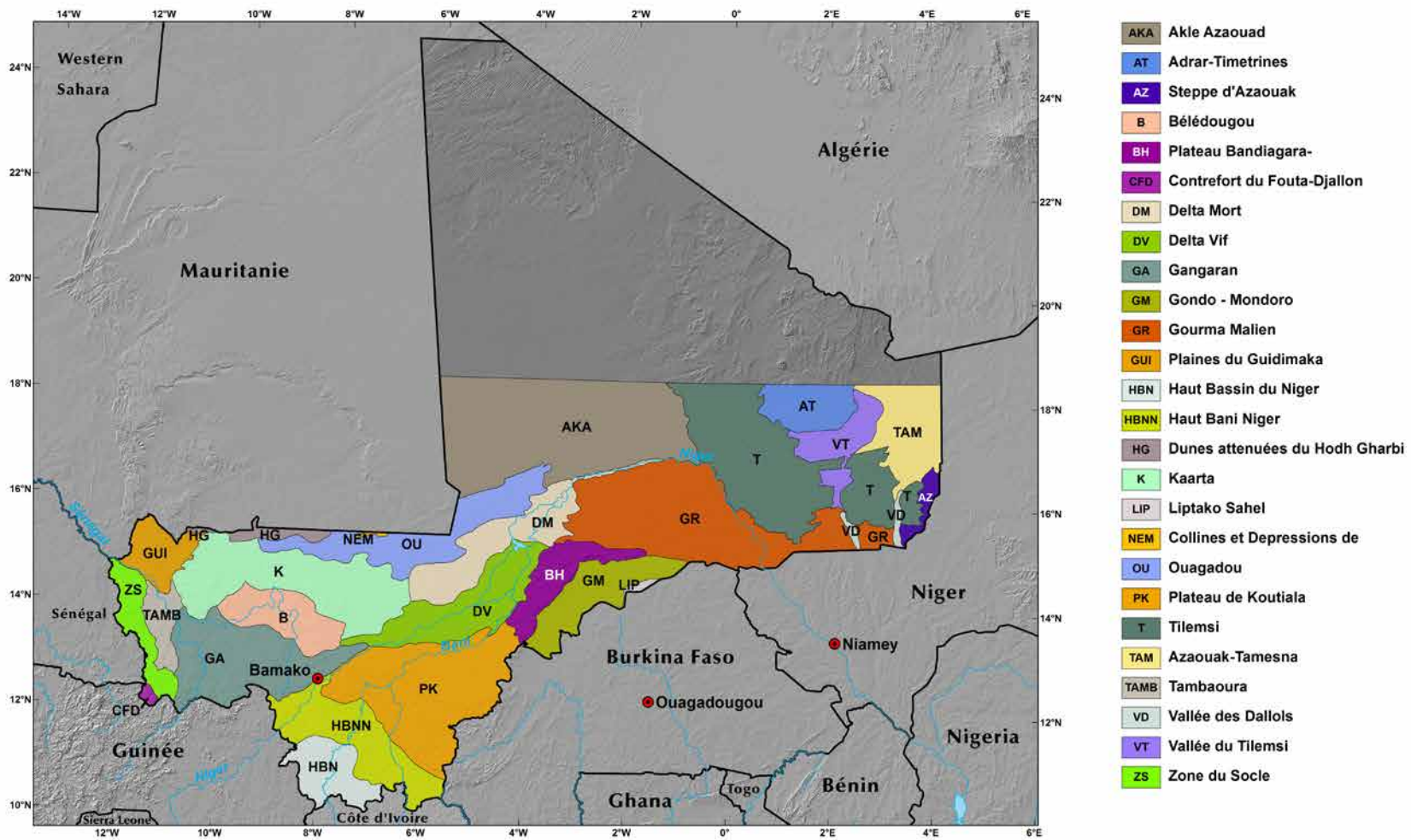
The Inland Delta of the Niger River spreads across central Mali — a unique ecosystem in West Africa. A result of the Niger River flowing into the sandy Sahelian plains, this vast network of channels, swamps, and lakes mitigates the severity of the arid climate and forms the second largest interior delta in Africa. Host to rice farming, fishing, and animal husbandry, the delta plays a critical role in the country's economy. Agriculture, which accounts for about 40 percent of the gross domestic product (GDP) and employs 74 percent of the labor force, remains the main economic sector in Mali, which ranks as Africa's fourth largest cotton producer (CIA, 2013). Gold mining has greatly increased since the beginning of the 2000s, accounting today for about 15

Environmental Highlights:

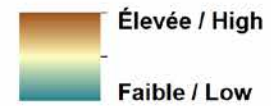
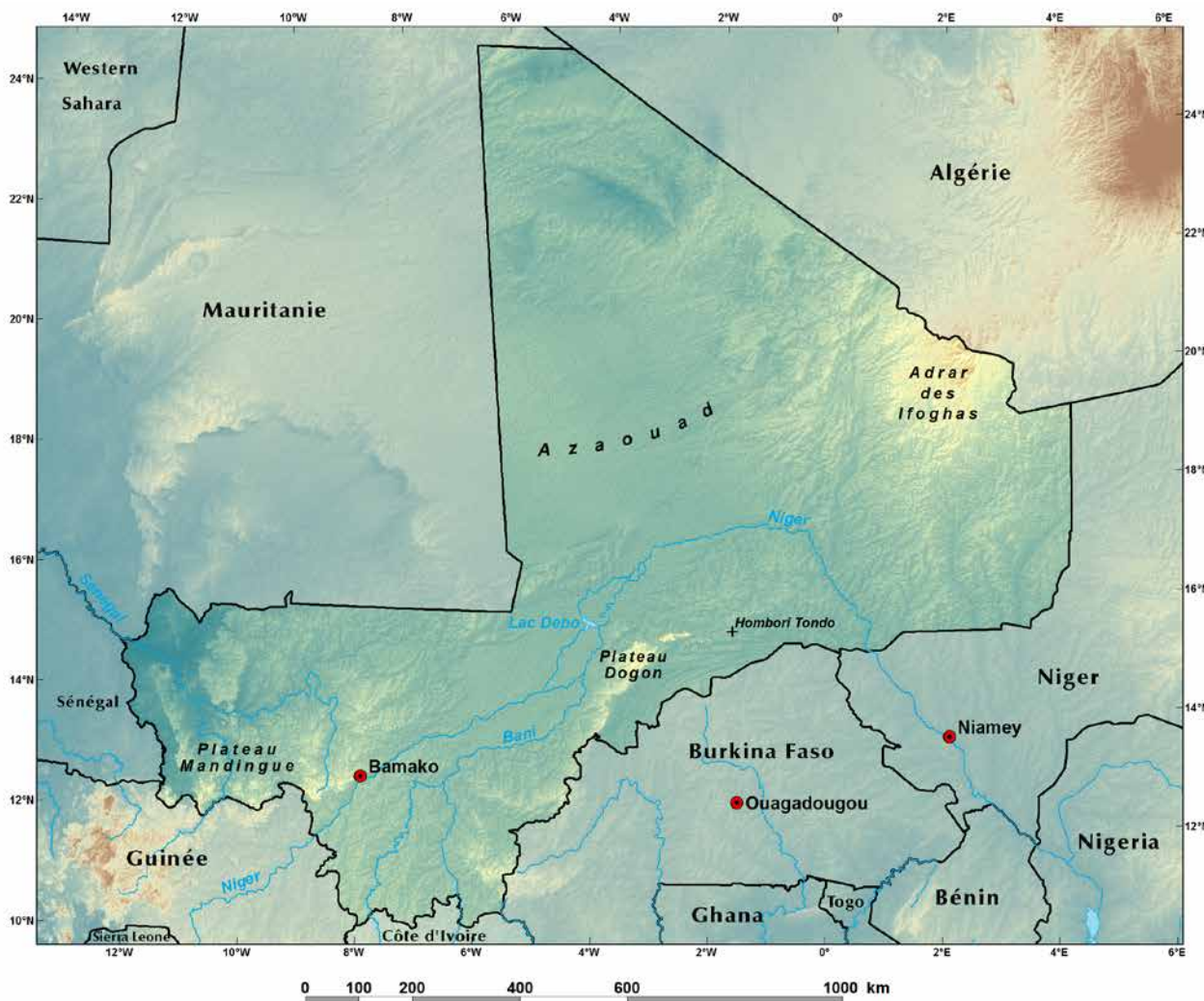
- Soil degradation and loss of vegetation cover
- Desertification
- Rich ecosystem of Inland Niger Delta
- Farmer-managed natural regeneration
- High tourism potential

percent of Mali's GDP and making it West Africa's second largest exporter of gold after Ghana (Hale, 2002). Mali has major tourist attractions with sites such as the Bandiagara escarpment, known for its stunning landscapes with centuries-old village architecture, and the famous city of Timbuktu, a UNESCO World Heritage site.

Ecoregions



Shaded Relief

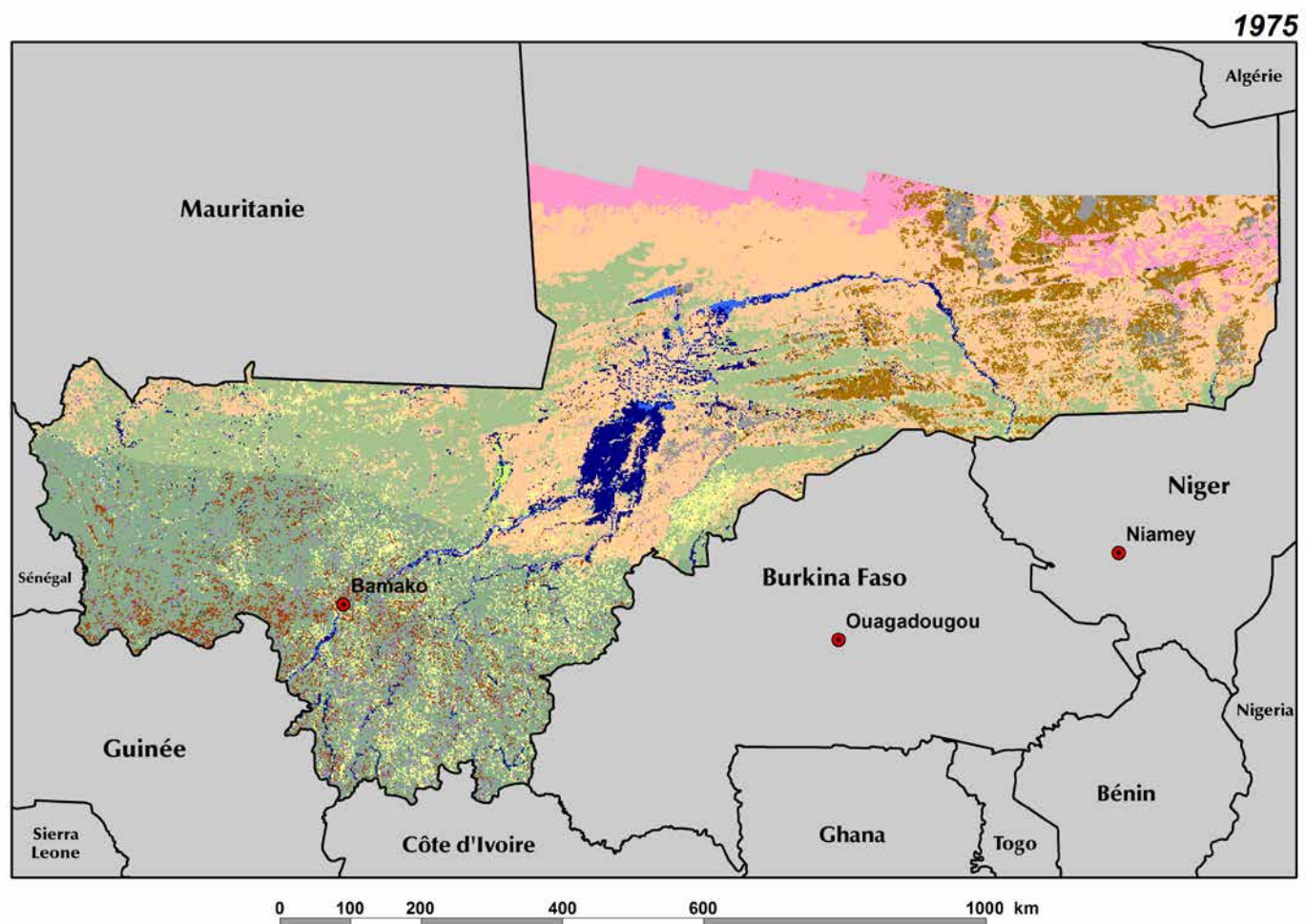


Mali has flat to rolling landscapes, occasionally interrupted by high rising plateaus. In the north, the Sahara Desert covers almost half of the country. The open steppes of the Akle Azaouad (AKA) plateau and rocky terrain of Adrar-Timetrines (AT) and of Tilemsi (T and VT) make large east-west swaths across the country. The southern Sahara transitions into the semiarid Sahel Region — the domain of pastoralists — interrupted in central Mali by the seasonally flooded alluvial plain of the Inland Niger Delta (DV, DM). The southern strip of this large plain is bordered by the Koutiala (PK) and Bandiagara-Hombori (BH) plateaus, the latter rising to 1,155 m. In southern Mali, the plains of the Sudanian Region account for the majority of the country's agricultural land.

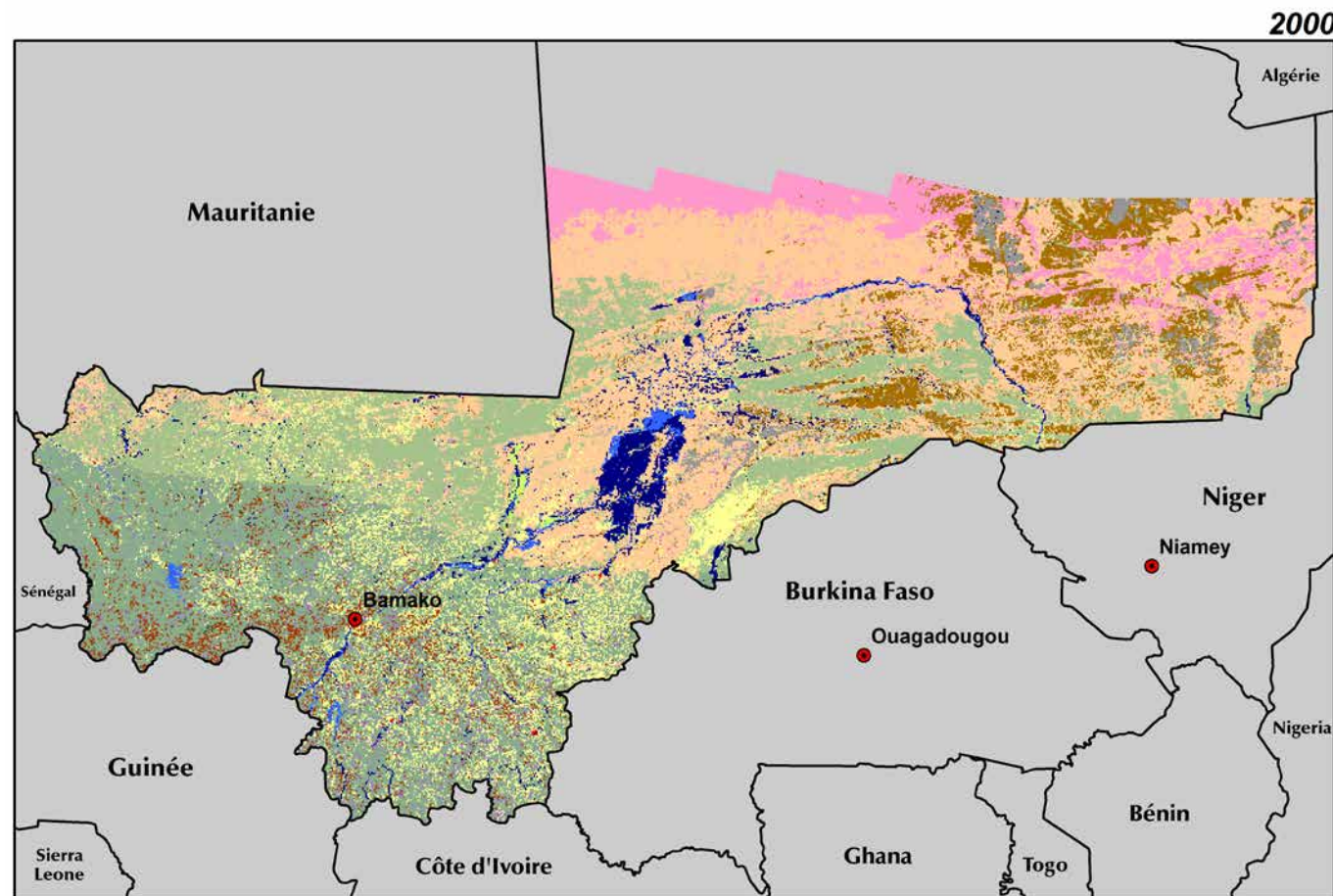
Land Use, Land Cover and Trends

Overall, steppes, Sudanian savannas and Sahelian short grass savannas have experienced dramatic losses during the last 38 years, yet they remain the predominant land cover classes, accounting for 30 percent, 18.5 percent, and 15 percent of the mapped area, respectively, in 2013. The decrease in steppe is largely explained by the expansion of sandy areas in the Akle Azaouad (AKA) and Tilemsi (T) ecoregions. Increasing aridity also impacted the steppes, pushing them southward, in places encroaching on the Sahelian savannas. Losses of Sahelian and Sudanian savannas, however, result more from human activity—the expansion of agriculture that has occurred across southern Mali.

Cropland area increased by a factor of 2.3 over the 38-year period, which is equivalent to an average annual increase of 3.5 percent, or 1,300 sq km per year. Agricultural expansion can be seen across the south, especially in Haut Bani Niger (HBNN – Upper Bani Niger), Koutiala Plateau (PK) and Kaarta (K) ecoregions. In these regions, agricultural landscapes now predominate over natural ones. In 1975 the Séno Plain, east of the Plateau Dogon in the Gondo-Mondoro (GM) ecoregion, was already predominantly agricultural. By 2013 it is uniformly devoted to cropland (see pages 144–145). Cropland expansion is driven by the need to feed a rapidly increasing population and has accelerated between 2000 and 2013, facilitated by modern technology. Likewise, irrigated agriculture areas have increased

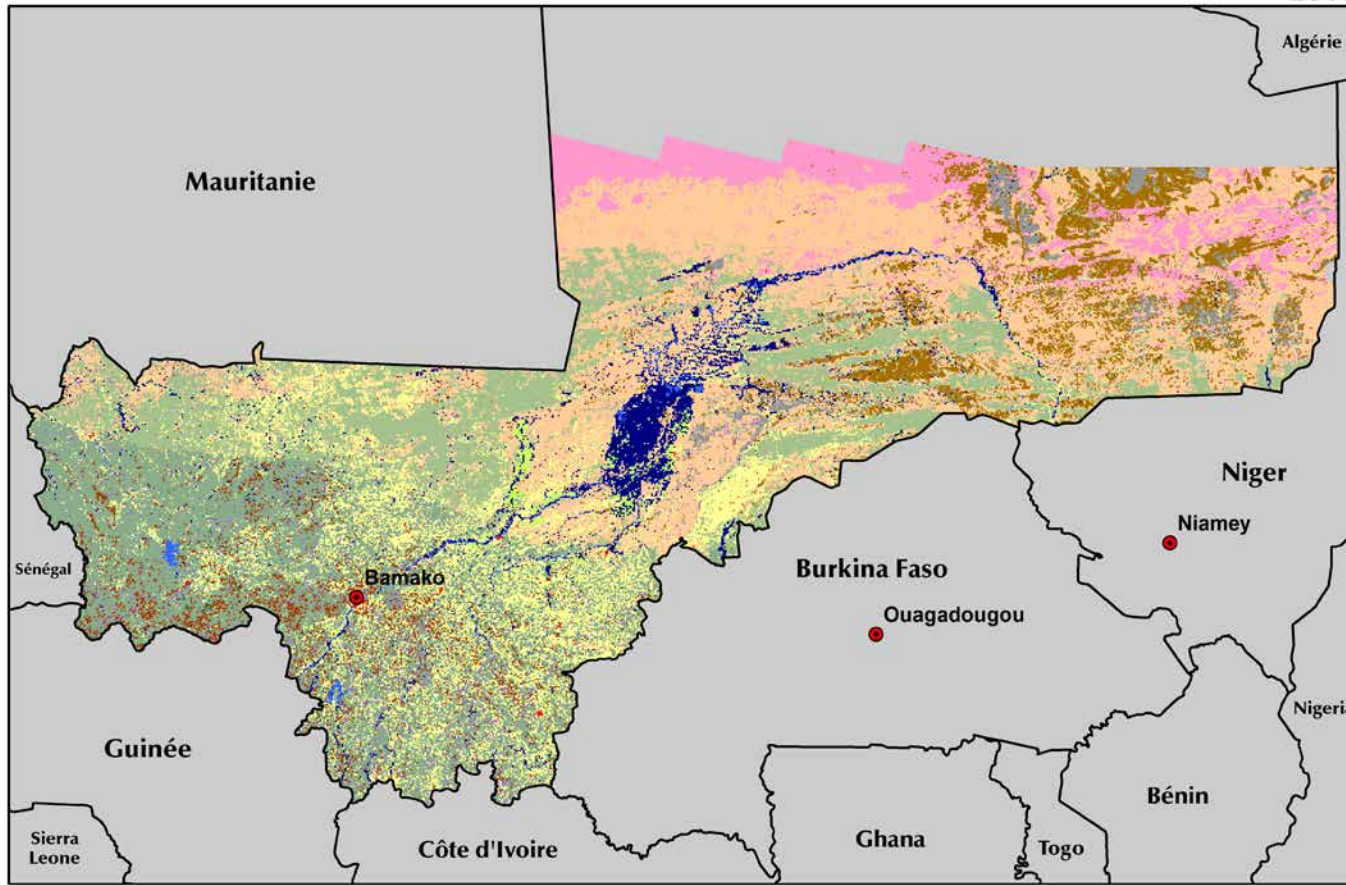


Mali's northern half is a desert, with a sparse but relatively stable vegetation cover. Consequently, only the southern half of the country was mapped in order to monitor and analyze land use and land cover dynamics.



● Capitale Nationale / National Capital

2013



Occupation des Terres / Land Cover

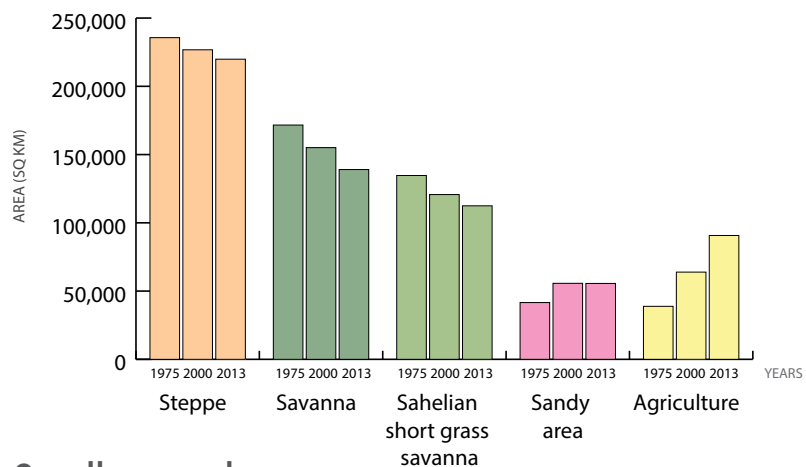
Forêt galerie & formation ripicole / Gallery forest & riparian forest	Bowé	Sols dénudés / Bare soil
Forêt claire / Woodland	Zone de culture / Agriculture	Terrains rocheux / Rocky land
Forêt marécageuse / Swamp forest	Cultures irriguées / Irrigated agriculture	Surfaces sableuses / Sandy area
Savane / Savanna	Cultures des bas-fonds et de décrue / Agriculture in shallows and recession	Carrière / Open mine
Savane sahélienne / Sahelian short grass savanna	Plantation	Plans d'eau / Water bodies
Steppe	Habitation / Settlements	Prairie marécageuse - vallée inondable / Wetland - floodplain

by 400 percent, or 4,600 sq km, mainly along the Niger River and its tributaries in the southern part of the Inland Delta.

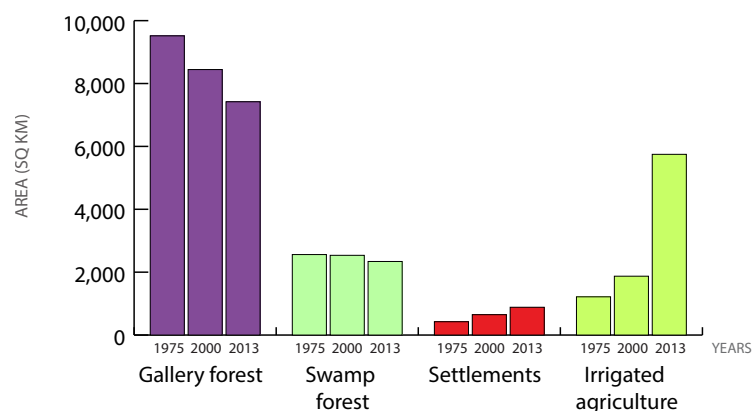
The Inland Niger Delta is a highly dynamic and complex ecoregion of landscapes that interact with the ebb and flow of seasonal flooding (see pages 146–147). There is also considerable year-to-year variation in the extent of flooding. Despite this, the land cover types within the Delta have remained relatively stable, although there has been some encroachment of irrigated cropland in the southern Delta.

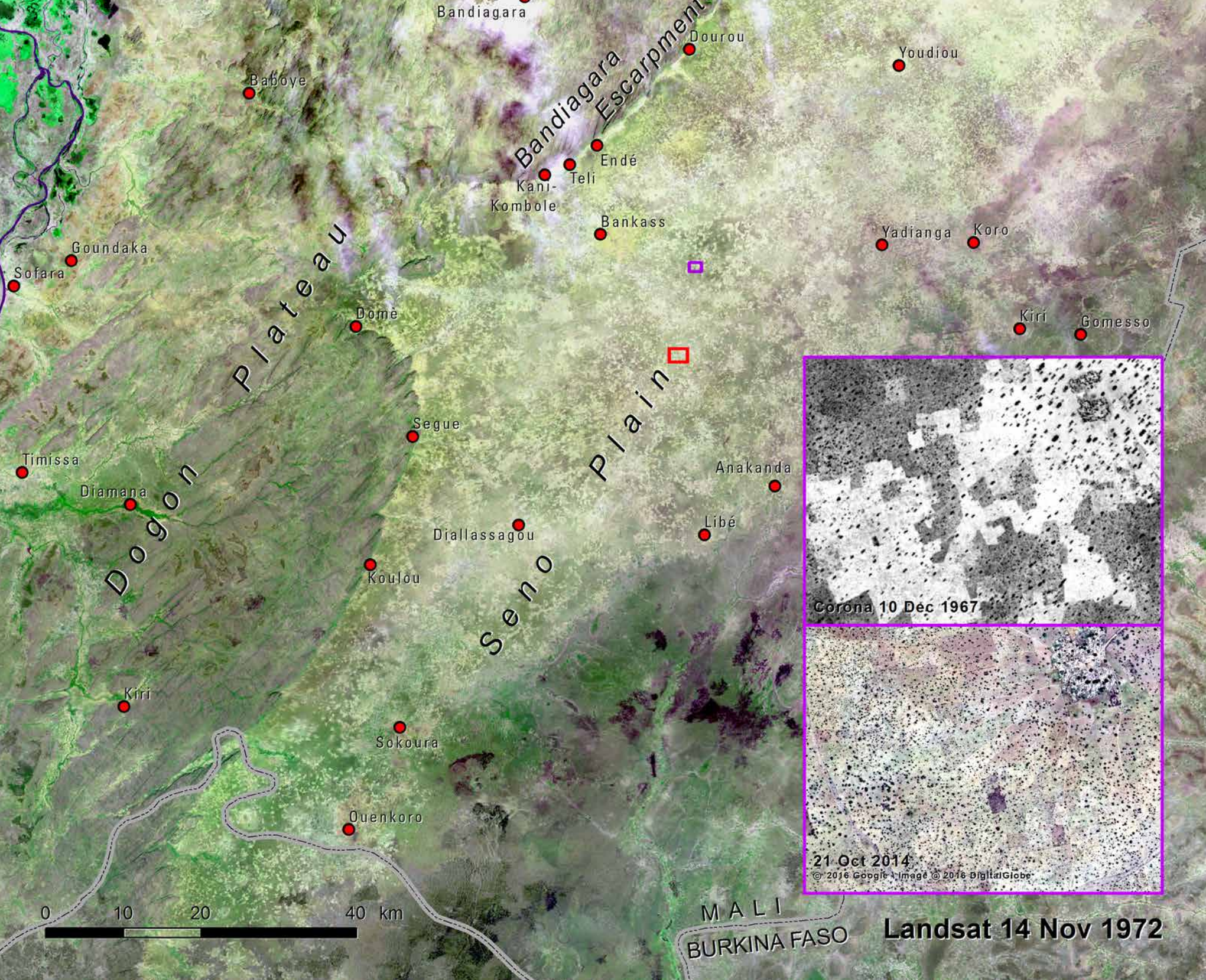
Natural habitat destruction is a major environmental issue in Mali. In addition to savannas, gallery forests have decreased by 23 percent due to population and agriculture pressures between 1975 and 2013. Clearing these forests causes severe water erosion, which removes the topsoil, reducing land productivity and creating conditions that lead to desertification. On a positive note, the hundreds of swamp forests that occur in natural depressions across the semiarid Sahel remain largely intact, providing critical habitat for wildlife.

Large area classes



Small area classes



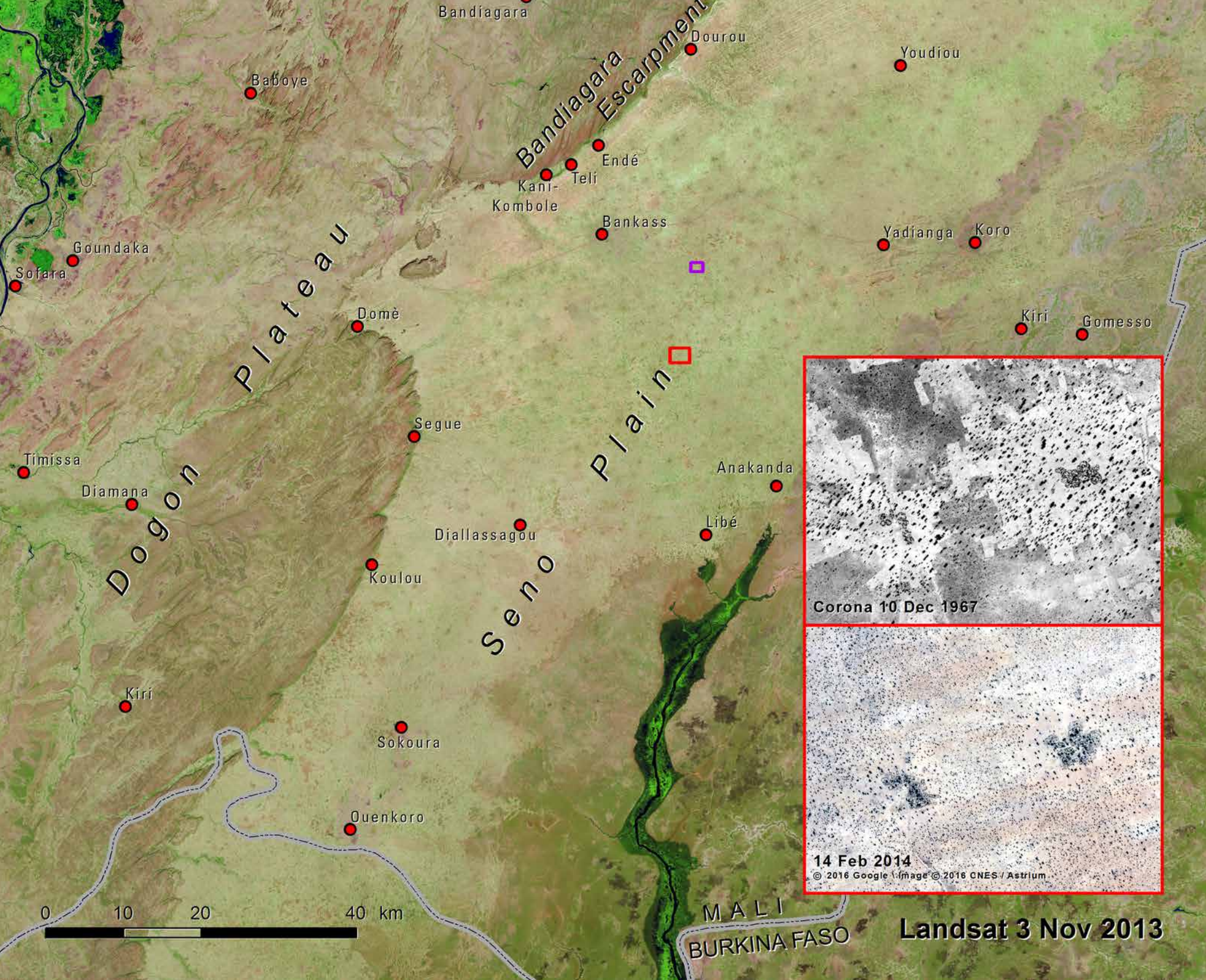


Building land-based resilience to drought and climate change on the Seno Plain

Between the rocky Dogon Plateau in central Mali and the border with Burkina Faso stretches the Seno Plain and its densely settled farmland. The Seno Plain is located in the Sahel, where limited and highly variable rainfall (500–600 mm per year) makes farming a challenge. Indeed, land degradation, deforestation, and out-migration from the Seno Plain were common during the long series of devastating droughts that affected the entire Sahel from the late 1960s to the 1980s. Despite the earlier out-migration, population has steadily increased in recent decades, increasing human pressure on the land.

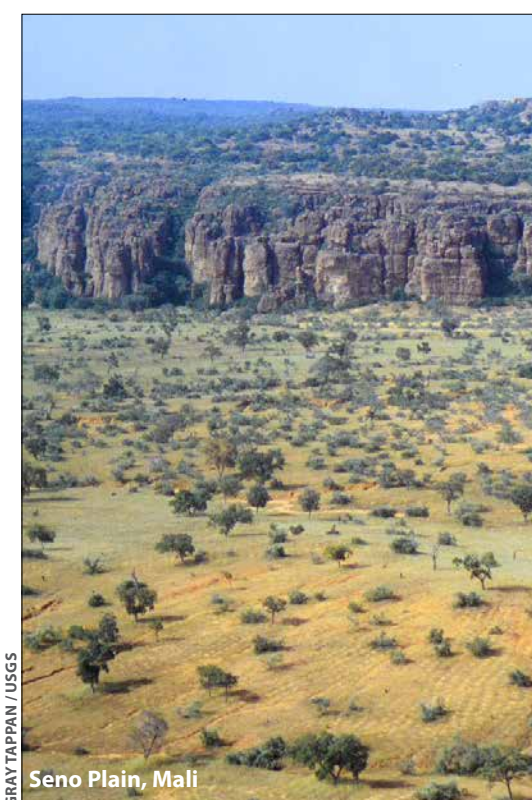
The views from space tell a story of change—including a positive development that is often missed. In the 1972 Landsat image, we see a patchwork of cultivated land (light areas) and shrub and tree savanna (darker areas). Farmers still practiced crop rotation that included leaving land in bush fallow. As population increased, more and more land was put into cultivation, virtually eliminating the fallow area. The 2013 image shows the continuous cropland, with hundreds of villages (dark spots) scattered throughout the sandy plain. The villages stand out in part because of their built-up surfaces and shade trees, but also because of the fertilizing effect of household and animal waste in the fields adjacent to each village.

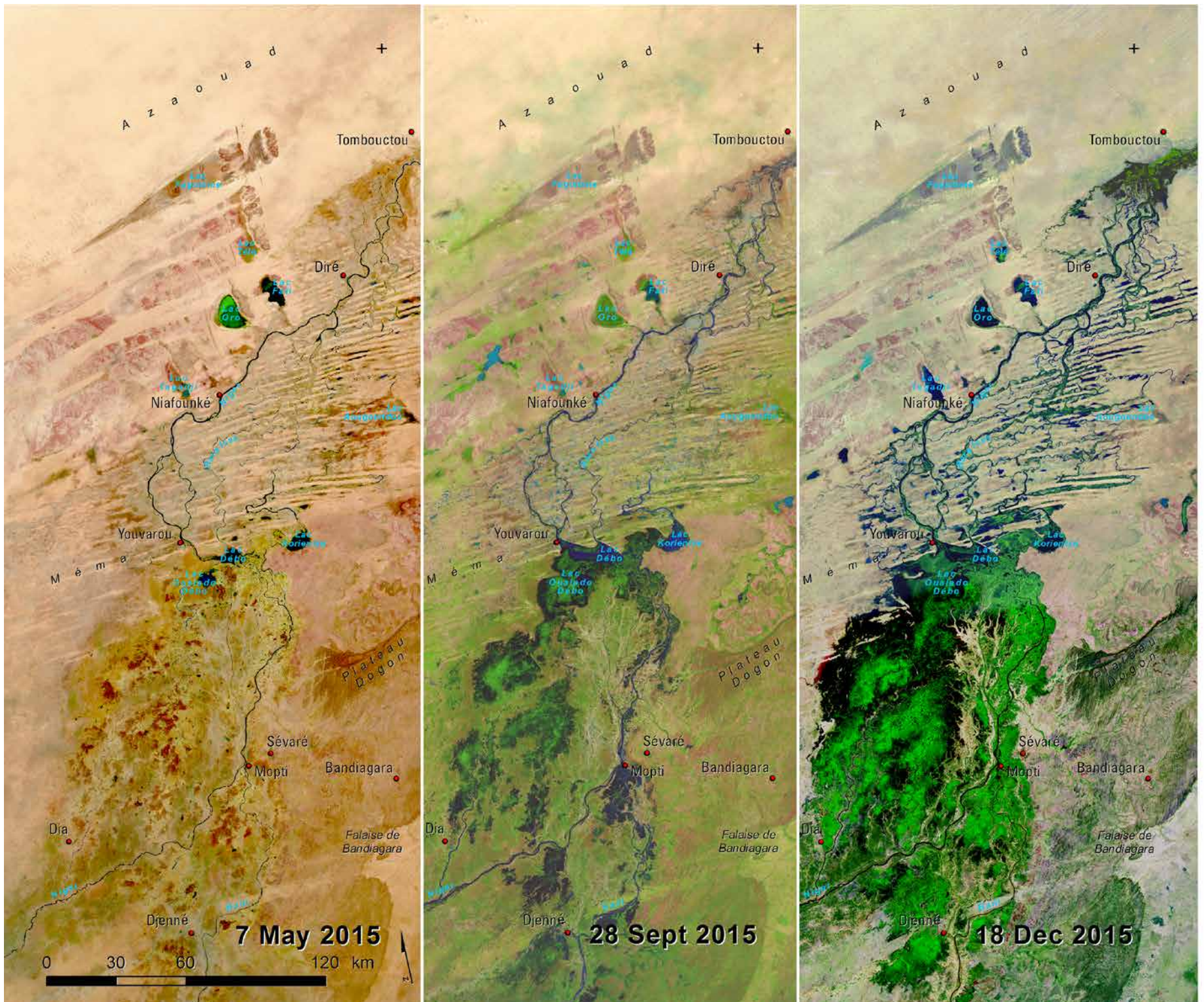
A closer look using detailed imagery shows another feature around every village—a relatively dense parkland of trees (see insets). Indeed, by mapping tree cover with high-resolution imagery, we found that medium to high



densities of field trees currently cover about 4,500 sq km in the Seno Plain. Field surveys suggest that most of the trees are less than 15 to 20 years old, meaning that much of today's parkland is very young. Corona space photographs taken in 1967 show that most villages maintained a parkland in the fields close to the village, but that tree densities dropped considerably beyond the inner circle of fields. Shrub savanna — rather than tree parklands — characterized the extensive bush fallow between villages.

The two detailed comparison images show the transformation that is typical around villages in the Seno Plain over the past 47 years. In the 1967 views, bright fields stand out from the surrounding bush fallow. The parkland of trees tends to be limited to the fields immediately adjacent to each village. In the 2014 image, the villages have visibly increased in size, and the surrounding land is completely saturated with cropland. Many of the large, older trees seen in 1967 did not survive the drought years and the increased pressure for firewood and fodder; however, in a positive development, a parkland of young trees has replaced them — extending well beyond the inner fields to the entire landscape around each village. Many local farmers confirm the decline in tree cover in the 1970s and 1980s, and the widespread re-greening of the Seno Plain since then. While improving rainfall conditions in the past two decades might have helped trees to regenerate on these farmlands, most of the changes can be attributed to human activity (Spiekermann and others, 2015). Since the mid-1990s, international and local non-governmental organizations have jointly promoted farmer-managed natural regeneration, echoing the success stories from the Maradi and Zinder regions of Niger. The new forestry law of 1995 has promoted a more decentralized forest management approach, which has facilitated improved environmental management by local institutions.





Landscape diversity and dynamics of the Inland Niger Delta

The Inland Niger Delta is the largest wetland in West Africa. It is spectacular in both its landscape diversity and dynamics. Water from the Niger River, which originates 900 km upstream in the Guinean Highlands, spreads out into a wide floodplain about 380 km long in central Mali. It has a very gentle gradient, dropping only 8 m over its entire length. The floodplain is a highly dynamic complex of wetlands, channels, islands and lakes that provides important habitat for fish, water birds, and other wildlife. The seasonal flooding also supports pasture and rice farming. The delta has provided livelihoods for people for millennia. Today, over 1 million people depend on the resources of the delta. About a quarter of the Delta's population lives in cities like Djenné, Mopti, Niafouké, and Timbuktu.

In the recent geologic past, the Inland Delta area was once a huge lake, fed by the Upper Niger River. At some point in that wet period, the lake overflowed to the east through a breach. The interior lake was drained, although a number of small relic lakes remain.

The three Landsat images capture the dynamics of natural flooding as seen in May, September, and December 2015. The May image shows the extreme dryness of the land at the peak of the hot, dry season. The semi-permanent water bodies (dark blue and green) of the Delta stand out. Several major lakes have dried out since the early 1970s, most notably Lake Faguibine, whose arrowhead-shaped lakebed is clearly seen in the north. The low flood levels of the drier years are insufficient to reach many lakes and depressions. Flooding begins when the Niger and the



PHOTOS: GRAY TAPPAN / USGS; MICHEL KUPERS; RICHARD JULIA

Bani Rivers begin to rise. Starting in July, the Niger River rises about 4 m in 100 days. Peak level may even reach 6 m in the years of high rainfall (Zwarts and others, 2009). As the center image shows (opposite page), by late September the natural flooding of the Inland Delta is well underway. Acting like a giant sponge, vast wetlands come to life. The southern Delta swells and greens first, while the northern Delta area experiences a two- to three-month delay in flooding. In the December image, the annual high water level has finally reached the northern Delta, while the southern Delta has already been drained of much of its water. Between the southern and northern floodplain, flooding permeates a total area of about 40,000 sq km. Numerous ephemeral lakes, along with the more permanent ones, like grapes on a vine, receive and store the floodwaters, releasing them gradually as the river level subsides.

Vast floating meadows of vegetation occupy the areas of deeper water, dominated by an aquatic grass species known locally as bourgou. During the flooding, bourgou, along with wild rice and other species, produce a considerable amount of habitat for fish and water birds and nutritious fodder for cattle during the dry season. As the water subsides in the dry season, the floodplain vegetation provides green pasture for the millions of cattle, sheep, and goats. Farmers cultivate rice, mainly in the southern Delta. They use a West African rice variety that grows well as the water rises. It is then harvested when the waters recede. This floodplain rice is more extensive than irrigated rice fields, which can also be found in the Inland Delta.

Flood forecasts will become increasingly important as the population grows and pressure on water resources increases. Water level measurements and satellite images help predict the onset of seasonal floods and help achieve food security. An early warning system will help predict drought and monitor food security. Data from both on the ground and satellites help manage water resources.

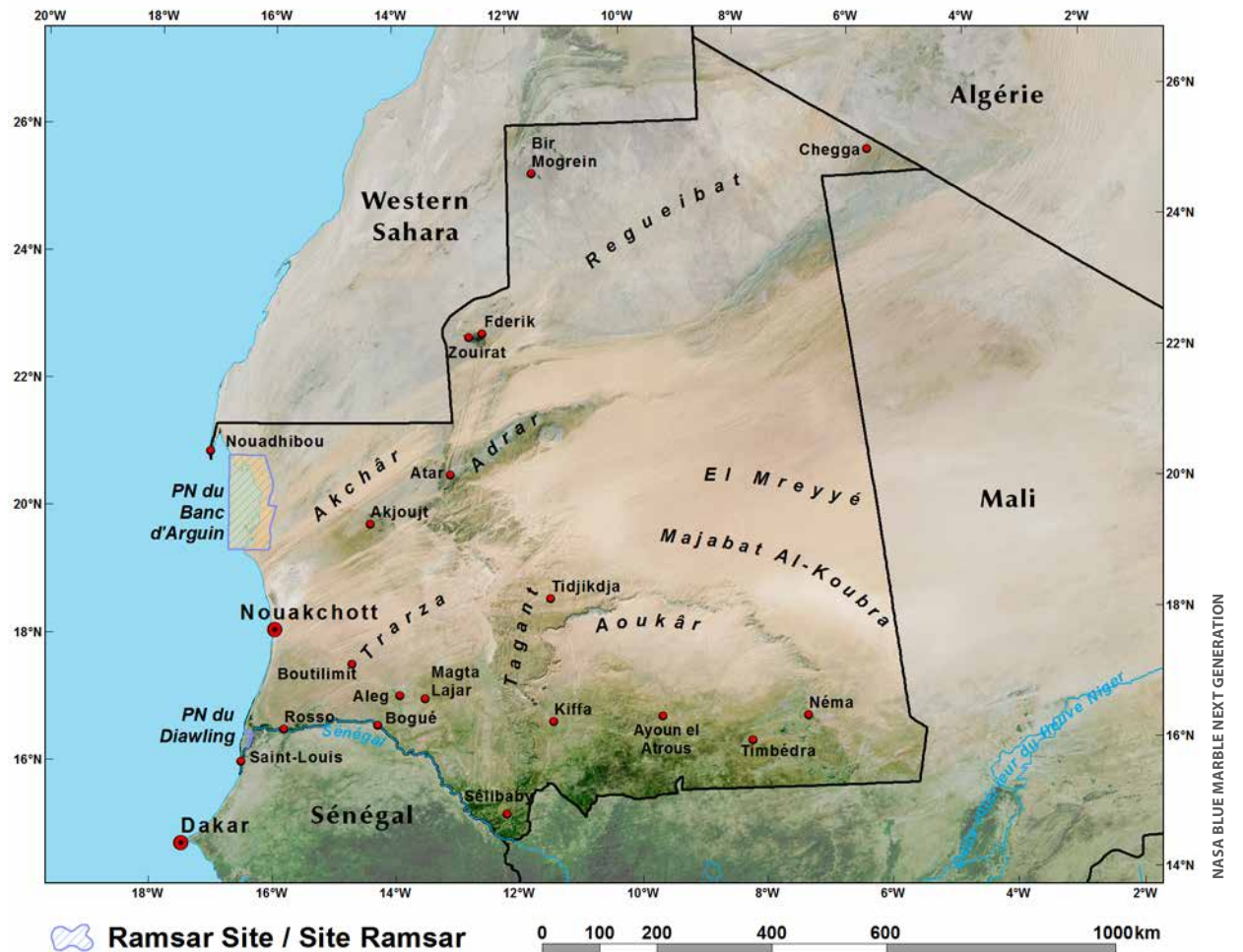




Islamic Republic of

Mauritania

Total Surface Area: 1,030,000 km²
Estimated Population in 2013:
3,873,000

Mauritania is situated at the crossroads of the Maghreb region and sub-Saharan Africa. With roughly four-fifths of its land area within the Sahara Desert (less than 200 mm mean annual rainfall), the population of this vast and sparsely populated country is mostly concentrated in the slightly less arid south, as well as in the Atlantic port cities of Nouakchott and Nouadhibou. Mauritania's historically nomadic population has seen a trend toward sedentarization and urbanization since independence in 1960, especially in response to increasingly dry climatic conditions. Mauritania is susceptible to periodic droughts and hot, dry dust- and sand-laden Harmattan winds, which threaten the small fraction of its land surface that is arable. Some irrigation potential has been developed in the Senegal River basin to increase food security in the face of vulnerability to drought. The country's wealth lies in its extensive mineral deposits and rich fishing grounds in the Atlantic Ocean. Key biological resources include extensive seasonal wetlands in the southeast of Mauritania as well as coastal wetlands on the Atlantic shore. These wetlands stand out as hotspots of biodiversity against the vast stretch of sand dunes and rock formations of the Sahara and the sparsely vegetated Sahel zone, where freshwater is scarce. They constitute critically important breeding, transit and wintering grounds for millions of migratory birds.



-  Ramsar Site / Site Ramsar
-  National Park / Parc National
-  Capitale nationale / National capital
-  Autre Ville / Other City

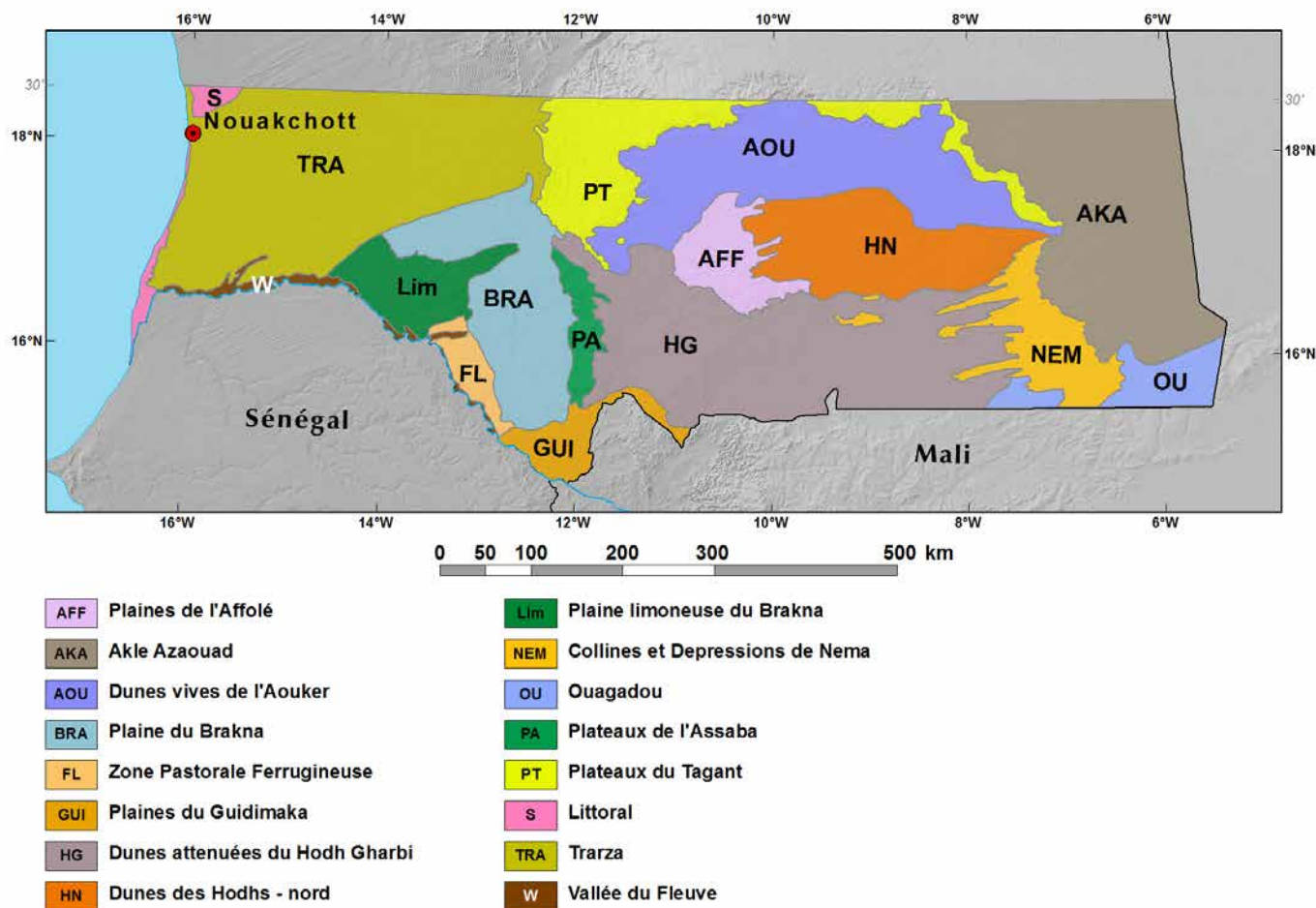
Environmental Highlights:

- Soil erosion
- Desertification
- Scarcity of freshwater resources
- Marine fishery resources
- Spectacular scenery



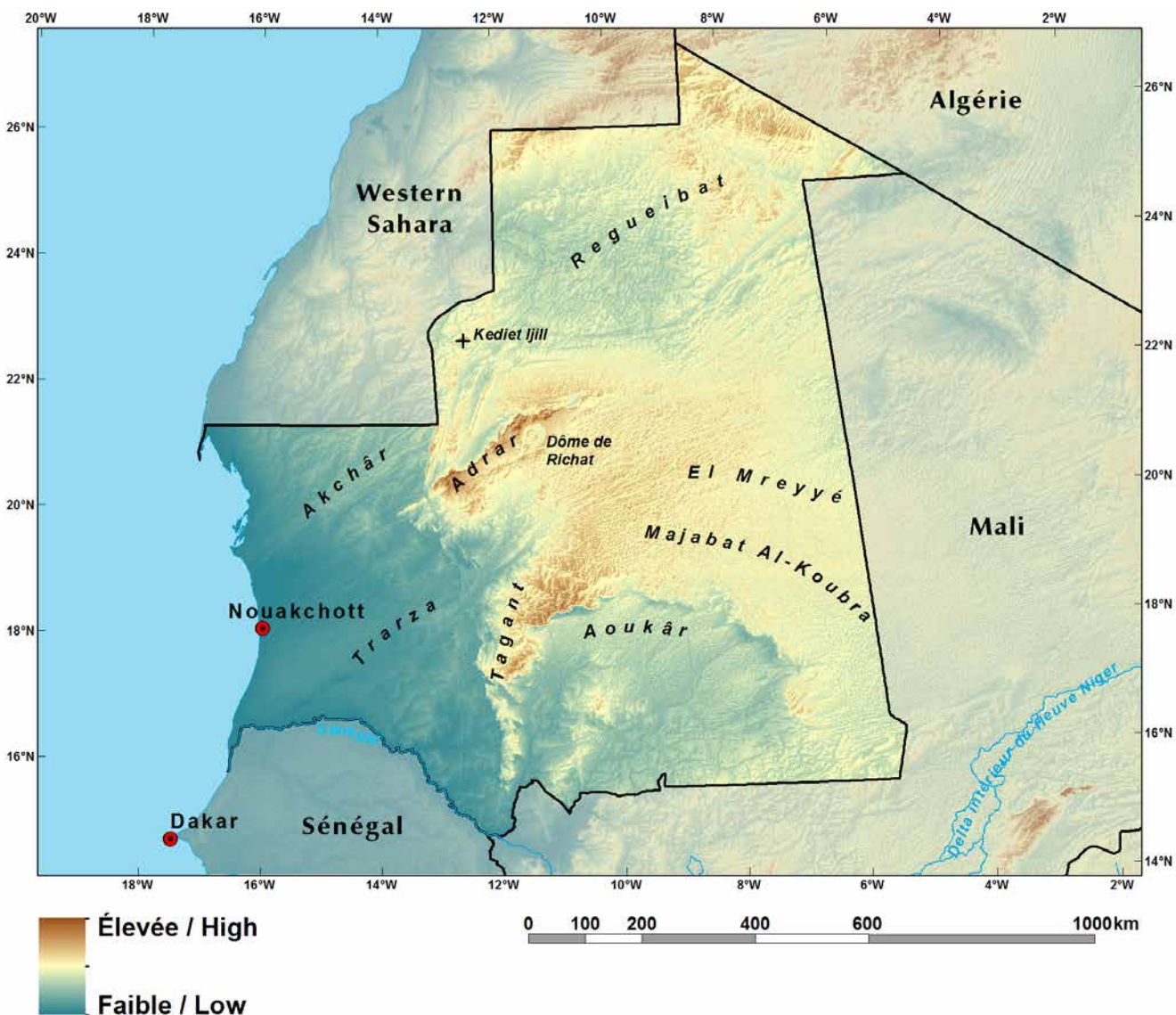
Adrar Plateau, Mauritania

Ecoregions



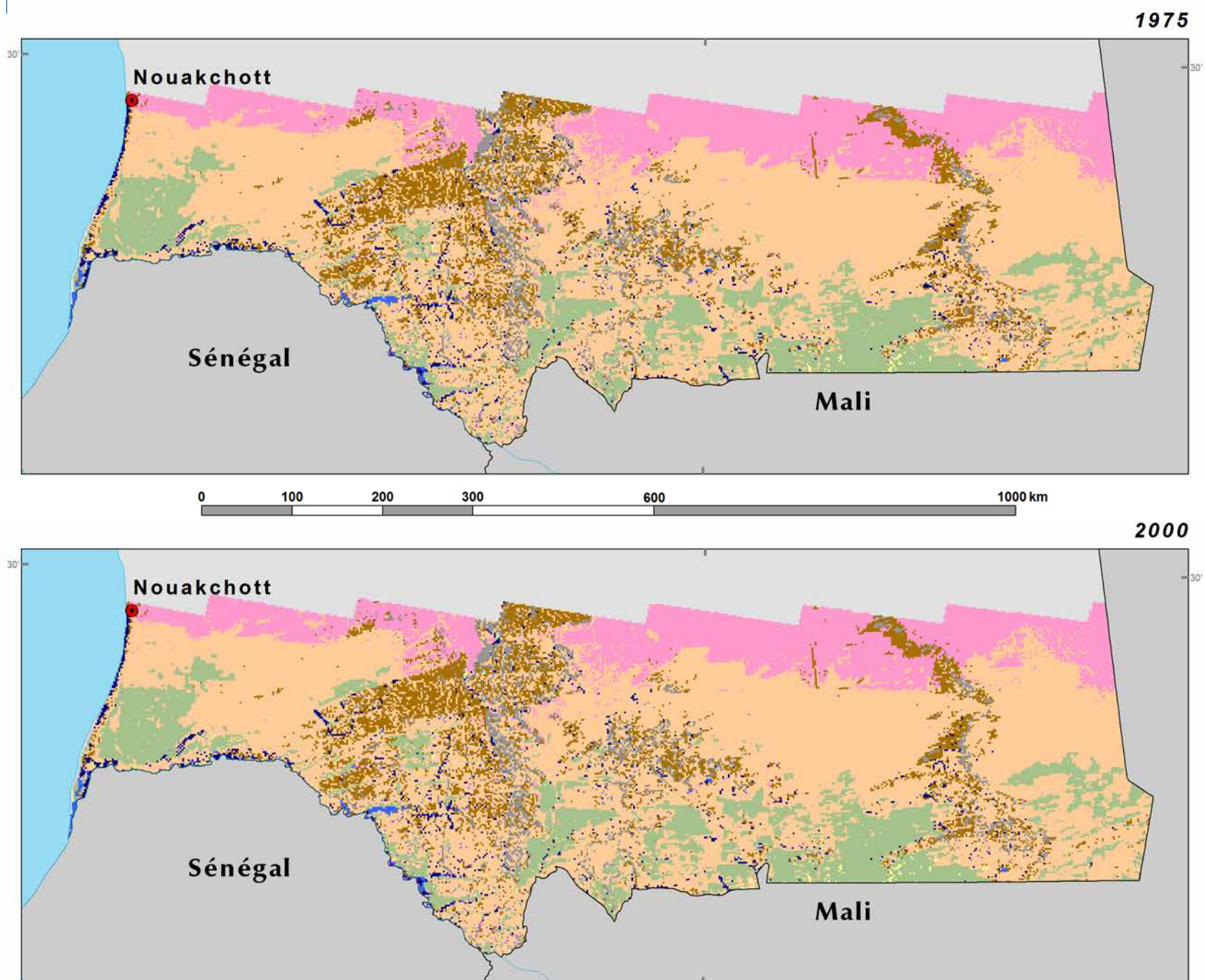
Mauritania is a generally flat country, with vast arid plains interrupted by impressive rocky plateaus and escarpments. These give rise to some of the most spectacular scenery found anywhere in both the Sahel and the Sahara. In the west, the extensive Trarza (TRA) is a plain mostly covered by old, longitudinal dunes that are stabilized by Sahelian short grass savanna and steppe. To the south, the plain is interrupted by the Senegal River Valley, with its unique *Acacia nilotica* forests. To the east, the broad plains are flanked by the Plateau du Tagant (PT) and Plateau de l'Assaba (PA), both rugged sandstone plateaus, with deep canyons and occasional springs that feed oasis settlements. East of the high plateaus, vast sandy plains with undulating sand dunes stretch nearly 500 km to the escarpment at Néma. Here lie the regions of the Hodhs—the North Hodh (HN) with increasingly mobile sand dunes, and the Hodh Gharbi (HG) to the south with ancient stabilized dunes that support extensive rangelands and relatively productive ferruginous soils with agricultural potential.

Shaded Relief



MICHEL KUPERS

Land Use, Land Cover and Trends



Large areas of northern Mauritania are occupied by mainly nonvegetated arid land cover types which are quite stable over time. For this reason, only the southern part of the country (south of approximately 18 degrees north latitude) was mapped.

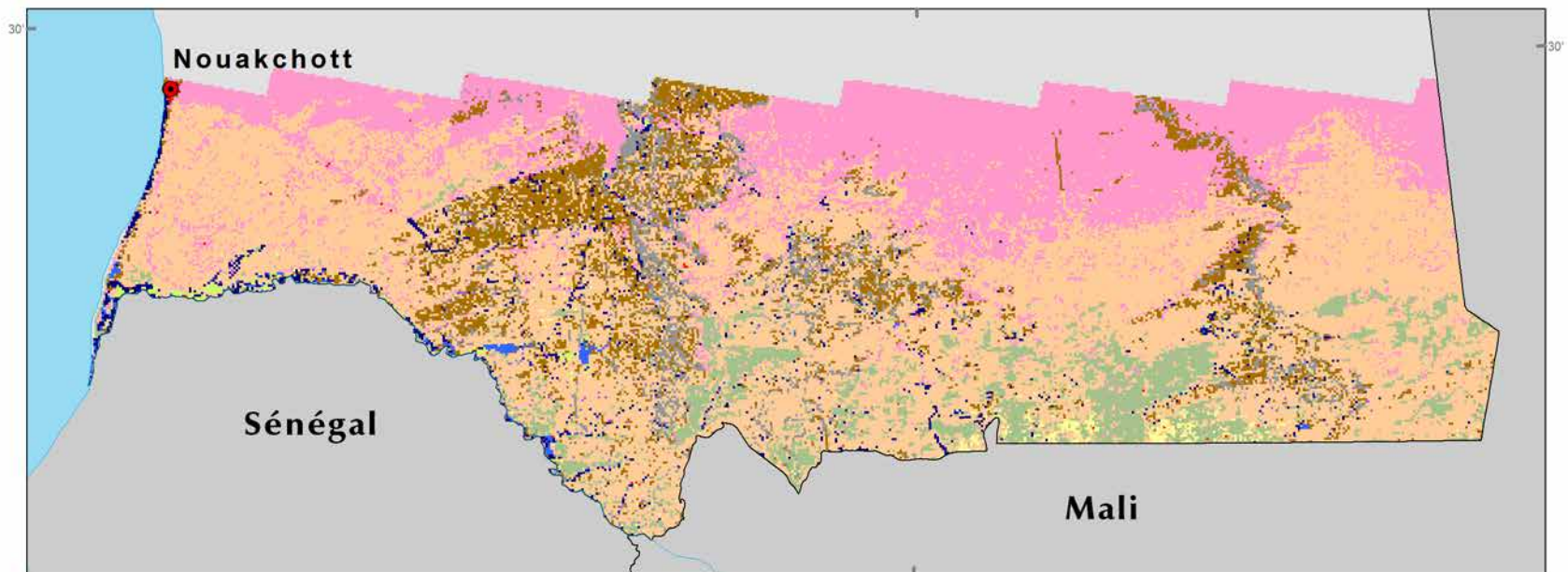
● Capitale Nationale / National Capital

Steppe is the dominant land cover type in southern Mauritania, occupying more than 50 percent of the mapped area. The second most common are sandy areas, which made up almost 25 percent of the mapped area in 2013, and, in descending order, bare soil, Sahelian short grass savanna, rocky land, and wetland and floodplain, all of which occupy between 1 percent and 10 percent of the mapped area. Less than 1 percent is mapped as agricultural land. This makes Mauritania the least cultivated country of the 17 West African countries. Likewise, other “bioproductive” land cover types — forest, gallery forest and swamp forest — make up only tiny fractions of the land area. Although these bioproductive land cover types are small in area, their importance in both ecological and economic terms is large.

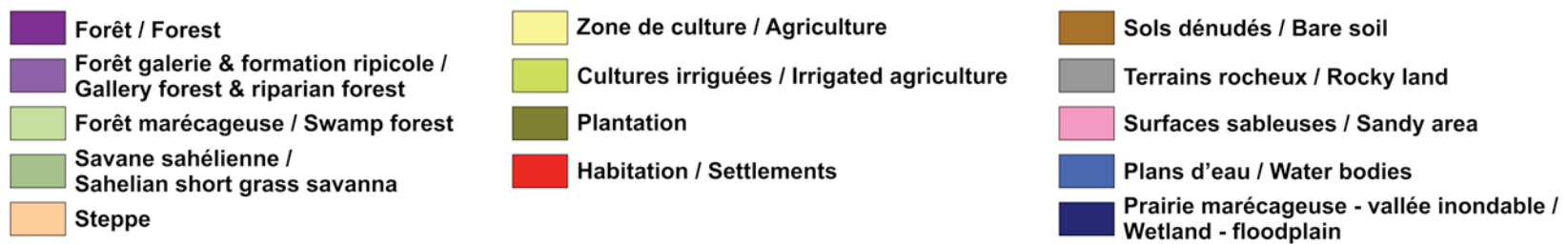
The overall rate of change in land use and land cover has accelerated from 0.4 percent per year between 1975 and 2000 to 0.7 percent per year between 2000 and 2013. Compared to the annual rates of change for the entire region of West Africa — 0.6 percent and above 1 percent, respectively — the land cover in Mauritania has changed relatively slowly.

Lower rural population densities in Mauritania compared to the average in the region might offer one explanation for the relatively slower conversion of land use and land cover.

Over both time periods, the two most widespread natural vegetation cover types and important pasture grounds, steppe and Sahelian short grass savanna, were affected by the largest losses in terms of area. Almost 19,000 sq km of steppe were lost between 1975 and 2000, and over 15,000 sq km between 2000 and 2013. For Sahelian short grass savanna, these figures amount to over 12,000 sq km from 1975 to 2000 and almost 11,000 sq km from 2000 to 2013. Steppe has given way to large swaths of sandy areas — an expression of the classic picture of desertification, where productive and stabilizing vegetation cover is lost and sandy substrate mobilized, giving the impression of an encroaching desert. Sahelian short grass savanna, on the other hand, has largely been replaced by steppe, and to a much lesser extent by sandy area. These changes point to a progressive aridification and subsequent southward shift of the major vegetation cover types in southern Mauritania.

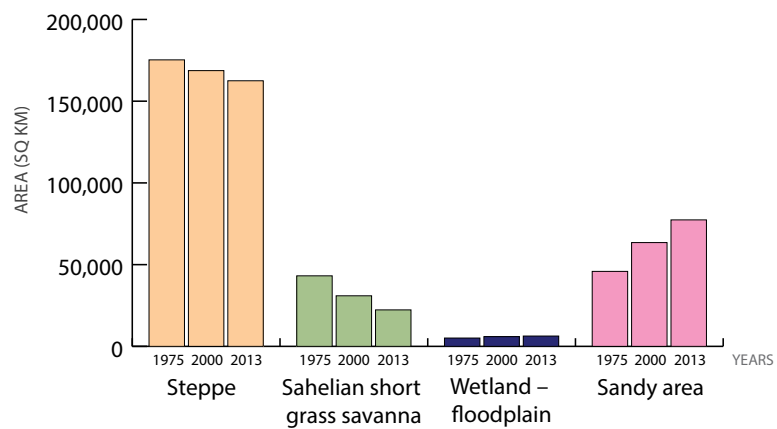


Occupation des Terres / Land Cover

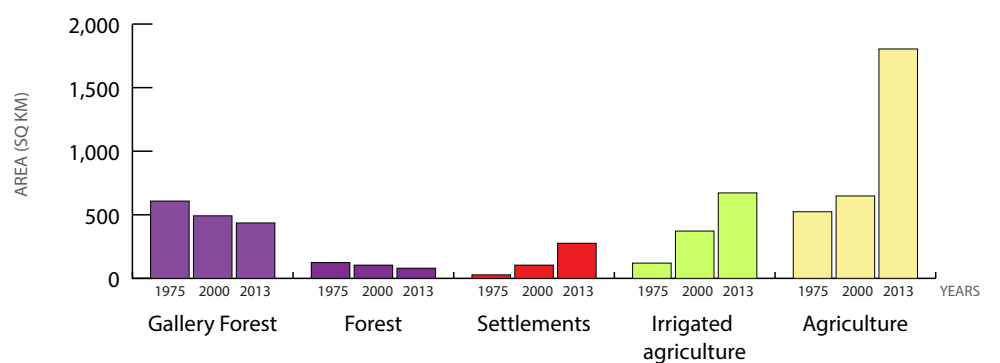


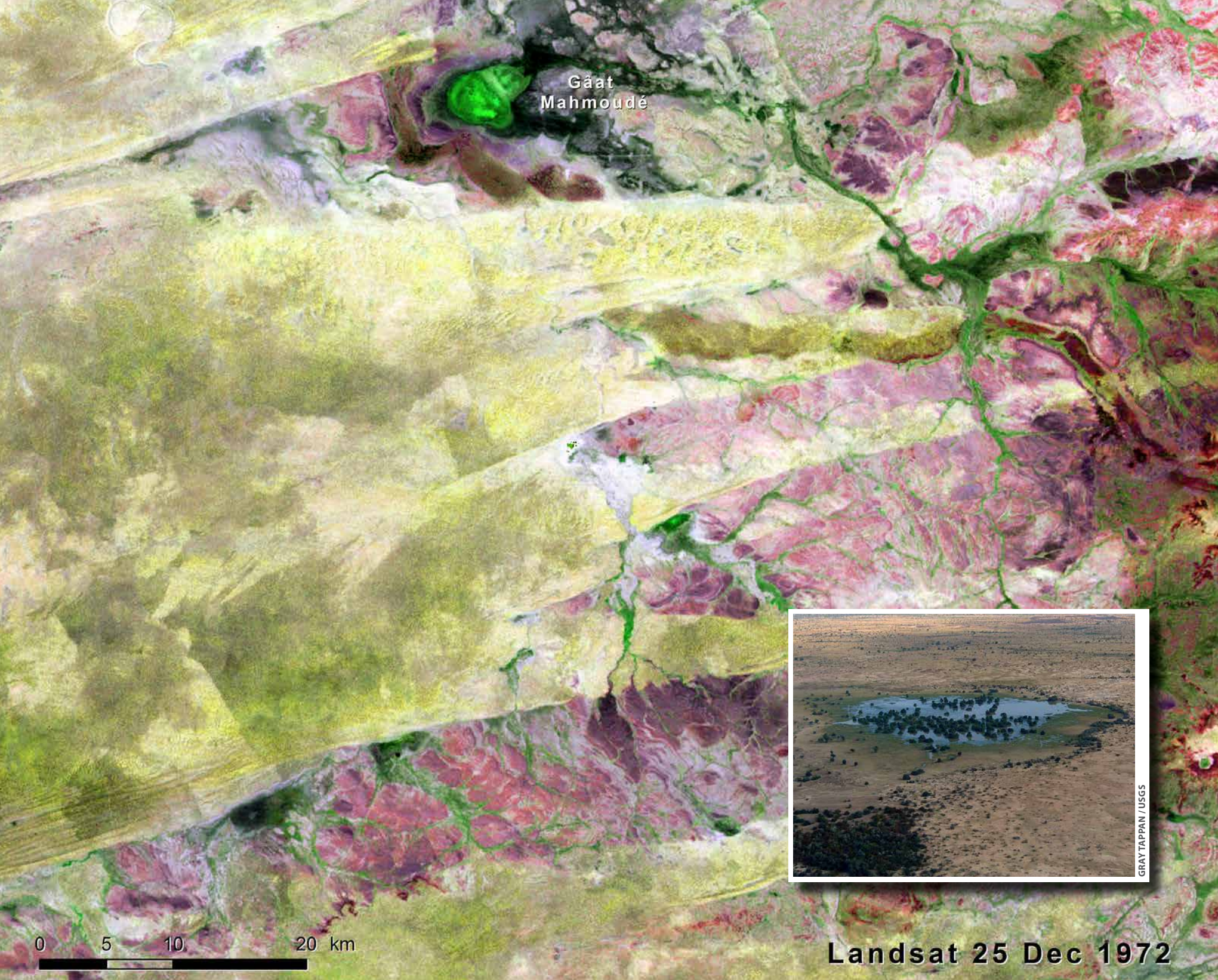
In addition to those changes of large geographic extent, some changes smaller in area are nonetheless significant due to their very high change rates. These include settlements, the area of which increased by a factor of ten between 1975 and 2013, as well as agriculture. The area of rainfed agriculture more than tripled, whereas irrigated agriculture increased almost six-fold over the same time period. The rate of agriculture expansion dramatically increased between 2000 and 2013, reaching an average of 89 sq km of additional cropland each year. In contrast, the already small but ecologically important areas covered by forest and gallery forest have been reduced by 44 percent and 30 percent, respectively, due to drought and agricultural pressure. Mauritania's forests are all located in the Senegal River Valley, whereas the remaining gallery forests are also found along some of the permanent and ephemeral tributaries to the Senegal River, such as the Gorgol, with very few occurring along the wetlands of southeastern Mauritania. The disappearance of forests is concerning, because they constitute hotspots of biodiversity in this predominantly arid country and offer important habitat for wildlife, including migratory birds, as well as repositories of medicinal plants. By contrast, another land cover type of high significance for biodiversity, the wetlands, has been remarkably stable over this almost 40-year period.

Large area classes



Small area classes





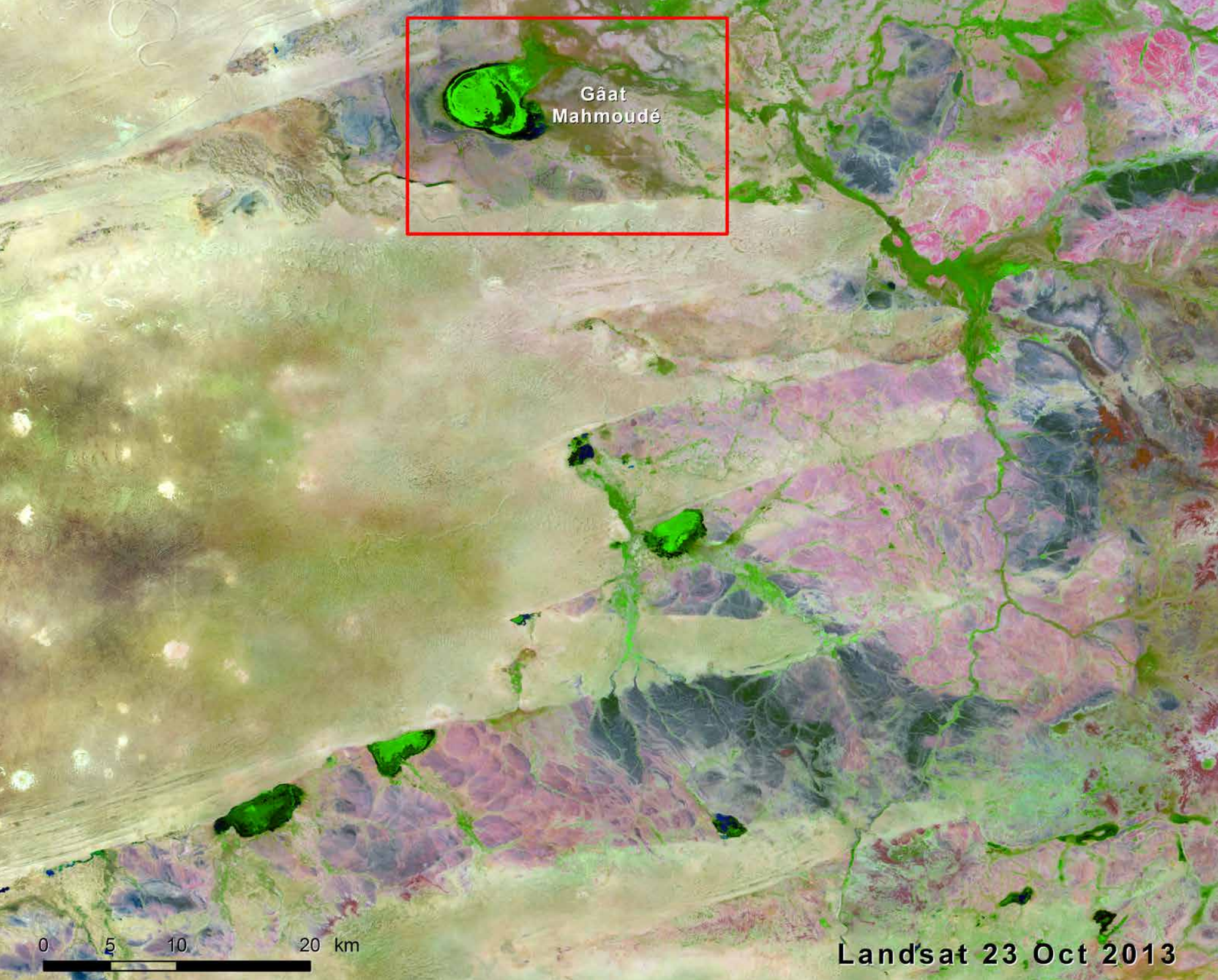
GRAY TAPPAN / USGS



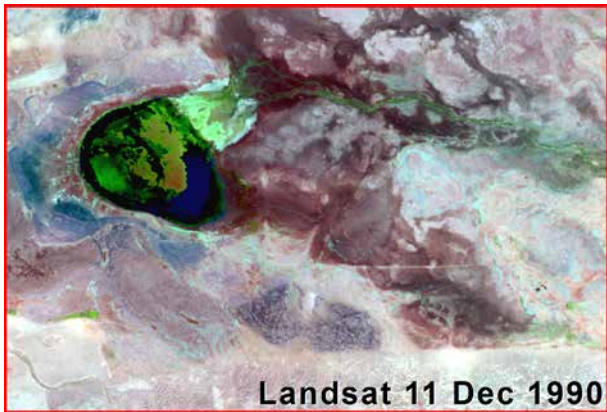
Dynamics of ephemeral wetlands in eastern Mauritania

In the arid northern Sahel, where people, plants, and animals all live on the edge of what is ecologically sustainable, wetlands stand out from their surroundings by the rich and diverse flora and fauna they support. As islands of resources, the ephemeral wetlands of eastern Mauritania fulfill key ecological and economic functions. However, because rainfall varies so much in eastern Mauritania, the water levels and vegetation in ephemeral wetlands fluctuate from year to year, and can even change significantly within a single year.

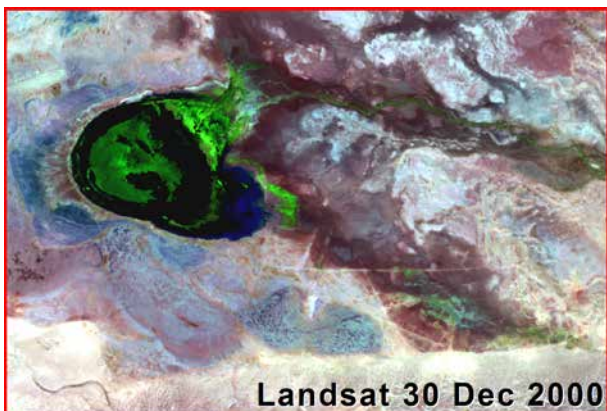
Landsat images of the Department of Néma in eastern Mauritania from 1972 and 2013 show many wetlands that occupy channels and depressions. These wetlands stand out in imagery from the nearby strips of sandy and bare soils. In the middle of the sandy zones covered by Sahelian short grass savanna, localized eroded areas around boreholes and villages appear as bright aureoles — they are especially visible on the 2013 image. Using local terms, Mauritanian wetlands include tamourts (forested closed basins), gâats (herbaceous closed basins or flats) and oueds (seasonal watercourses). Tamourts are contained in deep depressions, characterized by stands of *Acacia nilotica*, and have the longest mean water duration. Gâats are open wetlands present in a more shallow topography and typically cultivated during the dry season (Shine, 2011). These wetlands are fed by rainfall and runoff from their catchment areas and reach their maximum water level after the rainy season in October or November. On average, this region receives 280 mm of rainfall per year (Shahin, 2007). Because they rely on annual precipitation, the duration, depth, and size of these wetlands vary widely from year to year. A closer view of the Gâat Mahmoudé, the largest wetland in eastern Mauritania, illustrates this dynamic (see adjacent insets).



Landsat 23 Oct 2013



Landsat 11 Dec 1990



Landsat 30 Dec 2000

The runoff washes fine clay particles and organic matter into the wetland depressions, which makes the wetland soils more productive than the surrounding sandy soils. The increased nutrient availability and moisture in the wetlands attract a variety of economic activities. Indeed, livestock rely on the surface water and pasture in the wetlands for part of the year, bringing additional nutrients into the system. Flood recession agriculture is also practiced in some of the wetlands, as well as fishing and hunting. The tamourts provide wood for construction and fuel, wild foods and medicinal plants.

Wildlife also depends on water and vegetation resources offered by the wetlands and oftentimes competes with economic activities, sparking debate about conservation and management. The role of wetlands as stop-over, over-wintering sites and breeding grounds for migratory birds has received particular attention. Aerial surveys have been used to monitor Black Stork populations, whose concentrations in the wetlands vary from year to year in response to the variable and unpredictable surface water. In favorable years, Black Storks over-winter in the Gâat Mahmoudé; in other years they continue to more permanent wetlands in Mali, Niger, and Burkina Faso (Shine, 2001).



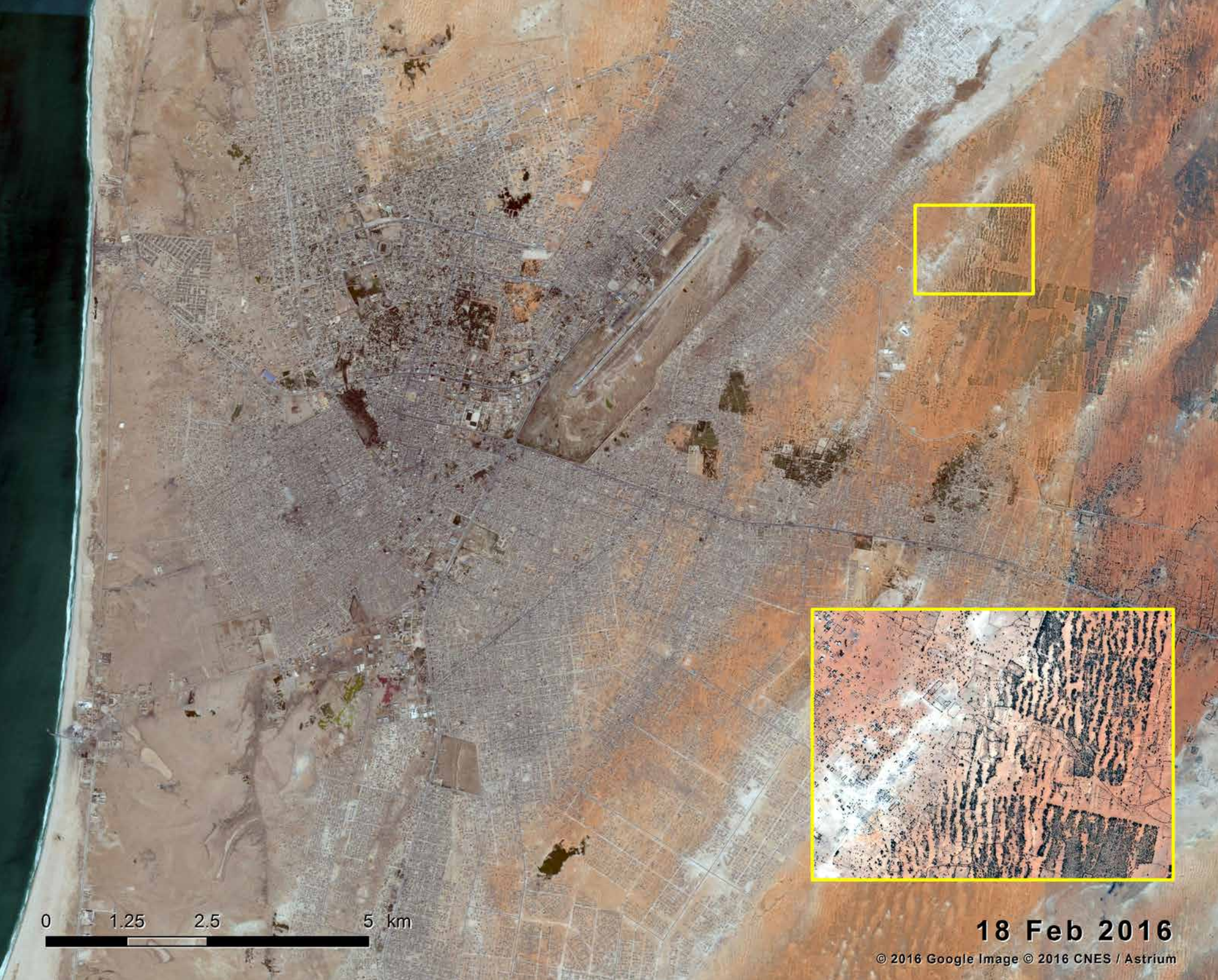
Nouakchott: urbanization at the gates of the desert

Unlike other capital cities in West Africa, Nouakchott did not serve as capital of Mauritania for most of the colonial time, inheriting this function from Saint Louis only in 1958, shortly before independence in 1960. Until that time, Nouakchott was a small fishing town of only 200 inhabitants. In the following decades, Mauritania underwent very rapid urbanization from 858,000 to 3,873,000 inhabitants between 1960 and 2013. The urban growth occurred primarily in the coastal cities of Nouakchott and Nouadhibou. A study of settlement patterns in Nouakchott showed that much of the city's rapid growth has been in informal settlements with limited access to urban services (Urban Habitat, 2016).

The rapid growth of the city was driven by a long series of drought years since the beginning of the 1970s, and by the degradation of the land and vegetation resources that ensued. As wells dried up and forage and firewood became harder to find, many rural Mauritians migrated to Nouakchott in search of work and a better life. Those



RICHARD JULIA



environmental refugees added to the refugees displaced by the Western Sahara war in the 1970s, who had swelled the population of the city.

A comparison of a Corona satellite image from 1965 and a high-resolution image from 2016 illustrates the dramatic expansion of the city, whose urbanized area sprawled from only 5 sq km in 1965 to 150 sq km in 2016. Low density development, including considerable undeveloped open space, predominates in the urbanized area, due to a cultural preference for detached single-family houses on large tracts of land.

Sand dunes advancing from the east are threatening buildings and infrastructure, particularly in the rapidly growing peri-urban areas. In a major dust storm, dunes may move several meters. In order to protect the city from the encroaching sands, the Nouakchott Green Belt was first established in 1975; however, it had to be extended in the 2000s as the city had grown beyond its boundaries. Up until today, a total of 12.7 sq km have been stabilized by afforestation with *Prosopis juliflora*, *Euphorbia balsamifera*, *Leptadenia pyrotechnica*, *Acacia senegal* and *Balanites aegyptiaca* as well as sowed with grasses such as *Aristida pungens* and *Panicum turgidum* (see above inset and adjacent picture). In addition to curbing sand encroachment, the green belt has provided employment opportunities and fostered agro-silvo-pastoral development (Berte, Ould Mohamed, and Ould Salek, 2010).

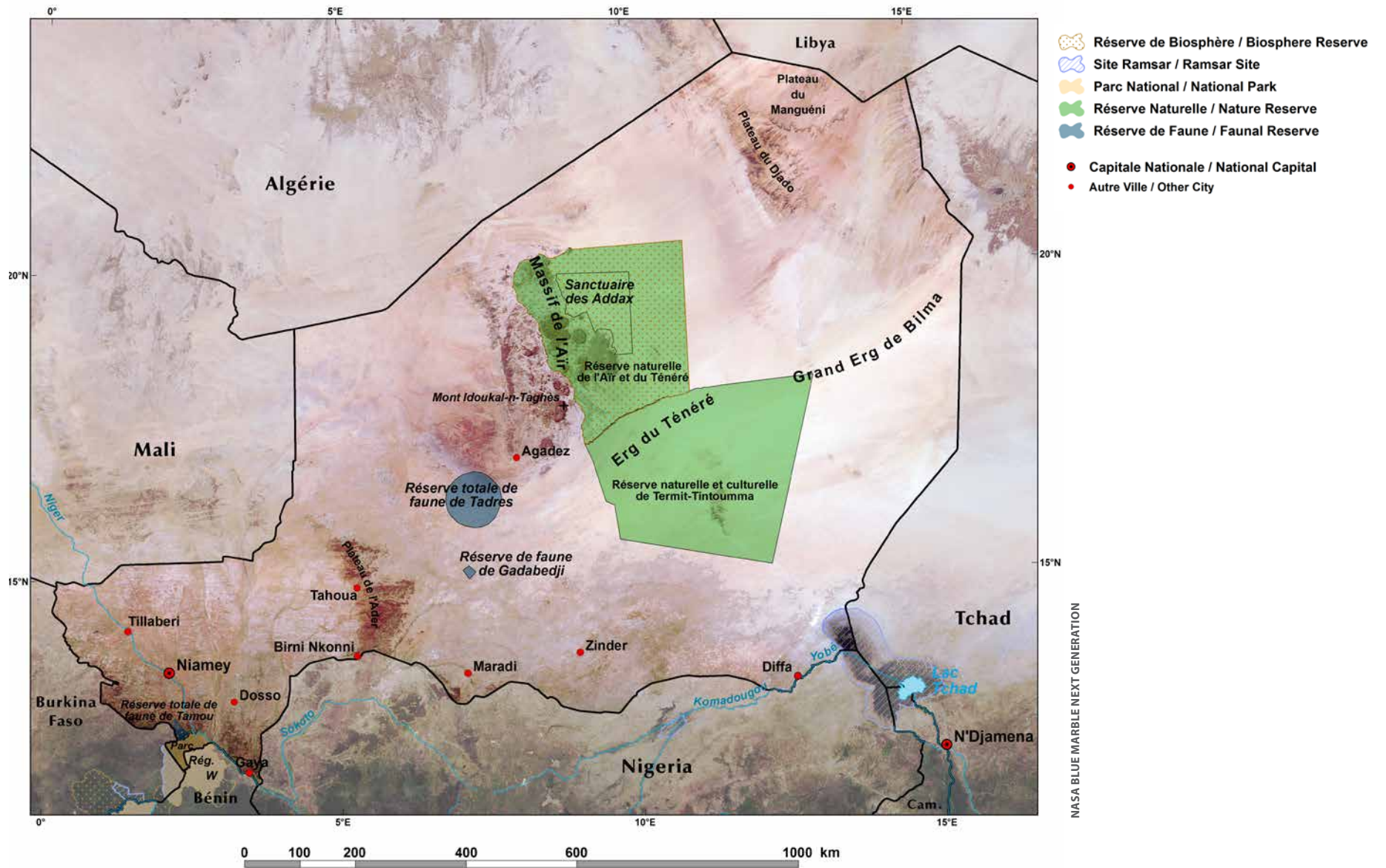


BERTE, OULD MOHAMED, AND OULD SALEK, 2010

Dune stabilization



Republic of Niger



Total Surface Area: 1,267,000 km²
Estimated Population in 2013: 18,359,000

Niger is one of the largest inland countries in West Africa and is historically a gateway between North Africa and sub-Saharan Africa. With two-thirds of the country lying within the Sahara Desert, it is one of the hottest countries in the world. Niger is mostly a vast plateau, with an average elevation of 500 m, with low local relief. In the Sahelian zone of the country, the climate becomes semiarid and the vegetation cover increases. The central part of Niger is dominated by an extensive pastoral zone — mostly steppes or short grass savannas with shrubs and sparsely scattered trees. Most of the people derive their income from agriculture and stock raising and are highly vulnerable to periodic droughts and desertification. Moreover, land potential for agriculture is very unevenly distributed among Niger's regions, with the southern regions providing nearly 98 percent of the arable land. The Niger River, for which the country is named, nourishes a ribbon of life as it flows about 550 km through western Niger. The river is the main source of freshwater and an important part of the economy through transportation and irrigation. Niger is a leading producer of uranium and is rich in many other minerals.

Environmental Highlights:

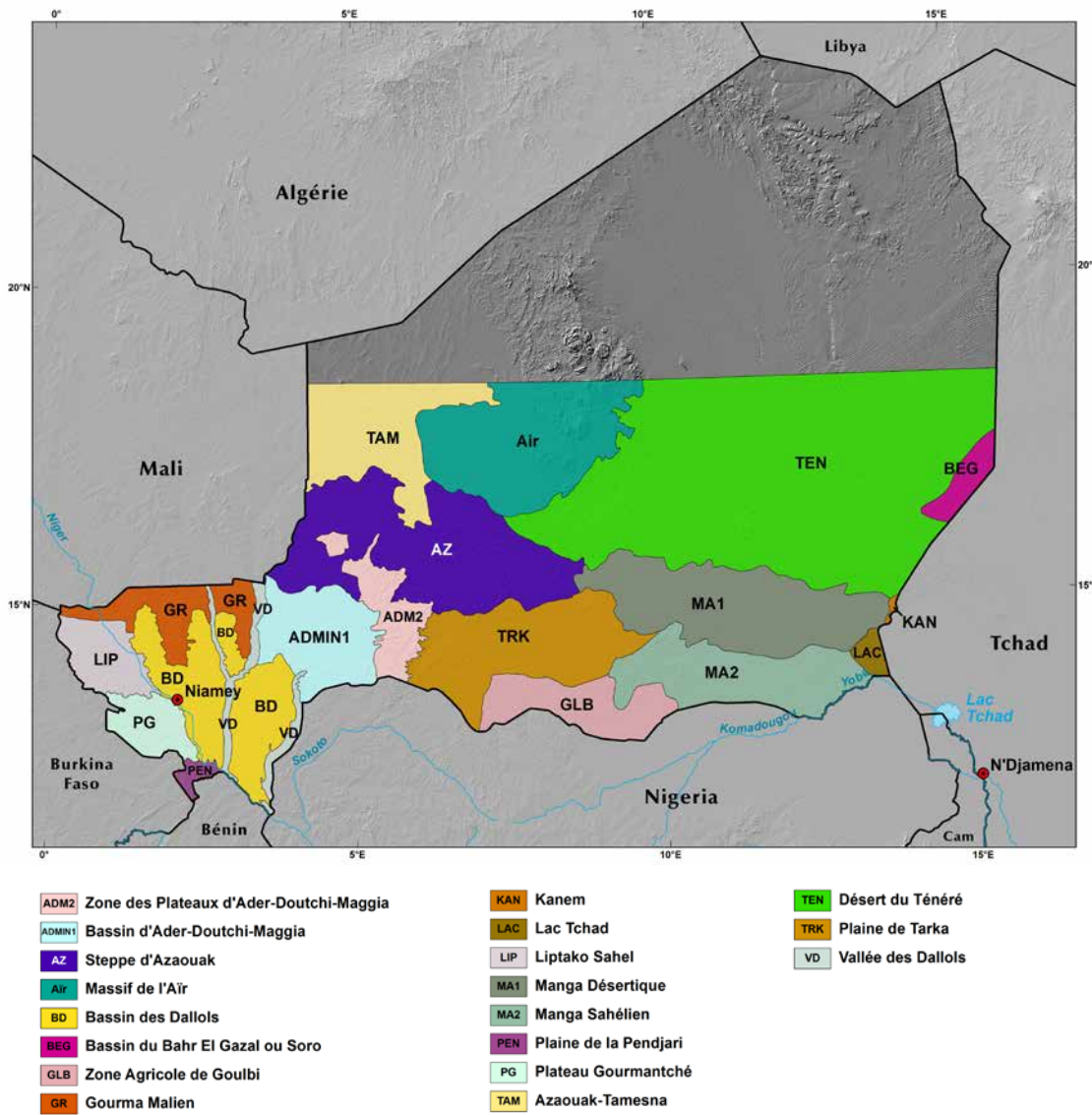
- Desertification
- Land degradation
- Re-greening of its agricultural lands
- Spectacular desert scenery



Timia, Air Mountains, Niger

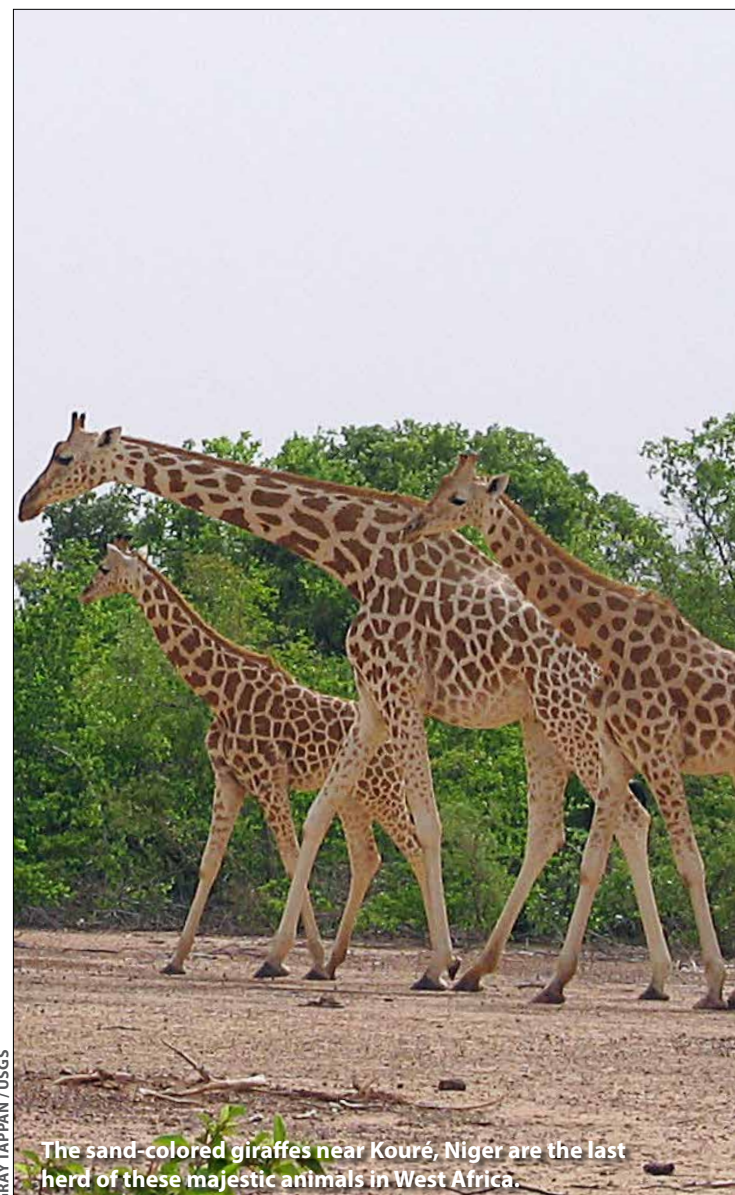
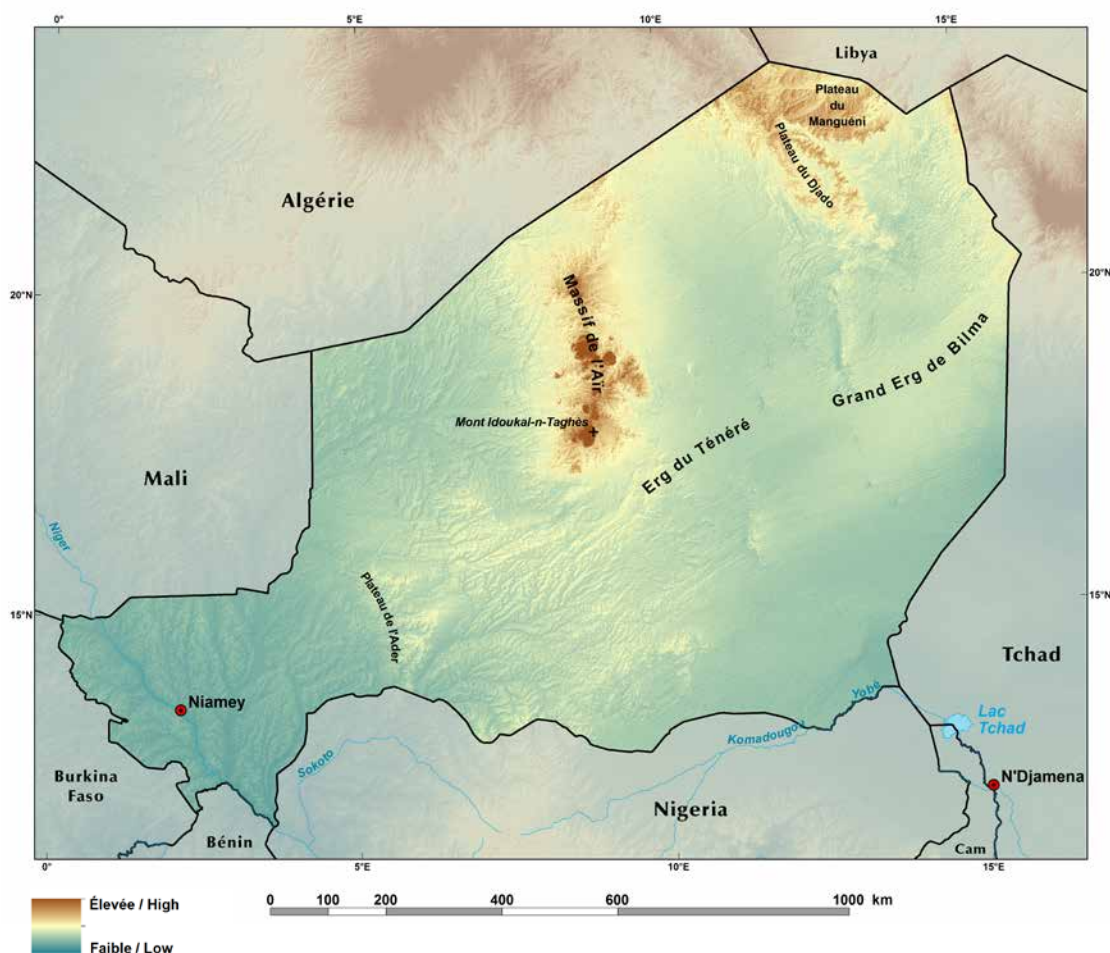
MICHEL KUPERS

Ecoregions

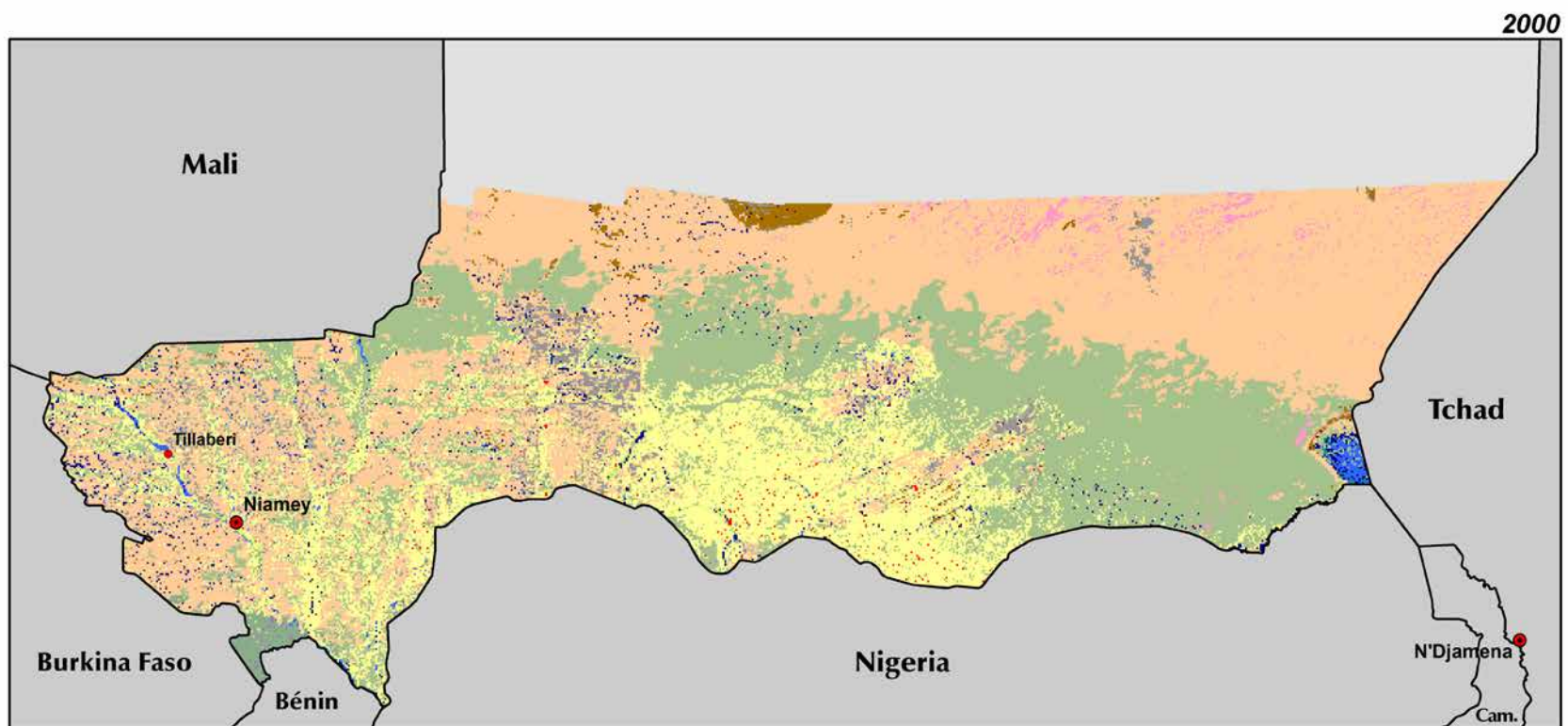
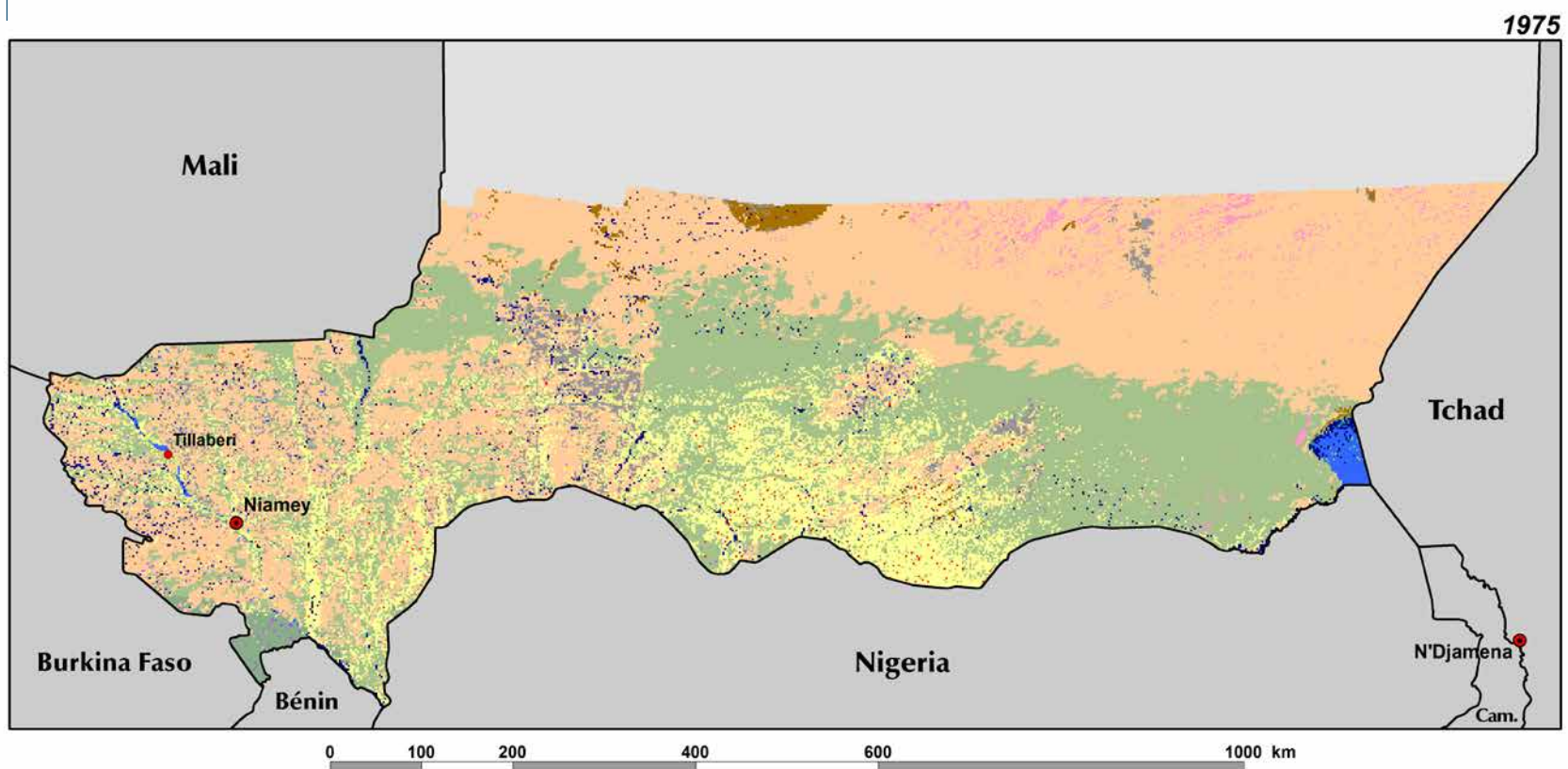


The Sahara Desert landscape, which covers about 65 percent of Niger, is made up of endless stretches of shifting sand dunes and broad gravel and stony plains. In years when the monsoon rains reach the southern Sahara, the wadis of the Aïr Massif and the plains of the Tamesna (TAM) are relatively more productive than the surrounding plateaus. To the south, the rest of the country is located within the Sahel, a transition zone between the desert and tropical West Africa. Across central Niger, from the Malian border to Chad, the pastoral zone of the Manga (MA1 and MA2) and Azouak (AZ) regions forms a wide strip of steppes and savannas. The Maradi-Zinder region (TRK and GLB) constitutes the largest agricultural region of Niger. In these ecoregions, the average bioproductivity gradually increases toward Niger's southern border, where farmers are conserving trees in their fields by encouraging natural regeneration. In western Niger, the productive ancient alluvial valleys of the Bassin des Dallols (BD) contrast with the less productive steppes and tiger bush of the surrounding plateaus and terraces.

Shaded Relief



Land Use, Land Cover and Trends



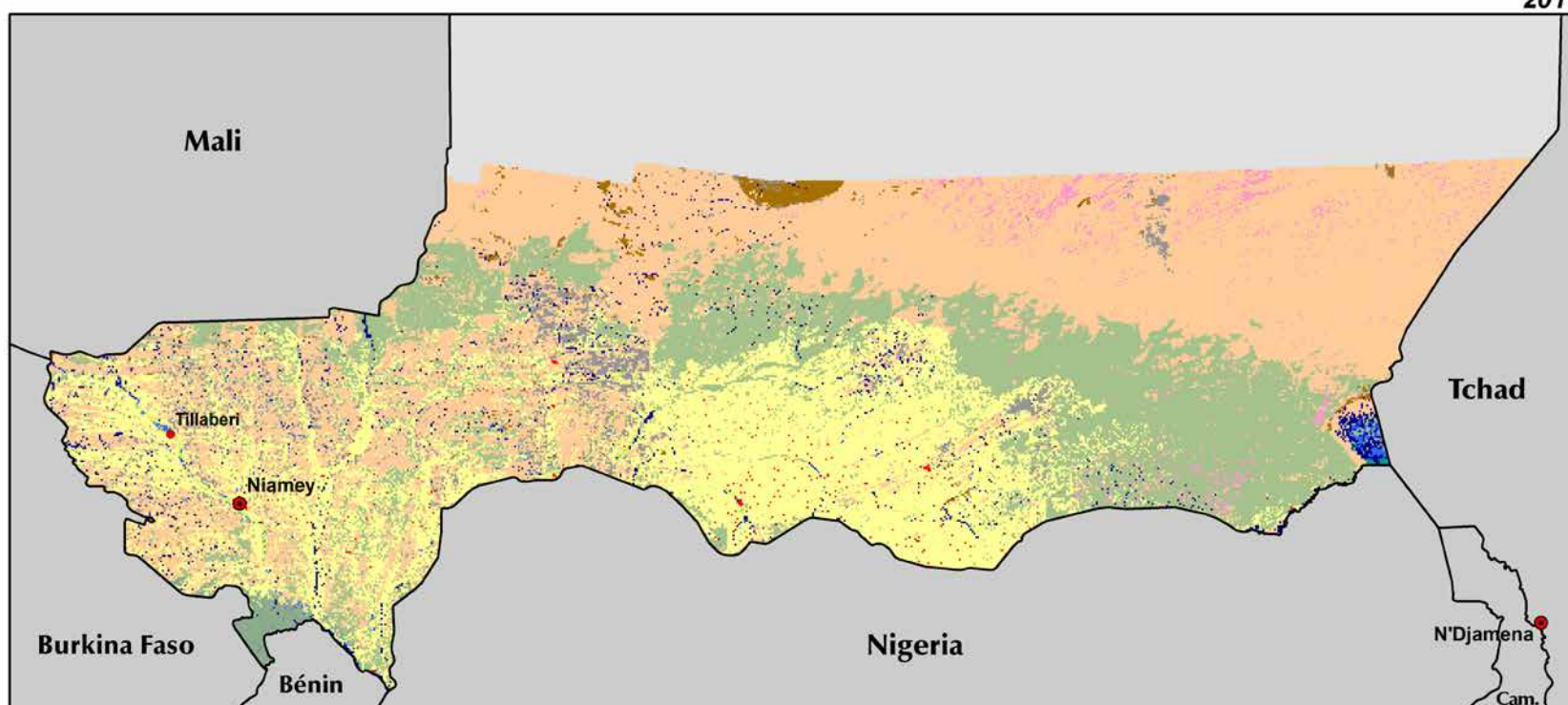
Because most of the northern part of Niger is covered by desert, only the southern half of the country was mapped in this atlas to analyze land cover and vegetation change.

● Capitale Nationale / National Capital

With an annual rate of 4.0 percent, Niger has one of the highest population growth rates in West Africa. Driven by the rapid population growth and the increasing demand for food, agricultural expansion is the most dramatic change in Niger's landscapes. Over the period 1975–2013, cultivated areas have increased from 12.6 percent in 1975 to 18.1 percent in 2000 and 24.5 percent in 2013. This represents a total increase of 94.2 percent. Agriculture expansion mostly occurred on the productive sandy soils of the valleys in the Tillabéri region, where cropland is now encroaching on traditional pastoral lands. On the surrounding plateaus and terraces of western Niger, a mosaic of steppe and short grass savanna dominates. The Zinder-Maradi region, already heavily cultivated in 1975, is now a wall-to-wall homogeneous agricultural landscape. However, agriculture is still expanding eastward on the remaining short grass Sahelian savannas

of the Manga regions. In addition, an increase of 50 percent in irrigated agriculture was observed along the Niger River.

Across the whole country, steppes remain the dominant land cover class and have remained more or less stable (about 45 percent of the mapped area). The more productive natural vegetation, however, suffered a sharp decline. The Sahelian short grass savanna (usually present on sandy soils) contracted in area by 26.7 percent from 1975 to 2013. Gallery forests, representing the most dense and biologically diverse vegetation in Niger, have also significantly declined. Their total area has always been low (about 470 sq km in 1975) but significantly decreased (66 percent) in the 38-year period. Indeed, these forests mainly occupy the narrow valleys which are now heavily cultivated.



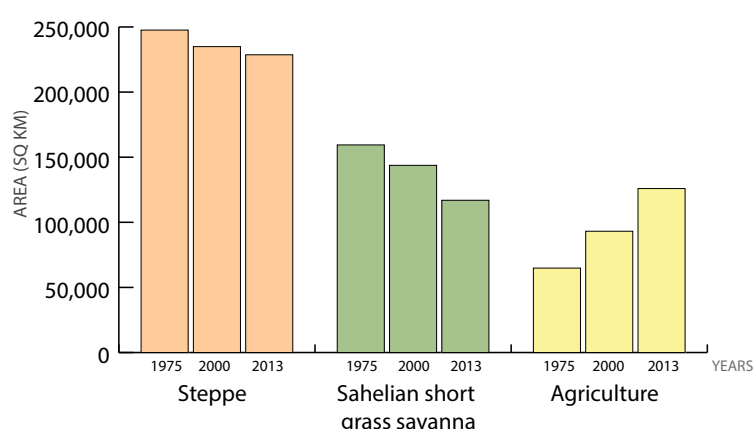
Occupation des Terres / Land Cover



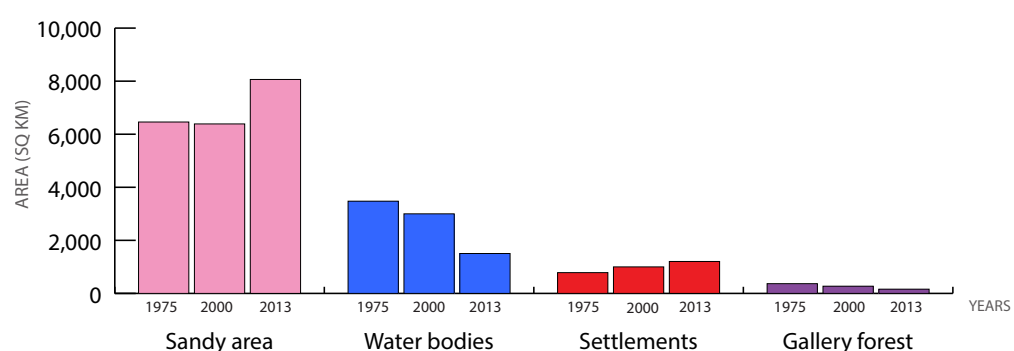
Sandy areas have increased by 24.8 percent since 1975. This trend is a concern because it indicates a decrease in soil stability and a loss of vegetation cover in some areas of Niger. Moreover, the trend appears to have become more acute since 2000. This change occurs mainly in the Manga pastoral ecoregions (MA1 and MA2) characterized by ancient sand dunes stabilized by the natural Sahelian short grass savanna. During the drought years of the 1970s and 1980s, many of these dunes became active when vegetation cover was lost. In addition, wind erosion, overgrazing on low vegetation, and loss of woody cover from drought and deforestation, often result in land degradation and enhance the process of desertification.

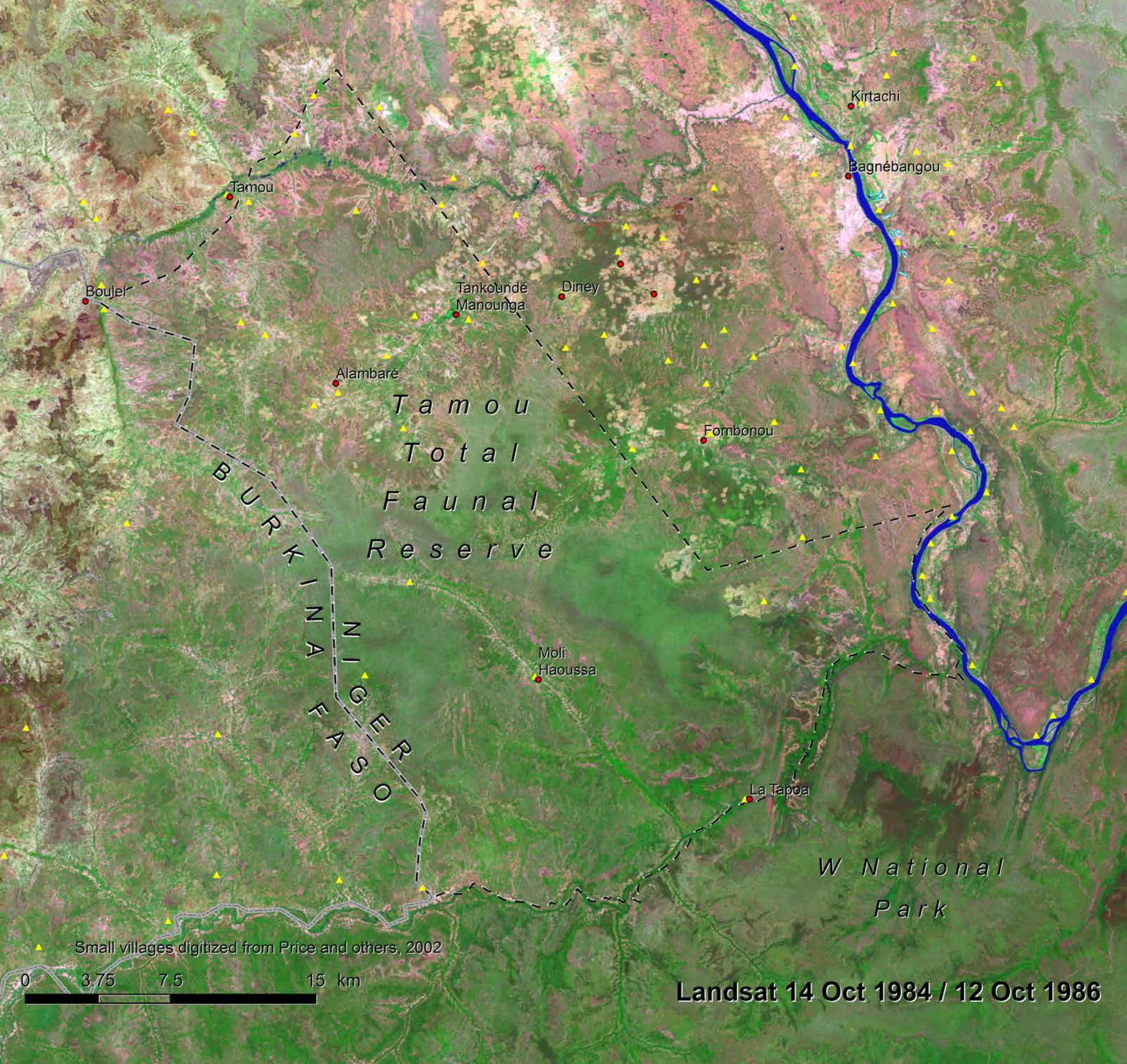
Mapping land use and land cover is an important part of the big picture of how land resources are changing. However, it characterizes an important dimension of land change that of land cover conversion from one type to another. Another type of change, often more subtle but equally important, is a change in the quality of the land cover, often called land cover modification. There are major examples of land cover modification in Niger. In the short grass savanna, there has been much loss of shrub and tree cover following drought periods and from cutting trees for firewood. On the positive side, Niger is the home of one of West Africa's most significant success stories—the re-greening of its agricultural lands by hundreds of thousands of farmers who have adopted an agroforestry practice that increases and maintains on-farm tree cover (see pages 70–71 and 162–163). This is a major development in land cover modification.

Large area classes



Small area classes

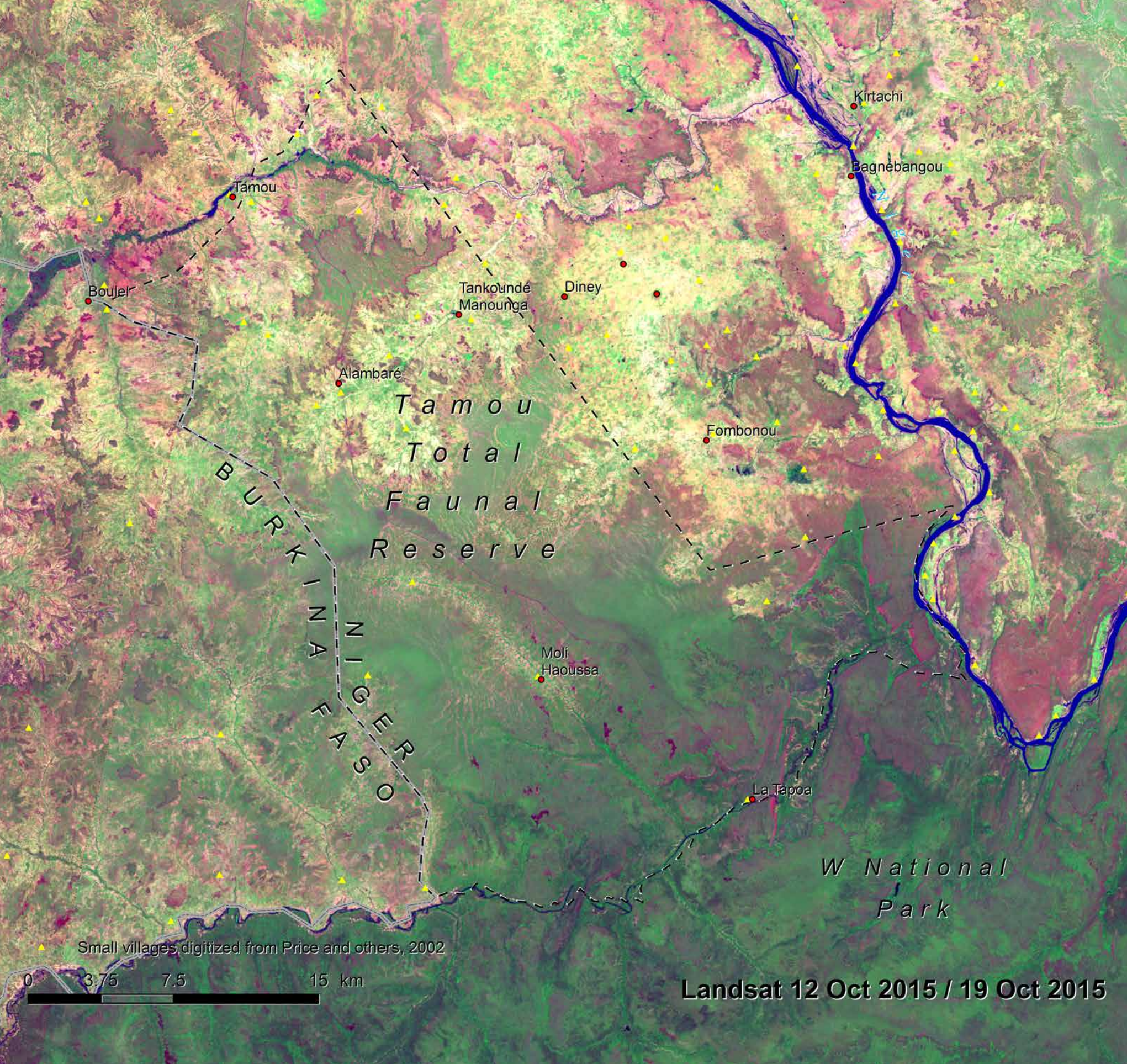




Food insecurity drives deforestation in the Tamou Total Faunal Reserve

The Tamou Total Faunal Reserve was created in 1962 to serve as a buffer zone for the W National Park of Niger and for the large transboundary W Regional Park. The reserve is located in the Rural Community of Tamou in Niger's southwestern corner. Initially covering 1,400 sq km (Bouamrane, 2006), the legal area of the reserve was reduced to only 760 sq km in 1976 when its eastern zone was decommissioned (Benoit, 1998). The Government of Niger decommissioned half of the reserve in response to food insecurity. This triggered a dramatic migration of people to this area along the Niger River floodplain where fertile soils and availability of water promised economic opportunity. Uncontrolled establishment of new villages and farms lead to the loss of large areas of relatively natural savanna habitat.

The W National Park and Tamou Reserve fall in the transition zone between savanna and woodlands in the Sudano-Saharan bioclimatic region. Tamou Reserve's natural habitat is made up primarily of shrub savanna and wooded

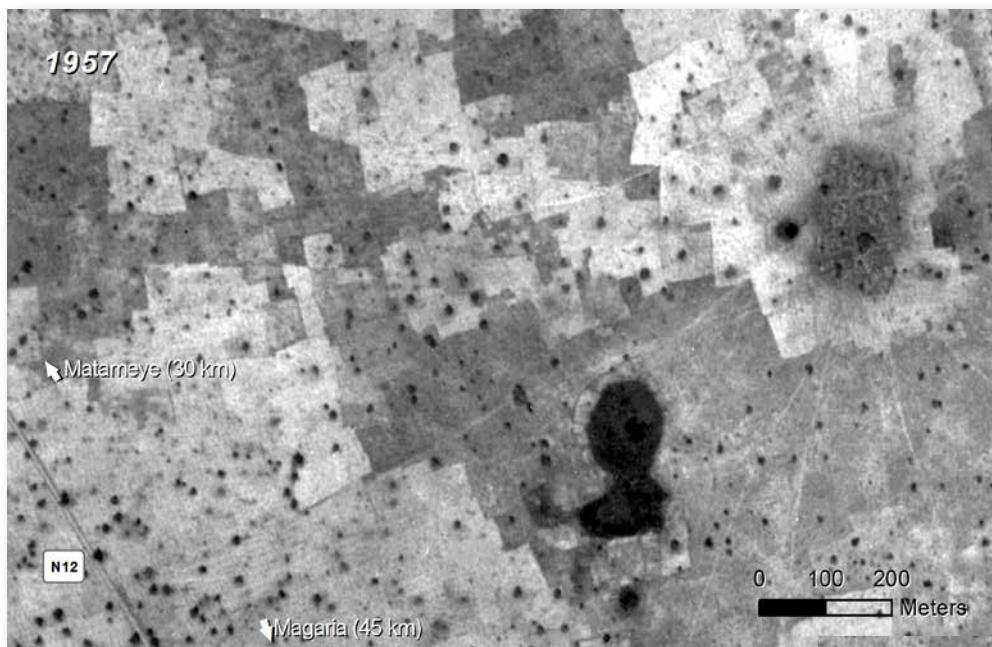


savanna with gallery forests running along the seasonal watercourses. The hundreds of native plant species in the two parks historically supported a range of fauna including elephants, lions, hippopotamuses, hyenas, cheetahs, warthogs, baboons, caracals, red and green monkeys, and a variety of avifauna (UICN/PACO, 2010). The natural flora and fauna are being lost as population pressure converts valuable habitat to farmland and villages.

The Landsat images show the expanding area of farm fields and villages between 1986 and 2015; most of this change followed the decommissioning of the reserve (Price and others, 2002). The changes are especially apparent

surrounding the named villages in the top center of the images. A study of pressure on the W Regional Park identified settlements surrounding the international park's perimeter (Price and others, 2002). The yellow triangles show the settlements they identified in the area around Tamou Reserve, most of them described as recent or new (as of 2002).

Despite the strong presence of rangers in the Tamou Reserve, who are there to enforce rules protecting the remaining reserve area, illegal activities persist, including clearing bush for new fields, poaching of both small and large game, illegal transhumance, felling of protected trees, and deliberate setting of fires.



Transforming farmlands through farmer-managed re-greening: The success story in southern Niger



A quiet but momentous agricultural and environmental transformation has been developing across southern Niger since the mid-1980s. As a result of an autochthonous process called farmer-managed natural regeneration (FMNR), farmers increased the number of on-farm trees in response to demographic and

resource-related constraints. Thus, they successfully restored degraded land and increased resilience in dryland areas.

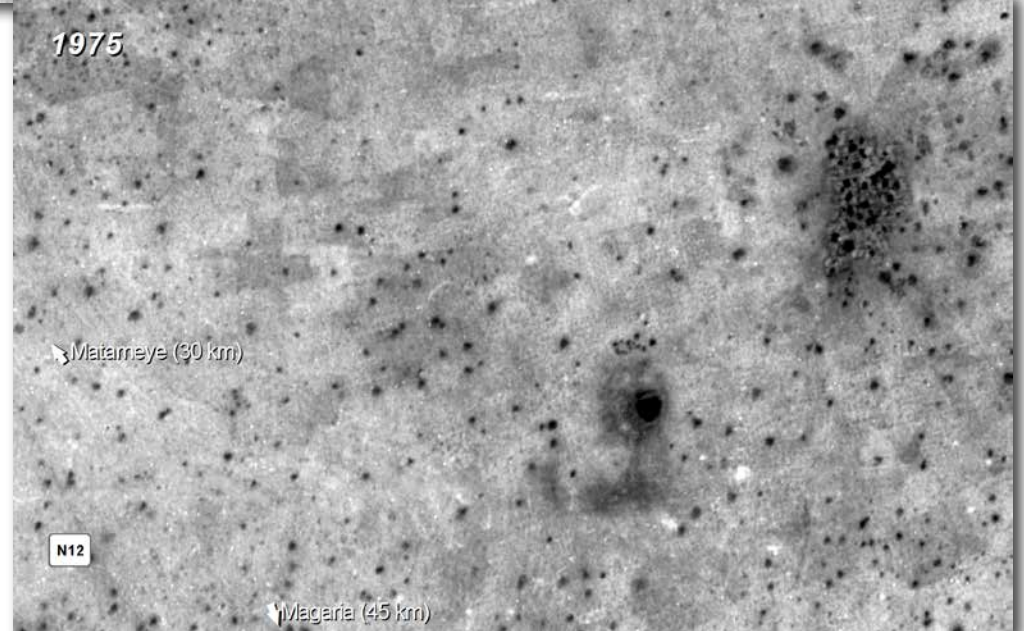
The regions of Maradi and Zinder are located on the lowest part of the Niger Plateau in south-central Niger and cover about 105,000 sq km. Both areas are located within the Sahelian bioclimatic region, which typically receive between 200 and 600 mm of rainfall per year and have high temperatures. These regions have high population densities and “wall-to-wall” agriculture, where cultivated fields extend across virtually the entire landscape (Reij and Winterbottom, 2015).

The second half of the 20th century witnessed a dramatic reduction in mean annual rainfall throughout the Sahelian region. According to a report by the Intergovernmental Panel on Climate change (IPCC), a rainfall decrease of 29–49 percent has been observed in the 1968–1997 period, compared to the 1931–1960 baseline period within the Sahel region (IPCC,

2001). Farmers faced significant tree losses in the 1970s and 1980s, as a result of drought, the expansion of cropland, and human pressures (Reij and others, 2009). Because few trees remained on the fields, farmers often witnessed their newly planted crops being destroyed by wind erosion. These environmental and economic crises induced farmers to invest in trees to fight desertification (Reij and Winterbottom, 2015). In the early 1980s, farmers in southern Niger started experimenting with a process known as farmer-managed natural regeneration (FMNR)—a low-cost way of encouraging the natural and spontaneous growth of trees and shrubs that provide useful food, fuel, and fodder (Reij and others, 2009). This practice spread from farmer to farmer, and currently about 3 million hectares (or 30,000 sq km) of land have been improved across the Maradi and Zinder regions.



The “magic tree,” *Faidherbia albida*

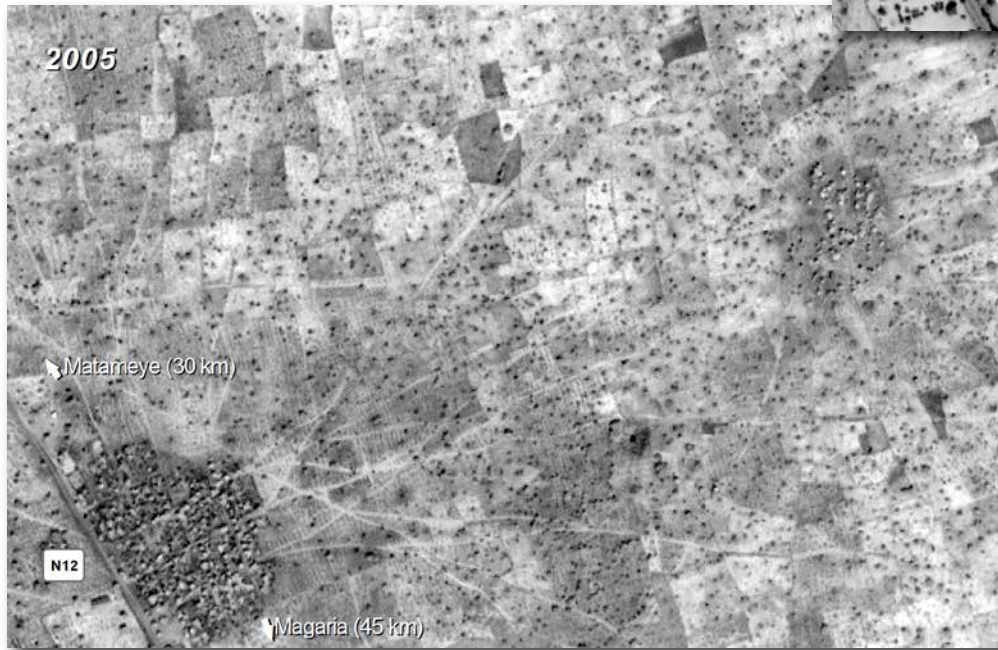
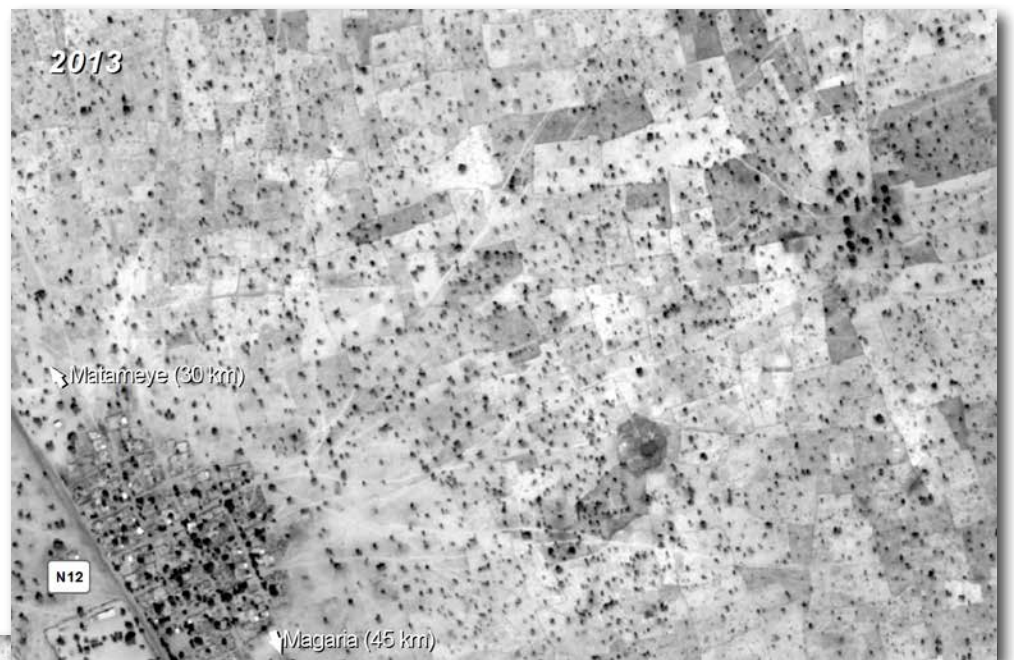
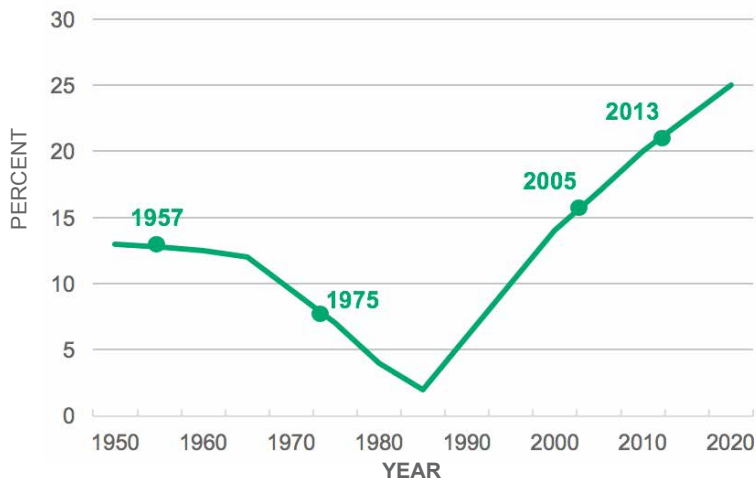


2001). Farmers faced significant tree losses in the 1970s and 1980s, as a result of drought, the expansion of cropland, and human pressures (Reij and others, 2009). Because few trees remained on the fields, farmers often witnessed their newly planted crops being destroyed by wind erosion. These environmental and economic crises induced farmers to invest in trees to fight desertification (Reij and Winterbottom, 2015).

In the early 1980s, farmers in southern Niger started experimenting with a process known as farmer-managed natural regeneration (FMNR)—a low-cost way of encouraging the natural and spontaneous growth of trees and shrubs that provide useful food, fuel, and fodder (Reij and others, 2009). This practice spread from farmer to farmer, and currently about 3 million hectares (or 30,000 sq km) of land have been improved across the Maradi and Zinder regions.

The high-resolution images present a time-series view of an agricultural landscape typical of the heavily settled plains south of Zinder, in 1957, 1975, 2005, and 2014. It highlights the increase in on-farm tree density between 1957 and 2014 (on-farm trees are seen as black spots on the images). The low on-farm tree densities in 1957 reflected colonial agricultural development policies. In those days, a farmer was perceived to be modern if he farmed his crop as a monoculture and had removed most on-farm trees to facilitate ploughing the land. Extensive areas of grassy fallow can be seen in the 1957 photograph—a practice that has almost disappeared. In 1975, the number of on-farm trees approached its lowest point. After

Evolution of tree density in south-central Niger since 1950

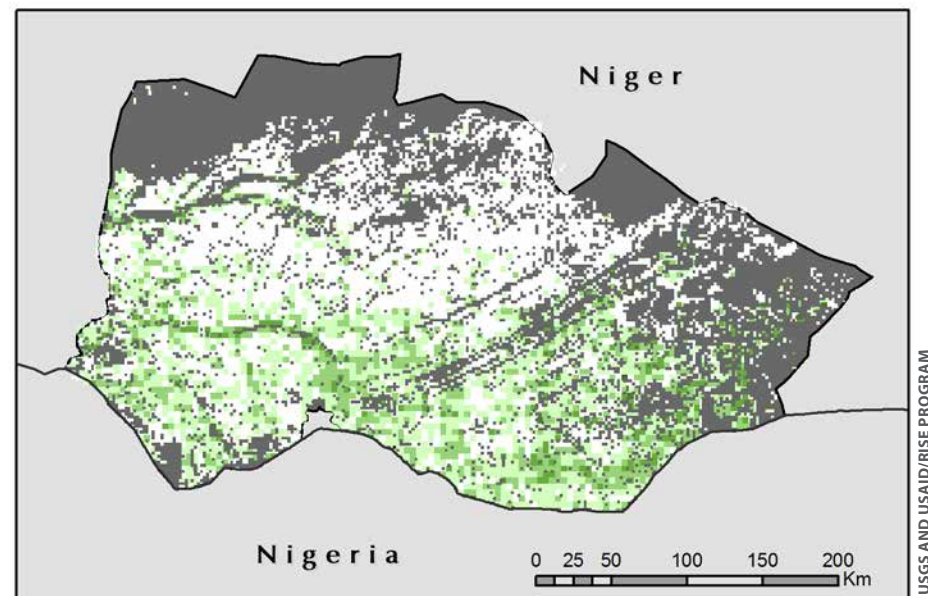


GRAY TAPPAN / USGS

the mid-1980s, tree densities steadily increased as farmer perceptions about tree ownership changed. By 2005, satellite images confirmed that a vast transformation was taking place. There were more villages, more people, but also many more trees (Reij and Winterbottom, 2015). This renewed resource generates a range of benefits for the population. Trees reduce wind speed and evaporation, produce at least a six-month supply of fodder for livestock, and provide firewood, fruit, and medicinal products that farm households can consume or sell. Moreover, certain tree species, such as the winterthorn acacia (*Faidherbia albida*), enhance fertility by adding nitrogen to the soil (Reij and others, 2009).

In the 1970s, it seemed as if Niger would be blown from the map. Drought and strong Harmattan winds from the desert created a general feeling of despair among the rural development community. No one could have imagined that farmers in densely populated parts of Niger would significantly increase on-farm tree densities with minimal external support. Today, the agricultural landscapes of southern Niger have considerably more tree cover than they did 30 years ago. These findings suggest a human and environmental success story at a scale not seen anywhere else in Africa.

On-farm tree cover density in south-central Niger

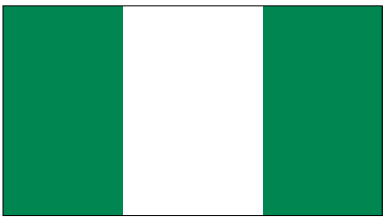


USGS AND USAID/RISE PROGRAM

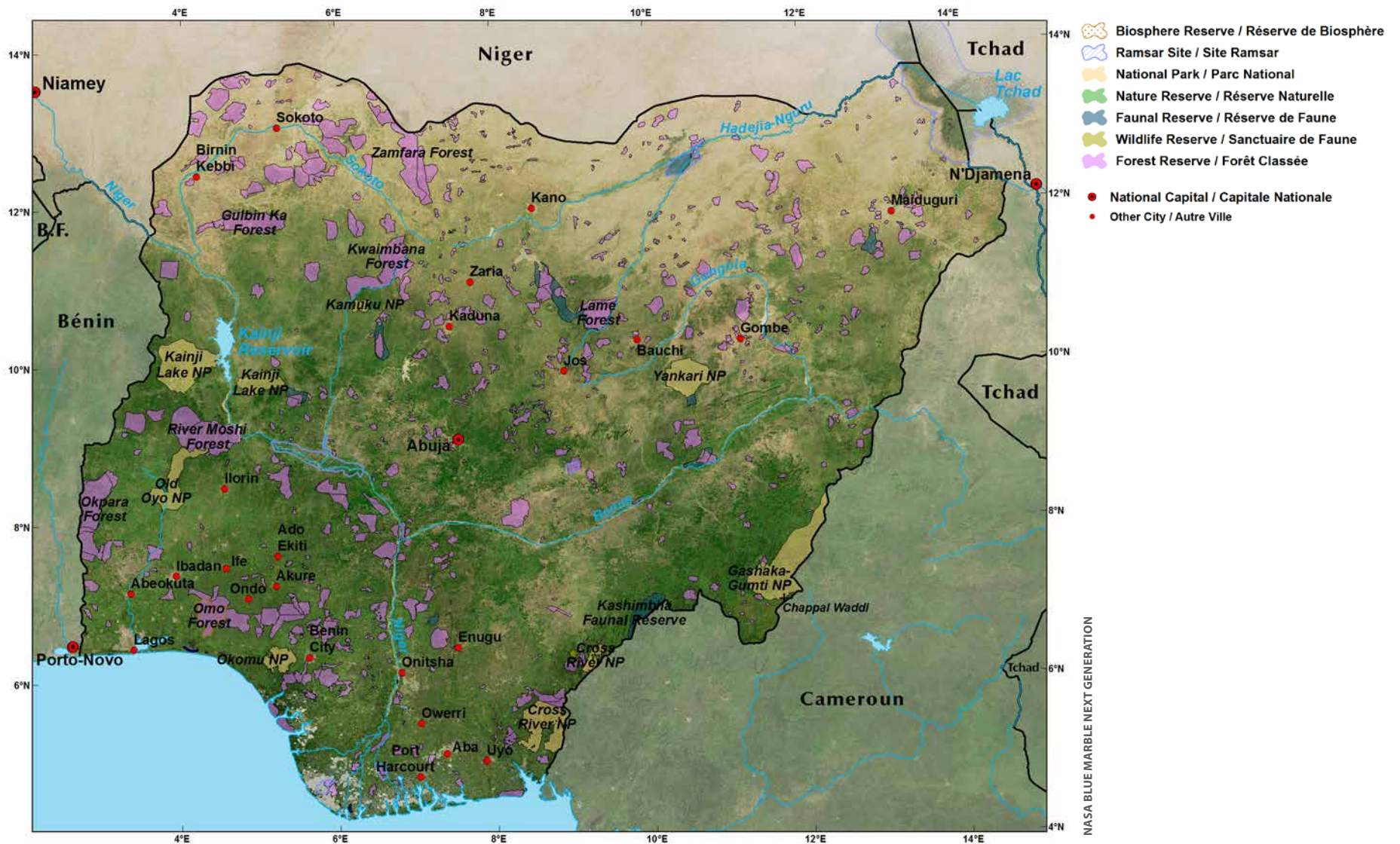
On-farm tree cover / Couvert arboré des terres agricoles

- Non farmland / Terres non-agricoles
- No tree cover / Pas d'arbres
- Open with isolated trees / Ouvert avec quelques arbres isolés (0-2%)
- Low density tree cover / Couvert arboré faible (2-5%)
- Medium density tree cover / Couvert arboré moyen (5-15%)
- High density tree cover / Couvert arboré élevé (15-25%)
- Very high density tree cover / Couvert arboré très élevé (>25%)

Patterns and extent of on-farm tree cover across the Maradi-Zinder agricultural region in 2013. This phenomenon is also visible in other regions (locally present in Tahoua and Dosso regions and in the northern part of the Tillabéri Region). Many of the trees are young, the hallmark of a recent and rapidly developing agricultural parkland still increasing in density and cover.



Federal Republic of Nigeria



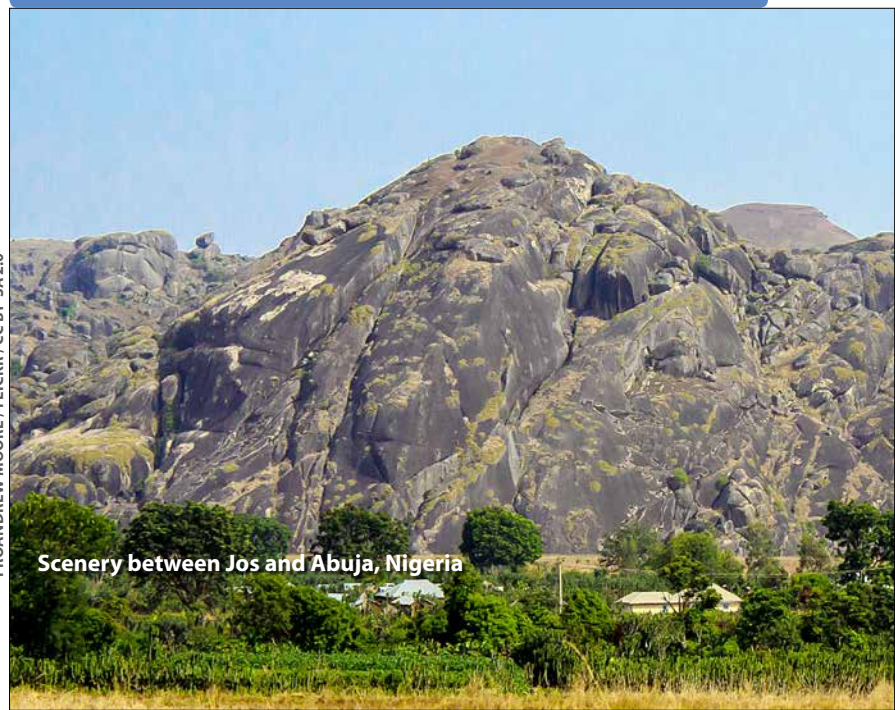
Total Surface Area: 923,768 km²
Estimated Population in 2013: 172,817,000

Nigeria is the most populous country in West Africa, and currently the seventh most populous in the world. About half of Nigerians are urban dwellers. Nigeria's urban character is unique in Africa, counting 11 cities of over 1 million, and more than 70 cities of over 100,000 inhabitants. Rapid growth in both population and the economy exerts a strong pressure on Nigeria's diverse natural resources, from the tropical coastal plains in the south to the Sahelian savannas in the north. After running 4,000 km from the Guinean Highlands through West Africa, which makes it Africa's third longest river, the Niger reaches the Gulf of Guinea on the Atlantic Ocean in Nigeria, where it ends in a network of channels forming a large coastal delta with extensive mangrove and swamp forests. The Niger Delta, which covers about 70,000 sq km, is a hotspot of plant and animal biodiversity, but it also holds Africa's second largest oil and largest natural gas reserves, which have fueled Nigeria's economy, the second largest in Africa by nominal gross domestic product (GDP). Diversity and extremes characterize Nigeria both culturally and environmentally, making it a microcosm of all Africa's promise and problems.

Environmental Highlights:

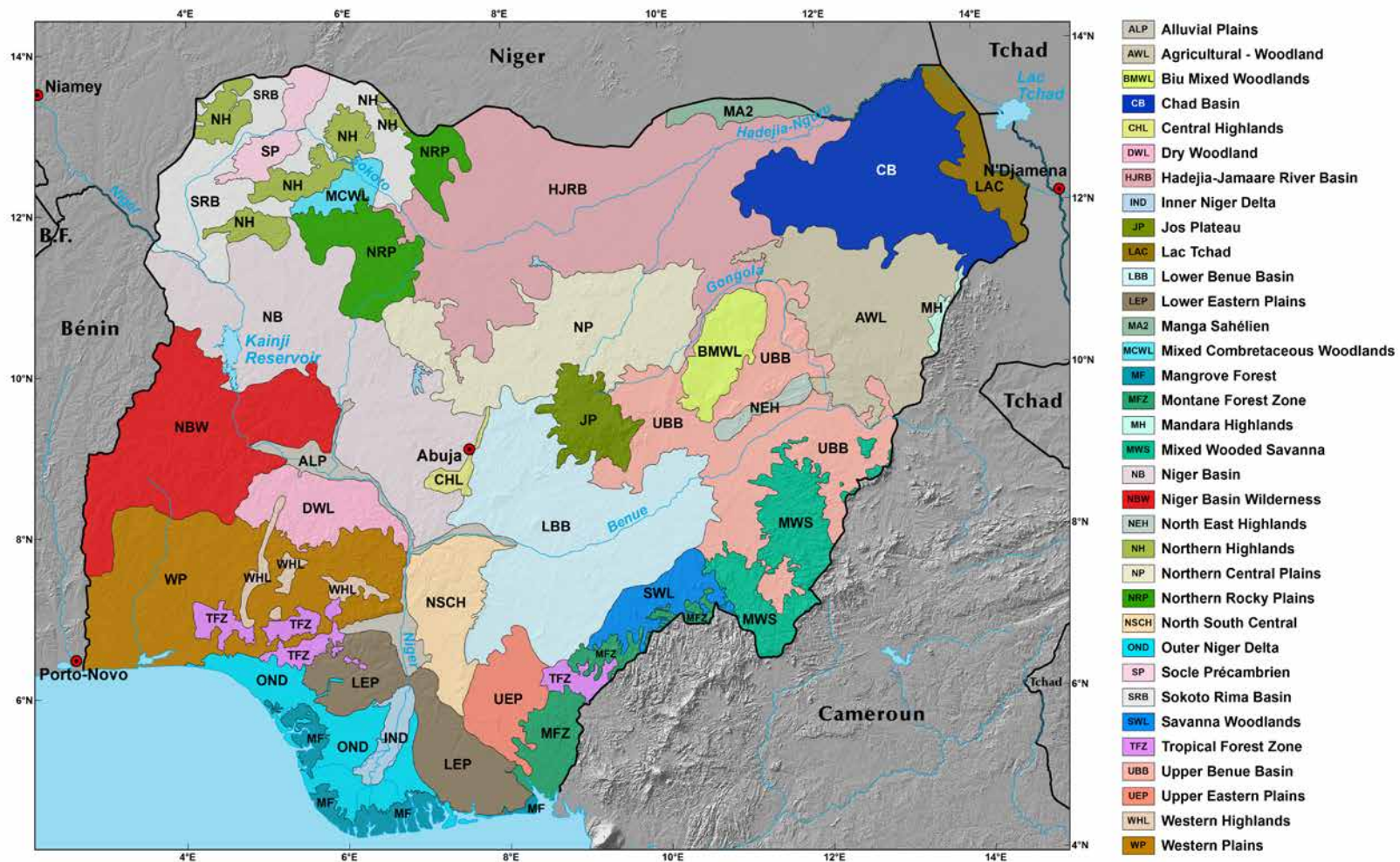
- Deforestation
- Desertification
- Crude oil pollution
- Second largest swamp forest on the continent (after Congolian swamp forest)

PROANDREW MOORE / FLICKR / CC BY-SA 2.0

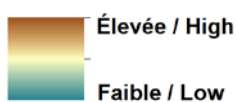
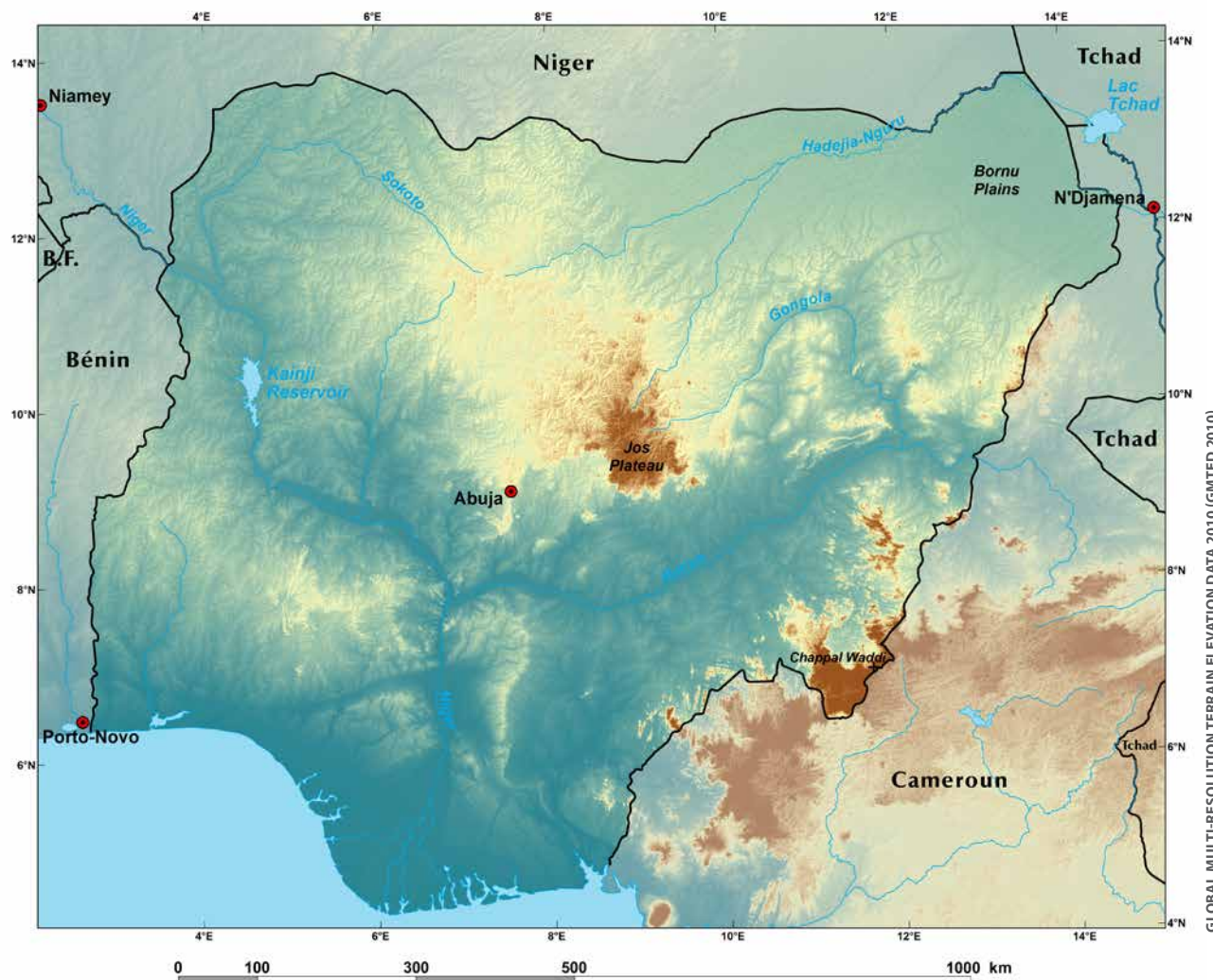


Scenery between Jos and Abuja, Nigeria

Ecoregions



Shaded Relief



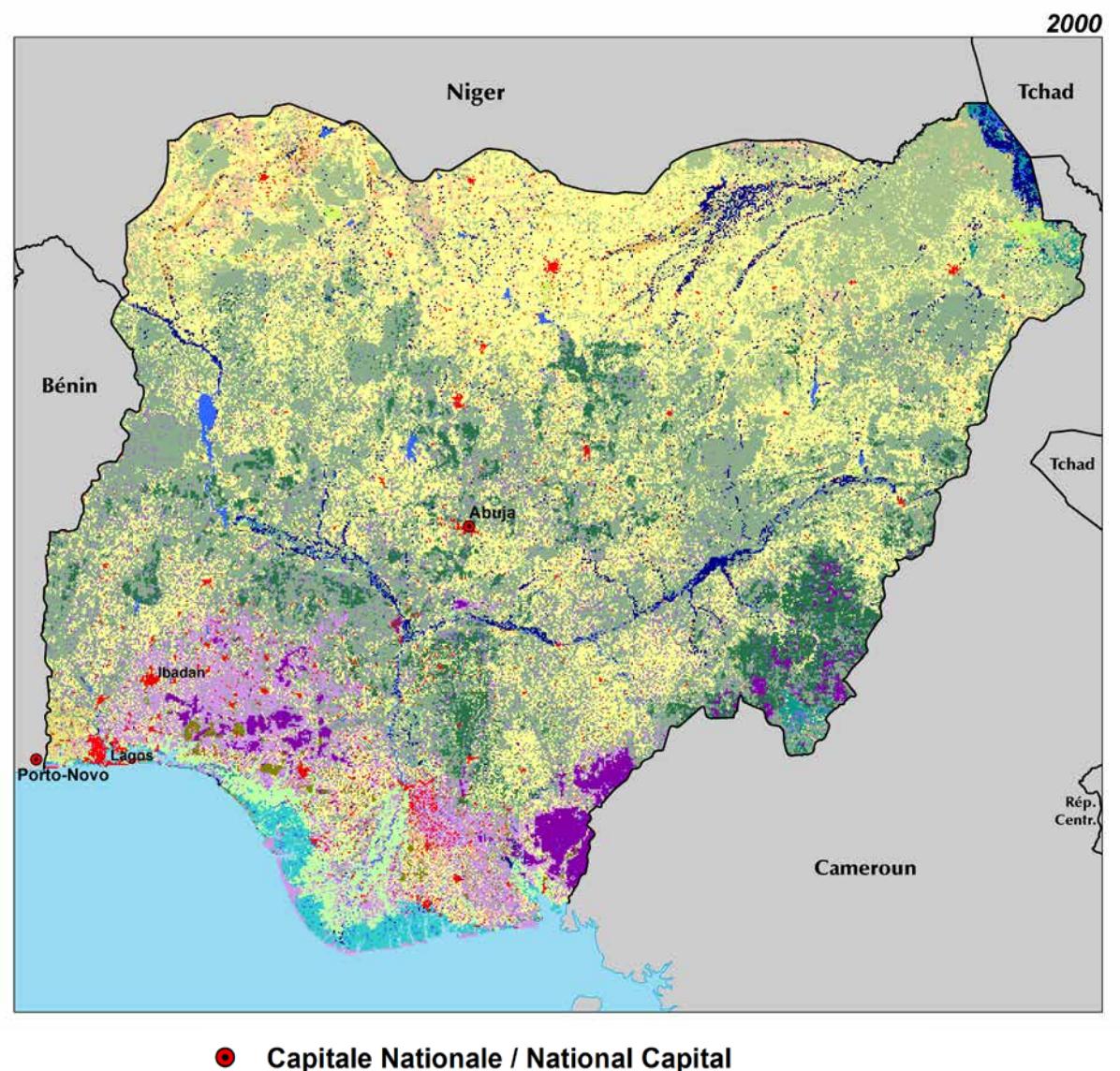
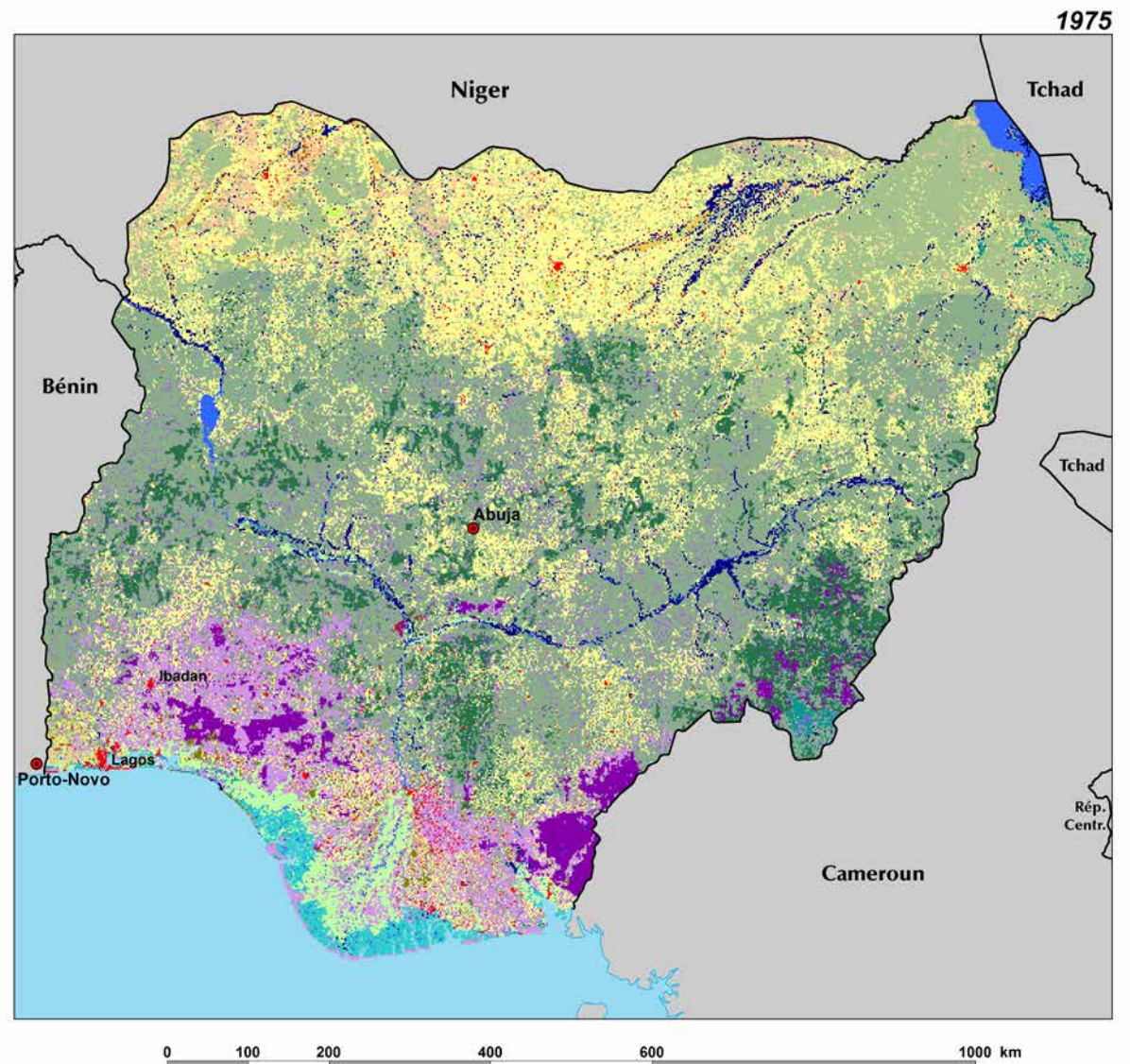
The majority of Nigeria's heartland is formed by the valleys of the Niger and Benue Rivers, which merge into each other, making a "y-shaped" confluence. The Niger River and its tributaries create a lifeline for Nigeria's agriculture in the semiarid northern and central parts of the country, as they supply water for a variety of food and cash crops. The coastal plains are found in both the southwest and the southeast, mostly covered by swamp and mangrove forests, merging into highly degraded forest inland. To the southwest of the Niger valley lies a rugged landscape defined by the Western Plains (WP) interspersed with the Western Highlands (WHL). The heavily populated Jos Plateau with its semi-temperate climate, Nigeria's largest area above 1,000-m elevation, rises prominently from the riverine plains. The northern part of the country is characterized by somewhat lower elevations, level terrain, and sandy soils, where agriculture dominates.

Land Use, Land Cover and Trends

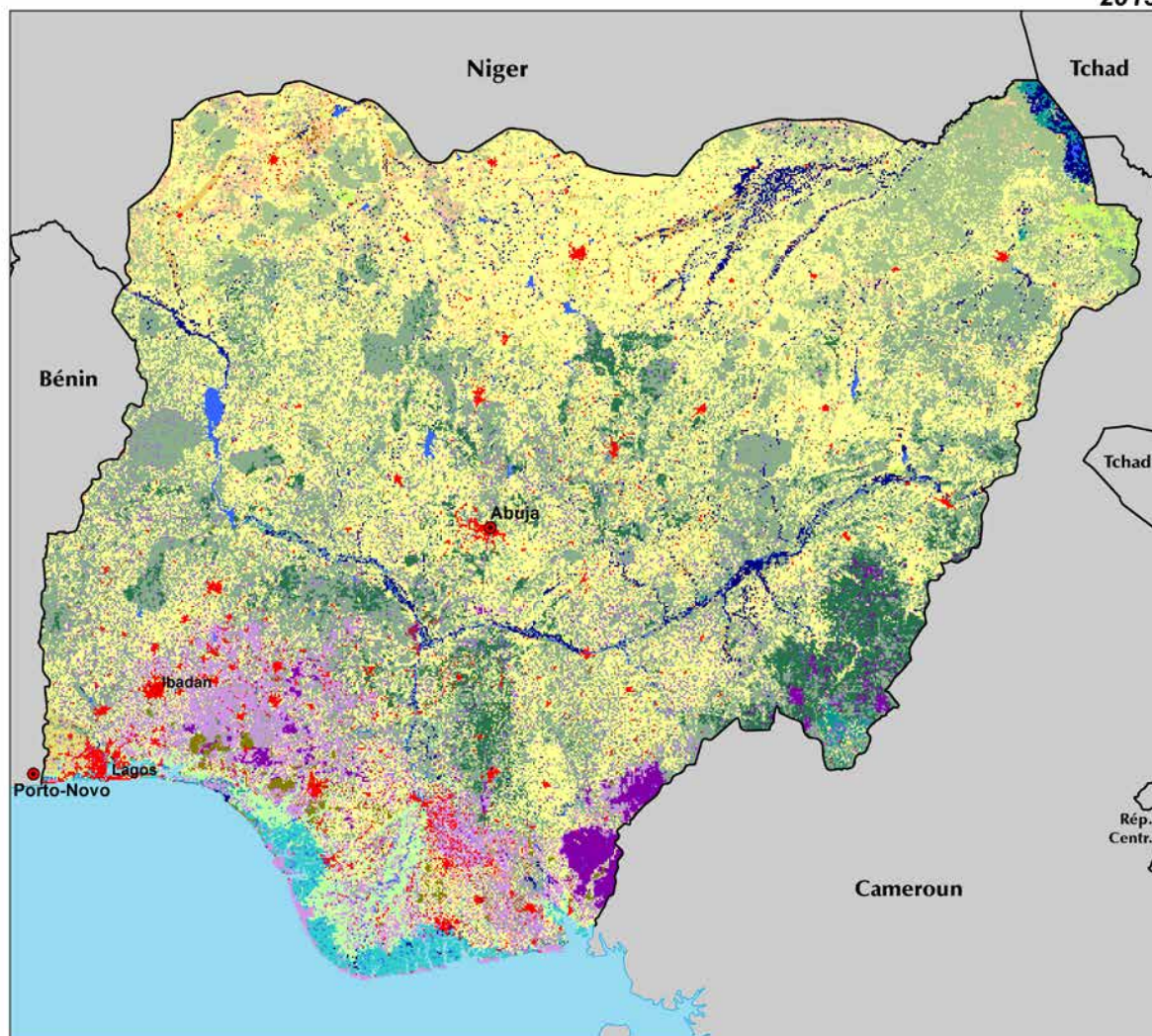
Not surprisingly, the country that is home to the largest population of the region also has by far the largest area under cultivation. In 2013, rainfed agriculture accounted for 380,000 sq km in Nigeria, covering over 40 percent of its national territory, up from 20 percent in 1975. From 1975 to 2000, 130,000 sq km of new agricultural land were taken under the plough, with an additional 110,000 sq km from 2000 to 2013. The magnitude of these transitions — together exceeding the size of the entire country of Ghana — is unparalleled in the region. Nigeria is also the only country of the region in which agriculture has traded places with savanna, and doubled its area in 38 years, to make it the largest land cover type.

The expansion of agriculture was observed across all ecoregions from the forest zone of southern Nigeria, where root and tree crops dominate, to the forest-savanna transition of the center of the country, where mainly root crops are found, to the grain belt of semiarid northern Nigeria. The Niger and Benue Basins, promoted as a prime agricultural development area and future bread basket since the 1970s, has seen the most prominent encroachment of agriculture into the savanna, sharpening the outlines of the remaining protected areas. Not all protected savanna areas, however, have been spared from the fast agricultural expansion.

While the transition from savanna to agriculture constituted the largest land cover change in



2013



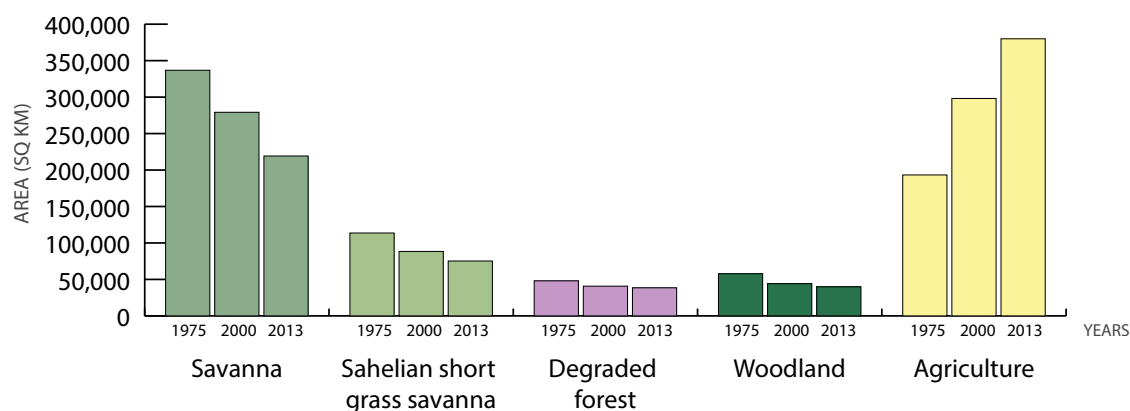
Land Cover / Occupation des Terres

- Forest / Forêt
- Gallery forest & riparian forest / Forêt galerie & formation ripicole
- Degraded forest / Forêt dégradée
- Woodland / Forêt claire
- Swamp forest / Forêt marécageuse
- Mangrove
- Savanna / Savane
- Sahelian short grass savanna / Savane sahélienne
- Herbaceous savanna / Savane herbacée
- Steppe
- Bowé
- Thicket / Fourré
- Agriculture / Zone de culture
- Irrigated agriculture / Cultures irriguées
- Agriculture in shallows and recession / Cultures des bas-fonds et de décrue
- Cropland and fallow with oil palms / Cultures et jachère sous palmier à huile
- Plantation
- Settlements / Habitation
- Bare soil / Sols dénudés
- Rocky land / Terrains rocheux
- Sandy area / Surfaces sableuses
- Open mine / Carrière
- Water bodies / Plans d'eau
- Wetland - floodplain / Prairie marécageuse - vallée inondable

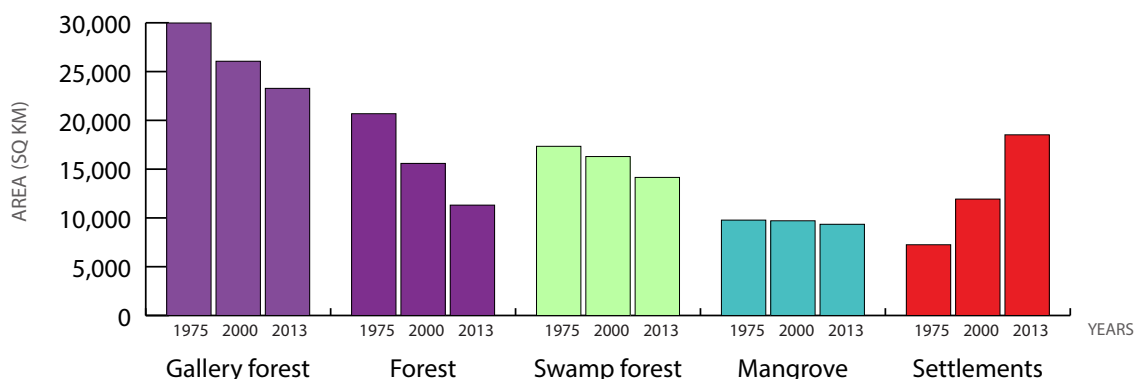
terms of area, some changes in the smaller land cover categories also stand out as important. High rates of change were observed for settlements, irrigated agriculture, plantation, and open mines, with gains accelerating from 1–2 percent per year between 1975–2000 to 2–4 percent per year in the 2000–2013 period. Under the pressures of a rapidly growing population and economy, forests, gallery forests and woodlands, in addition to the savanna land cover types, were all being diminished, with loss rates increasing to over 2 percent per year during the 2000–2013 period. Forest area decreased by 45 percent from 1975 to 2013.

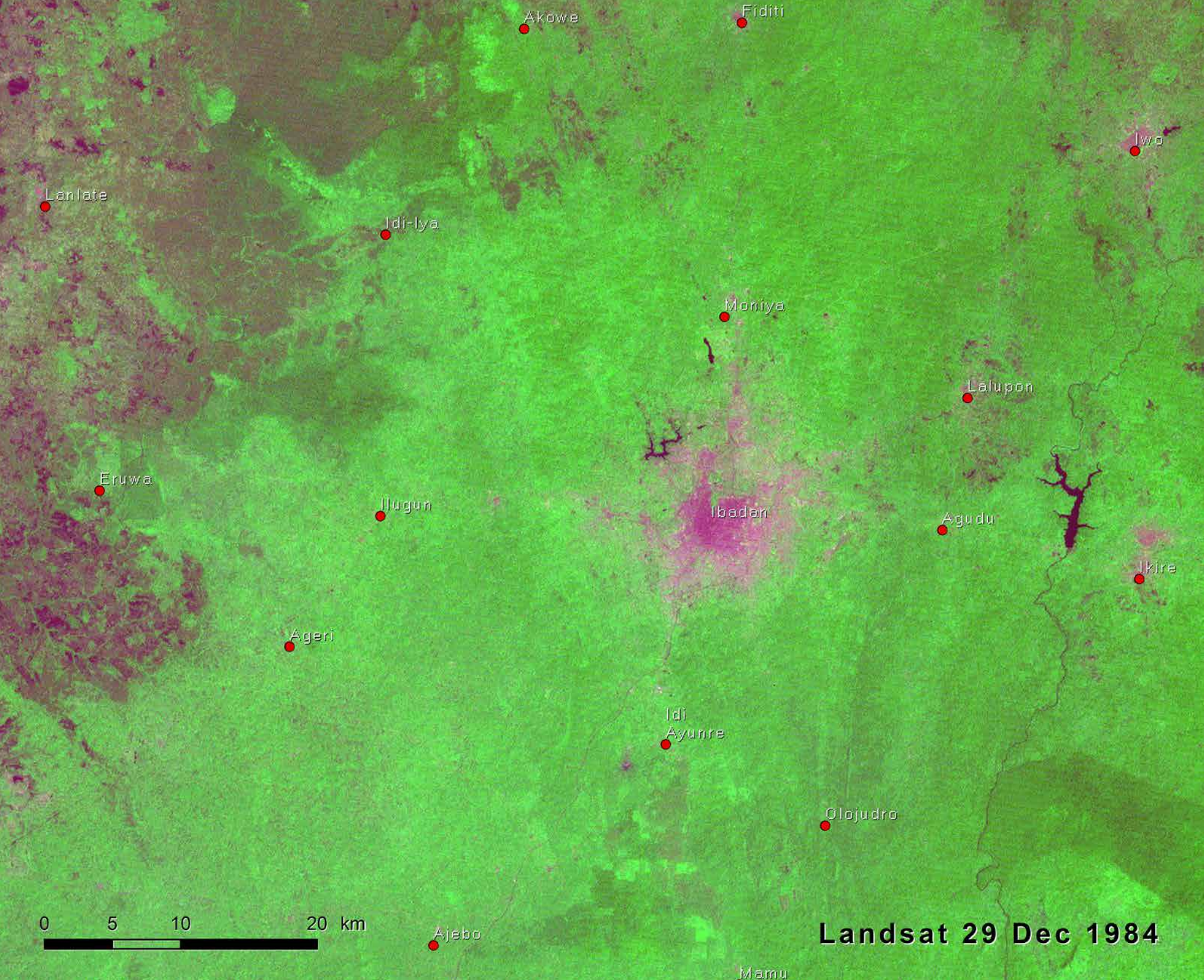
While the area of mangroves and swamp forests along the coast and in particular in the Niger Delta — important hotspots of biodiversity — has decreased less than that of some other land cover types, the health of these ecosystems has been severely damaged by recurrent oil spills caused by accidents, poor maintenance, and sabotage of the large-scale oil extraction infrastructure in the Delta. Environmental regulations are weak and rarely enforced, and there are no effectively protected areas in the Delta, whose forest and animal populations are considered under severe threat (World Wildlife Fund, 2016).

Large area classes



Small area classes



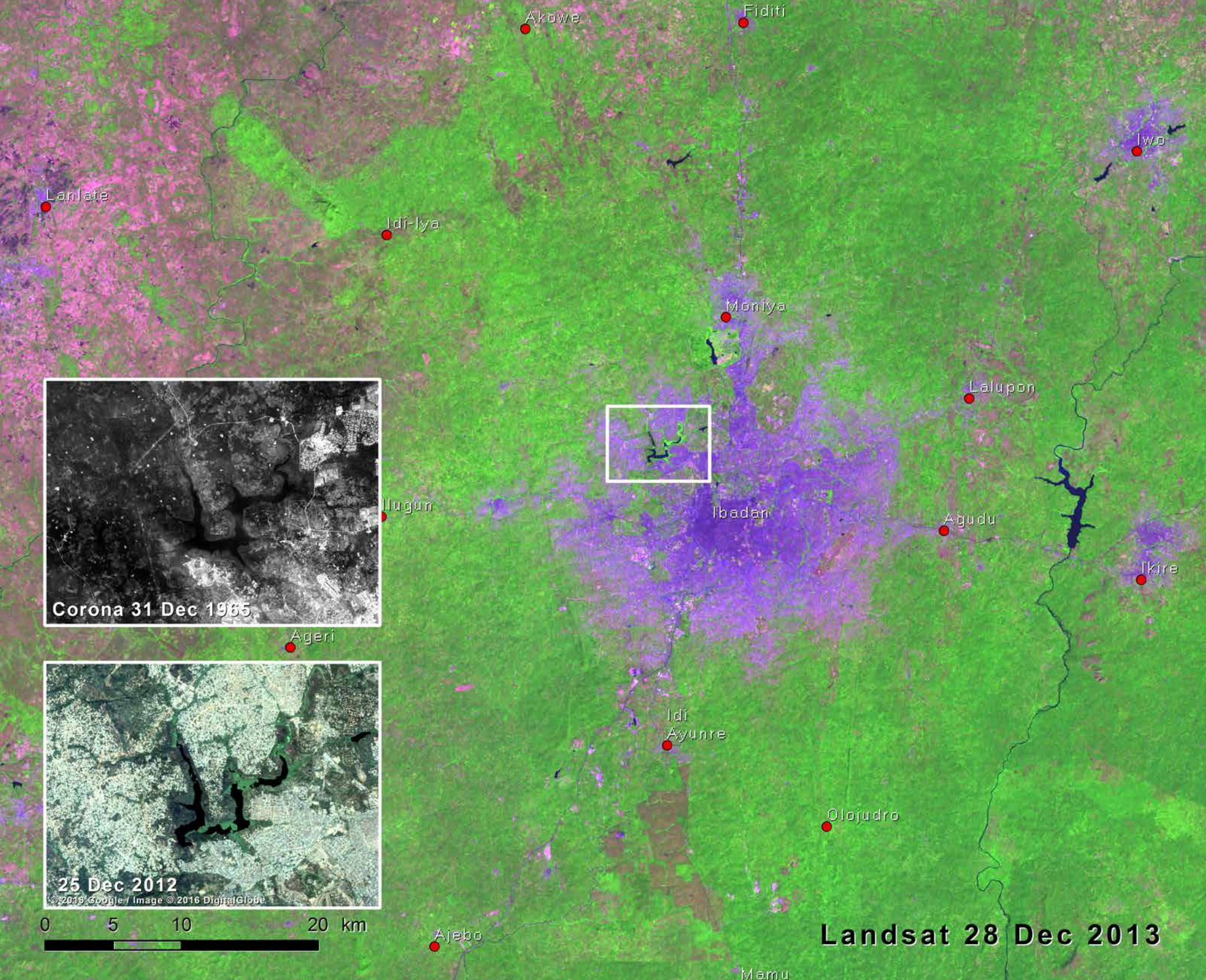


Urban sprawl of Ibadan into savanna and forest habitat

In pursuit of economic opportunity, many Nigerians have moved from rural to urban areas. As a result, the proportion of Nigerians living in cities has risen from 19 percent in 1975 to 46 percent in 2013, leading to a rapid physical expansion of urban areas (UN, 2015). The growth of the city of Ibadan is a good example of the urban sprawl seen in cities throughout Nigeria.

Ibadan was once a military stronghold of the Yoruba Empire, dating back to the 16th century. Ibadan's growth was spurred by a connection to the railroad in 1901, which cemented its role as a major trading center of agricultural goods produced in the surrounding region, such as cassava, cocoa, cotton, rubber, timber, and palm oil. Today, Ibadan is a vibrant commercial, industrial, and administrative center, which hosts chemical and electronic industries, motor vehicle assembly plants, and a number of other industries, including flour milling, leather working, and furniture making (Fourchard, 2003).

Until 1970, Ibadan was the largest city in sub-saharan Africa (Fourchard, 2003). Population figures are sparse but suggest a population of 847,000 in 1975 rising to about 2,790,000 in 2013 (UN, 2015). According to the land cover maps (see pages 166–167) the city's built-up area increased from 84 sq km in 1975 to 528 sq km in 2013. New development occurred particularly along the major road axes, such as the Ibadan-Lagos expressway to the south of the city and the Eleyele expressway to the northwest. By 2013, the cities of Moniya and Agudu were already parts of the Ibadan metropolis. If the present rate of expansion continues, surrounding towns such as Idi Ayunre



(to the south), Ikire (to the east), Fiditi (to the north), and Ilugun (to the west) will be linked to the built-up area of the sprawling metropolis. The rapid sprawl has eaten into forested areas, savanna, farmland, fallow lands, and river floodplains. Forests and wetlands have been degraded. In the Eleyele wetland — a modified natural riverine wetland in the northwest quarter of Ibadan — an estimated 66 percent of the wetland riparian forests were lost between 1984 and 2014 due to the urban expansion (see inset). Waste effluent discharge from the city also contributed to deterioration in water quality (Tijani, Olaleye and Olubanjo, 2012).

Like other cities in Nigeria and the developing world, Ibadan has been growing at a very rapid rate, but the provision of social services and basic infrastructure has not kept pace. Unmanaged urban growth and haphazard development of informal housing have resulted in a gradual deterioration of the environment and a decline in the quality of life.





Progressive expansion of agriculture in Niger State, Nigeria

The Middle Belt of Nigeria, which straddles the southern Sudanian and northern Guinean climatic zones, has historically been sparsely populated. In the 1970s, it was seen as the last land frontier and future bread basket of the nation. The area around the Zugurma Sector of the Kainji Lake National Park and the Dagida Forest Reserve exemplifies the significant land use transformation that the Middle Belt has gone through in the past 40 years.

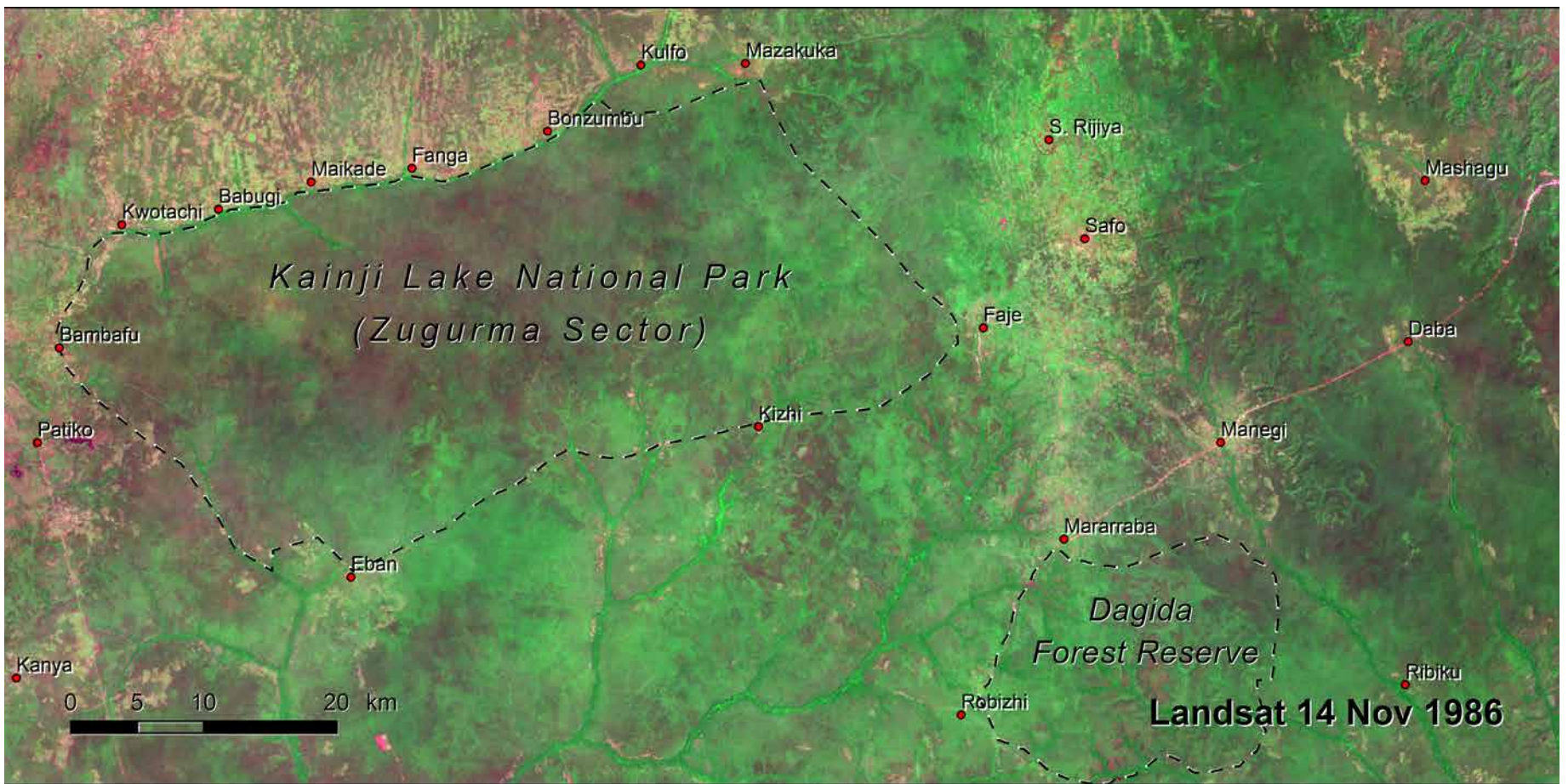
The three Landsat images from 1972, 1986 and 2015 show the dramatic transformation in the area surrounding these two protected areas. In 1972, the darker green of the mostly unbroken wooded savanna has only scattered plots of shifting cultivation (lighter green areas). By 1986 the area north of Zugurma Sector and surrounding some of the villages is being converted to farmland (light tan, light green and pink areas). By 2015 the transformation of the area to farmland is almost complete, with a few islands of wooded savanna inside the protected areas.

The rapid expansion of agriculture in this formerly semi-natural area can be understood in the context of a changing Nigerian political economy. The oil boom of the 1970s and enactment of the Land Use Act of 1978 sparked a rush for land acquisition of formerly communal lands by wealthy private owners. The food crisis of the 1980s and restructuring of the economy along the lines of the International Monetary Fund (IMF) renewed the emphasis on food production. In 1984, the government of Nigeria banned the import of agricultural raw materials by the local bottling, flour and confectionary industries, which pushed these industries to acquire land at a large-scale to grow wheat and other grain crops.



A Kob in Kainji Lake National Park

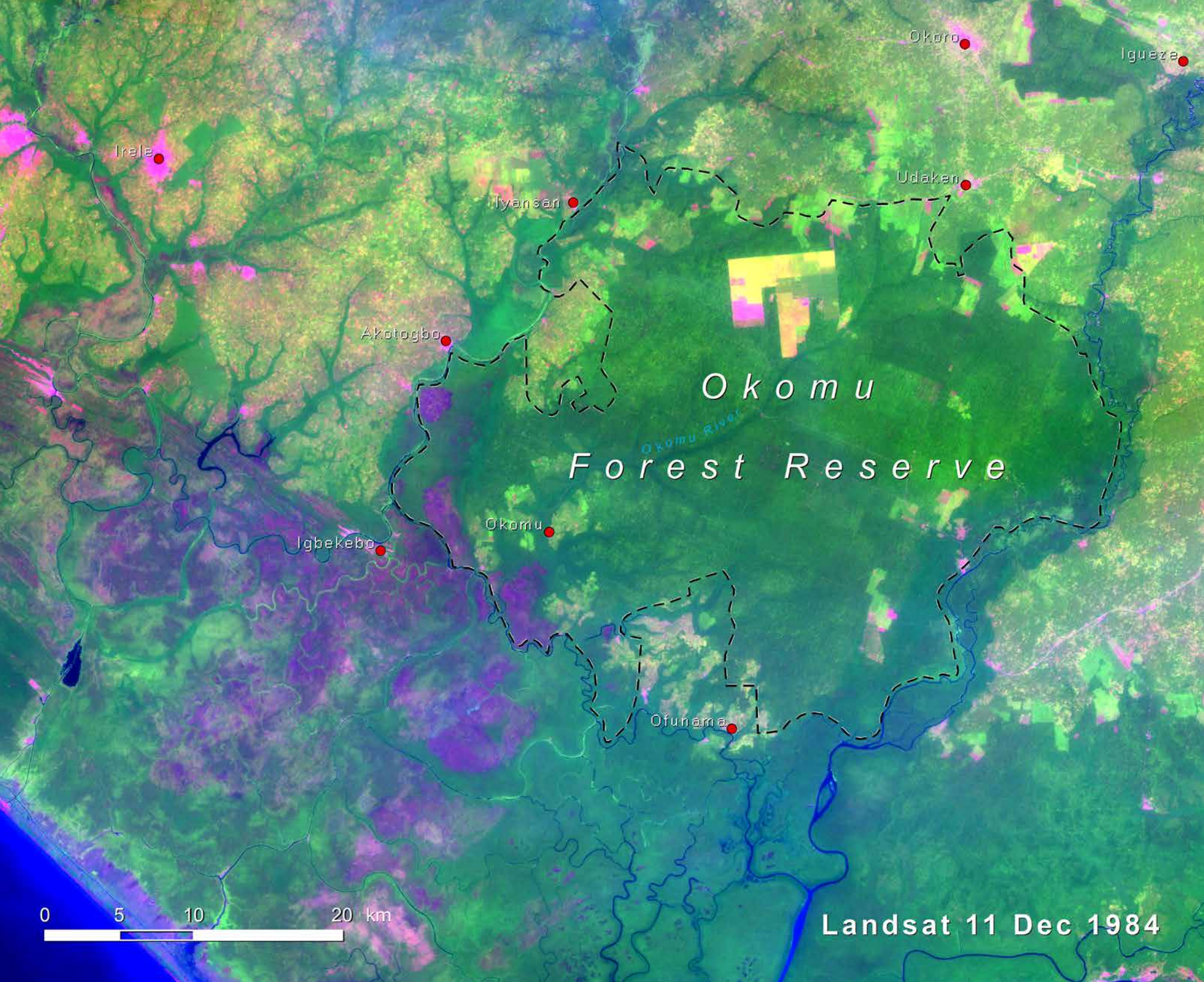
JEREMY WEATE / FLICKR / CC BY 2.0



The land acquisitions by large owners engendered land use competition and conflicts between (1) a small land-owning class and a large class of landless peasants, (2) peasant farmers and migratory pastoralists who have seen their main source of dry season pasture shrink, and (3) peasant farmers, migratory pastoralists and the wildlife and forestry conservation authorities who are faced with increasing land use pressure around the parks as well as grazing and cropland encroachment into the parks.

If left unaddressed, the lack of an integrated policy that regulates access of different user groups to land resources will continue to threaten wildlife and biodiversity conservation within the game reserves in a State which currently records the highest population growth in Nigeria at 3.4 percent per year.



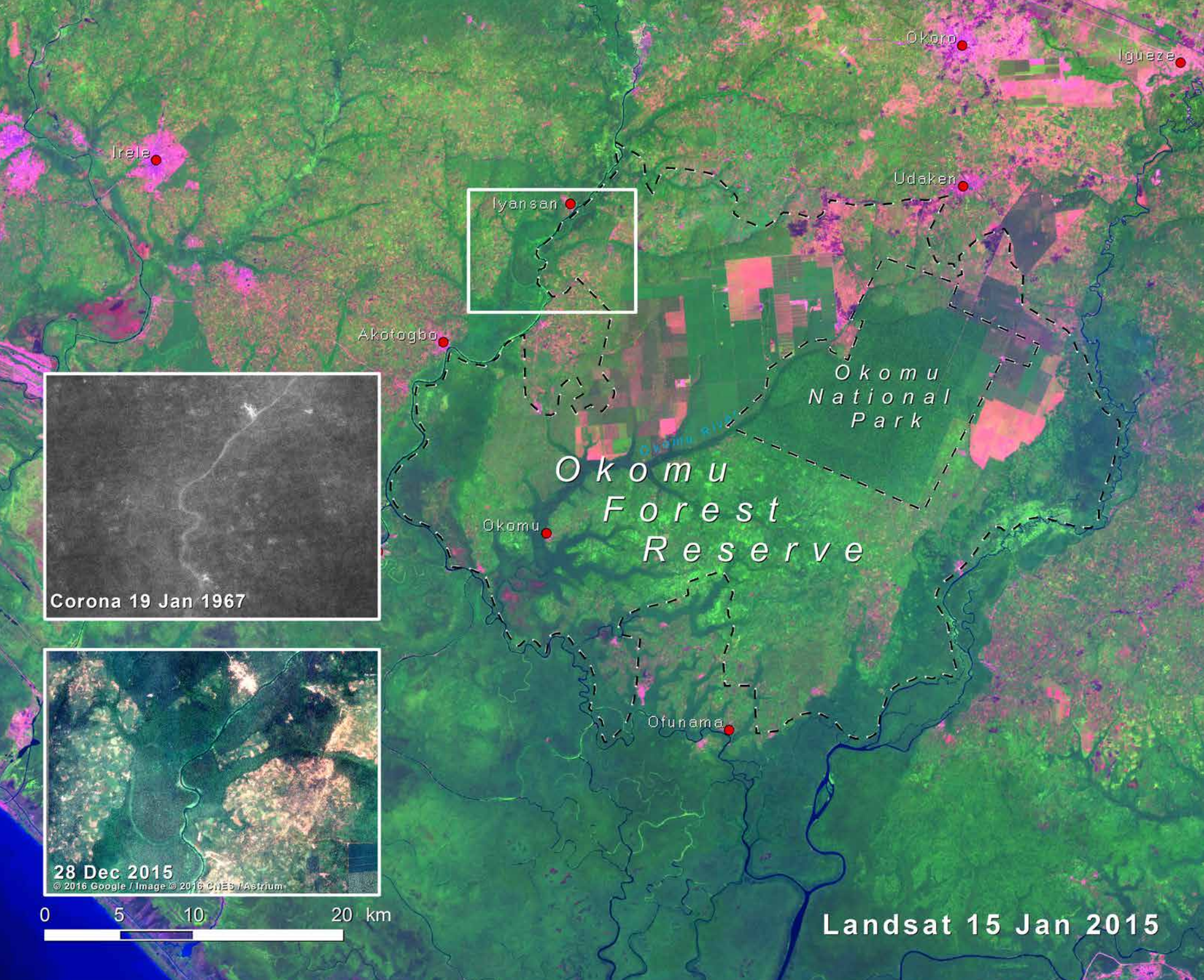


Tropical forest threatened by human activities in the Okomu Forest Reserve

Closed-canopy tropical moist forest once covered large parts of southern Nigeria, where some of the earliest ecological studies of tropical rain forest were carried out in the 1930s (Ajayi, 1998). Since that time, excessive logging and conversion to plantations and farmland have caused major losses of natural forest. Although no longer a pristine wilderness, the Okomu Forest Reserve still supports a small population of forest elephants and several species of threatened primates, including a viable population of the rare white-throated guenon, a monkey endemic to southwestern Nigeria (Oates, 1995).

The Okomu Forest Reserve was originally established by the British colonial government in 1912. It comprised 777 sq km, to which another 411 sq km were added to the north and east in 1935. From the beginning, it was planned that the reserve would be managed as a source of timber, and it has been exploited for its rich stands of mahogany. Since the 1940s, systematic rotational logging as well as “taungya” farming have been practiced in the reserve. In this forest management system, an area of forest is allocated to local farmers to be cleared and farmed, and subsequently reforested with useful tree species.

The Corona satellite photograph (see inset) from 1967 shows a still-intact forest canopy on both sides of the river, which delimits the northwestern boundary of the reserve. It is likely that the whole Okomu Forest Reserve



was blanketed with a continuous dense forest at that time. By 1984, large parts of the Okomu Forest Reserve had been converted to plantations of oil palm and rubber trees — partly as official concessions, partly illegally or only lightly controlled. A network of roads and settlements, along with farmland encroachment into the reserve, can be seen as well. Each year, a larger area of the reserve was assigned to taungya farmland. Although the taungya scheme had been envisaged to serve the local farming population, it soon attracted immigrant farmers from more densely populated areas of the country, leading to an increase in the overall population pressure on the reserve.

In 1985, a wildlife sanctuary of 114 sq km was carved out of the most intact area of the forest reserve. Poaching was brought under control in the sanctuary, which is a habitat to several endangered species including red-capped mangabeys, white-throated monkeys, chimpanzees, leopards, and the African forest elephant. In 1999, the Okomu Wildlife Sanctuary was designated a national park to increase its protection from the immense

pressure from high rates of exploitation and human settlement expansion on its periphery (Onojeghuo and Onojeghuo, 2015). Okomu National Park remains the only fully protected part of the reserve and stands out against its surroundings in the 2015 Landsat image. The visible impact of rapid plantation expansion can be seen in the northern half of the reserve, which is dominated by large-scale rubber and oil palm plantations, whereas farmland has colonized the southern half.

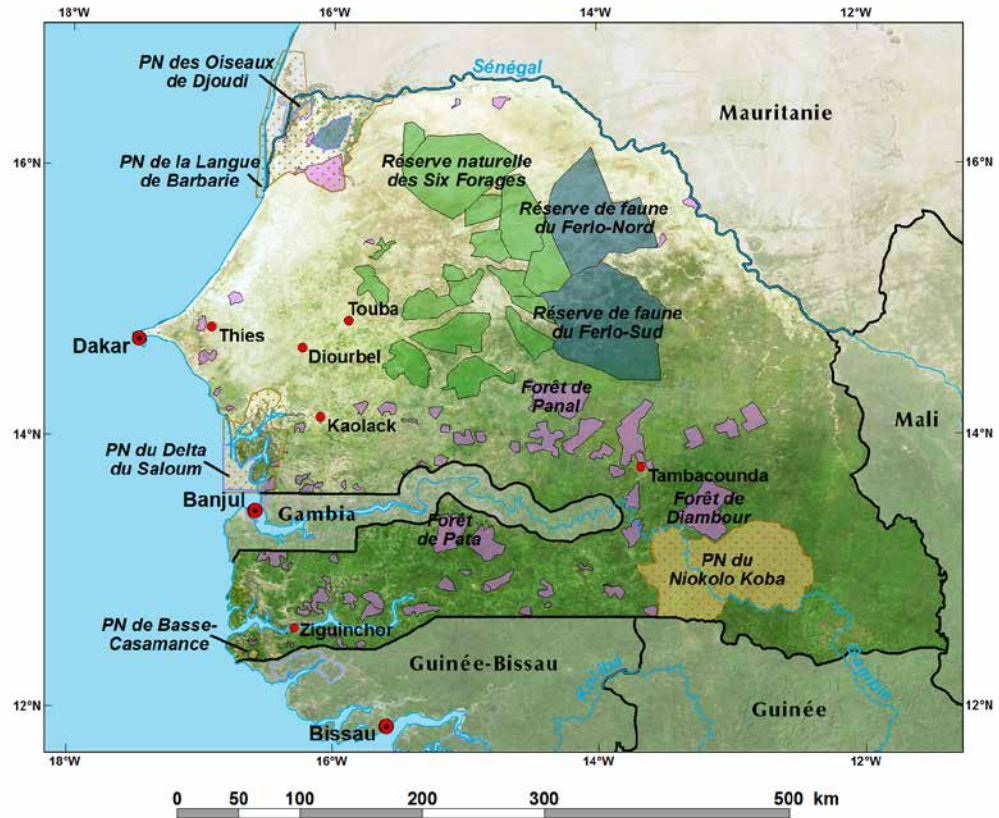
Efforts have been made to provide sustainable livelihood opportunities to local communities, including controlled logging and hunting, reforestation, livestock rearing, and agricultural practices compatible with forest conservation. However, Okomu's status as a national park has not fully prevented the effects of deforestation within and around the reserve. Multipurpose forest management has been praised by some, but others have criticized it for neglecting protection efforts, arguing that integrating a development component has put Okomu at risk of ecosystem degradation.



Republic of Senegal

Total Surface Area: 196,722 km²
Estimated Population in 2013: 14,421,000

Senegal is the westernmost point on the African mainland, and its capital, Dakar, has historically served as the gateway to West Africa. Senegal's economy is based primarily on agriculture, particularly the production of peanuts and cotton, but this sector has been hurt by drought and low commodity prices. A rapidly growing population is placing enormous stress on Senegal's limited land resources, agricultural production, and forest resources. Over 80 percent of the population lives in the western half of the country; nearly 70 percent are farmers, but the urban population is steadily increasing. Senegal has a wide range of bioclimatic regions. The semiarid Sahel in the north is home to pastoral societies. The Sudanian region in the central and southern part of the country has a mix of settled farming communities and wooded savannas. In the sub-Guinean region of the southwest, rice-producing peoples live among forests and mangrove-fringed estuaries. Many of the woodlands in the central and southern regions have been degraded by charcoal production and overharvesting of timber for export. The large Niokolo-Koba National Park in the southeast still preserves diverse landscapes, flora and fauna once found across much of West Africa.



- Réserve de Biosphère / Biosphere Reserve
- Site Ramsar / Ramsar Site
- Parc National / National Park
- Réserve Naturelle / Nature Reserve
- Réserve de Faune / Faunal Reserve
- Forêt Classée / Forest Reserve
- Capitale Nationale / National Capital
- Autre Ville / Other City

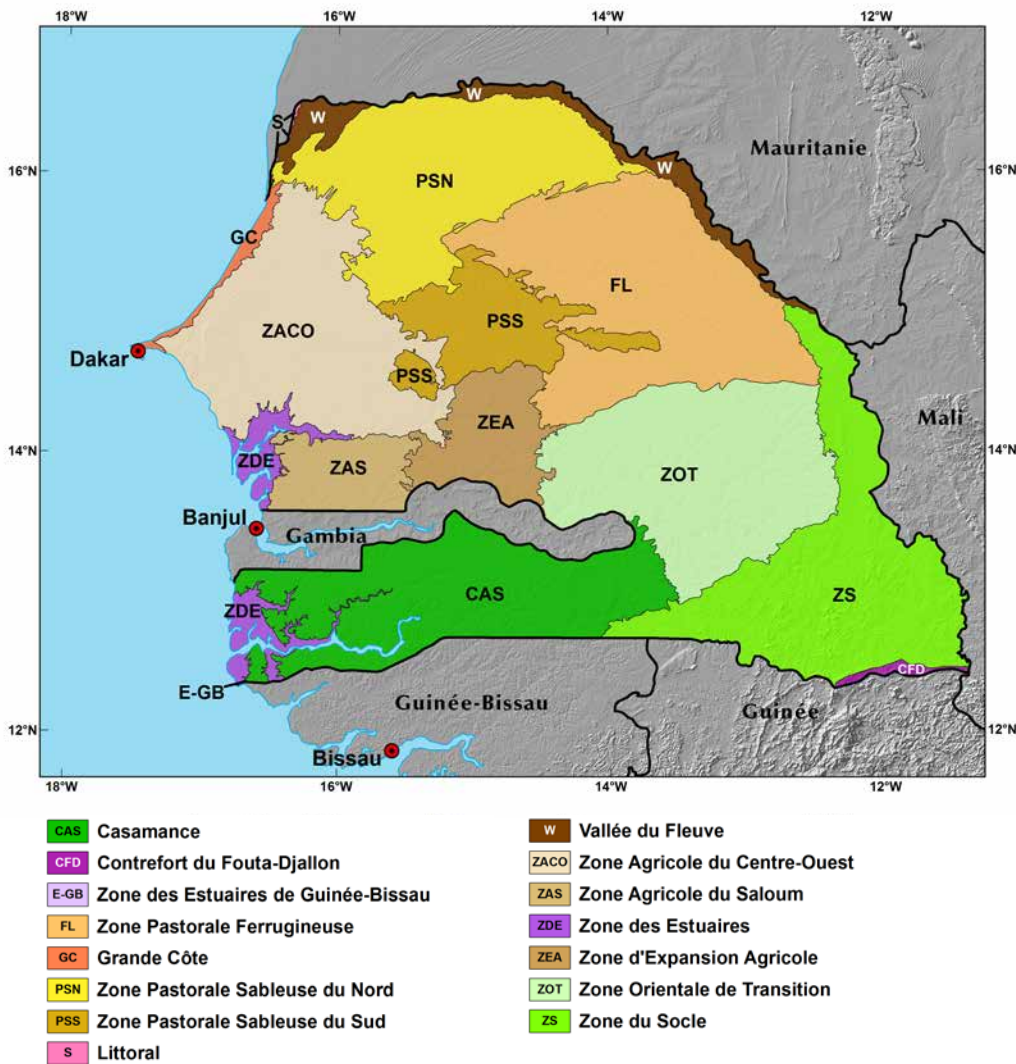
Environmental Highlights:

- Deforestation
- Desertification
- Large number of protected areas
- Extensive use of agricultural parkland



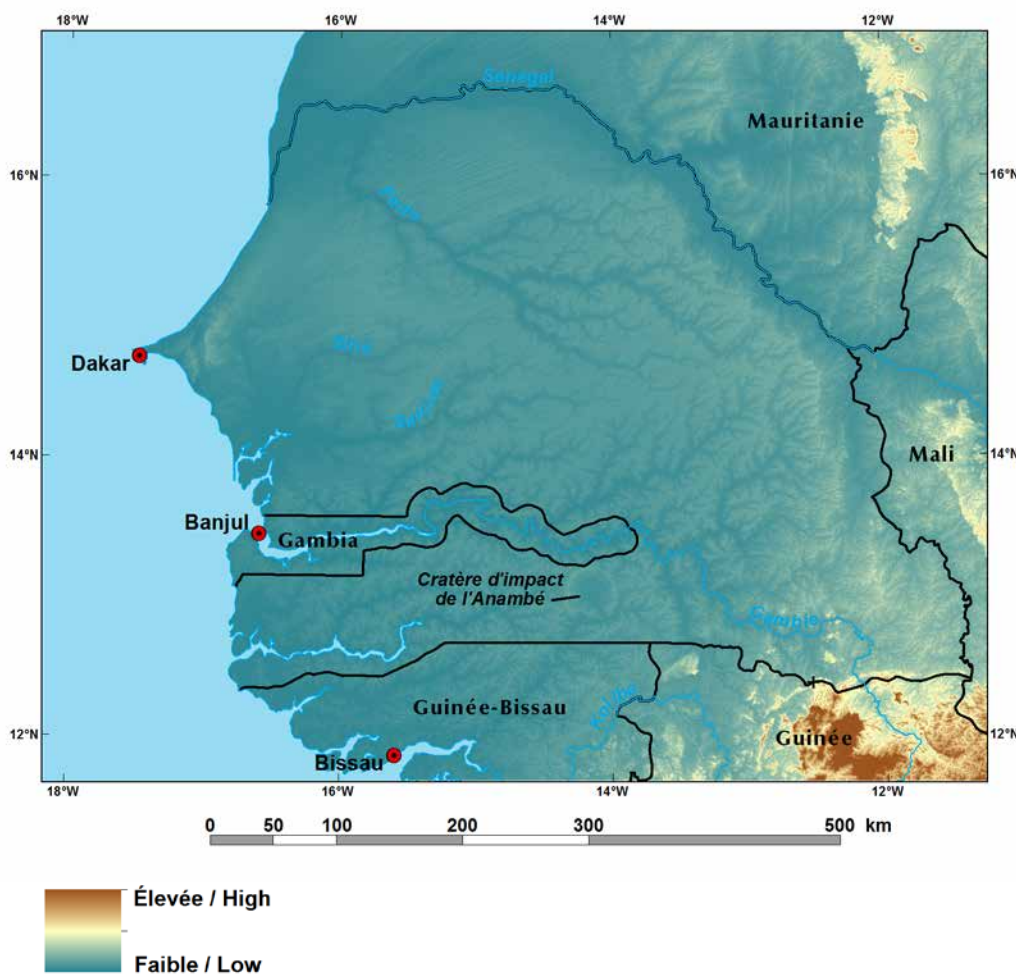
Wet season landscape along the Thiès escarpment

Ecoregions



Senegal is fairly flat, and is drained by several large rivers, including the Gambia and the Senegal. Its geological structure is a sedimentary basin of sandstones covered by more recent wind and water deposited sediments, and intermittent plateaus capped with lateritic hard pan. The ecoregion map depicts Senegal's landscape diversity. The pastoral semiarid regions in the north are typical of the Sahel climatic zone. The wetter southern areas are part of the Sudanian climatic zone. Other regions, such as the Zone Agricole du Centre-Ouest (ZACO – West-Central Agricultural Zone), also known as the Peanut Basin, or the Zone Agricole du Saloum (ZAS – Saloum Agricultural Zone), are densely settled areas characterized by high rural population density which has completely transformed the original wooded savannas. The ecoregions in the east and southwest (ZOT – Zone Orientale de Transition and ZS – Zone du Socle), dominated by lateritic plateaus, have been spared from much of the agricultural expansion in the west, but are being subjected to extensive exploitation of their forest resources. In the south, the Casamance Region is well known for its woodlands, gallery forests, palm-fringed wetlands and valleys, and rice paddies.

Shaded Relief



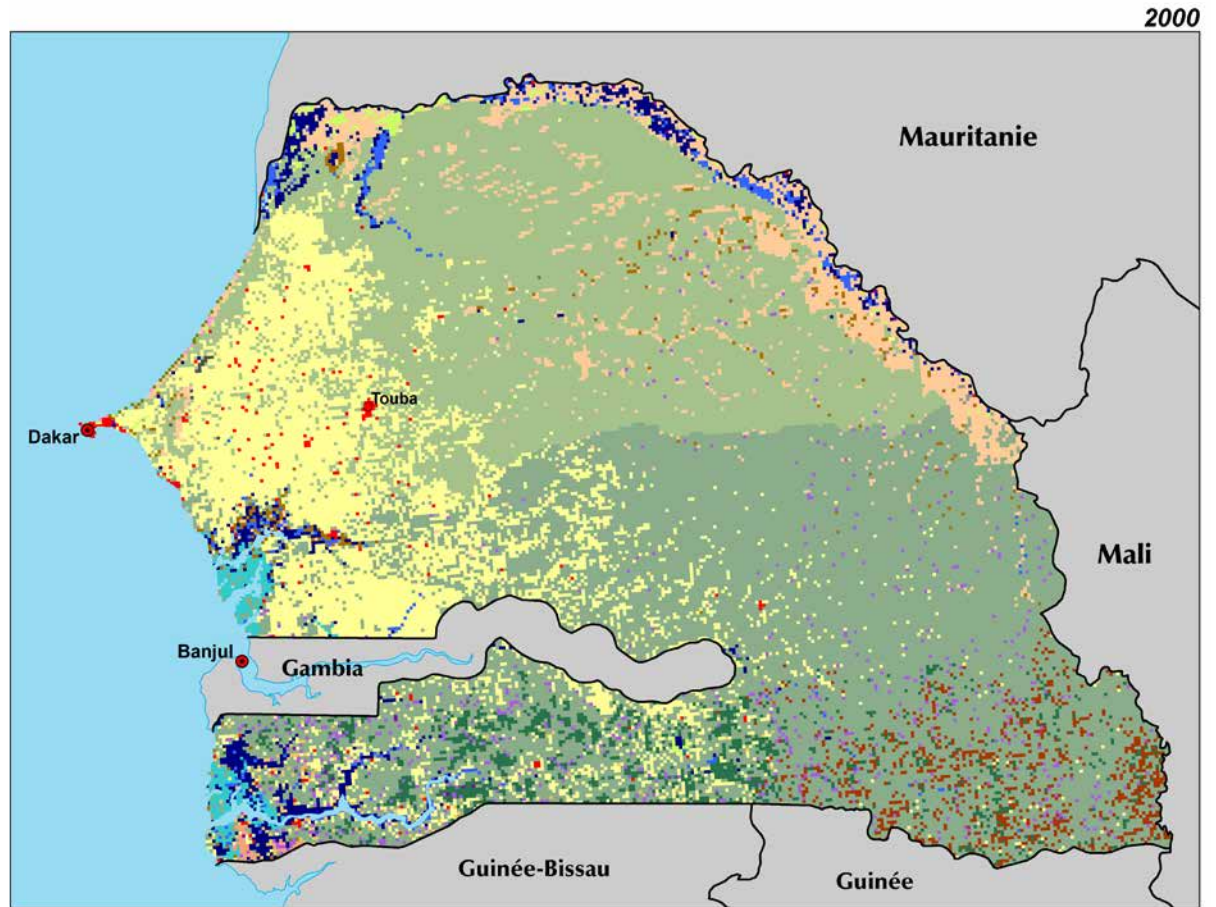
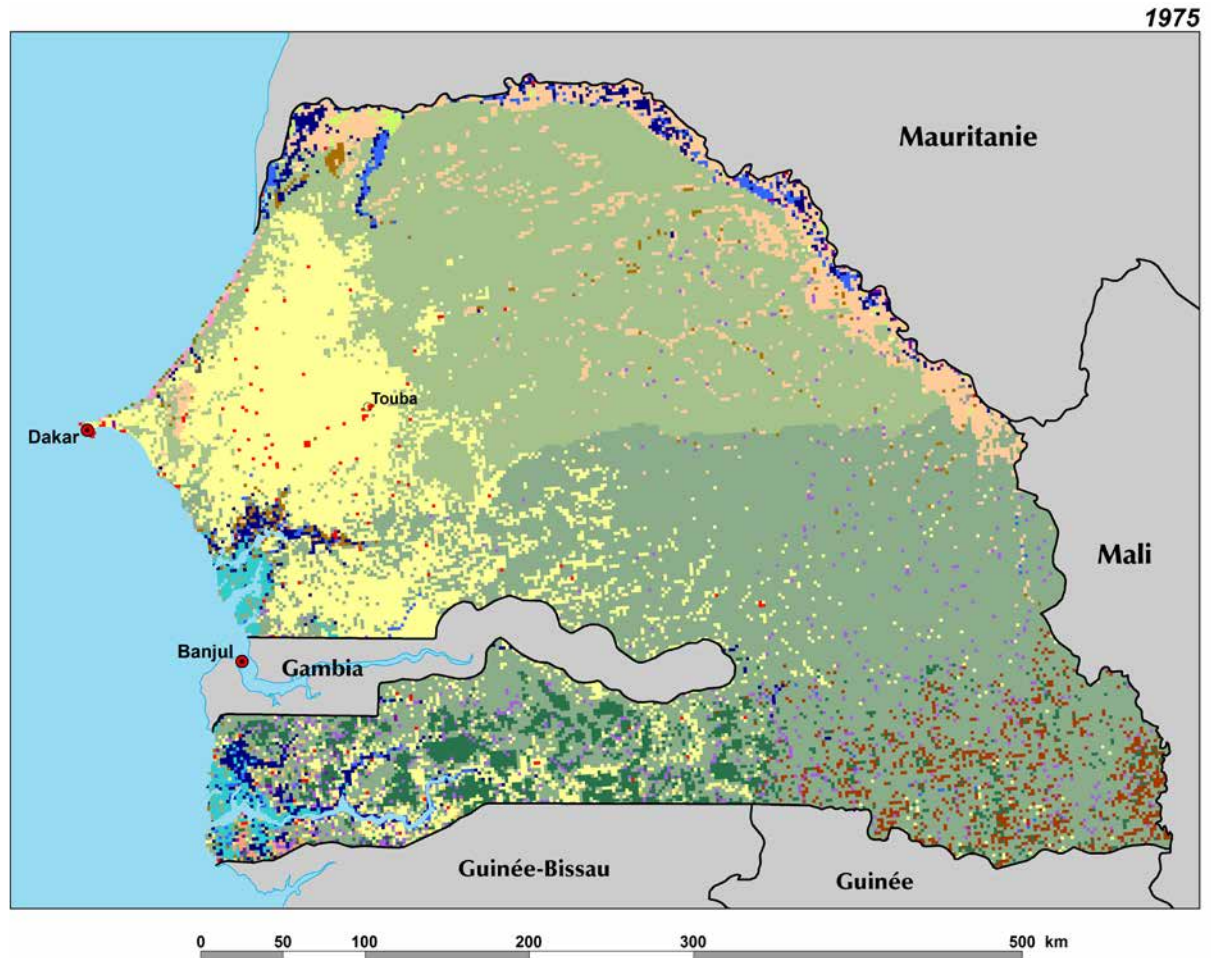
Land Use, Land Cover and Trends

The most significant change in Senegal is the evolving extent of cultivated areas. The overall expansion of cropland is relatively small, from 32,600 sq km in 1975 to 32,900 sq km in 2000 and 41,000 sq km in 2013, or a 26 percent increase between 1975 and 2013. However, the recent pattern and extent of cropland is profoundly modifying Senegal's landscapes. Agricultural expansion has resulted in fragmentation of the savannas and woodlands, replacing unbroken expanses of natural habitat with a mosaic of tilled fields and natural landscapes, eroding the quality of remaining natural ecosystems. Furthermore, the speed of agricultural expansion has increased between 2000 and 2013 compared to the previous 25 years. While the average annual increase of cultivated areas was modest between 1975 and 2000 (about 10 sq km per year), it rose dramatically between 2000 and 2013, to 630 sq km on average per year. This trend, however, masks much of the internal variation within the agricultural class.

In contrast to other regions of Senegal, the Peanut Basin experienced abandonment of agricultural lands in the 1980s. In the Peanut Basin, land devoted to rainfed crops remained fairly stable between 1975 and 2000. While agricultural expansion continued to make inroads in the east, in the west cropland was being abandoned, reverting to grasslands that were mapped as savannas in 2013. This conversion of cropland back to grassland in the Peanut Basin hides the actual magnitude of rapid agricultural land increases in central Senegal. The very low price of peanuts forced many farmers to abandon their fields and turn to other economic activities, which often meant migrating to Dakar, Touba, or other cities.

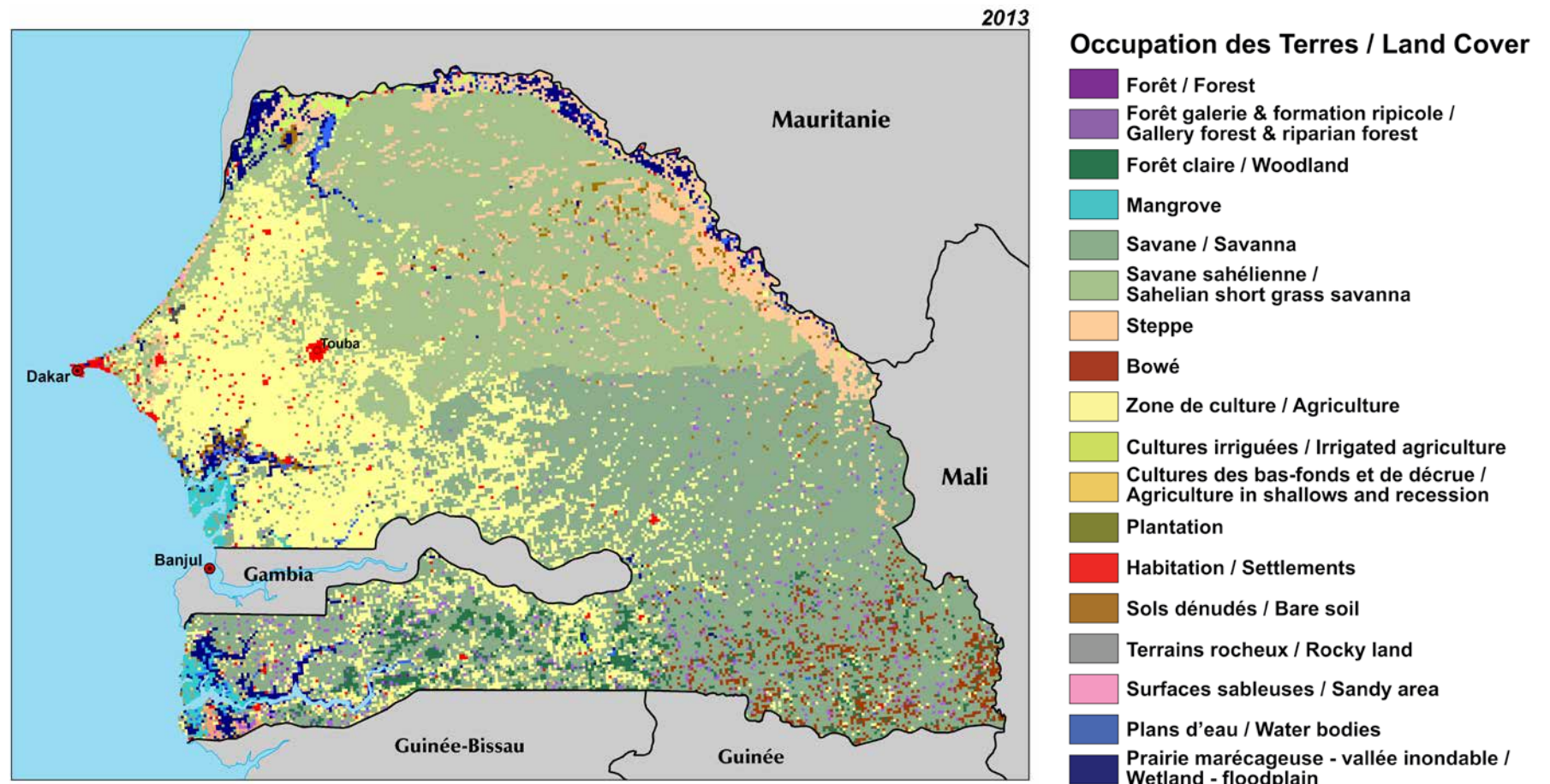
As in central Senegal, most of the south experienced major gains in agricultural area at the expense of savannas and woodlands, especially in the Casamance. As a result of agricultural expansion, Sahelian and Sudanian savannas have decreased by 8,200 sq km, or a 6.3 percent reduction of their 1975 area. Woodlands decreased by 42 percent, or 3,160 sq km. Gallery forests, which are found along much of Senegal's drainage network and known for their biodiversity, registered a decrease of 19 percent (or 570 sq km). However, most of the reduction of gallery forests appears to have occurred before 1975 (Tappan and others, 2004).

Wetlands and floodplains increased by 17 percent, due mainly to the recovery of wetlands from the severe drought of the 1970s, which dried out many wetlands. Since the end of the 1990s, rainfall



● Capitale Nationale / National Capital



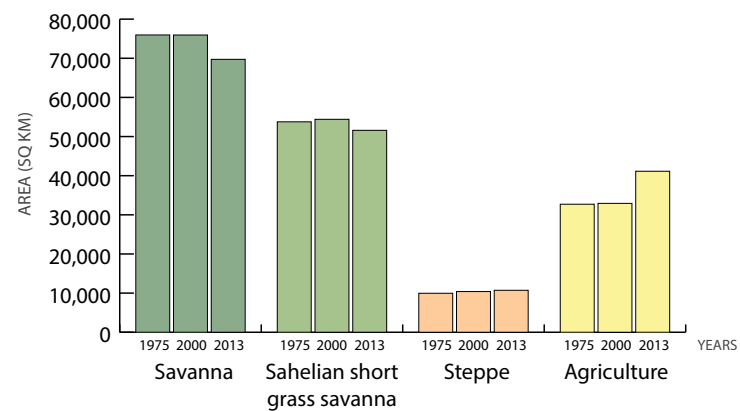


continues to fluctuate annually, but it has returned to levels more consistent with the longer term norm.

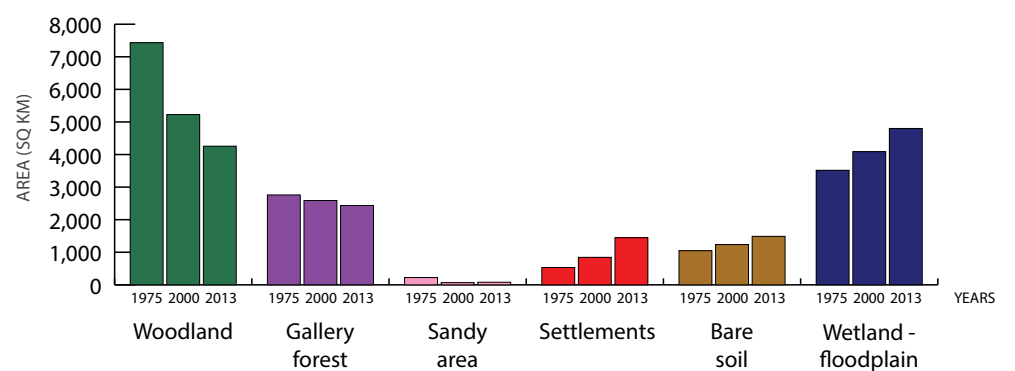
In the north, there are many local instances of savannas taking on steppe-like characteristics as years of drought, intensive grazing, and loss of topsoil combine to degrade the savanna structure, vegetation cover, and productivity. The maps reflect this process, with steppes replacing local areas of savanna in agro-pastoral regions (a 760 sq km gain between 1975 and 2013). Similarly, in more extreme cases of drought-induced loss of vegetation cover, overgrazing, and soil erosion, savannas or steppes become bare and unproductive, even in the rainy season. These areas are mapped as bare soils. The area of bare soil increased significantly, by 42 percent between 1975 and 2013, especially in the Pastoral Ferruginous Zone. This trend was confirmed by field studies, which also documented the expansion of the badlands along fossil valleys where severe erosion has removed the topsoil. On a positive note, the decrease of sandy surfaces (-144 sq km between 1975 and 2013) can be explained by the success of coastal dune reforestation and stabilization efforts.

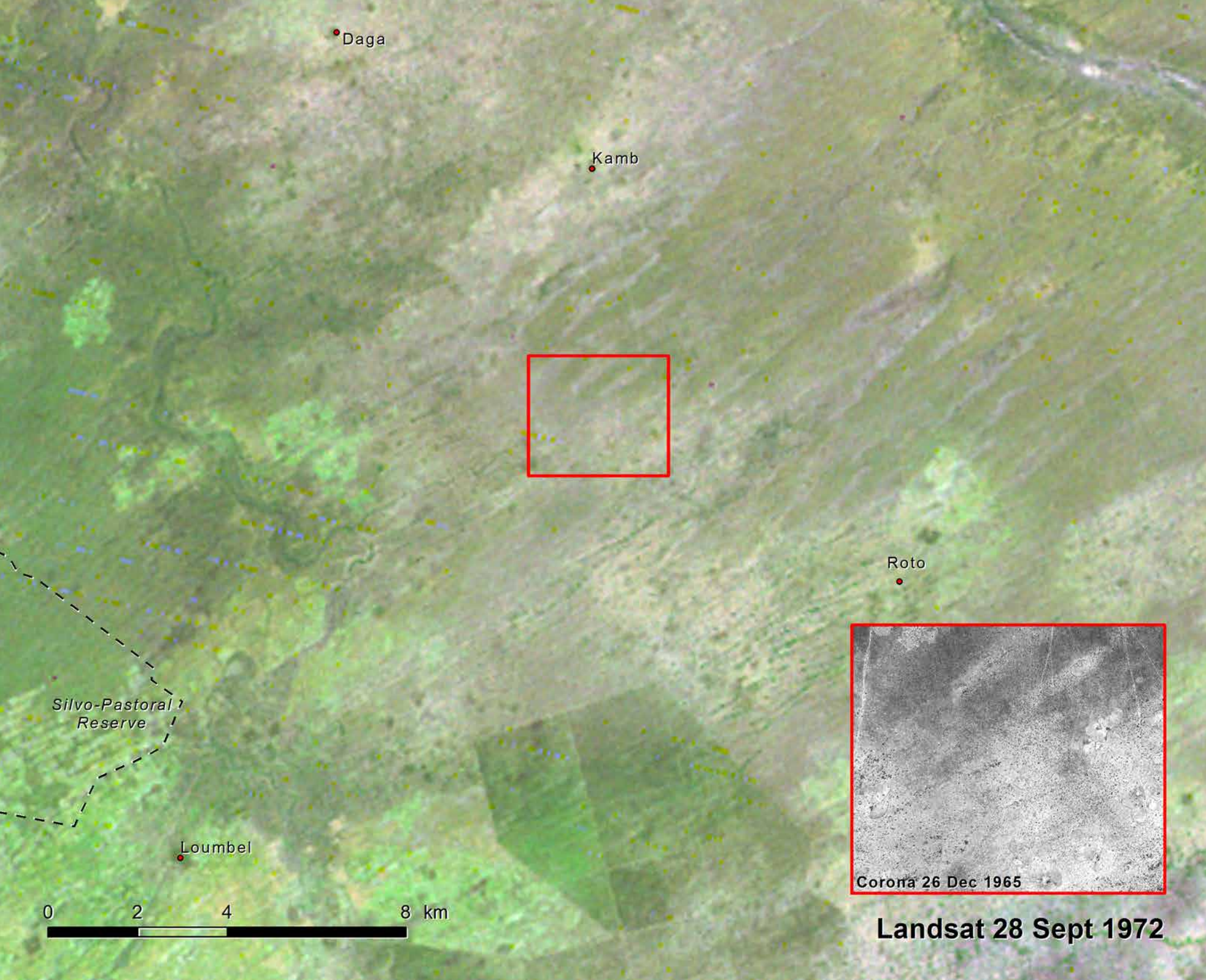
Finally, the large expansion of settlements — villages, towns and cities — illustrates the rapid population increase in Senegal, particularly in the big cities of Dakar and Touba. While the population tripled between 1975 and 2013, the area occupied by towns and cities grew from 530 sq km in 1975 to 850 sq km in 2000 and to 1,450 sq km in 2013, or a 172 percent increase over 38 years.

Large area classes



Small area classes

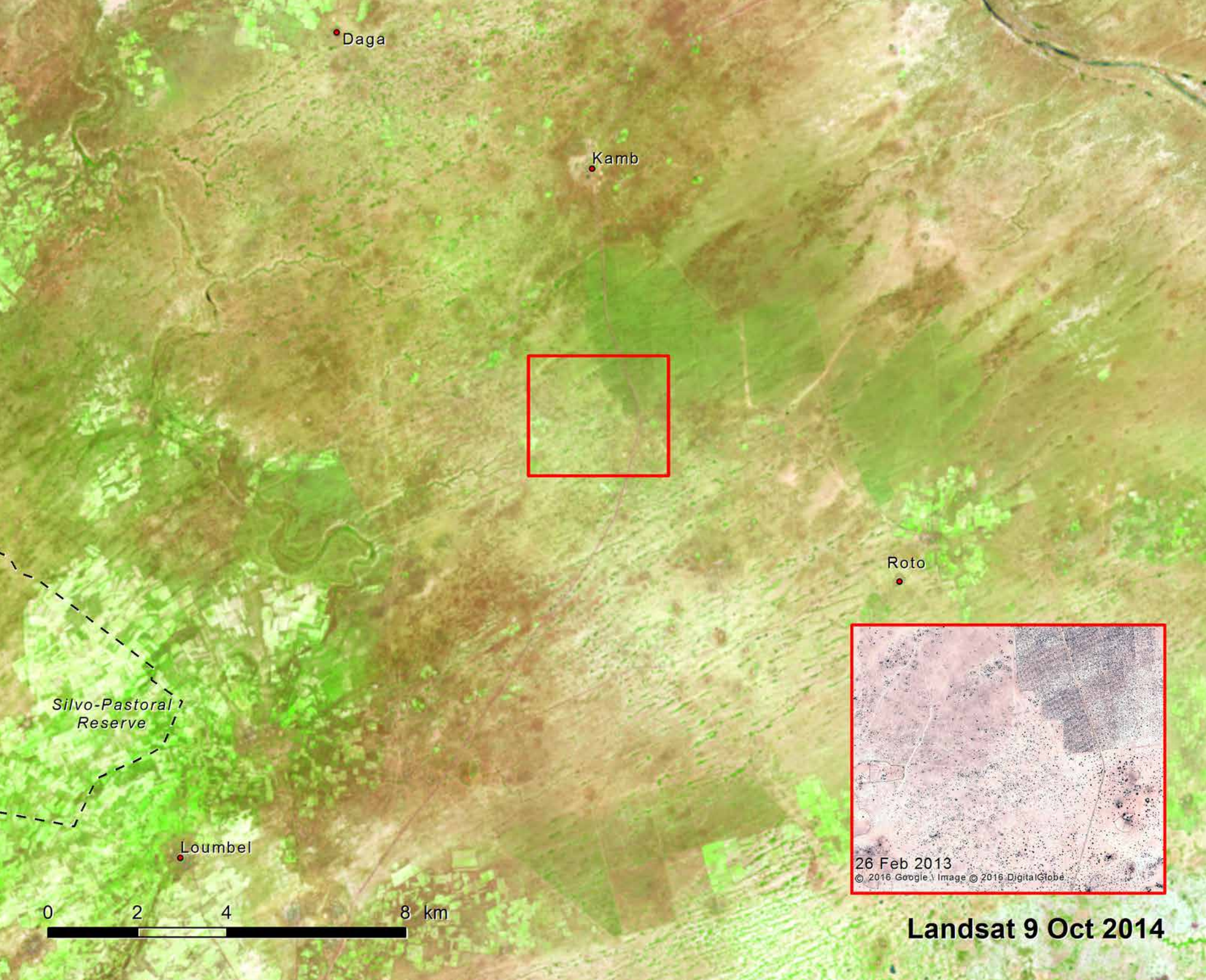




The re-greening of degraded land in Kamb in Senegal's northern pastoral region

Located in the Northern Pastoral Sandy Region of the Ferlo Region in Senegal, the Kamb site covered about 25 sq km. The Ferlo's climate is similar to much of the Sahel and characterized by two main seasons: a dry season that lasts nine months from October to June, and a rainy season of three months. Total annual rainfall is both low and highly variable, with an average of 422.6 mm per year from 1951–2004 (Ndiaye and others, 2014).

Before the droughts of the 1970s and 1980s, this sylvo-pastoral area used to be covered with a relatively dense wooded savanna. Most local inhabitants confirmed this and attributed the loss of woody vegetation not only to overuse by humans but also to droughts, lack of rain, and unfavorable soils (Tappan and others, 2004). Once vegetation is lost, soils become susceptible to erosion. The sandy soil loses its structure and becomes more mobile, prone to wind erosion. The 1972 satellite image confirms the loss of vegetation and the increase of degraded barren land subject to erosion in the Kamb area, shown in white patches on the image. One of the early fenced plantations can be seen 15 km south of Kamb to restore some degraded land.

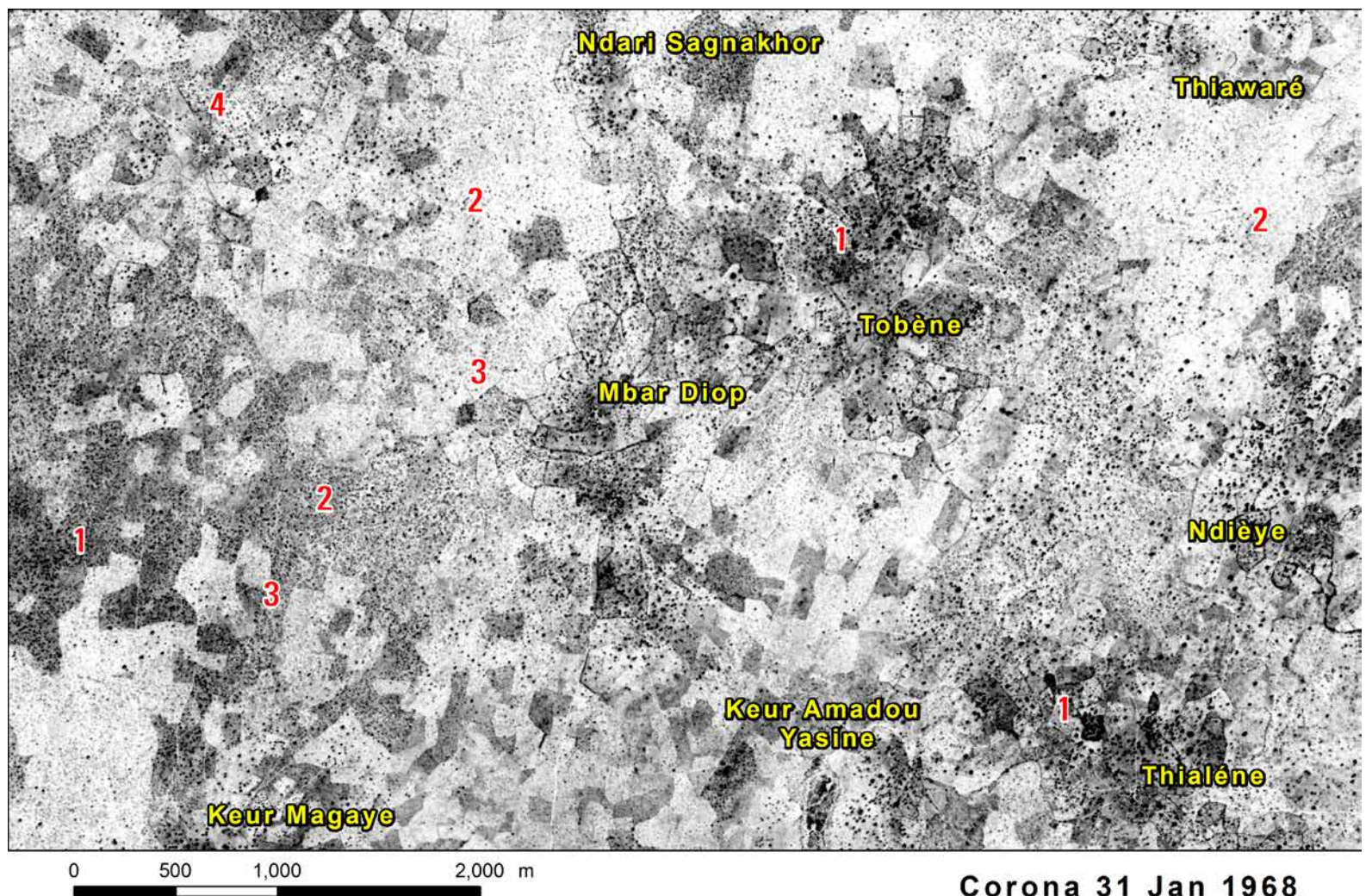


Recent high-resolution imagery shows significant re-greening south of Kamb. Supported by several afforestation projects, thousands of *Acacia senegal* (gum arabic tree) have been planted in large fenced areas, which in some cases are partly used for harvesting by the responsible village. Herders are allowed to graze livestock at the end of the dry season for a fee, which is used to maintain the protected area (Brandt, 2015). Even though the 2013 image shows a positive impact on the land from the re-greening resulting from tree planting, it does not translate directly into a positive picture of ecological recovery. The planted trees create a large monoculture, which lacks diversity. Fauna and flora biodiversity is much lower than it was before the degradation of the wooded savanna, and the population still speak of soil erosion and a lower water table.



SUZANNE COTILLON / SGT

Plantation of *Acacia senegal*



Corona 31 Jan 1968



Agroforestry with increasing field tree densities in the community of Mbar Diop

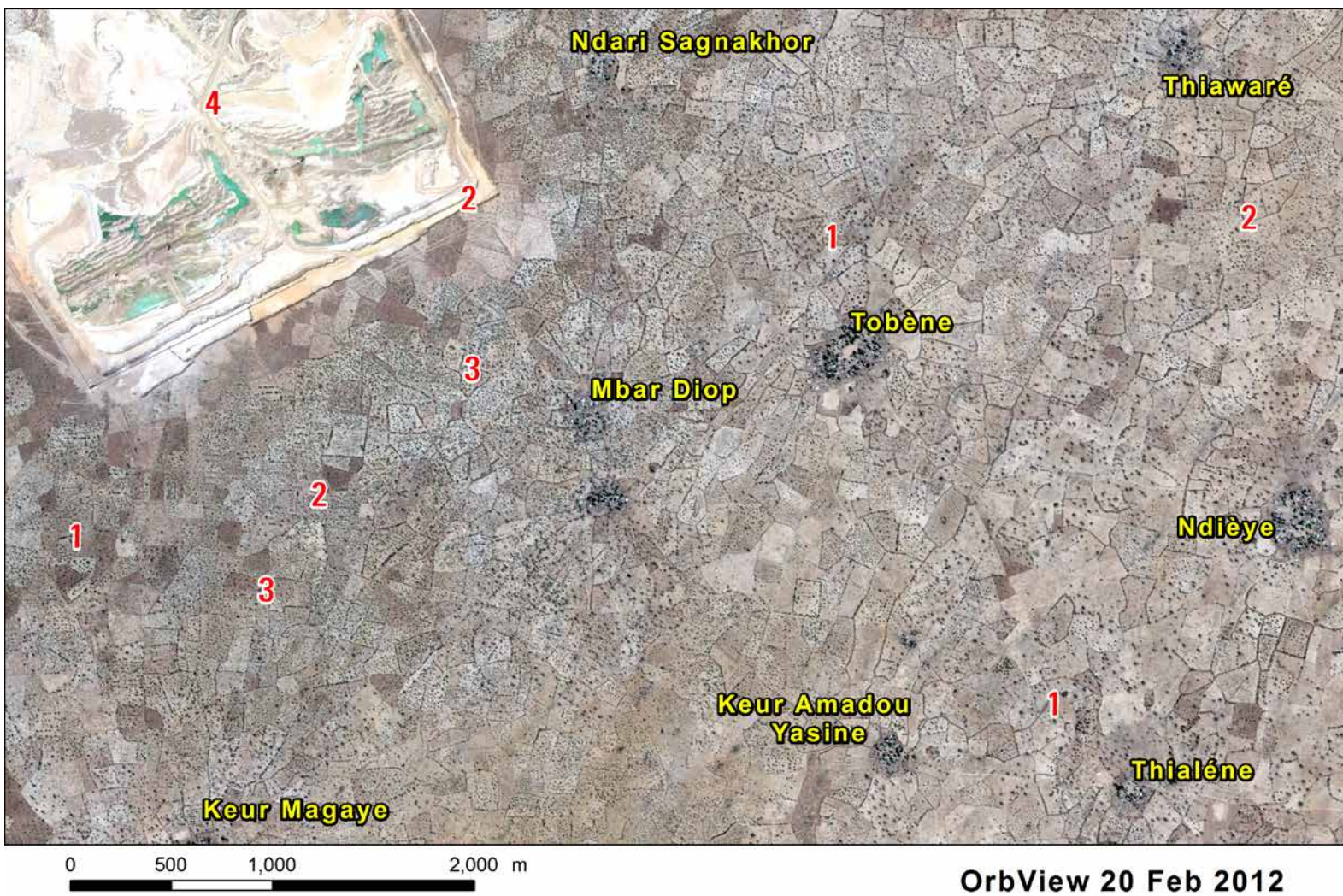
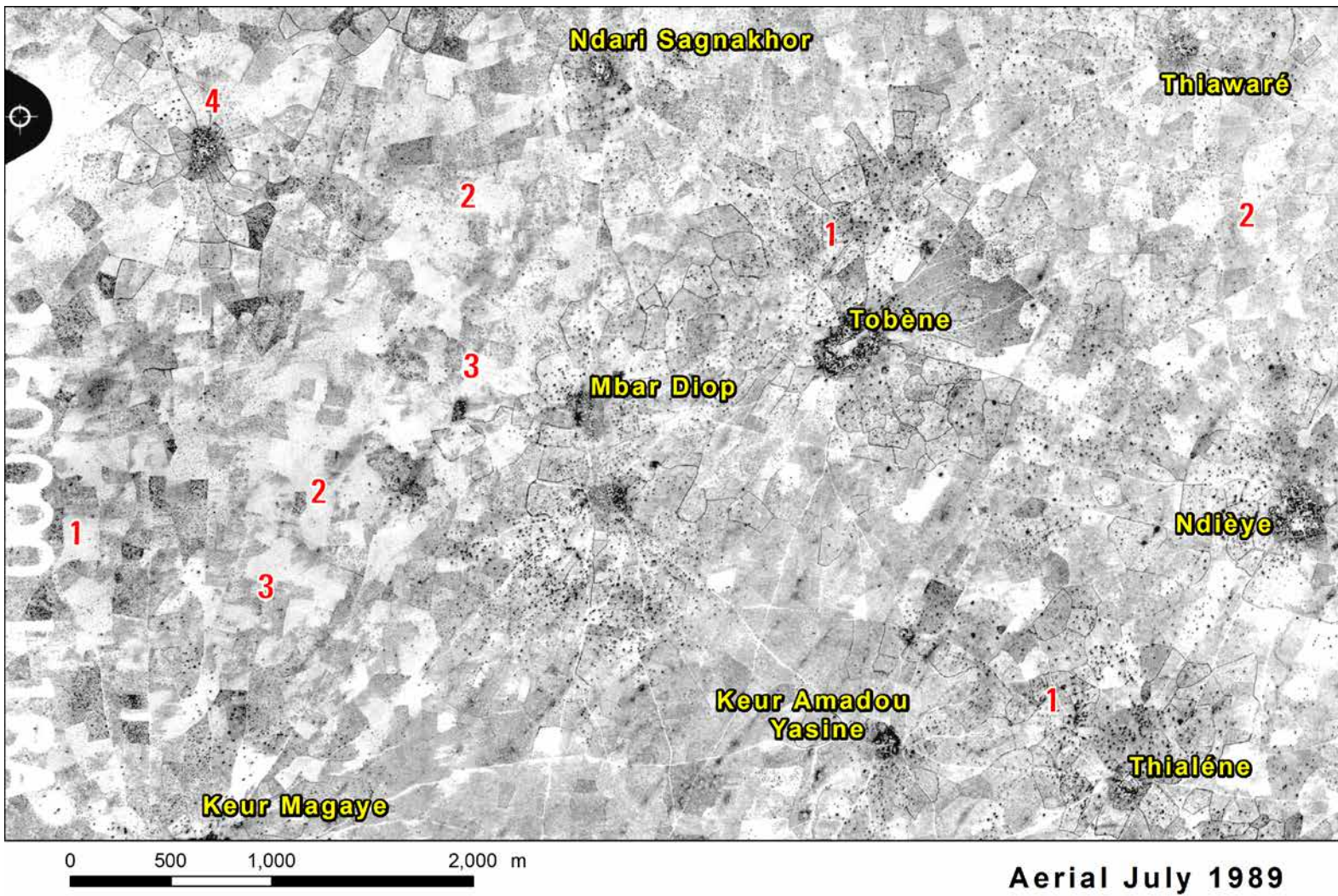
The Peanut Basin of west-central Senegal is an agricultural region that has been under intense cultivation since the 19th century. The last remainders of the original woody savannas in this region were cleared in the early 1900s, leaving in its place an agricultural parkland dominated by *Faidherbia albida*. Mechanization of the peanut production required farmland to be cleared of trees, which resulted in dwindling tree densities in (parts of) the parkland. The reduced tree cover combined with meteorological droughts brought about soil erosion, dust storms, and decreasing crop yields (Hirai, 2005).

The community of Mbar Diop, in the coastal part of the old Peanut Basin, has managed to turn this negative trend around. The *Projet de Reboisement Villageois dans le Nord-Est du Bassin Arachidier* (PREVINOBA – Village Afforestation Project of the Northwest Peanut Basin) began working in the area in 1987, promoting agroforestry activities with awareness campaigns on the importance of tree cover for sustainable farming. The tenure situation — trees belong to the farmer who plants them — was favorable in that it encouraged individual investments in afforestation. As a result, since the intervention of PREVINOBA, many orchards have sprung up, and the tree densities increased visibly. A series of high-resolution images illustrates the land cover dynamics over time. A Corona space

photograph from 1968 (see above image) shows remnants of relatively dense tree and shrub cover among the cultivated area (1). By 1989, the region had undergone a series of drought years, which, combined with increasing population pressure and the prevailing agricultural strategy of totally clearing field trees for the ease of mechanized agriculture, resulted in a noticeable decimation of the tree cover (2) (see top adjacent image). The OrbView satellite image from 2012 (see bottom adjacent image) shows the recovery of field trees, notably in the PREVINOBA intervention area around Mbar Diop (3). In addition to field trees, live hedges have contributed to the overall woody cover and act as windbreaks. Orchards increased from 27 percent of the cultivated area in 1989 to 58 percent in 2012. In the highest density orchards, up to 140 trees per hectare can be counted.

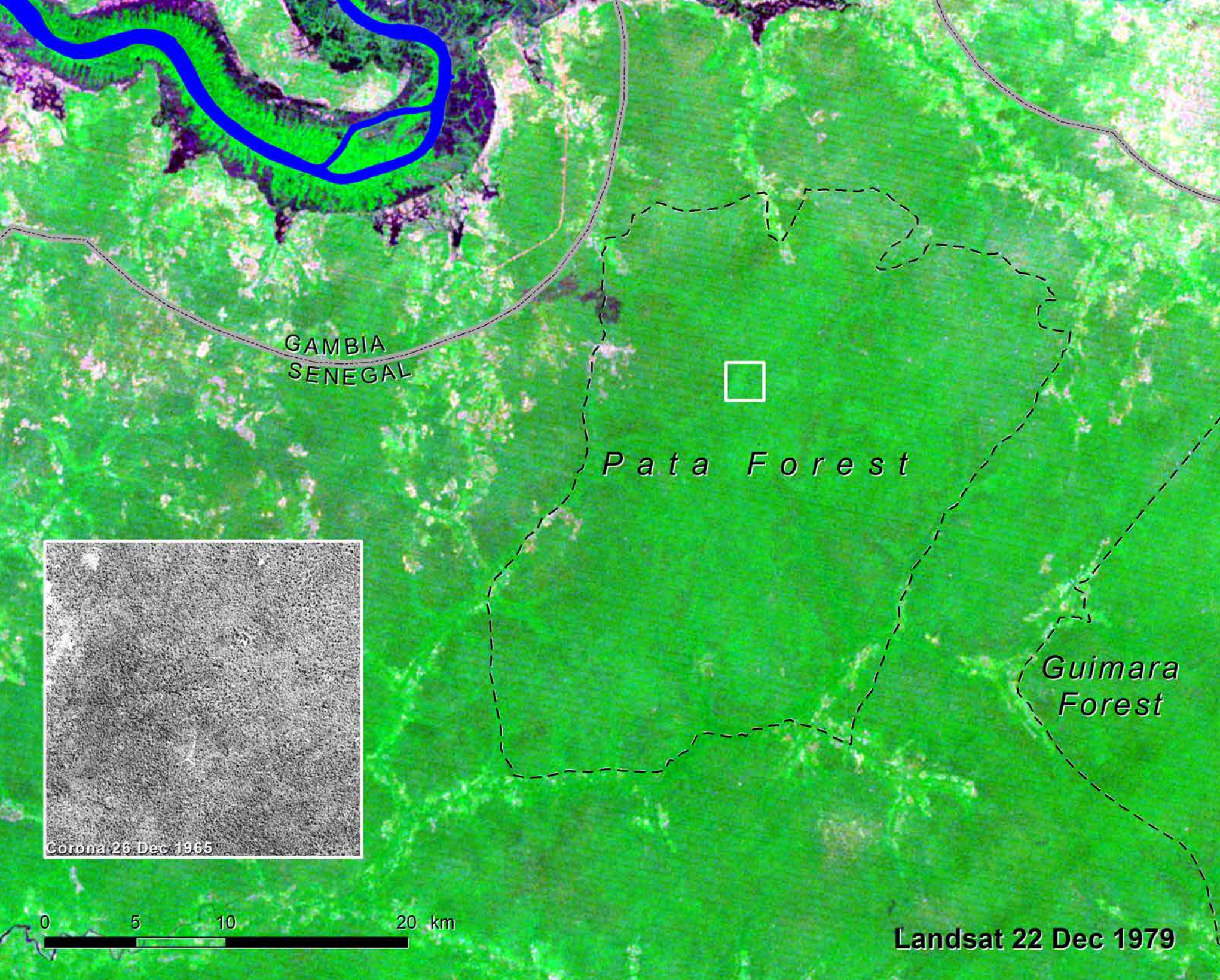
The population of Mbar Diop is well aware of the multiple benefits they draw from the trees. Dust storms have become less frequent and there is more shade. Some of the plant and animal species that had disappeared have returned to the area. They also attribute the fact that rainfall has improved recently to the increased tree cover. The economic benefits from the afforestation are also considerable. The sale of wood, nuts and fruits is estimated to generate a revenue of 1,500 to 2,400 US\$ per hectare per year. In addition, yields of field crops have improved.

However, the success of the afforestation investments is threatened by a mining operation, which can be seen to encroach the area from the northeast (4). It has already



displaced villages and continues to expand toward the densest orchards, causing great concern to the population of Mbar Diop. Not only do they fear for the existence of the village and its territory, but they already

feel the impacts of the chemical pollution coming from the phosphate mining. A discussion and settlement of the land use competition between farmers and the mining concession is urgent.



The Pata Forest Reserve in the Casamance: a window on a disappearing forest

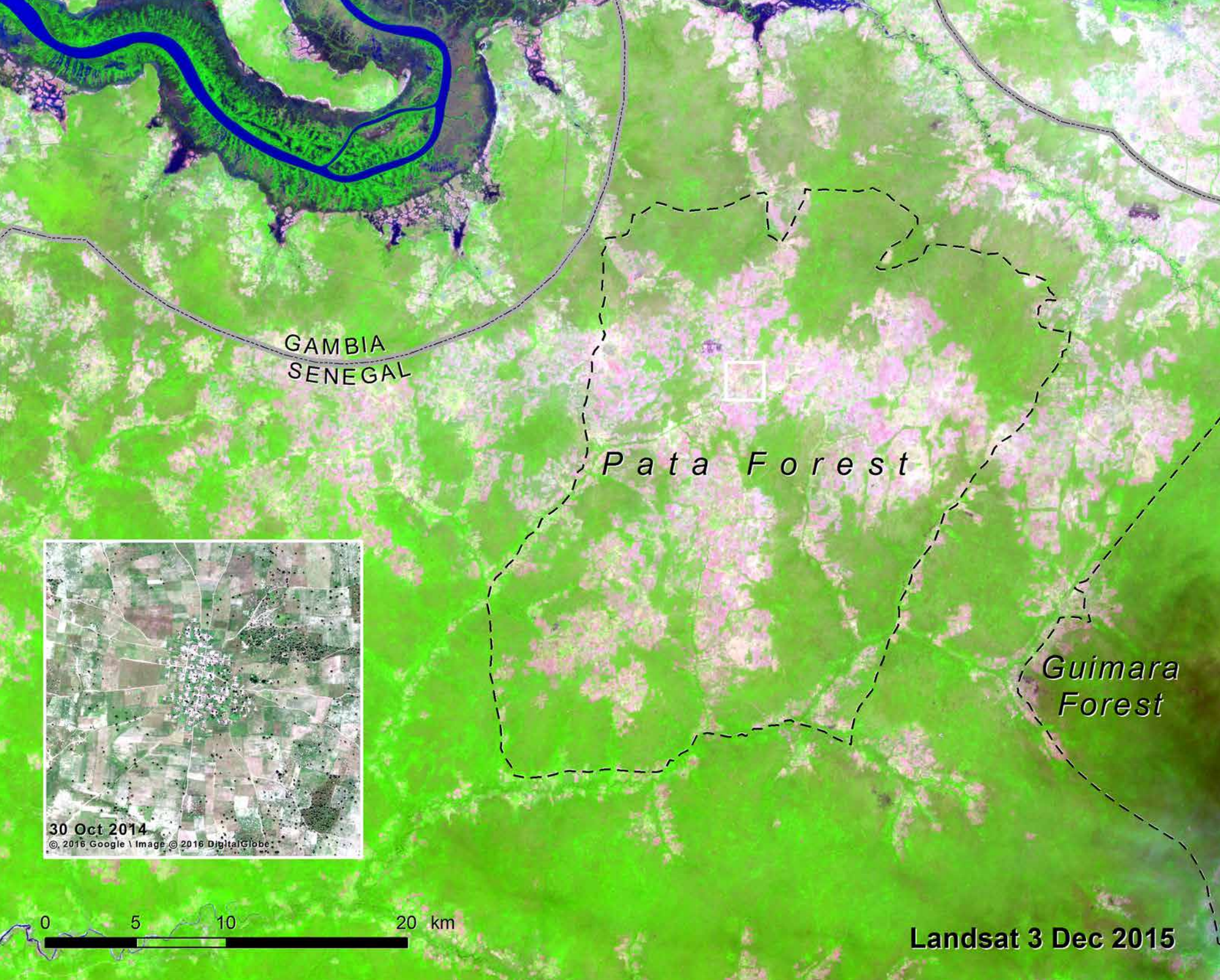
The Pata Forest Reserve was once part of a vast, unbroken Sudanian woodland that stretched from the Gambia River to the Casamance River, with narrow gallery forests following the watercourses. At least 20 species of woody plants are common throughout, with many more species of Guinean zone affinity found in the gallery forests (Stancioff and others, 1986). These woodlands are by nature very heterogeneous in floristic composition, which also makes them remarkably uniform in structure (Pélissier, 1966). Besides their value as a woodland ecosystem, they also serve as extensive grazing land for cattle.

Covering 640 sq km, the Pata Forest Reserve is the largest forest reserve in southern Senegal. From the 1930s to the early 1970s, the integrity of the forest reserve was respected. In the Landsat image from 1979, we can see



Charcoal production

GRAY TAPPAN / USGS



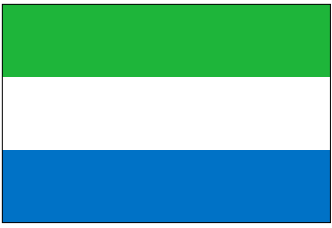
that the woodland is still intact within and outside the reserve, although a few minor incursions of cropland are visible. The situation changed dramatically in the late 1980s when Wolof farmers from the Saloum agricultural region, seeking new land, began moving into the valleys in and around the Pata Forest. By 1999, 28 percent of the Reserve had been cleared for agriculture, fueling tensions between the local agro-pastoralists and the recent migrants (Tappan and others, 2004).

As seen in the 2015 Landsat image, the Pata Forest Reserve has almost ceased to exist as a forested landscape. Unchecked agricultural expansion surrounding numerous new settlements, tree harvesting for charcoal production, and selective logging for valuable timber have combined to decimate the woodland (see inset). In 2013, focus group discussions were conducted by AGRHYMET's national team in Senegal in several villages surrounding the Pata Reserve to capture local perspectives on landscape changes. Local inhabitants cite the increase in population, increasing the demand for farmland. They also point to the significant in-migration and settlement of families from the Saloum. As secondary factors, they cite environmental change, particularly the decrease in rainfall and increasing temperature which, combined with bush fires, have accelerated degradation of the forest. They also spoke of the commercialization of valuable wood, with strong demand and flow of timber to The Gambia for export to China.



GRAYTAPPAN / USGS

Aerial view of Pata Forest Reserve



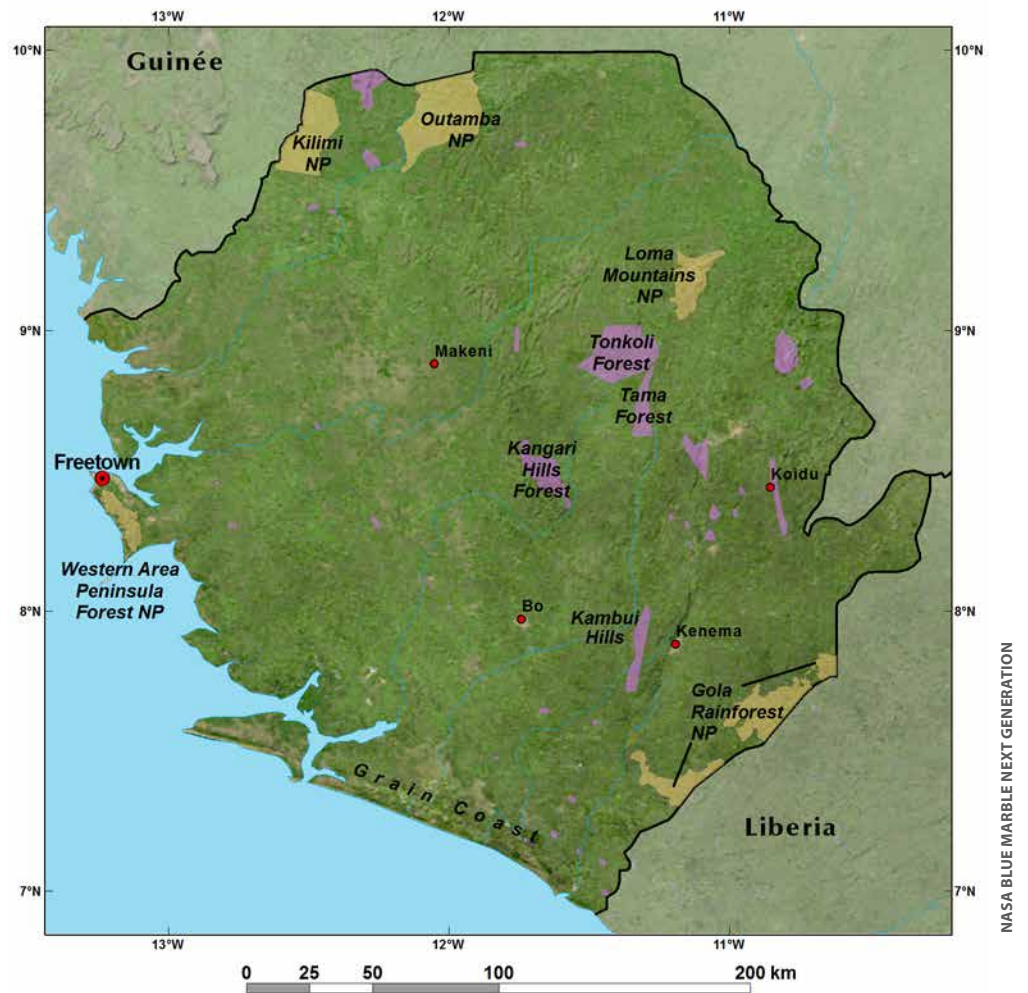
Republic of

Sierra Leone

Total Surface Area: 71,740 km²

Estimated Population in 2013: 6,179,000

Sierra Leone has a special significance in the history of the transatlantic slave trade. Its capital, Freetown, was founded in 1787 as a home for repatriated former slaves from London and the Americas. Sitting on a coastal peninsula, the city overlooks the Sierra Leone Harbor, the world's third largest natural harbor. The country is characterized by a humid tropical climate. Annual rainfall ranges from 1,900 mm in the northwest to over 4,000 mm on the coast, which makes Sierra Leone the wettest country in West Africa. Its landscape includes a flat coastal zone with fringing mangrove swamps. A large plain extends inland that transitions into wooded hills and an interior plateau interspersed with forested high mountains in the east. The country's vegetation is highly complex and characterized by a matrix of patches of forest, woodland, savannas, and cropland. Sierra Leone's economy stems from its rich natural resources but is still recovering from a civil war that destroyed most institutions before ending in the early 2000s. Agriculture, as the primary occupation, employs two-thirds of the labor force and accounts for 66.8 percent of the country's gross domestic product (GDP) (CIA, 2013). Sierra Leone also possesses substantial mineral resources, particularly iron ore, and has relied on mining for its economic base in recent years. In addition, the country is among the largest producers of titanium and bauxite, a major producer of gold, and in the top ten diamond-producing nations.



-  National Park / Parc National
-  Wildlife Sanctuary / Sanctuaire de Faune
-  Forest Reserve / Forêt Classée
-  National capital / Capitale nationale
-  Other City / Autre Ville

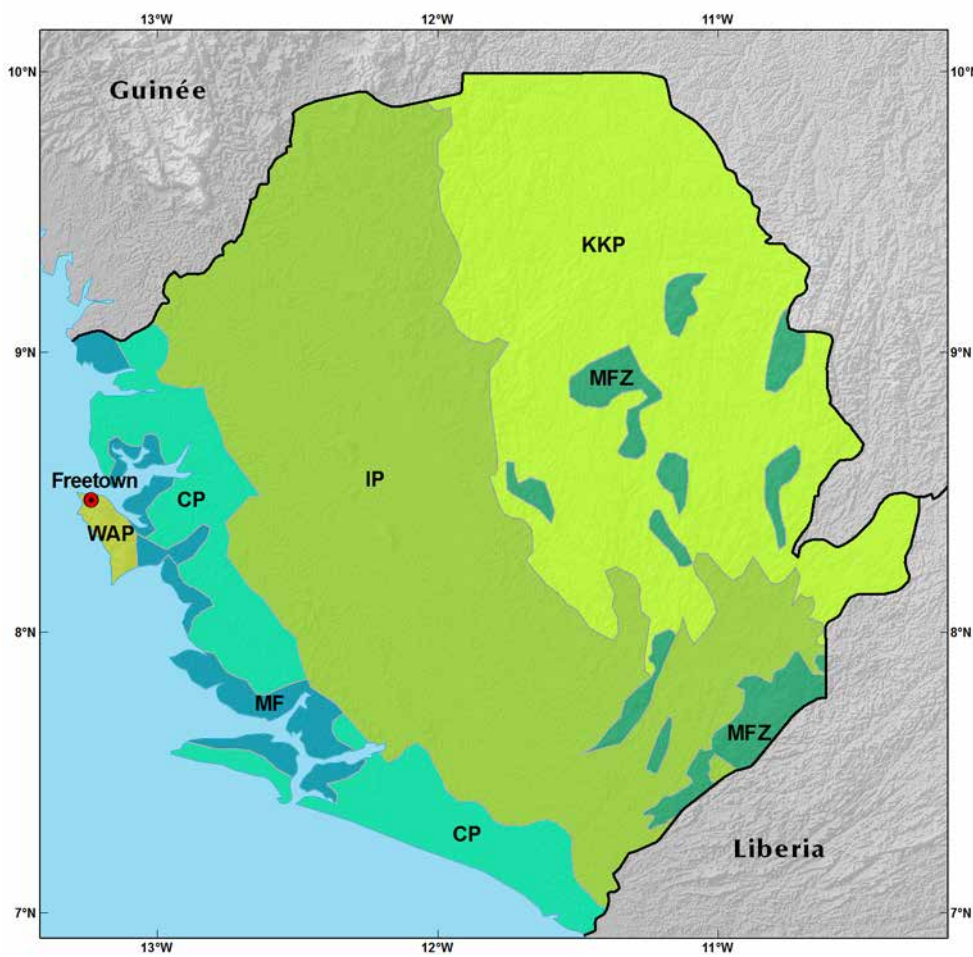
Environmental Highlights:

- Deforestation
- Loss of biodiversity
- Wettest country in West Africa
- Substantial mineral resources
- High potential for ecotourism



Woodland in the Outamba-Kilimi National Park

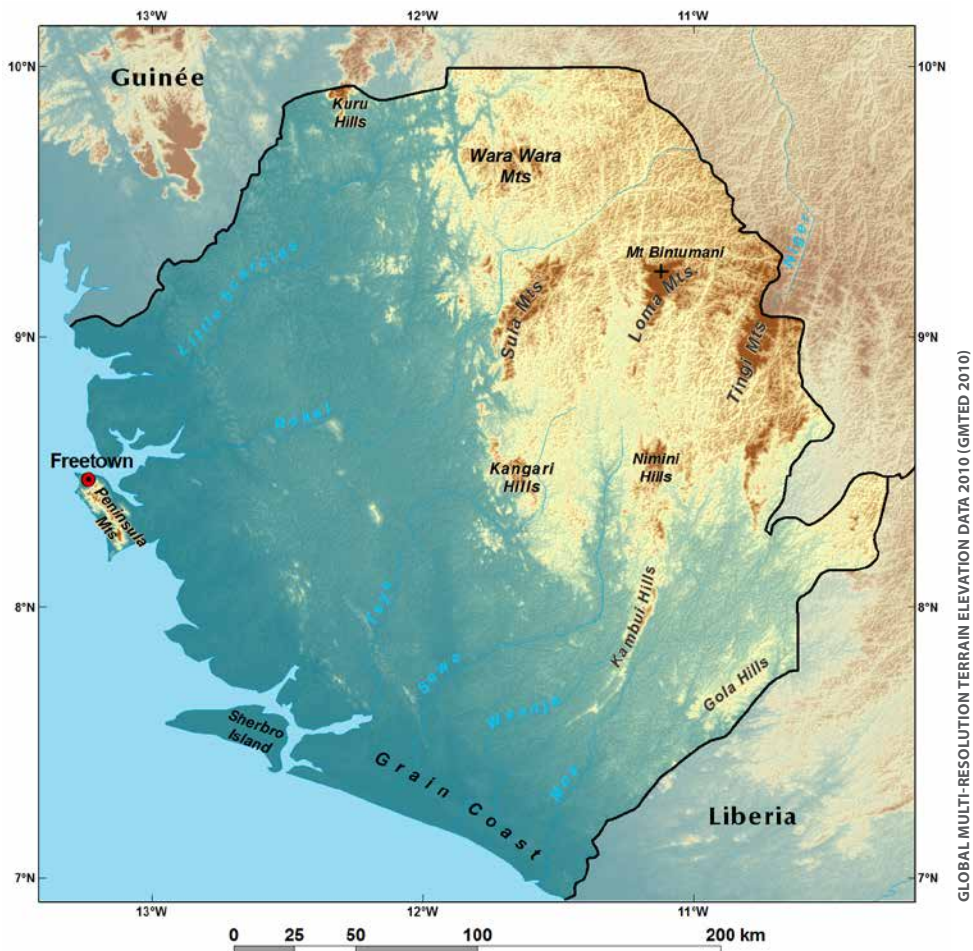
Ecoregions



- | | |
|--|---|
| CP Coastal Plains | MF Mangrove Forest |
| IP Interior Plains | MFZ Montane Forest Zone |
| KKP Koinadugu and Kono Plateaus | WAP Western Area Peninsula |

Sierra Leone is divided into four main regions. In the east and the north, the Koinadugu and Kono Plateaus (KKP) ecoregion is an extension of the Guinea Highlands with several isolated mountains including the Tingi Hills, and the Loma Mountains where Mount Bintumani reaches 1,948 m. The plateau is mostly covered by a mosaic of woodland and savannas, interspersed with cropland. The high mountains of the Montane Forest Zone (MFZ) are dominated by tropical rain forests, often protected as forest reserve or national park. The northern part of the Koinadugu and Kono Plateaus (KKP) receives relatively less rainfall, often resulting in less dense and lower canopy height, even among mature stands of woodland (Munro and van der Horst, 2012). Parallel to the coastline, but inland of the coastal belt, are the Interior Plains (IP). This ecoregion of lowland plains, containing forest regrowth, woodland, savannas, and farmland, makes up about half of the country. Adjacent to the Atlantic shoreline are the Coastal Plains (CP) and the Mangrove Forest (MF) zones. The Gabro massif, confined to the Western Area Peninsula (WAP) where the capital city of Freetown is located, rises impressively from 200 m to 1,000 m above the low-lying narrow coastal area.

Shaded Relief



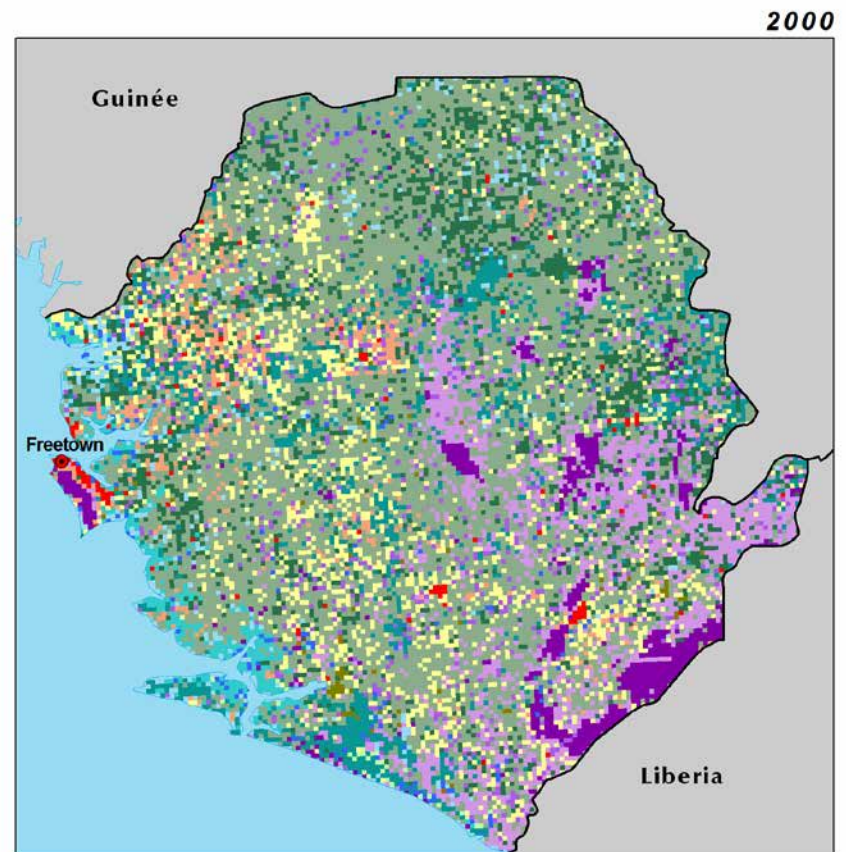
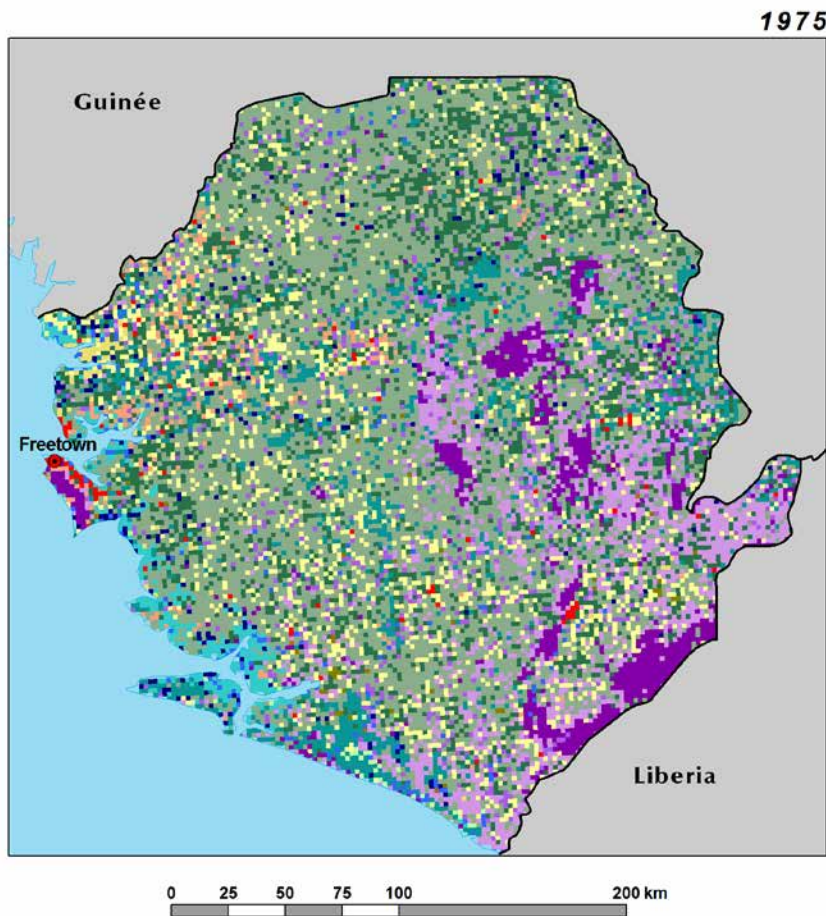
- | |
|--|
| High / Élevée |
| Low / Faible |



GRAY TAPPAN / USGS

Rapids on the Little Scarcies River, Outamba-Kilimi National Park

Land Use, Land Cover and Trends



● Capitale Nationale / National Capital

The most extensive land cover change in Sierra Leone was the loss of woodland and forested area across the country.

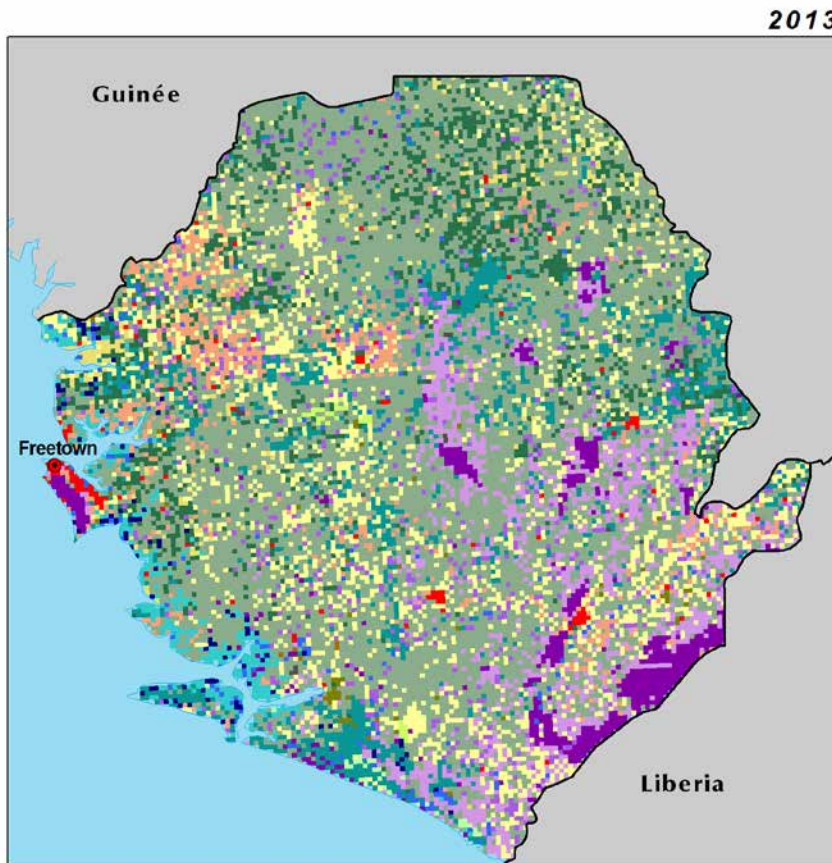
Dense forest is rare and mainly found on hill slopes in the Montane Forest Zone. Even though the country is located within the Upper Guinean forest ecosystem, it is unlikely that it was ever heavily covered by dense forest (Munro and van der Horst, 2012). Between 1975 and 2013, Sierra Leone lost 30 percent of its forest cover, or about 1,100 sq km, at an average annual rate of 0.8 percent. However, this rate has slowed since the end of the civil war, averaging 0.4 percent of annual forest loss between 2000 and 2013. The main loss of forest occurred in the Tama-Tonkolili and Nimini Hills highlands. In 1975, these tracts of dense forest were located among a patchwork of degraded forest, gallery forest, and woodland — none of which has been spared by deforestation. Degraded forest decreased

by 26 percent, or about 2,000 sq km, and gallery forest by 22 percent, or 700 sq km. Woodland is one of the dominant land cover types in Sierra Leone. It is found in the major ecoregions — on slopes and uplands of the Koinadugu and Kono Plateaus, and on the Interior and Coastal Plains, among the savannas and thickets. In 1975, woodland was the second largest land cover class in terms of area after the savannas, covering 15.5 percent of the country. Over the 38-year period, its area decreased by 48 percent, or 5,400 sq km, shrinking to a mere 8 percent of the country in 2013. Accounting for all the forest classes together, Sierra Leone lost a total 36 percent of its forest and woodland habitats since 1975.

Cropland expansion, slash-and-burn agriculture, logging, mining, and cattle grazing activities were the dominant factors affecting vegetation and land use. Indeed, resulting from an increasing demand for forest products and



The Kuru Hills



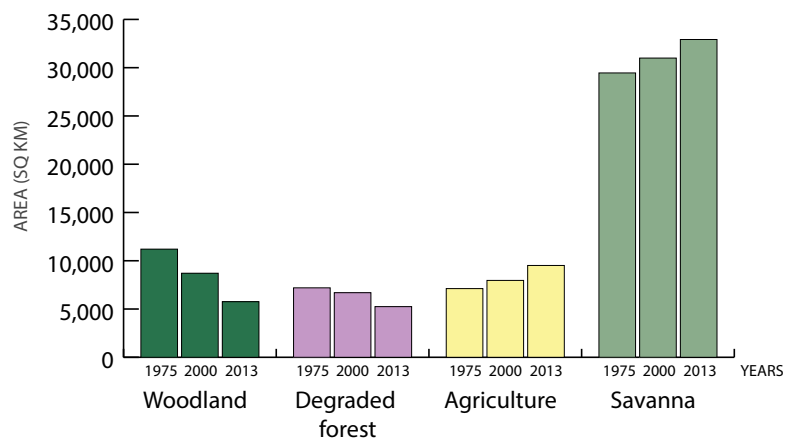
Land Cover / Occupation des Terres

- Forest / Forêt
- Gallery forest & riparian forest / Forêt galerie & formation ripicole
- Degraded forest / Forêt dégradée
- Woodland / Forêt claire
- Swamp forest / Forêt marécageuse
- Mangrove
- Savanna / Savane
- Herbaceous savanna / Savane herbacée
- Bowé
- Thicket / Fourré
- Agriculture / Zone de culture
- Irrigated agriculture / Cultures irriguées
- Agriculture in shallows and recession / Cultures des bas-fonds et de décrue
- Plantation
- Settlements / Habitation
- Bare soil / Sols dénudés
- Rocky land / Terrains rocheux
- Open mine / Carrière
- Water bodies / Plans d'eau
- Wetland - floodplain / Prairie marécageuse - vallée inondable

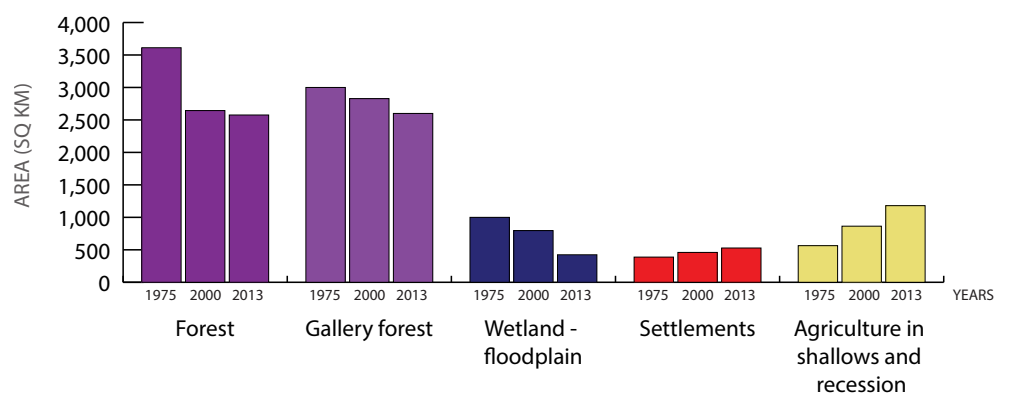
food production, half of the lost forest and woodland habitats were converted to savannas, and one-third to agriculture. Shifting agriculture has long been practiced in Sierra Leone. Under this system, a patch of forest is burned, cleared and cultivated usually for a short period of time (1–2 years), after which it is left fallow for several years. The rate of cropland expansion quadrupled after the end of the civil war, going from an average of 32 sq km per year in the 1975–2000 period to 130 sq km per year between 2000 and 2013. Overall, agricultural area progressed by 35 percent, or 2,400 sq km, between 1975 and 2013, mostly in the Interior Plains and in the northern part of the Koinadugu and Kono Plateaus. In Sierra Leone, where water is an abundant resource, bottomland and flood recessional agriculture is also very common. Many of the wetland areas mapped in 1975 have been converted to cultivated bottomland which has doubled in area, reaching 1,180 sq km by 2013.

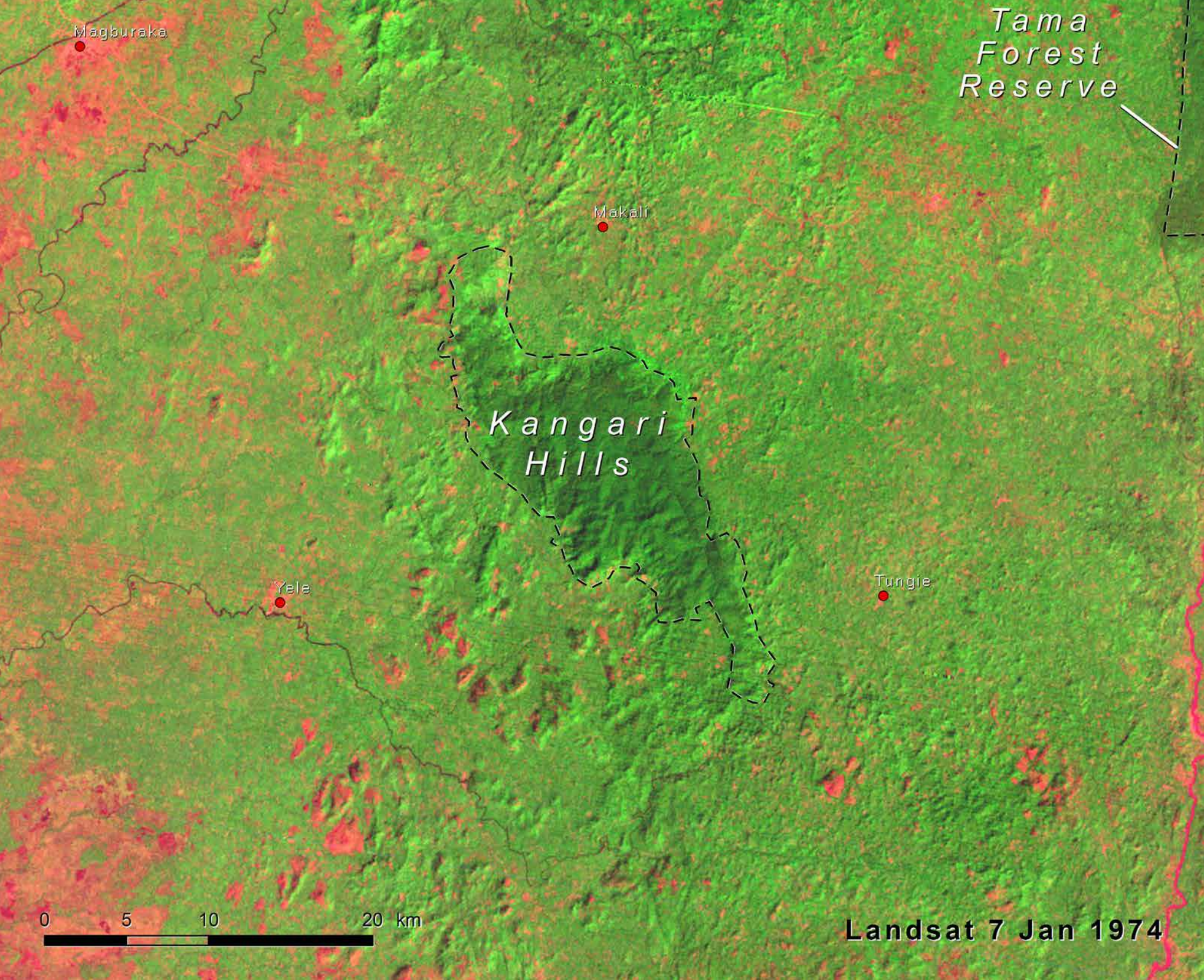
Because a large part of the population in Sierra Leone obtains its substance from farming, agriculture expansion was mostly driven by population growth. Whereas population increased steadily from 2.7 million to 6.1 million, a rise of 123 percent, the area occupied by settlements—towns and cities—only grew by 36 percent, or 140 sq km, from 1975 to 2013.

Large area classes



Small area classes

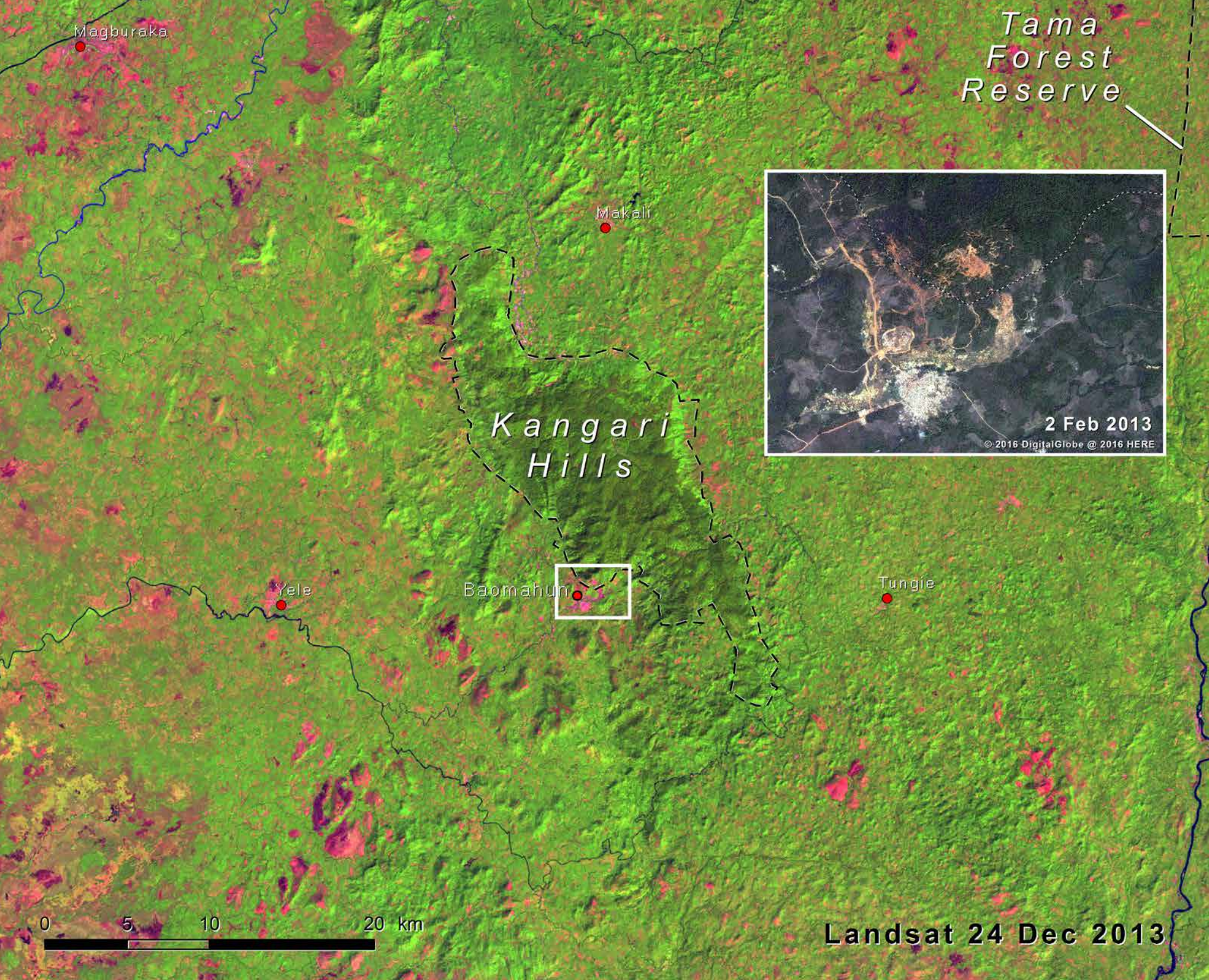




The Kangari Hills: A forest reserve with competing uses

Sierra Leone is endowed with two important natural assets, its mineral resources and its flora and fauna. Both can be found in the Kangari Hills. The Kangari Hills Forest Reserve covers 210 sq km and has been protected since 1924 as one of the few relics of the Upper Guinean forest ecosystem in the country. Key protected wildlife species include a remnant population of forest elephants, chimpanzees and other primates, as well as 115 documented bird species (Brcic and others, 2010). The forest is also used as a source of medicinal herbs and spices.

Landsat images from 1974 and 2013 evidence a remarkable stability of the extent of the forest in the Kangari Hills Forest Reserve. Forest stands out as the large dark green patch in the center of the images surrounded by a fine mosaic of farmland, savanna, and degraded forest. Some clearings are visible within the forest reserve as small brighter patches, but the extent of those has not significantly changed since the 1970s. Agricultural encroachment has taken place mostly from the north, where many villages are located. In contrast, the Tama Forest Reserve, located in the northeast of the images, had totally disappeared by 2013, entirely replaced by cropland and savanna. Logging roads also penetrate the southern part of the Kangari Hills Forest Reserve. The production and trade of charcoal has increased in the past decade and has become so lucrative that it has replaced farming. Unlike firewood, which is usually obtained from farms, wood for charcoal is harvested from forests and woodlands and often targets highly valuable hardwood species.



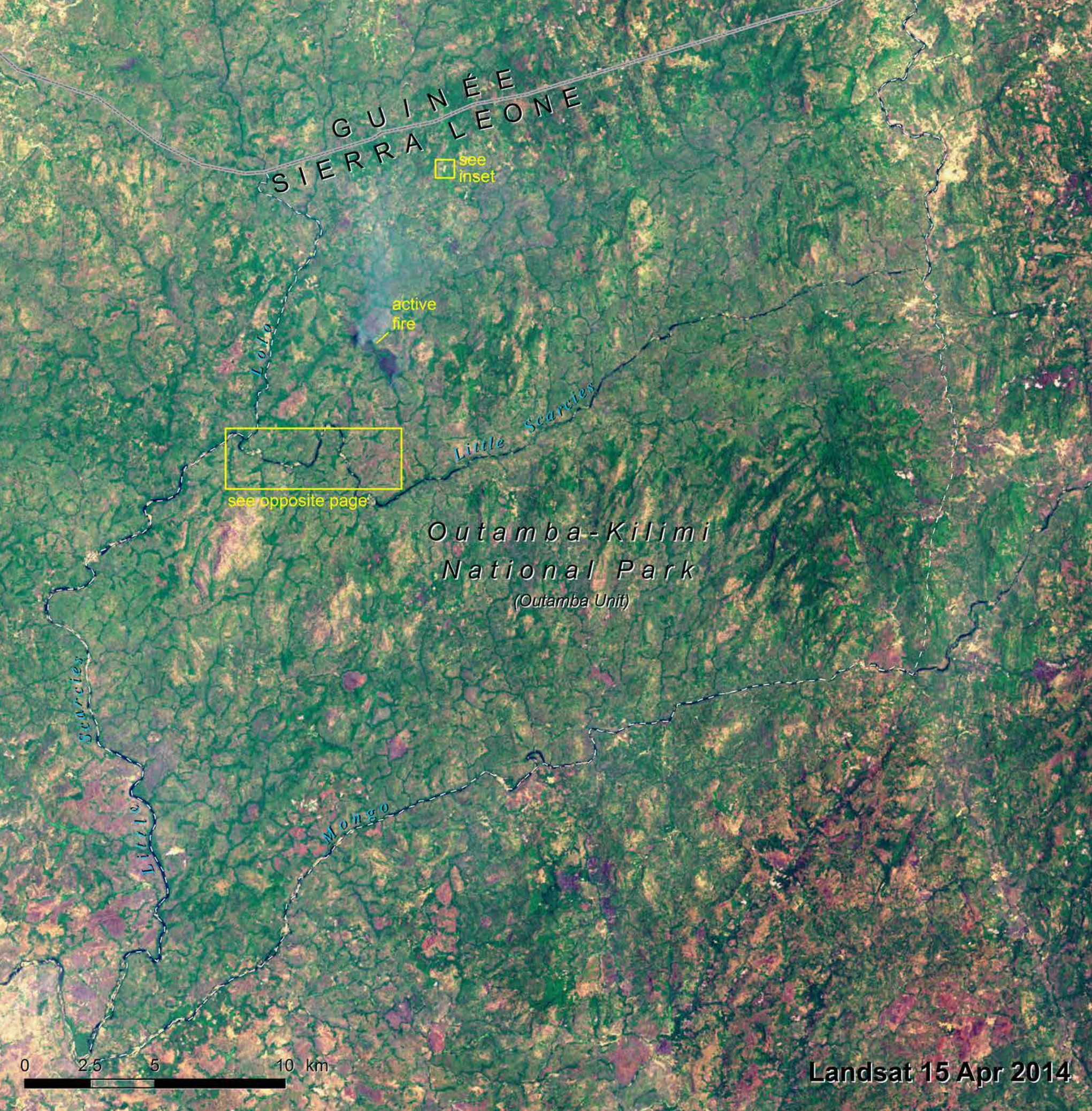
Illegal artisanal gold mining activities can be found throughout the Kangari Hills. With the British company Cluff Gold, the first industrial-scale gold mining operation began production in 2013 near the village of Baomahun, just to the southwest of the reserve (see inset). Cluff Gold claims to have found 3 million ounces of gold in and around the Kangari Hills. This value exceeds the entire Sierra Leonean economy by a factor of two, with the potential of tax revenues from the export of gold that can be invested into rebuilding the country's infrastructure (McClanahan, 2012). On the downside, the open pit mine leaves a huge scar on the land. Any form of deforestation diminishes forest resources, reduces wildlife habitat, and exposes the soil to erosion. With a mean annual rainfall of 3,500 mm, flash floods and landslides are common on denuded soil in this area.

With a relatively intact core of dense forest cover, the Kangari Hills Forest Reserve has an enormous potential for biodiversity conservation. Because of the carrying capacity and suitability of the habitat, it is being considered as a release site for rehabilitated captive chimpanzees. The massive demand for revenue from gold will undoubtedly put a lot of pressure on the reserve. The future of the reserve will depend on careful consideration of competing interests and striking a delicate balance between long-term restoration goals and income opportunities.



KENNY LYNCH / FLICKR / CC BY-NC-ND 2.0

Mining leaves forest degraded and vulnerable to soil erosion and landslides.



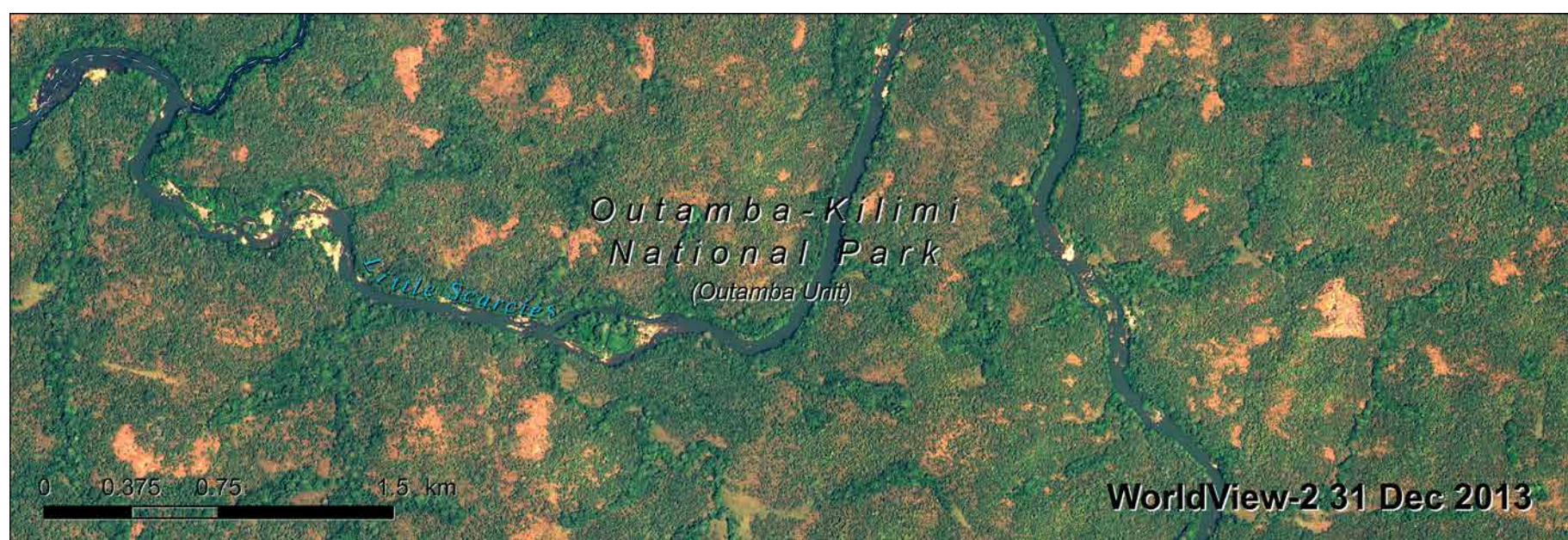
Landsat 15 Apr 2014



Outamba-Kilimi National Park

The Outamba-Kilimi National Park along Sierra Leone's northwestern border with Guinea is made up of two separate units; Outamba to the east (shown above) and Kilimi to the west. Both are predominantly covered by woodland savanna with smaller areas of forest, gallery forest and open grassland. Outamba is generally more wooded than Kilimi and has more relief. Created in 1995 when hunting pressure was increasingly threatening the area's wildlife, it was the country's first national park.

Most of the park's roughly 2,200 mm of rainfall falls from June to September followed by a dry season lasting from about November to April. Vegetation thrives during the rains and then much of it goes dormant during the dry season. This ready fuel makes fire a natural part of the Sudanian savanna landscape and it is fire that maintains



the boundaries between the grassy savanna and the denser forest areas which stay green year round (Trollope and Trollope, 2010; Hoffman and others, 2003). Fire scars and one still-burning fire can be seen in the Landsat image which was acquired as the 2014 dry season was ending (see image on the opposite page). The contrast between wet and dry seasons can be seen in the two high-resolution images. The top image (above) is from late in the dry season when savanna areas have gone dormant and fire scars are visible throughout the landscape; the image below is after the rains when all is green again and the next dry season is just beginning.

Human influence in Outamba-Kilimi is minimal with roughly 20 to 25 very small settlements (see adjacent inset) within the park (Brncic, 2010). While it is a national park and welcomes visitors, motor vehicles are restricted and visitors must explore the park on foot. The relatively pristine habitat of the park supports populations of several primates including the western chimpanzee, red colobus monkey, black and white colobus monkey, olive baboons, and the sooty mangabey (STEWART, 2012; Brncic, 2010). It is also home to a number of other large mammals including elephants, hippopotamuses, warthogs, red river hogs, leopards, African buffalo, bushbucks, bongo, duikers, gazelles and other antelope species (Brncic 2010). Bird species number over 250, including two which are of global conservation concern (Okoni-Williams and others, 2001).

The park's natural assets may provide potential for ecotourism development. Income from tourism could potentially provide the benefits to local communities that would help build trust and support for ongoing conservation efforts (Brncic, 2010). However, the park's remote location



and the memory of Sierra Leone's devastating civil war (1991-2002) has kept the number of visitors down.

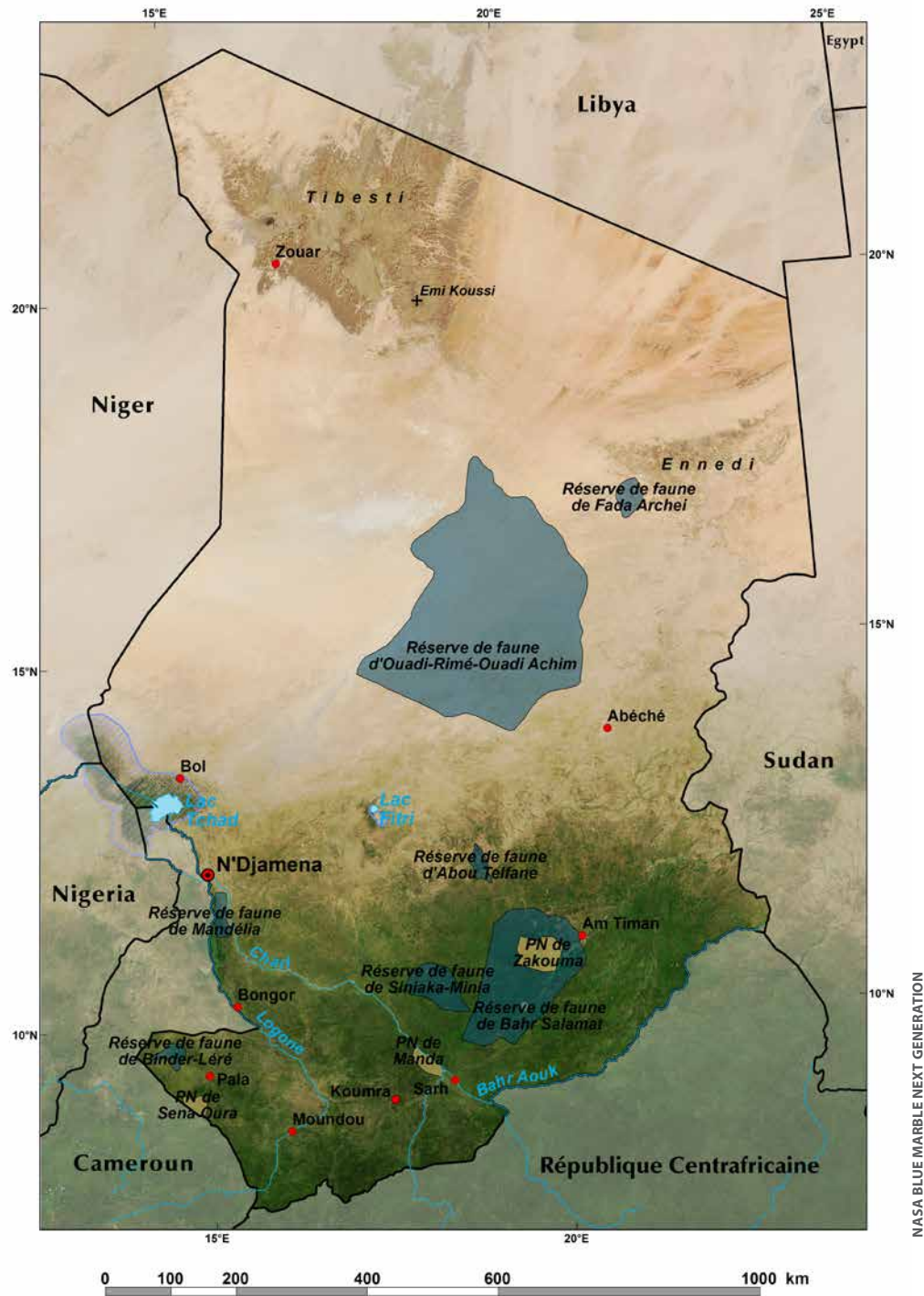
Other potential threats to the park's integrity include poaching and mining. Occasional poaching of elephants is a problem according to Outamba-Kilimi's senior ranger, Dio Metzgehe. A group of poachers was arrested after several elephants were killed in 2009. Poachers also take smaller animals for bushmeat and fish illegally within the park. Artisanal mining in the streambeds within the park has also been reported (STEWART, 2012).



Republic of Chad

Total Surface Area: 1,284,000 km²
Estimated Population in 2013: 13,146,000

Chad is the fifth largest country in Africa and ranks second among Sahelian countries after Sudan. Chad's land surface presents a dramatic variety of geographic contrasts. The vast northern third is located in the Sahara Desert and is sparsely populated, home to just 1 percent of Chad's population. The whole central swath is in the Sahel, with average annual rainfall ranging from 150 to 600 mm. Both N'Djamena, the capital, and Lake Chad are found in this region. Lake Chad is fed by the country's two main rivers, the Chari and the Logone. It is the largest body of water in the Sahel and a major center of economic activity for the region. However, due to erratic variations in the region's climate and overexploitation of the rivers that feed it, this shallow lake (1.5 m deep on average) has shrunk to a small fraction of its 1960 size. Chad's population lives mainly in the southern part of the country, in the more humid Sudanian climate zone, where average annual rainfall ranges between 600 and 1,300 mm. Southern Chad has the largest, relatively intact expanses of wooded savannas and woodlands of any of the Sahelian countries. Discovery of artifacts and fossils in northern Chad — especially the 7-million-year-old Toumaï skull from a hominid that is regarded as one of the oldest species in the human lineage — attests to the archaeological and historical richness of the country. Traditionally, Chad's economy has been based on farming and livestock, but in the last decade the economy has changed dramatically from the oil boom. Besides oil, there are also significant deposits of gold, marble, and sodium carbonate.



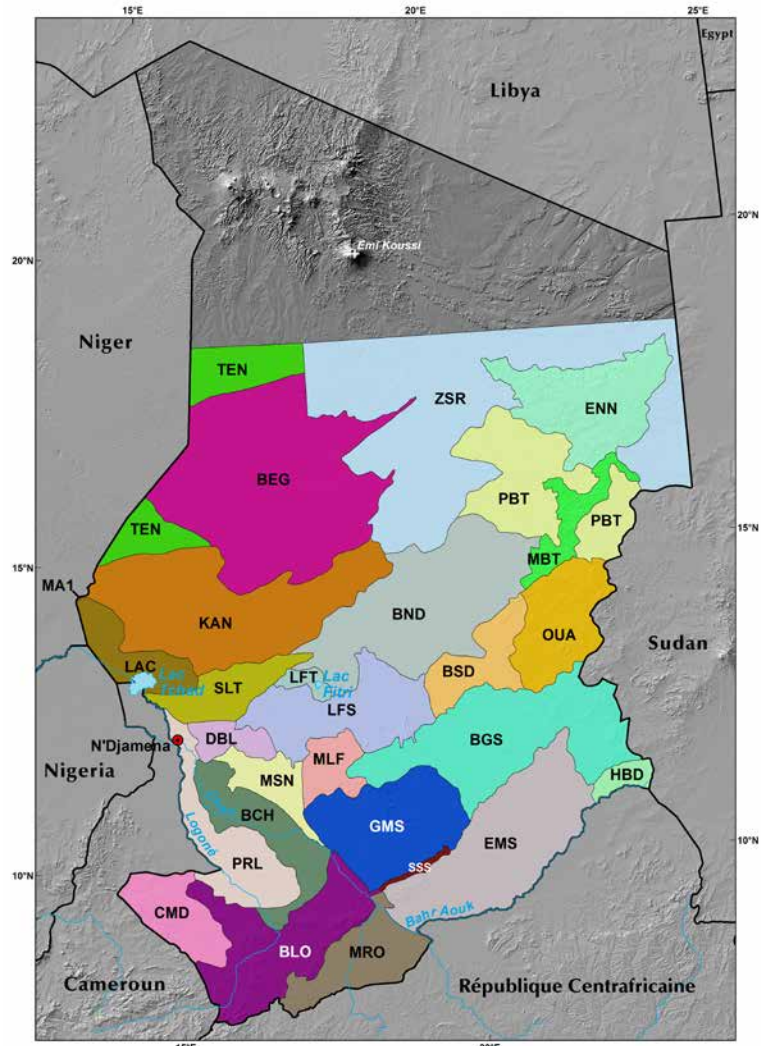
Environmental Highlights

- Desertification
- Deforestation
- The drying of Lake Chad
- Vast expanses of Sudanian woodland and savanna
- Oil resources

The Guéra Mountains near Mongo, whose profile suggests a woman asleep on her back, known locally as "The Queen of Guéra".



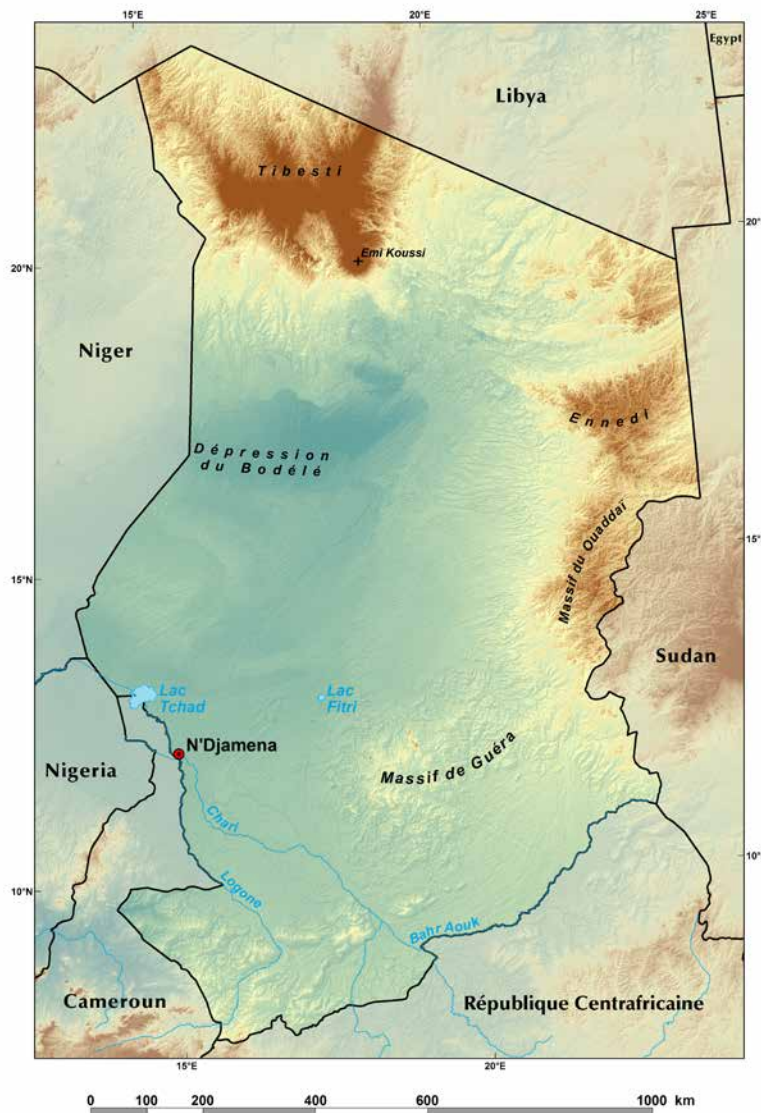
Ecoregions



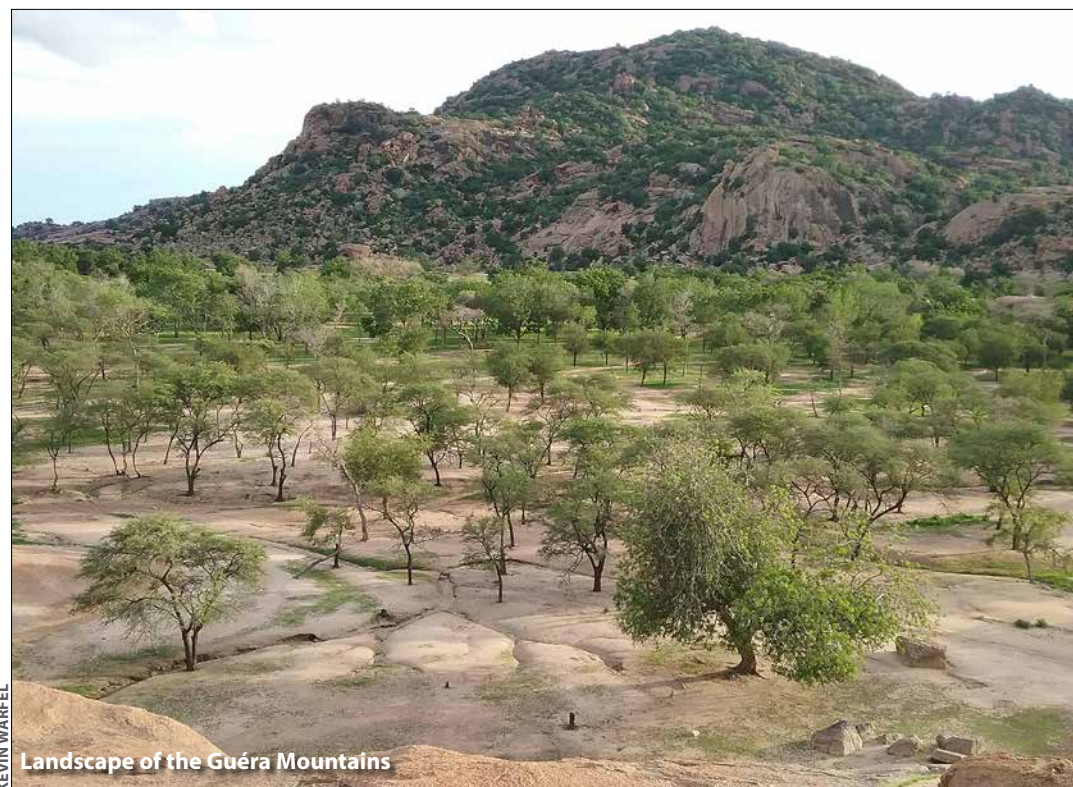
- | | |
|---|--|
| BCH Bas Chari | LFT Lac Fitri |
| BEG Bassin du Bahr El Gazal ou Soro | MA1 Manga Désertique |
| BGS Bande Guera-Salamat | MBT Massif du Biltine |
| BLO Bassin du Logone | MLF Melfi |
| BND Batha Nord | MRO Maro |
| BSD Batha Sud | MSN Massenya |
| CMD Collines du Mayo-Dala | OUA Ouaddai |
| DBL Dourbali | PBT Plaine du Biltine |
| EMS Est Moyen-Chari et Salamat | PRL Plaines Rizicoles du Logone |
| ENN Ennedi | SLT Sud-est Lac Tchad |
| GMS Sud Guera, Nord Moyen-Chari, Ouest Salamat | SSS Savane Soudanienne Sèche |
| HBD Hadjer Bandala | TEN Désert du Ténééré |
| KAN Kanem | ZSR Zone Saharienne |
| LAC Lac Tchad | |
| LFS Lac Fitri Sud-Est | |

Chad is located on a wide plain with flanks that rise gently eastward toward the Ennedi Range (ENN) and north toward the Tibesti Mountains, which culminate in the Sahara's highest peak, Emi Koussi, at 3,415 m. The country's northern third consists of vast sandy and gravel plains, too dry for cultivation except for small-scale traditional irrigated farming in scattered oasis towns. The high plateaus of the Ennedi and Ouaddaï (OUA) ecoregion gently slope toward the lower Sahelian plains of the Batha (BND and BSD) and Kanem (KAN) ecoregions, stretching to Lake Chad far to the west. The southern third of Chad is in the Sudanian climate region, with many ecoregions that are defined by plateaus and local highlands, expansive plains, and broad drainage channels that flood annually. To the west, these plains are more conducive to agriculture owing to their deep, rich alluvial soils. In contrast, the largest ecoregion in the southeast, Moyen-Chari and Salamat Plain (EMS – Eastern Middle-Chari and Salamat), contains large expanses of Sudanian zone woodlands and savannas where scattered communities are engaged in subsistence farming, fishing, and raising livestock.

Shaded Relief



- | | |
|--|---------------|
| | Élevée / High |
| | Faible / Low |

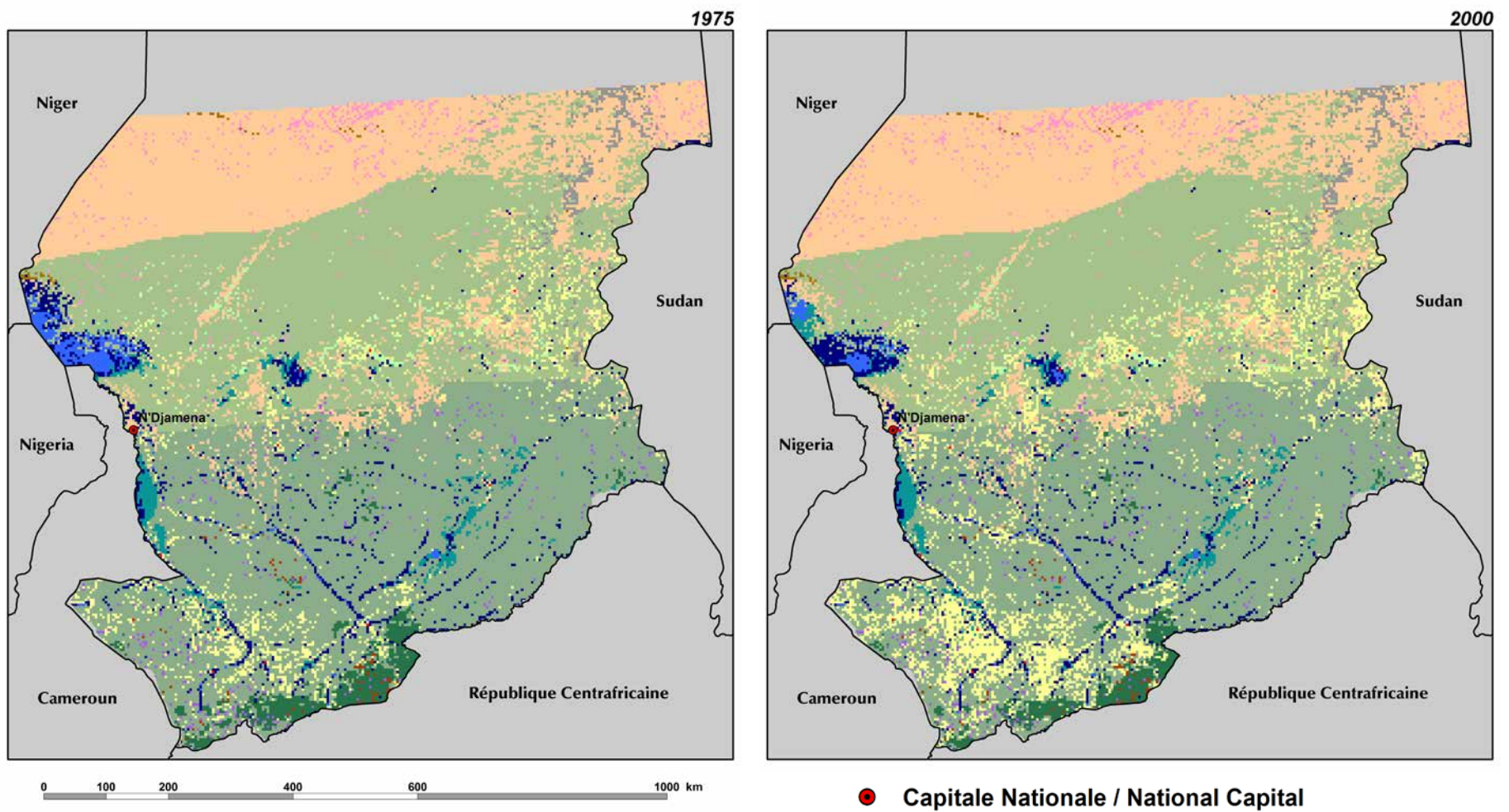


GLOBAL MULTI-RESOLUTION TERRAIN ELEVATION DATA 2010 (GMTED 2010)

KEVIN WARFEL

Landscape of the Guéra Mountains

Land Use, Land Cover and Trends



The northern third of Chad is a desert with vegetation cover found only in special niches where it can survive. Land cover was mapped only in the southern two-thirds of Chad, where seasonal vegetation and longer term land use and land cover dynamics are in play.

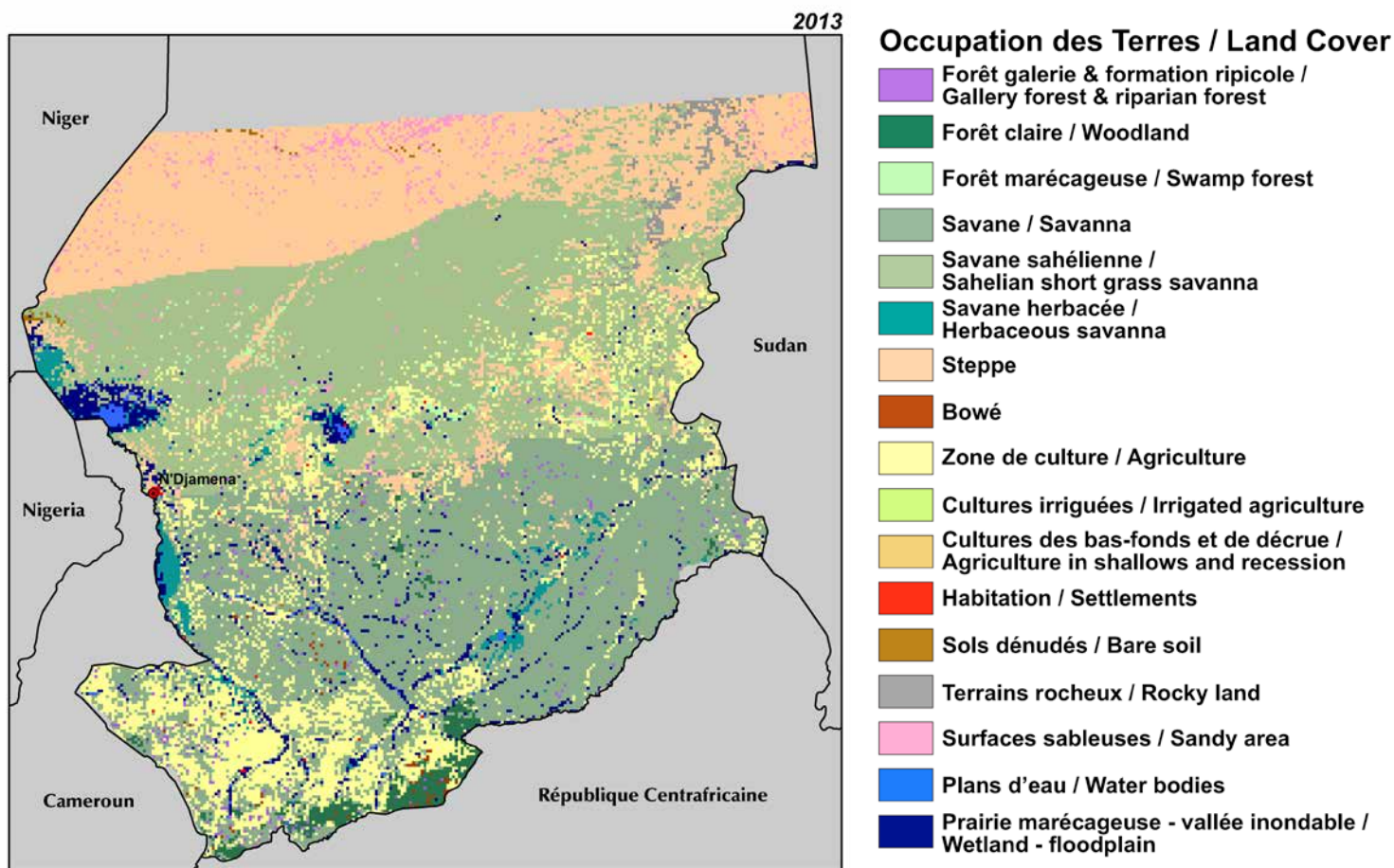
In the mapped area, Sudanian and Sahelian savannas are the major land cover classes, accounting for half of the country's land surface. Steppes also constitute a dominant land cover, covering 22 percent of the area mapped. Whereas the area of steppes remained relatively stable, savannas show a clear reduction between 1975 and 2013, especially in the Sudanian zone where they lost about 17 percent of their area over the 38 years.

Driven by an accelerated population growth and concomitant food demand, agricultural expansion is the main driver of the loss of Chad's natural landscapes. Between 1975 and 2013, the annual rate of agricultural expansion was 5 percent, one of the highest in the region. This means that croplands almost tripled between 1975 and 2013, although this expansion is not uniformly distributed across the country. The spread of agriculture occurred mainly in the south, especially in the Bassin and Plaines du Logone (BLO and PRL – Basin and Plains of Logone), Collines du Mayo-Dala (CMD – Hills of Mayo-Dala), and Maro (MRO) ecoregions. The transition area between the Sahel and Sudan climate zones is another area of steady encroachment by croplands, especially in the regions of Ouaddaï, Lake Fitri (LFS and LFT), and around N'Djamena. In these regions, agricultural landscapes now dominate the savanna.

Deforestation is a major environmental concern in Chad. Woodlands, mainly located in the south, have diminished by 29 percent between 1975 and 2013, amounting to a very significant loss of 4,700 sq km. The area of gallery forest also declined, but not as rapidly as woodlands. Their overall land surface was always relatively small, but it has decreased by 8.3 percent, a 400 sq km loss between 1975 and 2013.

In the Sahel regions of Bahr El Gazal (BEG) and Kanem (KAN), sandy areas have grown in a patchwork fashion, pushing into the steppes. Droughts in the 1970s and 1980s, as well as grazing pressure, have destabilized the already sparse vegetation cover, allowing the underlying sands to become more mobile. Between 1975 and 2013, sandy areas have increased by 22 percent.

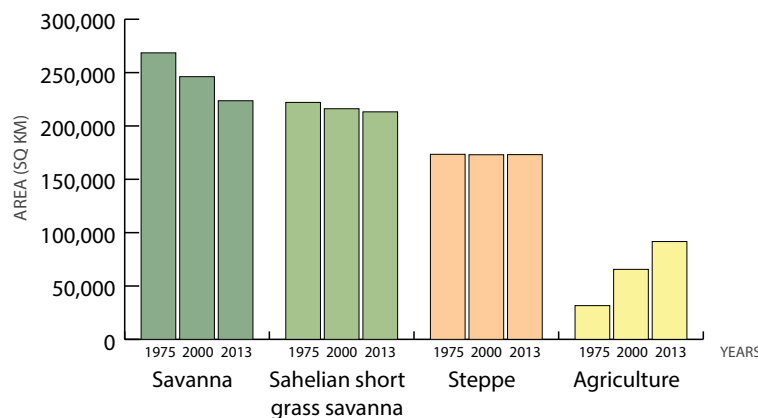
The reduction of surface water in Chad (a loss of 60 percent of surface water between 1975 and 2013) is mainly a result of the receding area of Lake Chad. Over 38 years, the overall surface area of the lake reduced by 87 percent. This is a concern not only to Chad, but to the region. Rainfall shortages combined with heavy use of the lake and river waters to irrigate and a major population increase in catchment area account for this decline. The entire



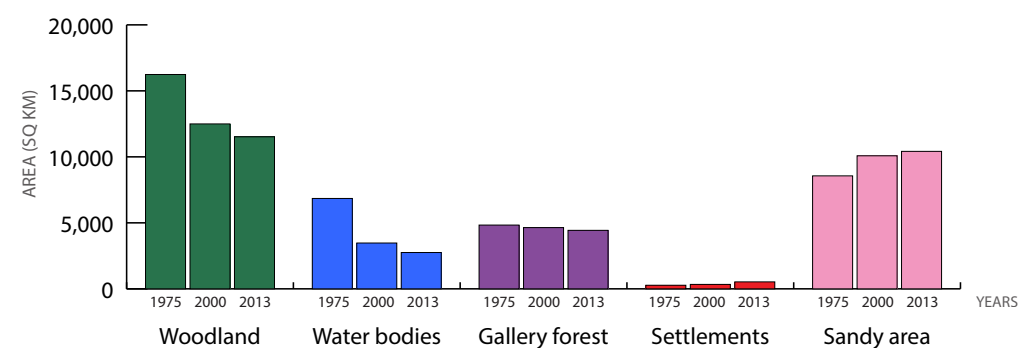
northern basin, which had water as recently as 1975, has completely dried out, replaced by steppes and herbaceous savanna. In 2013, only a core area of the southern basin still had water. In contrast, the smaller Lake Fitri, also situated in Chad's Sahel Region, appears to have been spared by the drying process. Lake Fitri's area did not change much between 1975 and 2013. Nevertheless, the lake's northern wetland area decreased, and agricultural pressure around the lake has visibly grown. These changes in the country's water resources have impacted its socio-economic life. There has been a migration of population toward the south where rainfall and pastoral resources are more abundant. The dramatic decline in the extent of Lake Chad has stranded many communities that are dependent on fishing and gardening, further fueling migration to Chad's urban areas.

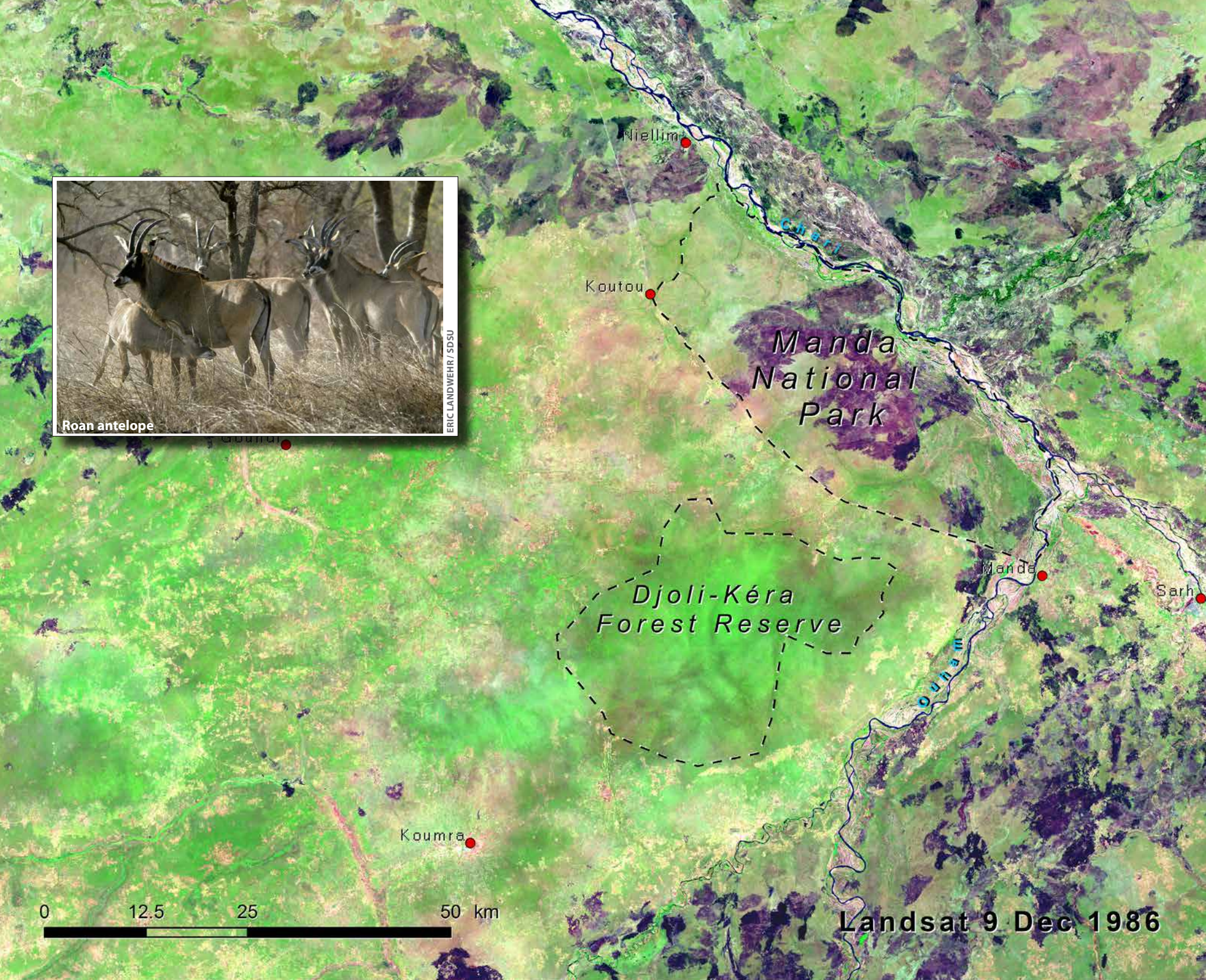
The recent oil boom in Chad is another factor affecting population migrations, changes in land cover, and natural resource degradation in the south, especially at Doba and Bongor. Chad became an oil exporter in July 2003, after over 30 years of prospecting by various international oil companies. Two years later, the country joined the African Petroleum Producers' Association (APPA) and created the Hydrocarbon Company of Chad in 2006.

Large area classes



Small area classes



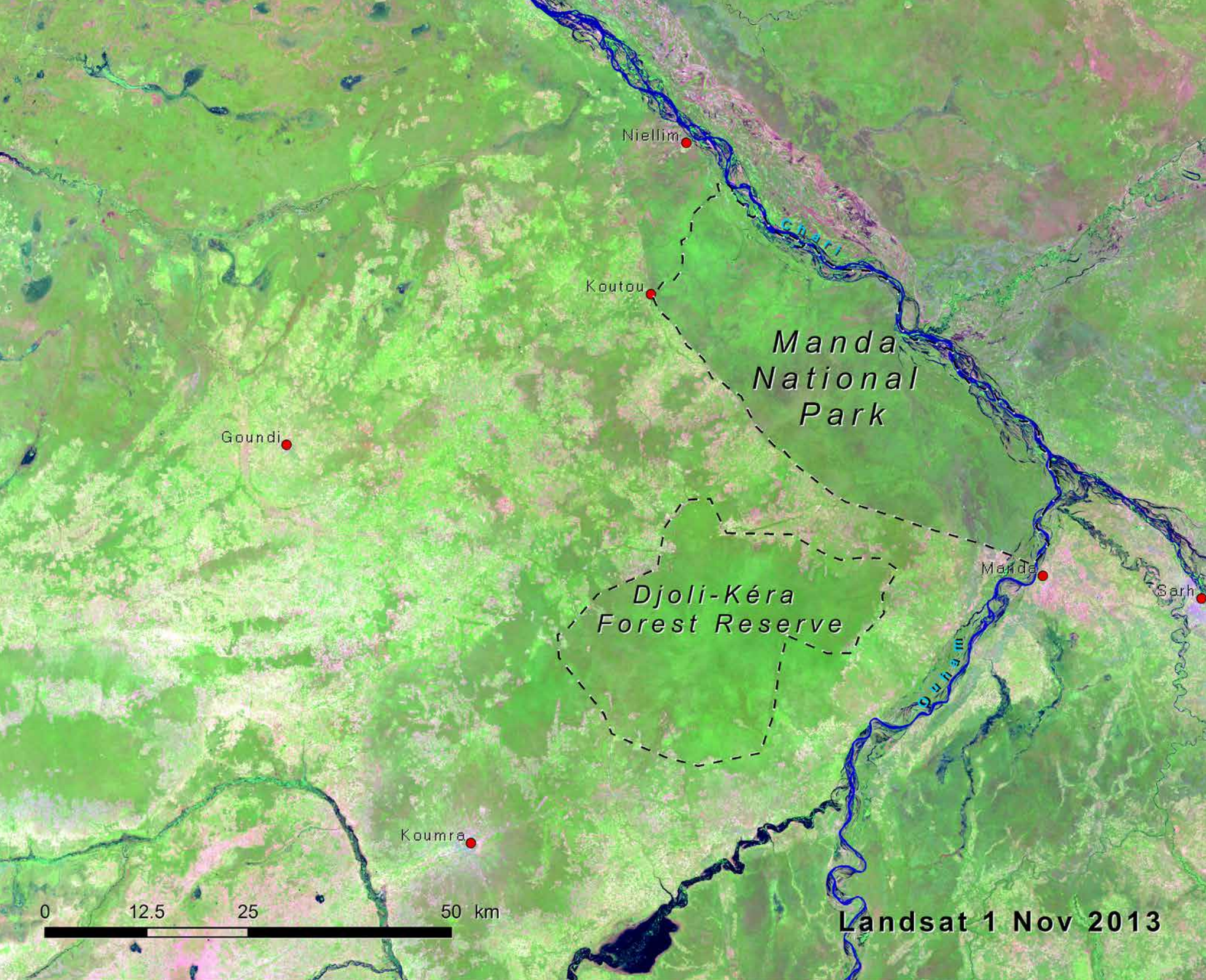


The increasing pressure on natural resources around Manda National Park

As one of the three national parks in Chad, Manda National Park protects a relatively well-preserved stretch of Sudanian savanna ecosystem. Manda constitutes one of the last wildlife refuges in the Middle-Chari region of Chad, but the increasing pressure on natural resources in the surrounding landscapes is threatening the integrity of the park.

Established in 1965, Manda National Park is located in south-central Chad, northwest of Sarh. The park covers about 120 sq km of wooded savanna, woodland, and grassy floodplain. It is bounded on the southwest by the Sarh–N’Djamena road and on the northeast by the Chari River. Rainfall that usually starts in late April causes seasonal flooding by the Chari.

Manda National Park is isolated from most other protected areas, which makes it difficult for wildlife to migrate from the park to other suitable habitats. However, one nearby protected area is the Djoli-Kéra Forest Reserve, a vast unbroken area of Sudanian savannas and woodland. Manda National Park was initially created for the protection of Derby’s eland, but like the African elephant, this species disappeared from the park at the end of 1980s. However, hippopotamuses are still found in the Chari River and small populations of African buffalo, roan antelopes, and a few species of primates persist in Manda National Park (UICN/PACO, 2006).



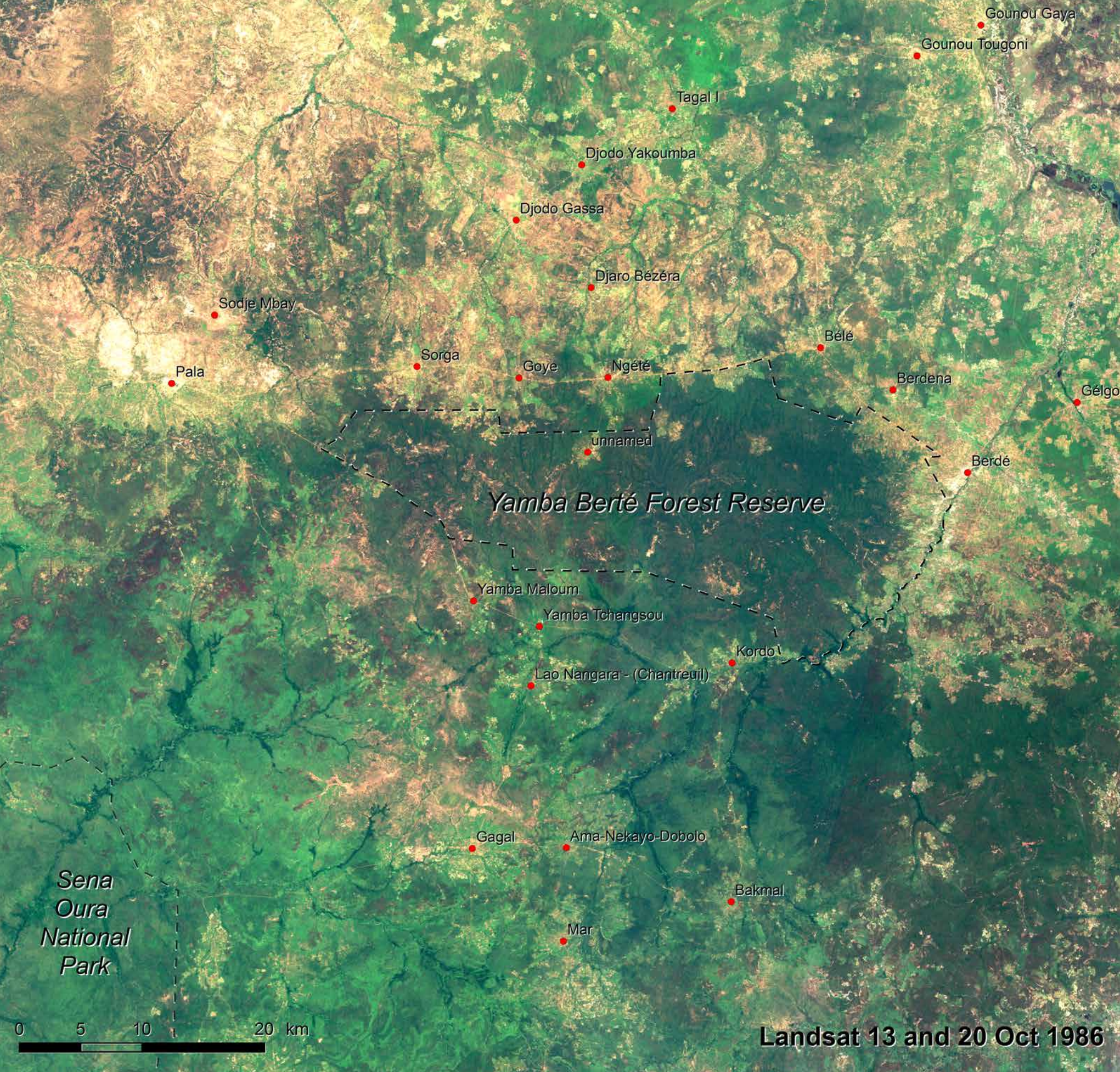
A comparison of satellite images from 1986 and 2013 shows the growing pressure on the land surrounding Manda National Park and the Djoli-Kéra Forest Reserve. According to the land cover maps (see pages 194–195), the landscape was dominated by savanna and woodland in 1975 — agriculture was not well-developed and covered less than 10 percent of the area. Several areas burned by seasonal wildfires are visible across the savanna landscape in the 1986 satellite imagery (dark patches), including parts of Manda National Park. By 2013, cropland covered about 30 percent of the area around the park and the forest reserve. The progression of agriculture came from the west and, so far, has not expanded much east of the Chari River.

Recent interviews conducted among local farmers and local stakeholders by the Centre National d'Appui à la Recherche (CNAR – National Center for Research) indicate that cropland expansion is not only related to the growing population and the associated need to produce more food, but also to land deterioration. Poor land management and recurrent wildfires led to soil deterioration and reduced agricultural yield. As a result, farmers

have been searching for new, fertile land, such as the surroundings of Manda National Park and Djoli-Kéra Forest Reserve. In addition, farmers have been shifting to more lucrative activities, such as timber commercialization or charcoal production (Nougagombe and others, 2012).

Another growing pressure on the land resources in this area is livestock grazing. In recent years, herders have brought their livestock into the park during their seasonal migrations to avoid drought conditions farther north, or because their traditional pasture lands were flooded during the rainy season. Local informants blamed herders for lopping branches to create fences and deliberately setting fires in the savannas to promote early greening and better access to grass shoots. The presence of herders in the park has been the source of several conflicts with farmers and park guards (Nougagombe and others, 2012).

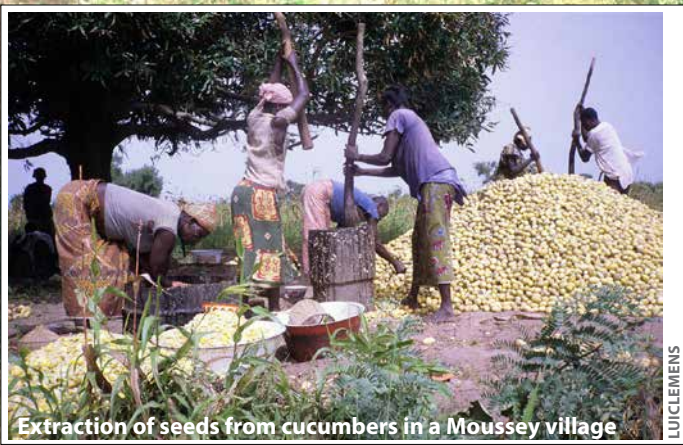
Satellite images show vegetation cover within the park to be relatively stable, but local inhabitants have witnessed a decrease in biodiversity and wildlife populations due to habitat deterioration and heavy poaching.



Yamba Berté Forest Reserve

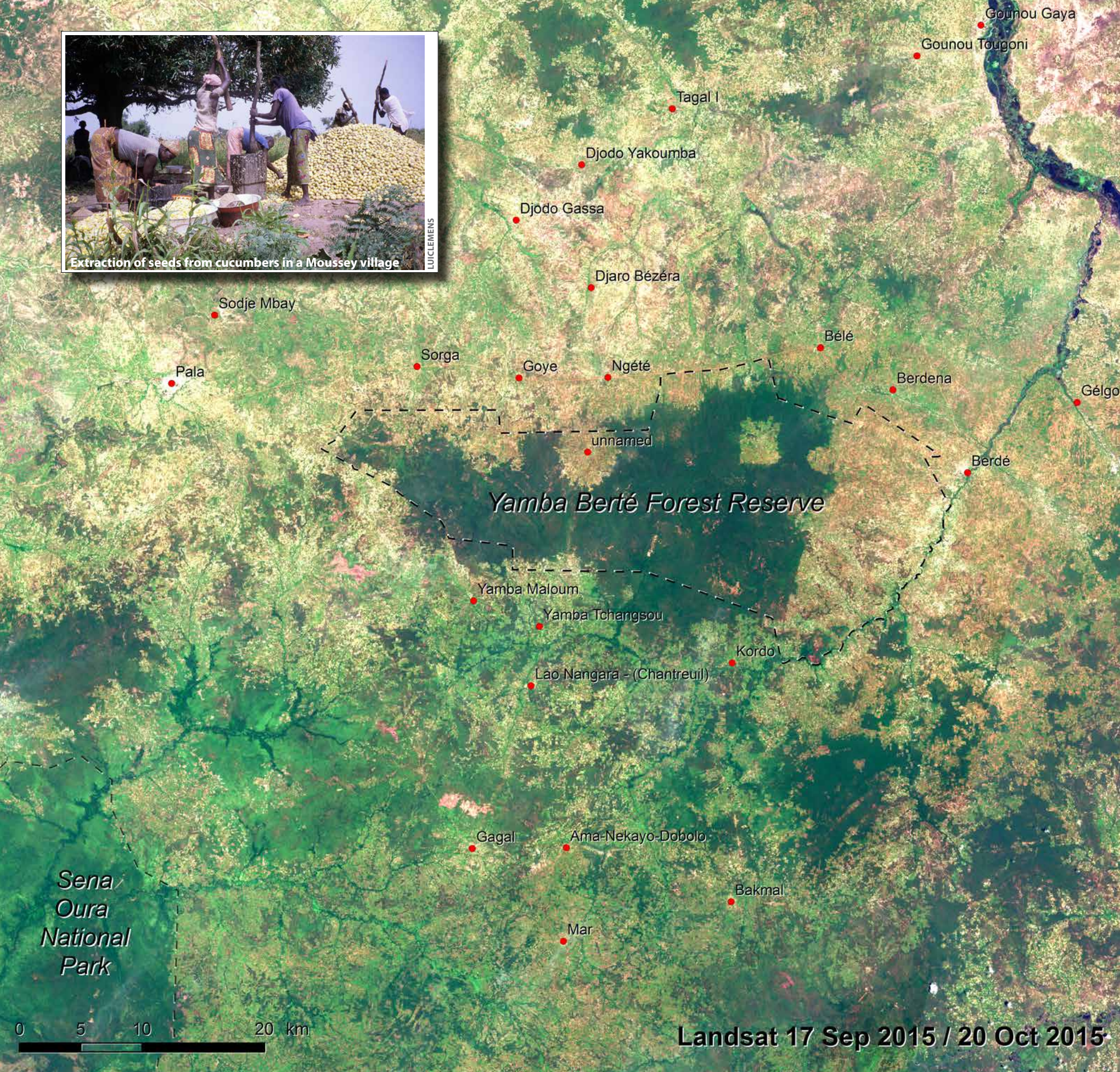
The Yamba Berté Forest Reserve lies in the relatively humid Sudanian Region of southwestern Chad. The reserve protects an island of relatively intact dense shrub savanna, gallery forests, wetlands and small lakes (GEF, 2004). Forests including African mahogany, néré, doka, tamarind, African copaiba balsam and shea trees provide good habitat for a variety of fauna including gazelles, eland and other antelope as well as monkeys, ostrich, giraffe and possibly some of Chad's remaining savanna elephants, among others (Chaintreuil and Conteau, 2000; IUCN, 2015). The reserve's proximity to Sena Oura National Park and the adjacent Bouba Ndjida National Park in Cameroon with patches of intact forest between the two areas has historically made up a much larger area of contiguous habitat. The amount of intact forest remaining in the area between the national parks and Yamba Berté has declined between the dates of the two satellite images above.

Rainfall in the area averages around 1,000 mm per year, but in the long term it is quite variable having been as low as 600 mm and as high as 1,400 mm between 1971 and 2006. While the area is considered quite good for



Extraction of seeds from cucumbers in a Moussey village

LUICLEMENS



agriculture, as in many areas of the Sudanian Region, farmers have to cope with this interannual variability, compounded by uneven spatial and temporal distribution of rains (Sougnabé, 2013). In part due to the in-migration attracted by the good farming and herding conditions, the population just in the area shown in the above images has grown from around 700,000 in 1990 to an estimated 1,490,000 in 2015 (CIESIN, 2005). Most of this population makes its living by farming or a combination of farming and herding (Sougnabé, 2013). In addition to subsistence crops such as maize millet and sorghum, the area is ideal for growing cotton and groundnuts, the two primary cash crops in the area (FEWSnet, 2005).

The growing demand for land has led to encroachment on the forest reserve with two villages clearly visible in the 2015 satellite image, and many areas of encroachment around the perimeter of the reserve. Additional pressures on the forest include charcoal production, poaching and grazing of livestock. There are reports of at least two instances of oil exploration work in the area of Yamba Berté since 2003 (Oyamta and others, 2013). In the 1970s over 85 percent of the area shown in the above images was shrub savanna and less than 7 percent was agriculture. By 2013 only about 39 percent of the same area was intact shrub savanna, while the area being farmed had grown to just under 54 percent.



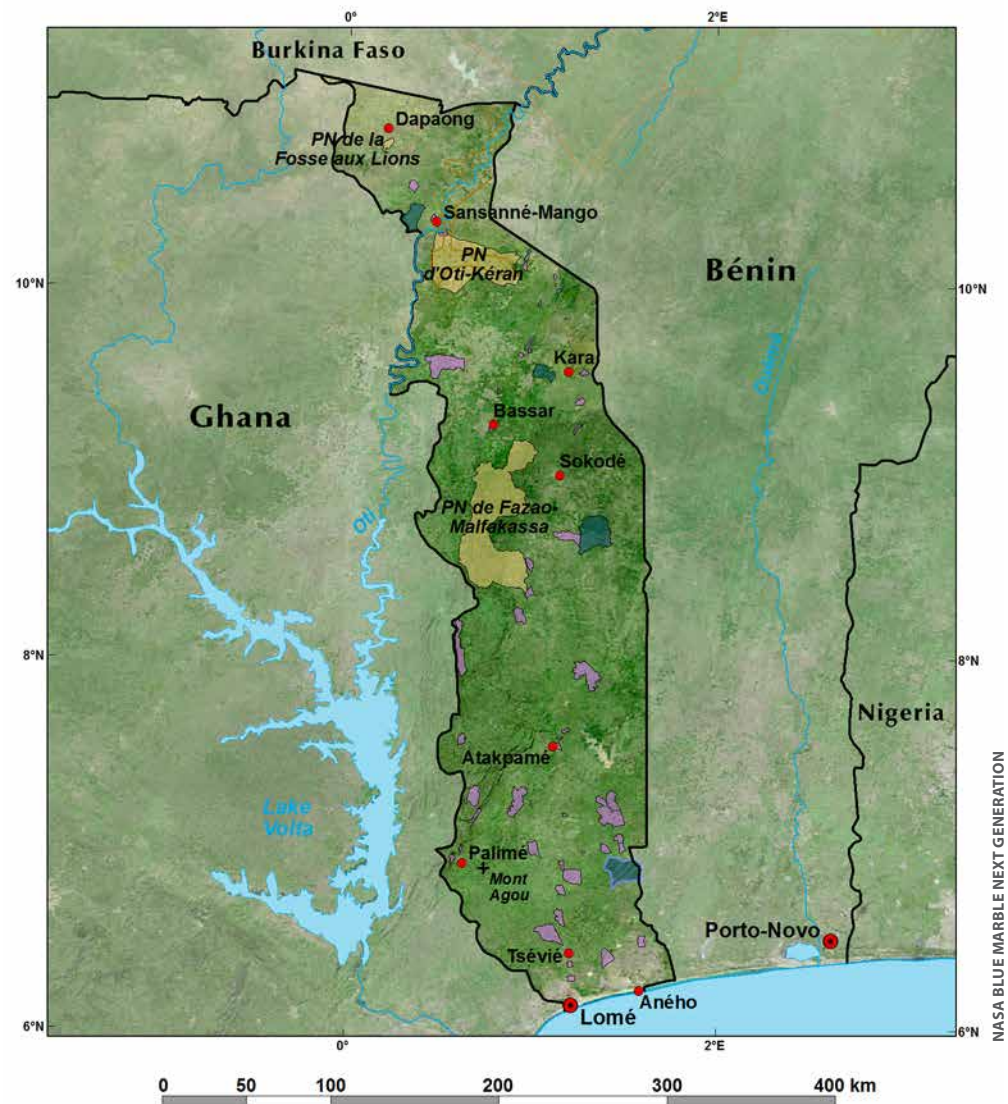
Togolese Republic

Total Surface Area: 56,785 km²
Estimated Population in 2013: 6,929,000

Togo is one of the smallest countries of West Africa. Nevertheless, Togo has a variety of landscapes and straddles several bioclimatic regions. Northern Togo is characterized by the seasonal Sudanian climate, with a single rainy season. Woodlands and savannas still predominate in the north, but they are losing ground to agriculture. This region is exposed to dry Harmattan winds and prone to drought. The Atacora Mountain range crosses central Togo, with more wooded landscapes, and a few isolated remnants of dense tropical forest. These forest relicts form the eastern limit of the Upper Guinean forest ecosystem. The southern half of Togo falls into the Guinean climatic region, characterized by two rainy seasons. The coastal area, however, is part of the Dahomey Gap, a relatively dry savanna zone that separates the high rainfall regimes outside of Togo to the east and west. The coast receives an average of only 900 mm of rainfall per year. Agriculture and mining are key economic activities in Togo. Food crops and cash crops such as cocoa, coffee, and cotton are the main sources of income for 80 percent of the population. Togo is also one of the world's five leading producers of phosphates.

Environmental Highlights

- High rate of agricultural expansion
- Fragmentation and loss of natural landscapes
- Soil degradation
- Coastal erosion

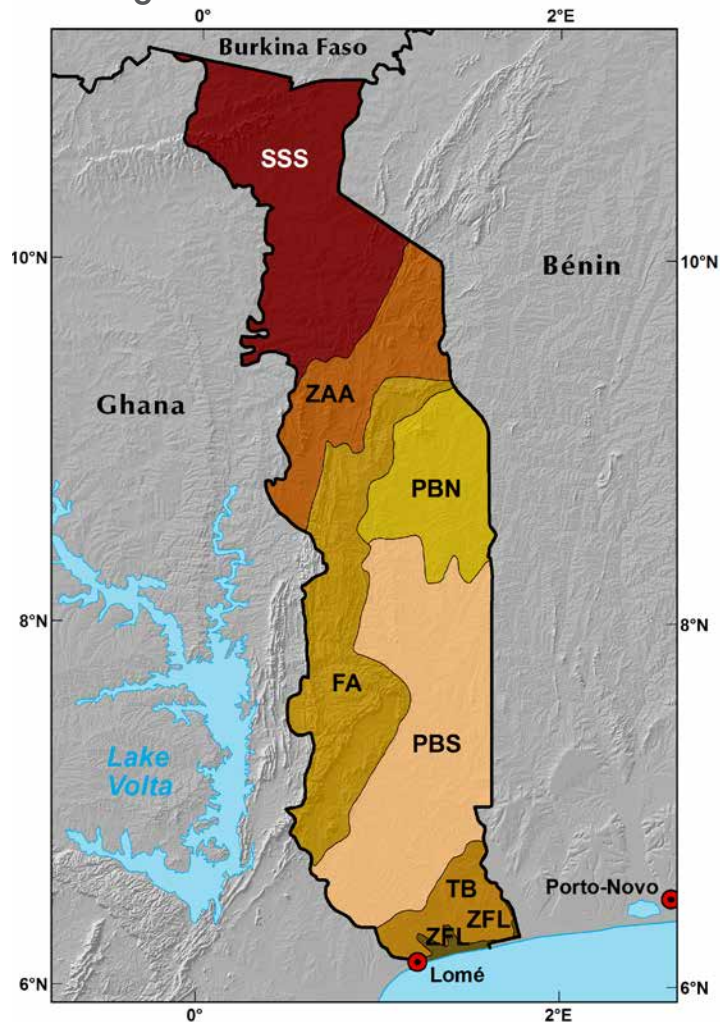


- Réserve de Biosphère / Biosphere Reserve
- Site Ramsar / Ramsar Site
- Parc National / National Park
- Réserve de Faune / Faunal Reserve
- Forêt Classée / Forest Reserve
- Capitale Nationale / National Capital
- Autre Ville / Other City



Landscape east of Dapaong, northern Togo

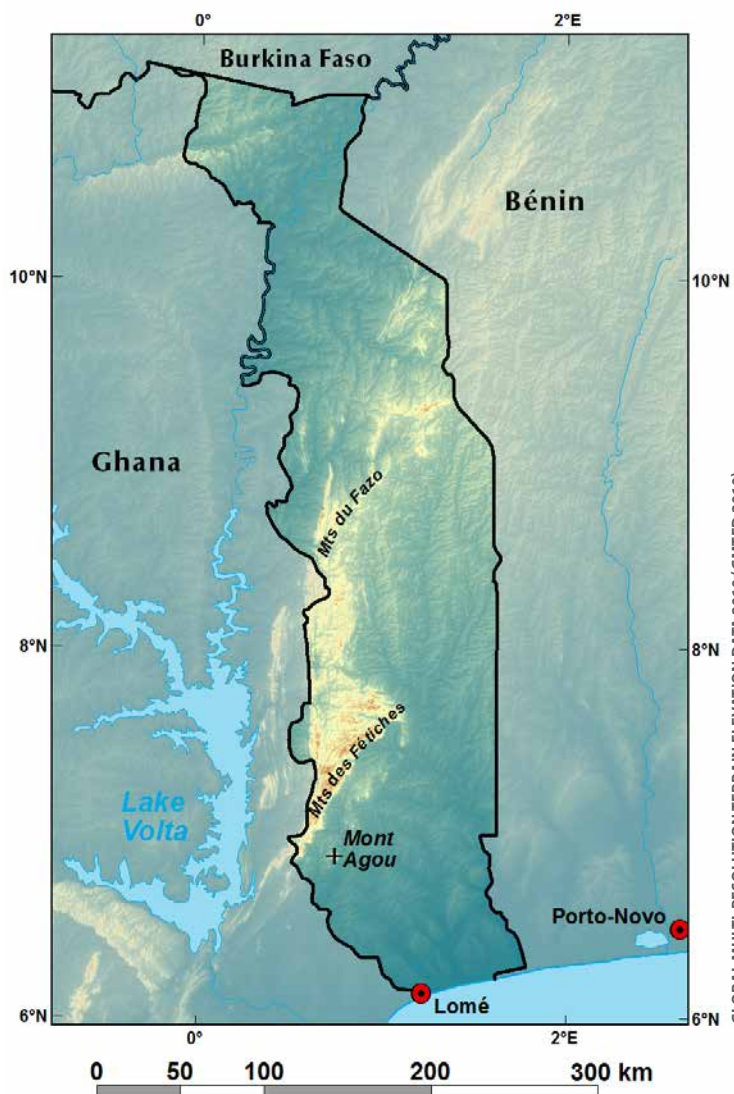
Ecoregions



- FA Forêt sur Atakora
- PBN Pénéplaine bénino-togolaise nord
- PBS Pénéplaine bénino-togolaise
- SSS Savane Soudanienne
- TB Terre de Barre
- ZAA Zone Agro-pastorale de
- ZFL Zone Fluvio-lagunaire

With the exception of the Atakora Mountain range, Togo's topography is one of gently rolling hills, shallow valleys, and two large alluvial plains. The chaîne de l'Atakora (FA – Atakora range), where natural forest and savanna landscapes can still be found, cuts diagonally across the central part of the country. Northern Togo — the Savane Soudanienne Sèche ecoregion (SSS – Dry Sudanian Savanna) — has become predominantly agricultural. Just south, a broad plain with the meandering Oti River is the setting for a large national park. In the country's southern half, Togo's agro-pastoral region (ZAA) and plateau regions (PBS and PBN) are characterized by a patchwork of savannas, gallery forest, and cropland. Here, too, there is extensive expansion of croplands, supplanting the natural vegetation cover. In the coastal plain, the zone Fluvio-lagunaire (ZFL – Fluvio-lagoon zone), with its complex of lagoons and swamps, is bordered by the Terre de Barre (TB), a plateau of ferruginous and clay soils, often covered by large palm plantations.

Shaded Relief

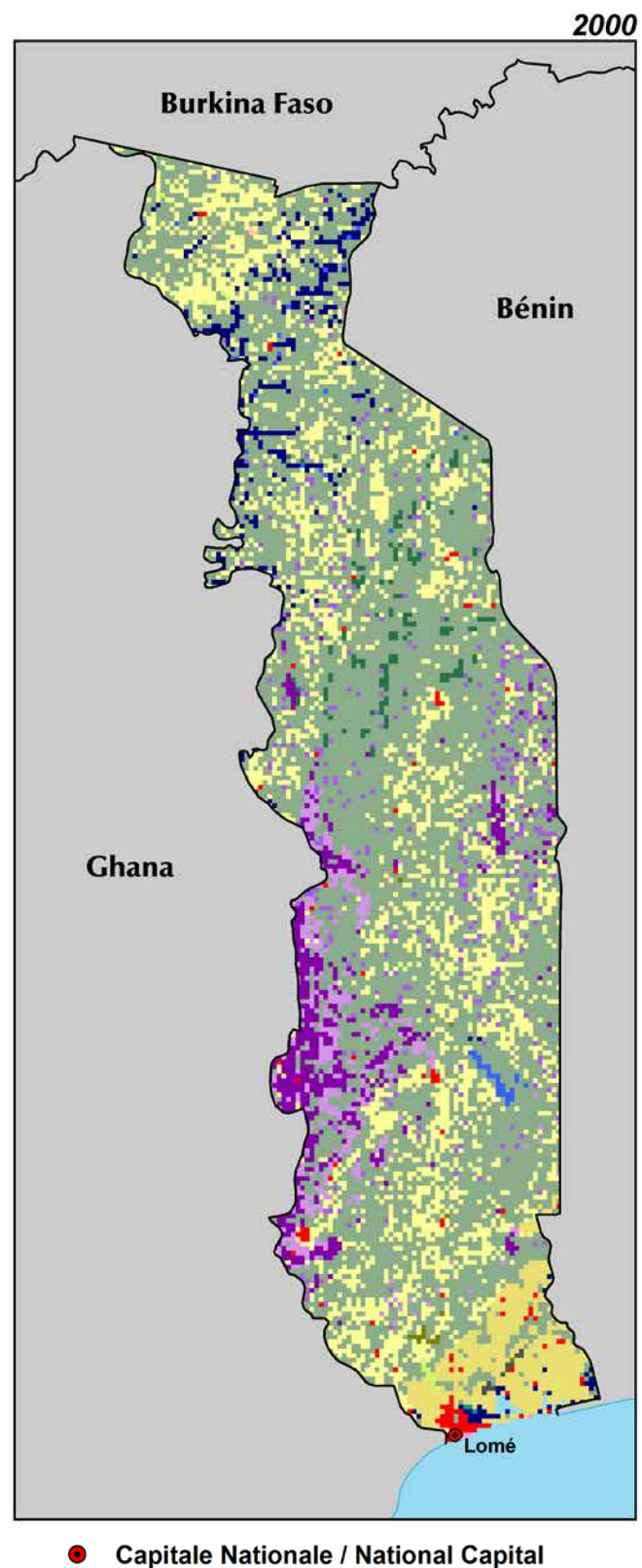
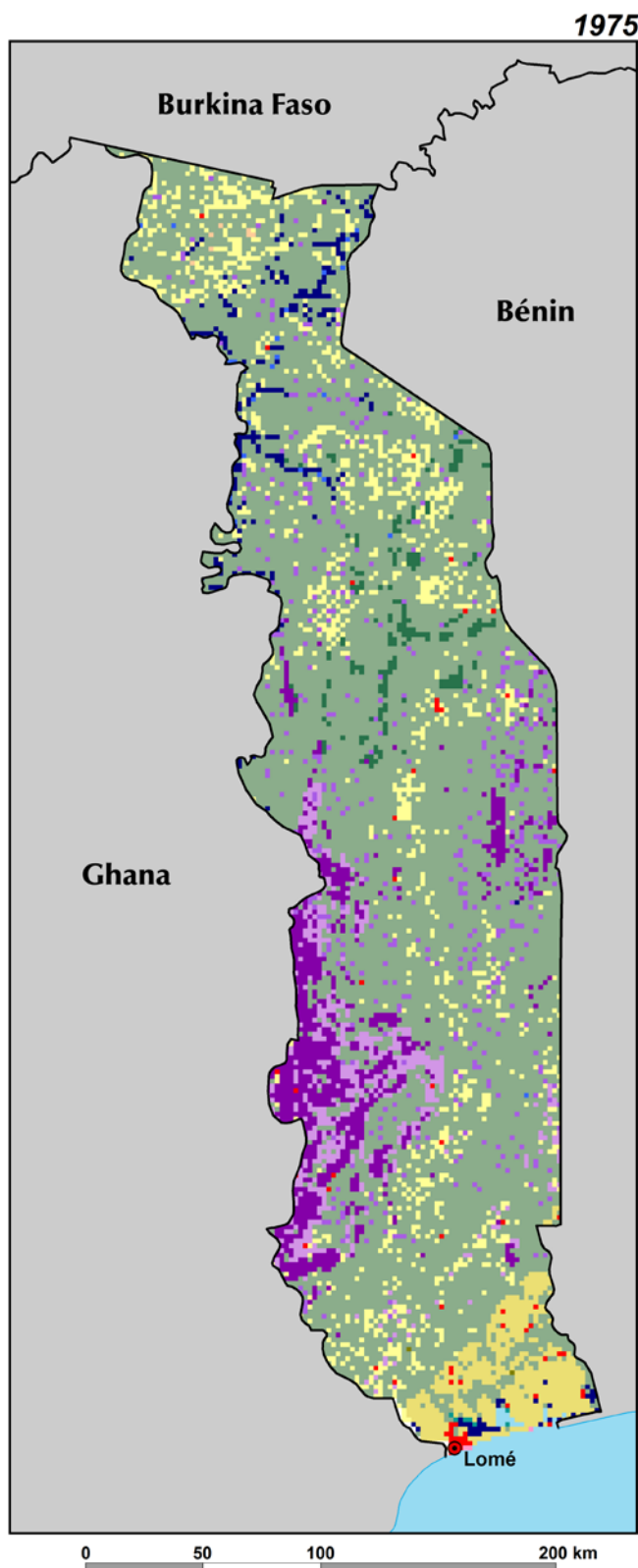


- Élevée / High
- Faible / Low



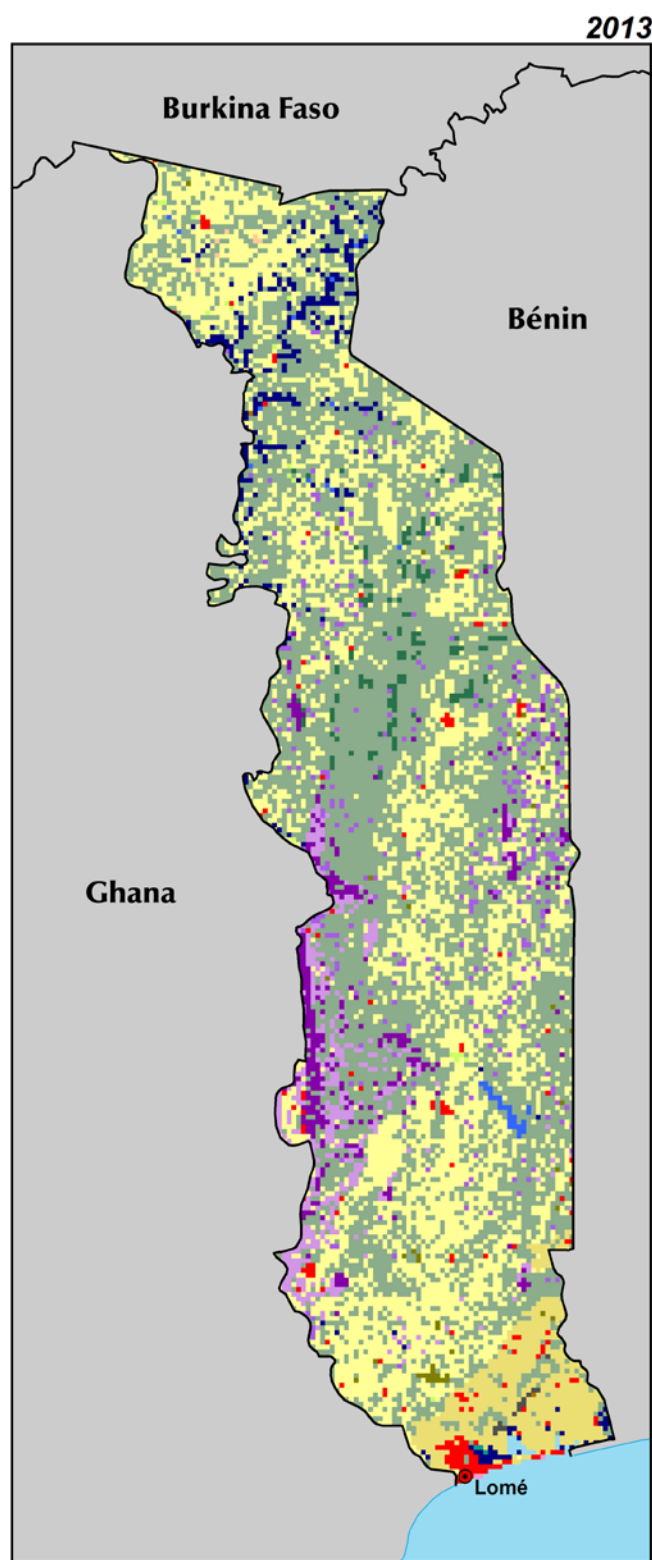
Steep slopes of the Monts de Défalé, with gallery forest.

Land Use, Land Cover and Trends



Although savannas remain the dominant feature in Togo's landscapes, agricultural expansion has greatly changed land cover in all parts of the country. In 1975, savannas covered 70 percent of Togo, and cultivated areas were mainly found around urban settlements and along the major roads. Between 1975 and 2013, agriculture increased by 14,000 sq km, or 266 percent. Togo's 7 percent annual expansion rate over this time period ranks as the highest in West Africa. Agricultural expansion occurred at the expense of natural ecosystems such as savannas, woodlands, and gallery forests. The natural landscapes have also become highly fragmented, further degrading ecosystem services. Cultivation has extended beyond the country's most suitable land and is now encroaching into areas of marginal soils. Furthermore, croplands encroach on most protected zones in Togo, including the Oti-Kéran National Park.

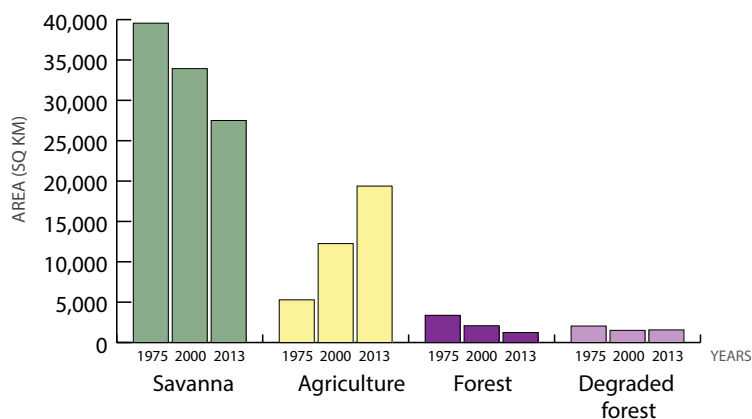
The Forêt de l'Atacora (FA – Atacora Forest), which was largely intact in 1975, has experienced a large incursion of cropland, in particular around the towns of Kpalimé and Atakpamé. Dense tropical forest that accounted for 5.9 percent of Togolese land surface in 1975 has now been reduced by half. The deforestation rate in the past decade appears not to have slowed. Without protection initiatives, the current rate will lead to the complete disappearance of Togo's forests by 2025. Degraded forests and gallery forests are also succumbing to deforestation and have decreased by 21 percent and 36 percent, respectively, between 1975 and 2013. Forest disappearance is particularly worrisome because it reduces biodiversity and negatively impacts a variety of ecosystem services that benefit humans. These trends of land cover and land use changes stem directly from the increasing pressure on natural resources driven by population growth.



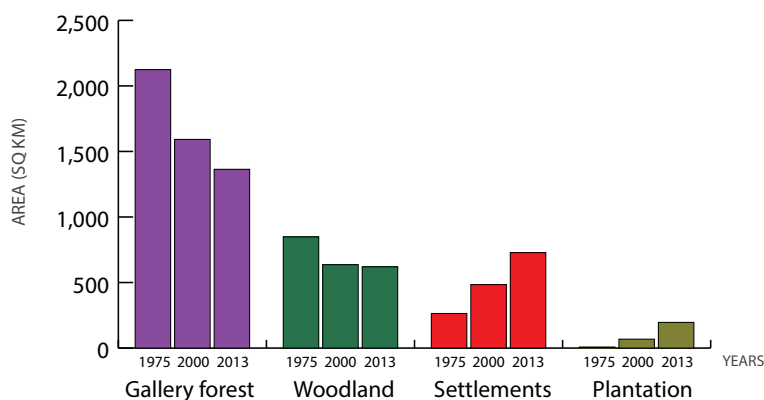
Occupation des Terres / Land Cover

- Forêt / Forest
- Forêt galerie & formation ripicole / Gallery forest & riparian forest
- Forêt dégradée / Degraded forest
- Forêt claire / Woodland
- Savane / Savanna
- Savane herbacée / Herbaceous savanna
- Steppe
- Zone de culture / Agriculture
- Cultures irriguées / Irrigated agriculture
- Cultures et jachère sous palmier à huile / Cropland and fallow with oil palms
- Plantation
- Habitation / Settlements
- Sols dénudés / Bare soil
- Terrains rocheux / Rocky land
- Surfaces sableuses / Sandy area
- Carrière / Open mine
- Plans d'eau / Water bodies
- Prairie marécageuse - vallée inondable / Wetland - floodplain

Large area classes

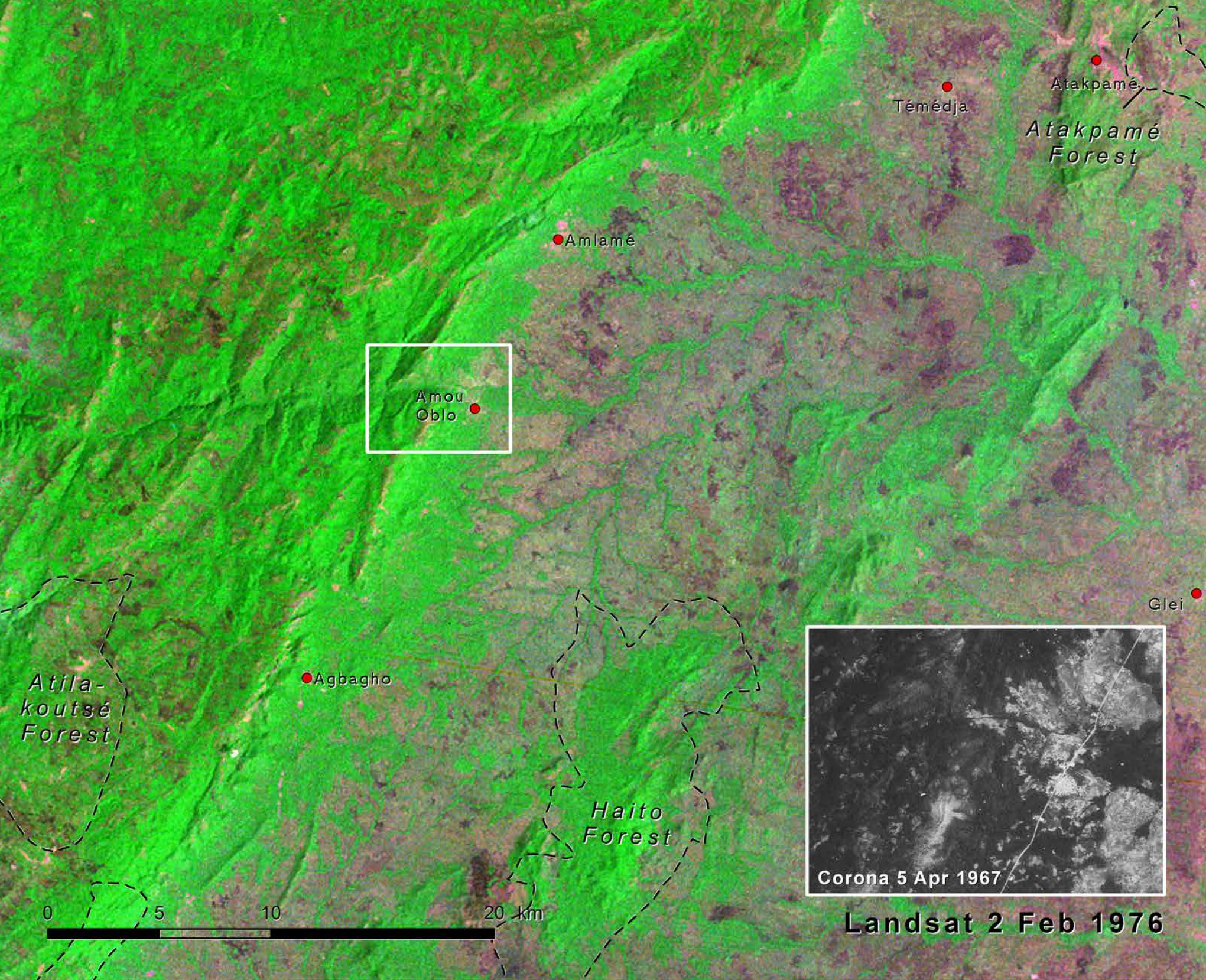


Small area classes



Togo's population grew from 2.4 to 6.9 million between 1975 and 2013, a 288 percent increase. Similarly, the area of Togo's cities and towns increased 176 percent.

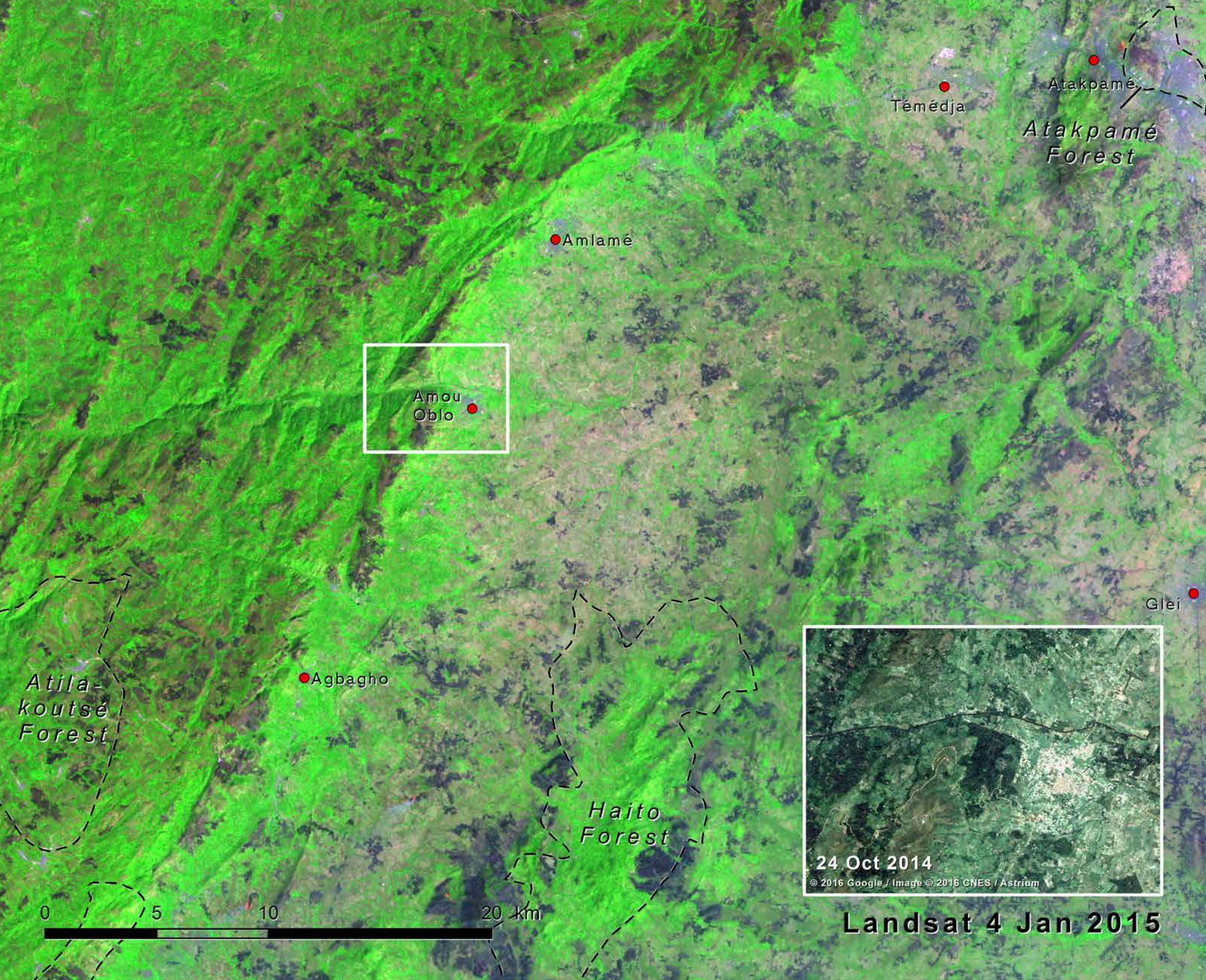
At a more local scale, irrigated agriculture and land devoted to plantations have also greatly increased. Irrigated agriculture hardly existed in Togo in 1975; it grew to 108 sq km in 2013. Plantations, formerly concentrated in coastal areas, have expanded greatly over the 38 years, covering almost 200 sq km in 2013. In contrast, wetlands in the Oti River floodplain were quite limited in 1975, owing to years of drought. They increased by 44 percent between 1975 and 2000 and have remained quite stable since then.



Natural Resources Degradation in the Plateaus Region of Togo

Togo lies in the Dahomey Gap, the part of the forest-savanna mosaic that separates the Upper Guinean forest zone to the west from the Guineo-Congolian forest region to the east. Home to the easternmost fringe of remaining Upper Guinean forest, the Plateaus region has the second largest concentration of people in Togo, after the Maritime region where the capital, Lomé, is located. It was subjected to major deforestation as a result of the socio-political turmoil in the 1990s. Forests have always been rare in Togo, yet in rural areas, more than 80 percent of the local communities use firewood for cooking and fuel. The lack of sound forest management has resulted in overharvesting for woodfuel, building materials, and other forest products. Because the laws consider forest products to be equivalent to other agricultural products, management objectives tend to favor economics, rather than the ecological role of the forests (USAID, 2008).

The pair of satellite images illustrates the drastic deforestation that has occurred over the past 40 years in the Amou prefecture of the Plateaus region, at the edge of the Fétiches Mountains range. In 1976, more than half the area was covered by forested habitats (28 percent forest, 22 percent degraded forest, and 3 percent gallery forest). Dense and degraded forests occupied most of the mountainous zones; a mosaic of savanna (43 percent) and cropland (4 percent), interspersed by thick gallery forests, blanketed most of the lowland. By 2015, unregulated use and exploitation had reduced forest areas by 76 percent, replaced mostly by savanna and degraded forest. Deforestation also occurred within protected forests, with major incursions from agriculture and growing settlements. Within the image area, cropland area increased by a factor of 11 between 1976 and 2013, and is now the dominant land cover. Cultivation of coffee, cocoa, and cotton, as well as subsistence farming, has cleared large tracts of land,



replacing the semi-natural landscapes with large-scale commercial agriculture (see insets) (Tchamie, 2000). The gallery forests that followed lowland watercourses were decimated. The darker areas visible on the 2013 Landsat image are burn scars from bush fires, ignited accidentally or intentionally for such uses as agricultural clearing or hunting. Burning occurs over large areas each dry season. These fires can degrade forested habitats, reducing their suitability as habitat for wildlife.

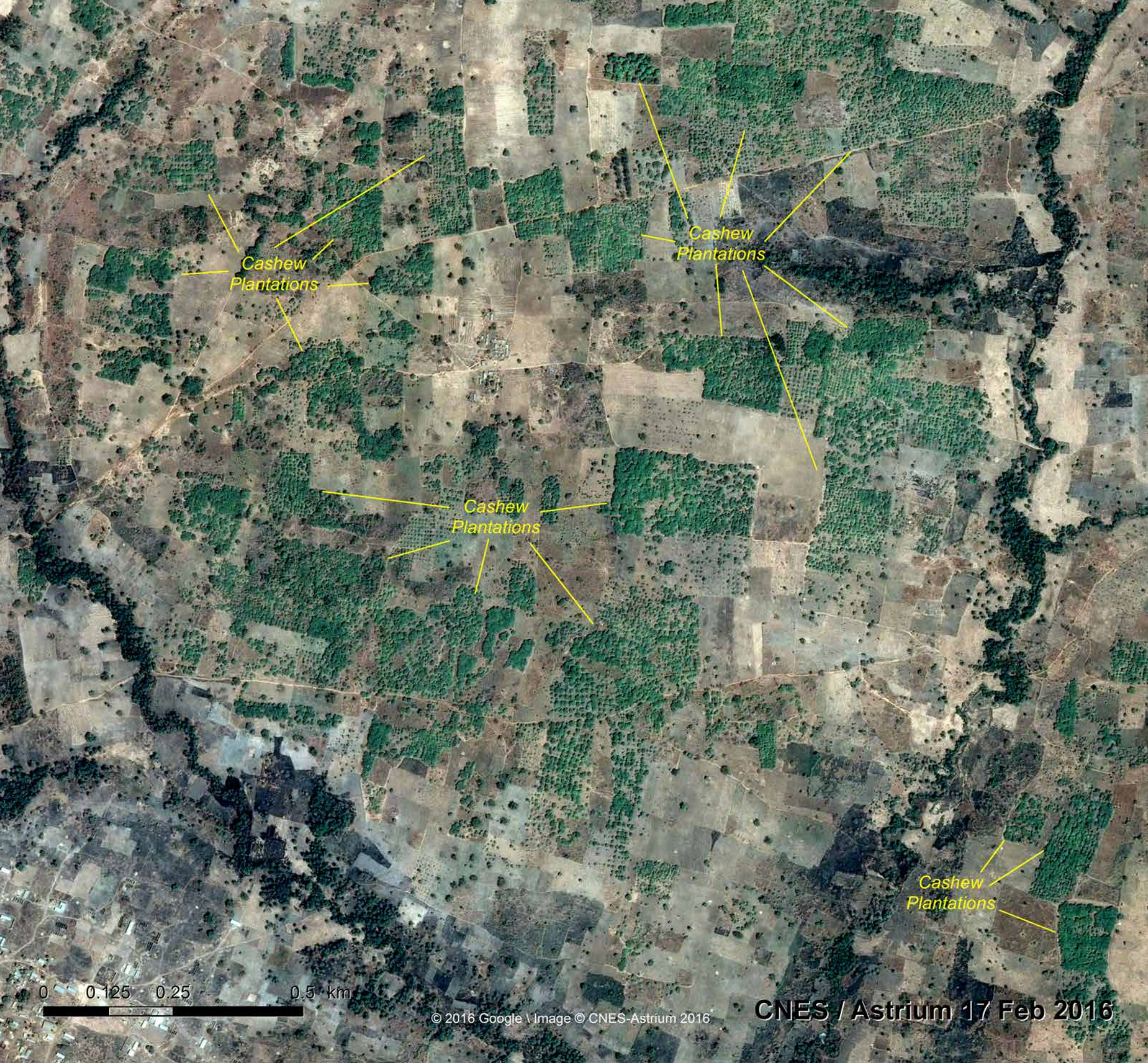
There are numerous forest “islands” throughout Togo, used by local people to perform ceremonies (Kokou, 2008). Many are considered sacred forests which also play an important role as isolated islands of biodiversity. The sacred forests are used for gathering firewood and medicinal products, and in some cases for hunting. Overexploitation of the sacred forests has reduced many in size and ecological complexity. Introduced species are replacing the native vegetation in some locations. Changing cultural and religious traditions are also leading to the abandonment or conversion of sacred forests to other uses, such as agriculture (USAID, 2008).

Forestry development, bush fires, and intensive land clearing, as well as the abusive exploitation of natural resources for human consumption, trade, and tourism, together constitute the principal pressures on the natural resources in the Plateaus region of Togo (Tchamie, 2000). The government and local organizations are now promoting reforestation in the Plateaus region, but the trees being planted are often non-native, high value species, such as the teak and eucalyptus (Kokou, 2008). Despite these efforts, the deforestation rate remains high.



GEOFF LIVINGSTON/FOTER.COM/CC BY-NC-SA

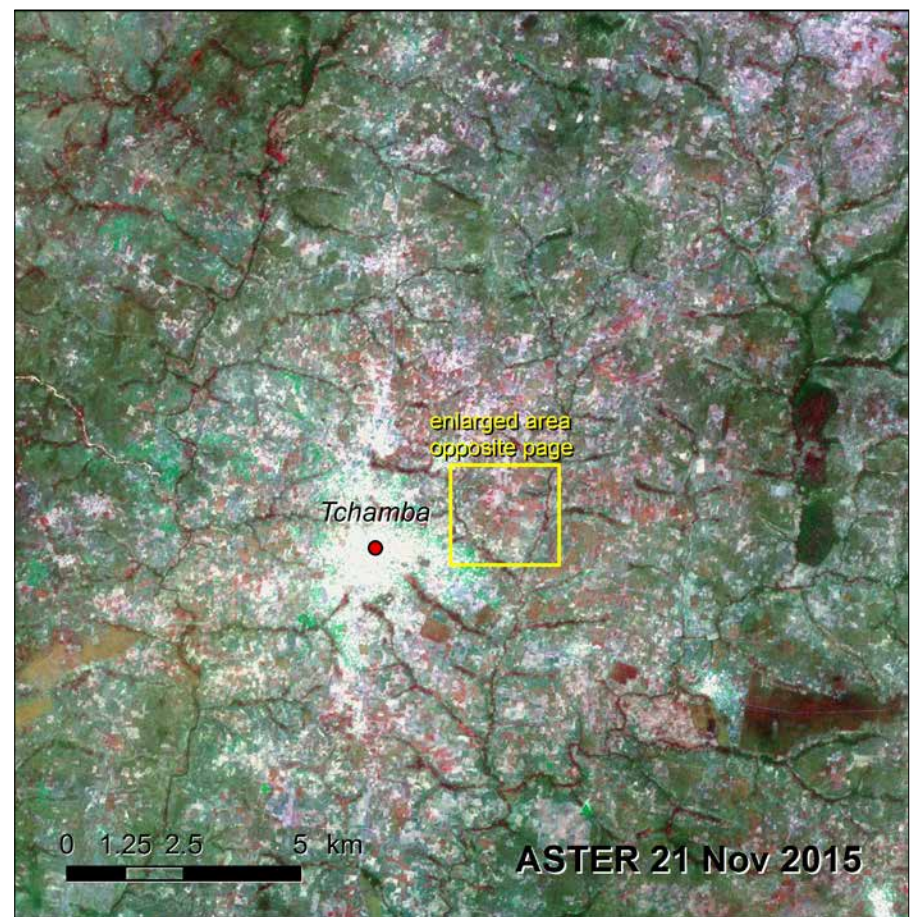
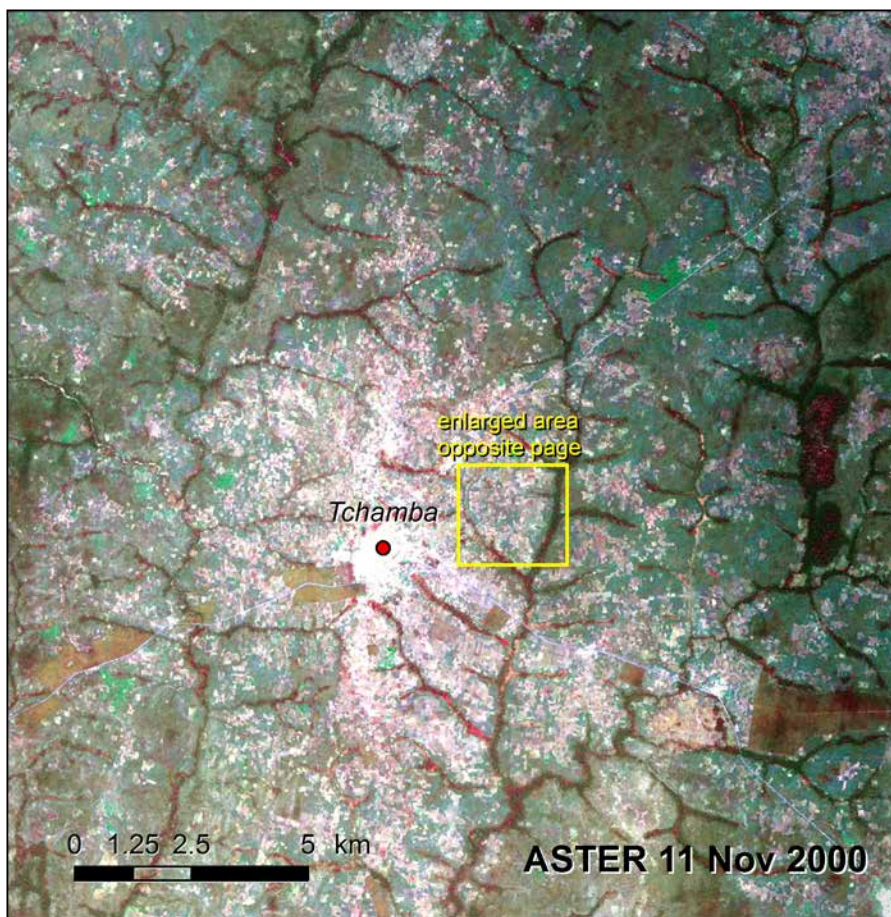
Coffee plant



Forest loss and sustainable agriculture in Tchamba Prefecture

The natural landscapes of Tchamba Prefecture in central Togo are mostly West Sudanian savanna — a mix of savanna, woodland, gallery forests, and some patches of denser forest. Much of the prefecture, including the area surrounding Tchamba town, experienced heavy deforestation during the 1990s as the area's growing population cut trees for timber and energy, and converted areas of wooded savanna to farm fields. In an analysis of land cover changes between 1990 and 2010 conducted by Togolese government agencies and the University of Lomé, Togo measured an 18 percent loss of forest and 7 percent loss of woodland primarily to expanding areas of agriculture, residential growth and bushland (Kokou and others, 2012). However, recent trends measured by analysis of MODIS satellite data show some encouraging signs. Primary productivity (a measure of plant growth, see pages 38–41) showed a positive trend between 2000 and 2010 in some parts of Tchamba Prefecture.

The ASTER image pair (opposite page, top) is focused on one of these positive developments. It reveals several areas of increased woody cover between 2000 and 2015 in the area surrounding Tchamba town. The high-resolution



ISSIFOU ALFARI/AGRHYMET

KOKOU AND OTHERS, 2012

image (opposite page) shows in greater detail what is behind this positive trend. Many of the areas that were being intensely farmed in 2000 with annual crops such as maize, sorghum, millet, rice, peanuts, cowpeas, soybeans, yams, cassava, sweet potatoes and cotton (Kokou and others, 2012) are now covered in trees. In many cases these are small-holder cashew plantations which use a system of integrating annual crops between the cashew trees (Tandjiékpon, 2010). As the trees mature and the amount of light reaching the annual crops diminishes, the crops change from cotton, yams and maize to crops that require less light. This intercropping system has been shown to be profitable for farmers, and the cashew trees help to restore degraded soils and sequester carbon (Opoku-Ameyaw and others, 2011; ACI 2010; Temudo and Abrantes 2014).

Agriculture directly or indirectly employs most of Tchamba Prefecture's population but has been the cause of dramatic unsustainable land cover change over the past decades. Finding sustainable strategies for meeting the development needs of local people while still preserving productive soils and important ecosystem services, biodiversity, natural heritage and beauty of the savanna landscape is a major challenge for Togo's policy makers. The successful intercropping of cashew and food crops may provide both short-term profits and long-term environmental benefits (Opoku-Ameyaw and others, 2011). In addition, a cashew processing facility was built in Tchamba town in 2005 and is providing hundreds of jobs and bringing new economic development to the community (African Cashew Alliance, 2013; Kokou and others, 2012).

References

FOLLOWING DATA SOURCES HAVE BEEN USED FOR:

Country boundaries:

Natural Earth, 2016, Admin 0 – Countries, Natural Earth at <http://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-admin-0-countries/>.

Population estimates:

United Nations, 2015, World Population Prospects: The 2015 Revision, United Nations, Department of Economic and Social Affairs, Population Division at <http://esa.un.org/unpd/wpp/dataquery>.

Rainfall maps:

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., and Hoell, A., 2015, The climate hazards infrared precipitation with stations — a new environmental record for monitoring extremes: *Scientific Data*, v. 2.

General reference maps:

Stöckli, R., Vermote, E., Saleous, N., Simmon, R., and Herring, D., 2005, The Blue Marble Next Generation—a true color earth dataset including seasonal dynamics from MODIS (NASA Earth Observatory): NASA Earth Observatory at <http://earthobservatory.nasa.gov/Newsroom/BlueMarble>

Shaded relief maps:

Danielson, J.J., and Gesch, D.B., 2011, Global multi-resolution terrain elevation data 2010 (GMTED2010), U.S. Geological Survey.

CHAPTER I :

Adam, J., 1966, Composition floristique des principaux types de végétation du Sénégal: *Journal of West African Science Association*, v. 11, p. 81-97.

Adepoju, A., 2003, Migration in West Africa: *Development*, v. 46, no. 3, p. 37-41.

AFROL, 2002, Mangroves of Western Africa threatened by Global Warming: *Afrol News* at http://www.afrol.com/Categories/Environment/env019_mangroves_threatened.htm

Arbonnier, M., 2002, Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest: Editions Quae.

Aubréville, A., 1938, La forêt coloniale: les forêts de l'Afrique occidentale française: Société d'éditions géographiques, maritimes et coloniales.

Bâ, A.T., Sambou, B., Ervik, F., Goudiaby, A., and Camara, C., 1997, Végétation et flore: Parc Transfrontalier Niokolo Badiar.

Bakarr, M., Oates, J., Fahr, J., Parren, M., Rödel, M.-O., and Demey, R., 2004, Guinean forests of West Africa, Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions: CEMEX & Conservation International, p. 123-130.

Beauchemin, C., 2005, Pour une relecture des tendances migratoires entre villes et campagnes: une étude comparée Burkina Faso-Côte d'Ivoire: *Etudes de la Population Africaine/African Population Studies*, v. 20, no. 1, p. 141-165.

Blanc, J., 2008, *Loxodonta africana*, IUCN Red List of Threatened Species, IUCN at <http://dx.doi.org/10.2305/iucn.uk.2008.rlts.t12392a3339343.en>.

Bossard, L., 2009, *West African Studies Regional Atlas on West Africa*: OECD Publishing.

Botoni, E., and Reij, C., 2009, La transformation silencieuse de l'environnement et des systèmes de production au Sahel: Impacts des investissements publics et privés dans la gestion des ressources naturelles: Ouagadougou, Burkina Faso et Amsterdam, The Netherlands, Comité Permanent Inter Etats pour la Lutte contre la Sécheresse au Sahel et Vrije Universiteit Amsterdam.

Brcic, T.M., Amarasekaran, B., and McKenna, A., 2010, Sierra Leone National Chimpanzee Census September, Sierra Leone Chimpanzee Rehabilitation Programme: Freetown, Sierra Leone, Tacugama Chimpanzee Sanctuary at http://tacugama.com/downloads/SLNCCP_Final_Report_TCS_Sep2010.pdf.

Church, R.J., 1966, *West Africa: a study of the environment and of man's use of it*: Longman's, Green and Co., Ltd.

CIESIN, 2005, Gridded population of the world version 3 (GPWV3): population density grids: Palisades, NY, Columbia University, Socioeconomic Data and Applications Center (SEDAC) accessed January 11, 2016, at <http://sedac.ciesin.columbia.edu/gpw>.

Clerici, N., Bodini, A., Eva, H., Grégoire, J.-M., Dulieu, D., and Paolini, C., 2007, Increased isolation of two Biosphere Reserves and surrounding protected areas (WAP ecological complex, West Africa): *Journal for Nature Conservation*, v. 15, no. 1, p. 26-40.

Cohen, J.E., 2003, Human Population: The Next Half Century: *Science*, v. 302, no. 5648, p. 1172-1175, at <http://dx.doi.org/10.1126/science.1088665>.

Corcoran, E., Ravilious, C., and Skuja, M., 2007, Mangroves of western and central Africa: UNEP/Earthprint 26.

Cormier-Salem, M.C., and Panfil, J., 2016, Mangrove reforestation: greening or grabbing coastal zones and deltas? Case studies in Senegal: *African Journal of Aquatic Science*, v. 41, no. 1, p. 89-98, at <http://dx.doi.org/10.2989/16085914.2016.1146122>.

Cour, J.-M., and Snrech, S., 1998, Preparing for the future: A vision of West Africa in the year 2020: OECD - Club Sahel.

De Jong, S.M., Bagre, A., Van Teeffelen, P.B., and Van Deursen, W.P., 2000, Monitoring Trends in Urban Growth and Surveying City Quarters in Ouagadougou, Burkina Faso Using SPOT-XS: *Geocarto International*, v. 15, no. 2, p. 63-70.

Dudley, N., 2008, Guidelines for applying protected area management categories, IUCN at <http://dx.doi.org/10.2305/iucn.ch.2008.paps.2.en>.

Durant, S.M., Wachter, T., Bashir, S., Woodroffe, R., De Ornellas, P., Ransom, C., Newby, J., Abáigar, T., Abdelgadir, M., El Alqamy, H., Baillie, J., Beddiat, M., Belbachir, F., Belbachir-Bazi, A., Berbash, A.A., Bemadjim, N.E., Beudels-Jamar, R., Boitani, L., Breitenmoser, C., Cano, M., Chardonnet, P., Collen, B., Cornforth, W.A., Cuzin, F., Gerngross, P., Haddane, B., Hadjeloum, M., Jacobson, A., Jebali, A., Lamarque, F., Mallon, D., Minkowski, K., Monfort, S., Ndoassal, B., Niagate, B., Purchase, G., Samaila, S., Samna, A.K., Sillero-Zubiri, C., Sultana, A.E., Stanley Price, M.R., and Pettorelli, N., 2013, Fiddling in biodiversity hotspots while deserts burn? Collapse of the Sahara's megafauna: *Diversity and Distributions*, v. 20, no. 1, p. 114-122, at <http://dx.doi.org/10.1111/ddi.12157>.

Fairhead, J., and Leach, M., 1996, *Misreading the African landscape: society and ecology in a forest-savanna mosaic*: Cambridge University Press.

FAO, 1983, *Integrating crops and livestock in West Africa*: Rome, Food and Agriculture Organization of the United Nations.

FAOstat, 2015, *Statistical Databases*: Rome, Food and Agriculture Organization of the United Nations at <http://faostat3.fao.org/home/E>.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., and Hoell, A., 2015, The climate hazards infrared precipitation with stations — a new environmental record for monitoring extremes: *Scientific Data*, v. 2.

Giannini, A., 2016, 40 Years of Climate Modeling: The Causes of Late-20th Century Drought in the Sahel, *The End of Desertification?*: Springer, p. 265-291.

Glantz, M.H., 1994, *Drought Follows the Plow: Cultivating Marginal Areas, Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics*, Cambridge University Press, p. 125-128, at <http://dx.doi.org/10.1017/cbo9780511608308.009>.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., and Toulmin, C., 2010, Food Security: The Challenge of Feeding 9 Billion People: *Science*, v. 327, no. 5967, p. 812-818, at <http://dx.doi.org/10.1126/science.1185383>.

- González, P.J., 1997, Dynamics of biodiversity and human carrying capacity in the Senegal Sahel: University of California, Berkeley.
- Gyasi, E.A., and Uitto, J.I., 1997, Environment, biodiversity and agricultural change in West Africa: perspectives from Ghana: United Nations University Press.
- HarvestChoice, 2001, Major River Basins (class), International Food Policy Research Institute, Washington, D.C. University of Minnesota, St. Paul, MN. at <http://harvestchoice.org/node/4966>.
- Henschel, P., Bauer, H., Sogbohossou, E., and Nowell, K., 2015, *Panthera leo* (West Africa subpopulation), IUCN Red List of Threatened Species, IUCN at <http://dx.doi.org/10.2305/iucn.uk.2015-2.rlts.t68933833a54067639.en>.
- Huete, A., Ponce-Campos, G., Zhang, Y., Restrepo-Coupe, N., Ma, Z., and Moran, M.S., 2016, Monitoring photosynthesis from Space, Remote Sensing Handbook Volume II: Land Resources Monitoring, Modeling and Mapping with Remote Sensing: Boca Raton, FL, Taylor & Francis Group, p. 3-22, at <http://dx.doi.org/10.5194/isprsarchives-xxxviii-8-w20-19-2011>.
- Hulme, M., 2001, Climatic perspectives on Sahelian desiccation: 1973–1998: Global Environmental Change, v. 11, no. 1, p. 19-29, at [http://dx.doi.org/10.1016/s0959-3780\(00\)00042-x](http://dx.doi.org/10.1016/s0959-3780(00)00042-x).
- Humle, T., Boesch, C., Duvall, C., Ellis, C.M., Farmer, K.H., Herbinger, I., Blom, A., and Oates, J.F., 2008, *Pan troglodytes ssp. verus*, IUCN Red List of Threatened Species, IUCN at <http://dx.doi.org/10.2305/iucn.uk.2008.rlts.t15935a5323101.en>.
- IUCN, 1992, Protected Areas of the World: A Review of National Systems. Volume 3: Afrotropical: Gland, Switzerland and Cambridge, UK, IUCN, p. xxii + 360pp.
- , 2015, IUCN Elephant Database at <http://www.elephantdatabase.org/>.
- IUCN, and UNEP-WCMC, 2016, The World Database on Protected Areas (WDPA) [On-line]: Cambridge, UK, UNEP-WCMC at www.protectedplanet.net.
- Joppa, L.N., Loarie, S.R., and Pimm, S.L., 2008, On the protection of “protected areas”: Proceedings of the National Academy of Sciences, v. 105, no. 18, p. 6673-6678, at <http://dx.doi.org/10.1073/pnas.0802471105>.
- Keay, R., 1959, Derived savanna: derived from what: Bulletin d’IFAN Ser. A, v. 21, no. 42, p. 7-438.
- Kelder, Y., 2011, The Ecology of Urbanization: The Case of Ouagadougou, Burkina Faso: Denmark, Roskilde University, 98 p., at http://diggy.ruc.dk/bitstream/1800/7285/1/The_whole_report%20final.pdf.
- Kokoye, S.E.H., Tovignan, S.D., Yabi, J.A., and Yegbemey, R.N., 2013, Econometric modeling of farm household land allocation in the municipality of Banikoara in Northern Benin: Land Use Policy, v. 34, p. 72-79, at <http://dx.doi.org/10.1016/j.landusepol.2013.02.004>.
- Konseiga, A., 2005, Regional integration beyond the traditional trade benefits: Labour mobility contribution: Development Economics and Policy, v. 46, p. 206.
- Kormos, R., Boesch, C., Bakarr, M.I., and Butynski, T.M., 2003, West African chimpanzees: Status survey and conservation action plan: International Union for Conservation of Nature and Natural Resources.
- Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C., and Xu, J., 2001, The causes of land-use and land-cover change: moving beyond the myths: Global Environmental Change, v. 11, no. 4, p. 261-269, at [http://dx.doi.org/10.1016/s0959-3780\(01\)00007-3](http://dx.doi.org/10.1016/s0959-3780(01)00007-3).
- Lillesand, T., Kiefer, R.W., and Chipman, J., 2014, Remote sensing and image interpretation: John Wiley & Sons.
- Lowman, P.D., 1968, Space Panorama: Weltflugbild, Zurich.
- Mallon, D.P., Hoffmann, M., and McGowan, P.J.K., 2015, An IUCN situation analysis of terrestrial and freshwater fauna in West and Central Africa: IUCN at <http://dx.doi.org/10.2305/iucn.ch.2015.ssc-op.54.en>.
- Mengue-Medou, C., 2002, Les aires protégées en Afrique : perspectives pour leur conservation: vertigo, no. Volume 3 Numéro 1 at <http://dx.doi.org/10.4000/vertigo.4126>.
- Michel, P., 1973, Les bassins des fleuves Sénégal et Gambie: étude géomorphologique.
- Michelot, A., and Ouedraogo, B., 2009, Transboundary Protected Areas: Legal Framework for the W Transboundary Biosphere Reserve (Benin, Burkina Faso, Niger): IUCN: Gland, Switzerland.
- Mitchell, T., 2013, Sahel Precipitation Index (20-10N, 20W-10E), 1900 - May 2015, JISAO.
- Mittermeier, R.A., Myers, N., Mittermeier, C.G., and Robles Gil, P., 1999, Hotspots: Earth’s biologically richest and most endangered terrestrial ecoregions: CEMEX, SA, Agrupación Sierra Madre, SC.
- Monod, T., 1963, Après Yangambi (1956): notes de phytogéographie africaine: IFAN.
- Moriconi-Ebrard, F., Harre, D., and Heinrigs, P., 2016, Urbanisation Dynamics in West Africa 1950–2010: Africapolis I, 2015 Update, West African Studies: Paris, OECD.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., and Kent, J., 2000, Biodiversity hotspots for conservation priorities: Nature, v. 403, no. 6772, p. 853-858, at <http://dx.doi.org/10.1038/35002501>.
- Niang, I., O.C., R., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., and Urquhart, P., 2014, Africa, Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge University Press.
- Nicholson, S.E., 2005, On the question of the “recovery” of the rains in the West African Sahel: Journal of Arid Environments, v. 63, no. 3, p. 615-641, at <http://dx.doi.org/10.1016/j.jaridenv.2005.03.004>.
- , 2013, The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability: ISRN Meteorology, v. 2013, p. 1-32, at <http://dx.doi.org/10.1155/2013/453521>.
- Norse, E.A.R., Wilcove, K.L., Wilcox, D.S., Norse, B.A.E.A., and Rosenbaum, K.L., 1986, Conserving biological diversity in our national forests: Washington, D.C., The Wilderness Society.
- PGRN, 2001, Nomenclature pour la construction de bases de données sur l’occupation des sols du Niger au sud du 16ème parallèle Projet Gestion des Ressources Naturelles: Niamey, Niger, Direction de l’environnement.
- PNGIM, Nomenclature nationale pour la constitution des bases de données de l’occupation des terres. Document de synthèse, version 1, Programme National de Gestion de l’Information sur le Milieu: Ouagadougou, Burkina Faso.
- Price, T.L., Aladji-Boni, A.S., Paolini, C., Konaté, K., Wilson, R., El Hadj Issa, A., Novelli, O., Niandou, I., Busson, F., and Dulieu, D., 2002, The “W” Regional Park of Benin, Burkina Faso and Niger — Building on a Process of Regional Integration to Address both Local Interests and Transboundary Challenges, in World Parks Congress 2003, Durban, RSA, at https://portals.iucn.org/library/efiles/html/CD-033/English/grfx/sessions/PDFs/session_1/Price.pdf.
- Reij, C., Tappan, G., and Smale, M., 2009, Agroenvironmental transformation in the Sahel: Another kind of “Green Revolution”: International Food Policy Research Institute.
- Reij, C., Tappan, G., Smale, M., Spielman, D., and Pandya-Lorch, R., 2009, Re-greening the Sahel: farmer-led innovation in Burkina Faso and Niger: Millions fed: proven successes in agricultural development, p. 53-58.
- Reij, C., and Winterbottom, R., 2015, Scaling Up Regreening: Six Steps to Success – A Practical Approach to Forest and Landscape Restoration: Washington, DC., USA, World Resources Institute.
- Riggio, J.S., 2011, The African lion (*Panthera leo leo*): a continent-wide species distribution study and population analysis: Durham, NC, Duke University.
- Rindfuss, R.R., Turner, B.L., Entwisle, B., and Walsh, S.J., 2004, Land Cover / Use and Population, Land Change Science, Springer Science, p. 351-366, at http://dx.doi.org/10.1007/978-1-4020-2562-4_20.

- Rippke, U., Ramirez-Villegas, J., Jarvis, A., Vermeulen, S.J., Parker, L., Mer, F., Diekkrüger, B., Challinor, A.J., and Howden, M., 2016, Timescales of transformational climate change adaptation in sub-Saharan African agriculture: *Nature Climate Change*, v. 6, no. 6, p. 605-609, at <http://dx.doi.org/10.1038/nclimate2947>.
- Salzmann, U., and Hoelzmann, P., 2005, The Dahomey Gap: an abrupt climatically induced rain forest fragmentation in West Africa during the late Holocene: *The Holocene*, v. 15, no. 2, p. 190-199, at <http://dx.doi.org/10.1191/0959683605hl799p>.
- Schumacher, F., and Chapman, R.A., 1942, *Sampling methods in forestry and range management*.
- Sinsin, B., Kampmann, D., Thiombiano, A., and Konaté, S., 2010, *Atlas de la Biodiversité de l'Afrique de l'Ouest, Tome I: Bénin: Cotonou et Frankfurt/Main*.
- Stancioff, A., Staljanssens, M., and Tappan, G., 1986, *Mapping and Remote Sensing of the Resources of the Republic of Senegal: A study of the geology, hydrology, soils, vegetation and land use potential*. : Brookings, South Dakota, USA, South Dakota State University, Remote Sensing Institute.
- Steffen, W., Crutzen, P.J., and McNeill, J.R., 2007, The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature: *AMBIO: A Journal of the Human Environment*, v. 36, no. 8, p. 614-621, at [http://dx.doi.org/10.1579/0044-7447\(2007\)36\[614:taahn o\]2.0.co;2](http://dx.doi.org/10.1579/0044-7447(2007)36[614:taahn o]2.0.co;2).
- Steffen, W., Grinevald, J., Crutzen, P.J., and McNeill, J., 2011, The Anthropocene: conceptual and historical perspectives: *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, v. 369, no. 1938, p. 842-867, at <http://dx.doi.org/10.1098/rsta.2010.0327>.
- Stock, R., 2012, *Africa South of the Sahara: a geographical interpretation*: New York, Guilford Press.
- Tappan, G.G., Sall, M., Wood, E., and Cushing, M., 2004, Ecoregions and land cover trends in Senegal: *Journal of Arid Environments*, v. 59, no. 3, p. 427-462.
- Tongway, D.J., Valentin, C., and Seghieri, J., 2001, Banded vegetation patterning in arid and semiarid environments: ecological processes and consequences for management: *Ecological Studies*, v. 149.
- Trochain, J.-L., 1957, *Accord interafricain sur la définition des types de végétation de l'Afrique tropicale*: Institut d'études centrafricaines.
- Tucker, C.J., 1979, Red and photographic infrared linear combinations for monitoring vegetation: *Remote Sensing of Environment*, v. 8, no. 2, p. 127-150, at [http://dx.doi.org/10.1016/0034-4257\(79\)90013-0](http://dx.doi.org/10.1016/0034-4257(79)90013-0).
- U.S. Census Bureau, 2011, *International Database* at <http://www.census.gov/ipc/www/idb/worldpopinfo.php>.
- UNCCD, 1994, *United Nations Convention to Combat Desertification* New York, United Nations.
- UNESCO, 1996, *Man and the Biosphere Programme Biosphere reserves: the Seville strategy and the statutory framework of the world network*, UNESCO.
- , 2005, *MAB Biosphere Reserves Directory* at <http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?mode=allandcode=BEN++BKF++NER+01>.
- United Nations, 2015, *World Population Prospects: The 2015 Revision*. : United Nations, Department of Economic and Social Affairs, Population Division at <http://esa.un.org/unpd/wpp/dataquery>.
- Unwin, A.H., 1920, *West African forests and forestry*: Smithsonian Institution at <http://dx.doi.org/10.5962/bhl.title.26864>.
- USAID, 2014, *Workshop Report: West Africa Regional Mangroves and Climate Change*, U.S. Agency for International Development at <https://sites.google.com/site/mangrovesworkshop>.
- Wetlands International, 2012, *African wetlands — Mangrove forests*: at <http://africa.wetlands.org/Africanwetlands/Mangroves/tabid/2938/language/en-GB/Default.aspx>.
- White, F., 1983, *The Vegetation of Africa: A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa: The Geographical Journal*, v. 151, no. 1, p. 132, at <http://dx.doi.org/10.2307/633318>.
- Woomer, P., Tieszen, L., Tappan, G., Touré, A., and Sall, M., 2004, Land use change and terrestrial carbon stocks in Senegal: *Journal of Arid Environments*, v. 59, no. 3, p. 625-642.
- Yamba, B., and Sambo, M., 2012, *La Régénération Naturelle Assistée et la sécurité alimentaire des ménages de 5 terroirs villageois des départements de Kantché et Mirriah (région de Zinder) - Rapport pour le Fonds International pour le Développement Agricole*.
- Zwarts, L., and van Horssen, P., 2009, *Living on the edge: wetlands and birds in a changing Sahel*: KNNV Publishing Zeist.

CHAPTER II :

Benin

BBC, 2015, *Benin country profile — Overview*: at <http://www.bbc.com/news/world-africa-13037572>.

U.S. Department of State, 2015, *Benin Investment Climate Statement 2015*. : Washington, D.C., at <http://www.state.gov/documents/organization/241695.pdf>.

United Nations, 2015, *World Population Prospects: The 2015 Revision*, United Nations, Department of Economic and Social Affairs, Population Division at <http://esa.un.org/unpd/wpp/dataquery>.

Burkina Faso

Dugué, P., 1989, *Possibilités et limites de l'intensification des systèmes de culture vivriers en zone Soudano-Sahélienne. Le cas du Yatenga (Burkina Faso)*.

Marchal, J., 1977, *Evolution des systèmes agraires: L'exemple du Yatenga (Haute-Volta): Environnement Africain. Cahiers d'Etude du Milieu et d'Aménagement du Territoire Dakar*, v. 2, no. 4-1, p. 75-88.

Pagen, 2006, *Rapport d'inventaire 2006 des mammifères diurnes de la Réserve de Biosphère de la Mare aux Hippopotames*, p. 48.

Reij, C., Tappan, G., and Smale, M., 2009, *Agroenvironmental transformation in the Sahel: Another kind of "Green Revolution"*: International Food Policy Research Institute.

Reij, C., and Waters-Bayer, A., 2001, *Farmer innovation in Africa: a source of inspiration for agricultural development*: London, Earthscan.

SP/CONEDD, 2012, *Suivi de la végétation, des écosystèmes et des paramètres socioéconomiques dans les sites ROSELT : Mare d'Oursi et Mare aux Hippopotames*, p. 83.

Cabo Verde

Anonymous, 1960, *Relatório da Missão Silvícola: Brigada Técnica de Fomento Agrário, Provincia de Cabo Verde*.

Benton, S.W., 2013, *Forestry on the island of Santo Antão, Cabo Verde, West Africa*: Sioux Falls, SoeD, USA.

Eklund, J., and Kronhamn, A., 2002, *The effects of afforestation - a minor field study of climate, soil, land use and socio-economy in two small areas on Santiago Island, Cape Verde*: Earth Sciences Centre, Göteborg University, at http://gvc.gu.se/digitalAssets/1347/1347874_b332.pdf.

Lopes, J.A., and Santos, M., 2010, *Facilitating Financing for Sustainable Forest Management in Small Islands Developing States and Low Forest Cover Countries - Country Case Study: Cape Verde*, Report prepared by Indufor for the United Nations Forum on Forests, United Nations.

Mannaerts, C.M., and Gabriels, D., 2000, *Rainfall erosivity in Cape Verde: Soil and Tillage Research*, v. 55, no. 3, p. 207-212.

Spaak, J.D., 1990, Boiser les Iles du Cap-Vert-pourquoi, comment, pour qui: Bois For. Trop, v. 225, p. 47-54.

WOCAT, 2015, Afforestation — Cape Verde: at https://qt.wocat.net/qt_summary.php?lang=english&qt_id=552

Côte d'Ivoire

AFP, 2014, Ivory Coast Elephants Get New Home as Habitat Shrinks: accessed December 8, 2015, at <http://phys.org/news/2014-01-ivory-coast-elephants-home-habitat.html>.

Denis, G., 2015, Le parc national de la Marahoué: de la logique de conservation à la logique de prédation: *European Scientific Journal*, v. 11, no. 8.

Ehutché, B., 2015, An analysis of dynamics of deforestation and agricultural productivity in Côte d'Ivoire: *International Research Journal of Agricultural Science and Soil Science*, v. 5, no. 4, p. 103-111.

Schulenberg, T., Short, C., and Stephenson, P., 1999, A biological assessment of Parc National de la Marahoué, Côte d'Ivoire: *RAP Working Papers*, v. 13.

UNEP-WCMC, 2014, Comoé National Park: UNEP World Conservation Monitoring Centre at <http://www.eoearth.org/view/article/151400>.

UNESCO, 2015, Comoé National Park: UNESCO World Heritage Centre at <http://whc.unesco.org/en/list/227/>.

The Gambia

Barlow, C., Wachter, T., and Dis-Sey, T., 1997, *The Birds of the Gambia*, Pica Press, UK.

CIESIN, 2005, Gridded population of the world version 3 (GPWV3): population density grids: Palisades, NY, Columbia University, Socioeconomic Data and Applications Center (SEDAC) accessed January 11, 2016, at <http://sedac.ciesin.columbia.edu/gpw>.

FAO, 2010, Forest Policy of the Gambia, Forestry Sub-Sector Policy Republic of the Gambia (2010-2019) at <http://faolex.fao.org/docs/pdf/gam148213.pdf>.

Thoma, W., and Camara, K., 2005, *Community forestry enterprises: a case study of The Gambia*: Rome, Food and Agriculture Organization of the United Nations.

UNDP, 2012, An Assessment of Investments and Financial Flows In the Gambian Forestry Sector, p. 41, at <http://www.undpcc.org/docs/Investment%20and%20Financial%20flows/I&FF%20reports%20and%20suppl%20information/Gambia/IFF%20final%20doc%20forestry%20%20Gambia.pdf>.

Wally, M., 2001, Ecotourism and sustainable wildlife management: Experiences in the Gambia at http://www.fao.org/fileadmin/templates/lead/pdf/02_article03_en.pdf.

Ghana

GSS, 2013, Population and Housing Census 2010, in Service, G.S. at <http://www.statsghana.gov.gh/>.

Namara, R.E., Horowitz, L., Nyamadi, B., and Barry, B., 2011, Irrigation Development in Ghana: Past experiences, emerging opportunities, and future directions: Ghana Strategy Support Program (GSSP) Working Paper, no. 0026.

Snyder, K., Lefore, N., de Silva, S., Venot, J.-P., and Merrey, D., 2013, Improving the sustainability of impacts of agricultural water management interventions in challenging contexts. Case study from Ghana., *International Water Management Institute*, p. 31.

Guinea

Brugiere, D., and Kormos, R., 2008, Review of the protected area network in Guinea, West Africa, and recommendations for new sites for biodiversity conservation: *Biodiversity and Conservation*, v. 18, no. 4, p. 847-868, at <http://dx.doi.org/10.1007/s10531-008-9508-z>.

Fairhead, J., and Leach, M., 1994, Contested forests: Modern conservation and historical land use in Guinea's Ziama Reserve: *African Affairs*, v. 93, no. 373, p. 481-512.

Guinea-Bissau

Corcoran, E., Ravilious, C., and Skuja, M., 2007, Mangroves of western and central Africa: *UNEP/Earthprint* 26.

FAOstat, 2015, Statistical Databases: Rome, Food and Agriculture Organization of the United Nations at <http://faostat3.fao.org/home/E>.

Nicholls, R.J., and Cazenave, A., 2010, Sea-level rise and its impact on coastal zones: *science*, v. 328, no. 5985, p. 1517-1520.

UNESCO, 2012, Adaptation to Climate Change in Coastal zones of West Africa. Responding to coastal changes and its human implications in West Africa through integrated coastal area management at <http://unesdoc.unesco.org/images/0021/002179/217953e.pdf>.

Liberia

CIFOR, 2005, Proceedings of the First International Workshop on Community Forestry in Liberia: Monrovia, Liberia, Center for International Forestry Research.

Dunn-Marcos, R., and Ranard, D.A., 2005, *Liberians: An introduction to their history and culture*: Center for Applied Linguistics, Cultural Orientation Resource Center.

FAO, 2014, Global Forest Resources Assessment 2015: Country Report Liberia, Food and Agriculture Organization of the United Nations, p. 75.

Ngafuan, R.F., 2010, The "Overcrowding" of Monrovia and its link to Rural-Urban Migration in Liberia: Causes, Consequences and Solutions: The Perspective at <http://www.theperspective.org/2010/0614201001.html>.

Mali

CIA, 2013, The World Factbook 2013-14: Central Intelligence Agency at <https://www.cia.gov/library/publications/the-world-factbook/index.html>.

Hale, B., 2002, Mali's Golden Hope: *BBC News* (BBC).

Spiekermann, R., Brandt, M., and Samimi, C., 2015, Woody vegetation and land cover changes in the Sahel of Mali (1967–2011): *International Journal of Applied Earth Observation and Geoinformation*, v. 34, p. 113-121.

Zwarts, L., and van Horssen, P., 2009, Living on the edge: wetlands and birds in a changing Sahel: *KNNV Publishing Zeist*.

Mauritania

Berte, C.J., Ould Mohamed, M., and Ould Saleck, M., 2010, Fighting sand encroachment: lessons from Mauritania: Rome, Food and Agriculture Organization of the United Nations at <http://www.fao.org/3/a-i1488e.pdf>.

Urban Habitat, 2016, Urban Habitat - A World Map of Urban Habitat as Seen by Civil Society: at <https://www.wm-urban-habitat.org/eng/mauritania-2/>.

Shahin, M., 2007, *Water resources and hydrometeorology of the Arab region*: Springer Science & Business Media.

Shine, T., 2011, The Conservation Status of Eastern Mauritania's ephemeral wetlands and their role in the Migration and Wintering of Black Storks.

Niger

- Benoit, M., 1998, Statut et usages du sol en périphérie du parc national du "W" du Niger: 1. Contribution à l'étude du milieu naturel et des ressources végétales du canton de Tamou et du parc du "W".
- Bouamrame, M., 2006, Biodiversity and stakeholders: concertation itineraries. Biosphere reserves, technical notes 1, MAB Secretariat, Parigi: Paris, France, UNESCO at <http://unesdoc.unesco.org/images/0014/001465/146566e.pdf>.
- IPCC, 2001, Climate change 2001 IPCC third assessment report: Intergovernmental Panel on Climate Change Geneva, IPCC Secretariat.
- Price, T.L., Aladji-Boni, A.S., Paolini, C., Konaté, K., Wilson, R., El Hadj Issa, A., Novelli, O., Niandou, I., Busson, F., and Dulieu, D., 2002, The "W" Regional Park of Benin, Burkina Faso and Niger — Building on a Process of Regional Integration to Address both Local Interests and Transboundary Challenges, in World Parks Congress 2003, Durban, RSA, at https://portals.iucn.org/library/efiles/html/CD-033/English/grfx/sessions/PDFs/session_1/Price.pdf.
- Reij, C., Tappan, G., Smale, M., Spielman, D., and Pandya-Lorch, R., 2009, Re-greening the Sahel: farmer-led innovation in Burkina Faso and Niger: Millions fed: proven successes in agricultural development, p. 53-58.
- Reij, C., and Winterbottom, R., 2015, Scaling Up Regreening: Six Steps to Success – A Practical Approach to Forest and Landscape Restoration: Washington, D.C., World Resources Institute.
- UICN/PACO, 2010, Parcs et Réserves du Niger, Evaluation de l'Efficacité de la Gestion des Aires Protégées: Ouagadougou, Burkina Faso, UICN – Programme Afrique centrale et occidentale (PACO).

Nigeria

- Ajayi, S., 2011, Case study 2: Multipurpose forest management for bush meat production: a success story from West Africa: Rome, Food and Agriculture Organization of the United Nations.
- Fourchard, L., 2003, Urban slums reports: The case of Ibadan, Nigeria: Understanding Slums: Case Studies for the Global Report on Human Settlements. Institut Français de Recherche en Afrique (IFRA), University of Ibadan, Nigeria.
- Oates, J.F., 1995, The dangers of conservation by rural development – a case-study from the forests of Nigeria: *Oryx*, v. 29, no. 02, p. 115, at <http://dx.doi.org/10.1017/s0030605300020986>.
- Onojeghuo, A.O., and Onojeghuo, A.R., 2015, Mapping forest transition trends in Okomu Reserve using Landsat and UK-DMC-2 satellite data: *South African Journal of Geomatics*, v. 4, no. 4, p. 486, at <http://dx.doi.org/10.4314/sajg.v4i4.9>.
- Tijani, M., Olaleye, A., and Olubanjo, O., 2012, Impact of Urbanization on Wetland Degradation: A Case Study of Eleyele Wetland, Ibadan, South West, Nigeria: COLERM Proceedings, v. 2, p. 434-456.
- United Nations, 2015, World Population Prospects: The 2015 Revision. : United Nations, Department of Economic and Social Affairs, Population Division at <http://esa.un.org/unpd/wpp/dataquery>.
- World Wildlife Fund, 2016, Western Africa: Southern Nigeria at <http://www.worldwildlife.org/ecoregions/at0122>.

Senegal

- Brandt, M., Mbow, C., Diouf, A.A., Verger, A., Samimi, C., and Fensholt, R., 2015, Ground-and satellite-based evidence of the biophysical mechanisms behind the greening Sahel: *Global change biology*, v. 21, no. 4, p. 1610-1620.
- Hirai, M., 2005, A vegetation-maintaining system as a livelihood strategy among the Sereer, west-central Senegal.
- Ndiaye, O., Diallo, A., Wood, S.A., and Guisse, A., 2014, Structural Diversity of Woody Species in the Senegalese Semi-Arid Zone-Ferlo: *American Journal of Plant Sciences*, v. 5, no. 3, p. 416.
- Pélissier, P., 1966, Les paysans du Sénégal: Imprimerie Fabrègue Saint Yrieux.
- Stancioff, A., Staljanssens, M., and Tappan, G., 1986, Mapping and Remote Sensing of the Resources of the Republic of Senegal: A study of the geology, hydrology, soils, vegetation and land use potential. South Dakota State University, Remote Sensing Institute: Brookings, South Dakota, USA.
- Tappan, G.G., Sall, M., Wood, E.C., and Cushing, M., 2004, Ecoregions and land cover trends in Senegal: *Journal of Arid Environments*, v. 59, no. 3, p. 427-462.

Sierra Leone

- Brcnic, T.M., Amarasekaran, B., and McKenna, A., 2010, Sierra Leone National Chimpanzee Census September, Sierra Leone Chimpanzee Rehabilitation Programme: Freetown, Sierra Leone, Tacugama Chimpanzee Sanctuary at http://tacugama.com/downloads/SLNCCP_Final_Report_TCS_Sep2010.pdf.
- CIA, 2013, The World Factbook 2013-14: Central Intelligence Agency at <https://www.cia.gov/library/publications/the-world-factbook/index.html>.
- Hoffmann, W.A., Orthen, B., and Nascimento, P.K.V.d., 2003, Comparative fire ecology of tropical savanna and forest trees: *Functional Ecology*, v. 17, no. 6, p. 720-726.
- McClanahan, P., 2012, Sierra Leone's dilemma: There's gold under those trees: *The Christian Science Monitor* at <http://www.csmonitor.com/World/Africa/2012/1015/Sierra-Leone-s-dilemma-There-s-gold-under-those-trees>.
- Munro, P., and van der Horst, G., 2012, The domestic trade in timber and fuelwood products in Sierra Leone: current dynamics and issues: Freetown: FAO/EU.
- Okoni-Williams, A.D., Thompson, H.S., Wood, P., Koroma, A.P., and Robertson, P., 2001, Sierra Leone, Important bird areas in Africa and associated islands, Priority sites for conservation: Newbury and Cambridge, UK, Birdlife International 11.
- STEWART, 2012, STEWARD Transboundary Community PES Scoping study report.
- Trollope, L., and Trollope, L.A., 2010, Fire effects and management in African grasslands and savannas: *Range and Animal Sciences and Resources Management*, v. 2, p. 121-145.

Chad

- Chaintreuil, I., and Contreau, C., 2000, Diagnostic des modes d'utilisation des ressources naturelles par les usagers de la forêt classée de Yamba Berte (Tchad), dans une perspective de gestion concertée de ces ressources.: Montpellier, France, CNEARC ESAT, 130 p.
- CIESIN, 2005, Gridded population of the world version 3 (GPWV3): population density grids: Socioeconomic Data and Applications Center (SEDAC), Columbia University: Palisades, NY, USA accessed January 11, 2016, at <http://sedac.ciesin.columbia.edu/gpw>.
- FEWSnet, 2005, Chad Livelihood Profiles USAID FEWS NET at <http://www.fews.net/livelihoods/files/td/profiling.pdf>.

GEF, 2002, GEF Project Brief – Community Based Integrated Ecosystem Management Project under PROADEL: at http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2004/08/18/000112742_20040818161300/Rendered/PDF/298290Chad0IEM1ject0Brief10Final004.pdf.

IUCN, 2015, IUCN Elephant Database at <http://www.elephantdatabase.org/>.

Nougagombe, A., Ouya, B., Doassal, B., Denenodji, A., and Gongstar, A., 2012, Rapport provisoire de l'enquête légère sur les hotspots du Tchad, Centre National d'Appui à la Recherche (CNAR).

Oyamta, B., Bayang, D., and Mianyo, D., 2013, Étude sur les Ressources minières et pétrolières dans le Mayo Kebbi Ouest, Tchad, Groupe Ressources pour la Paix accessed February 23, 2016, at http://www.erdoel-tschad.de/tl_files/publikationen/Rapport%20Etude%20Ressources%20mines%20MKO%2025-06-2013.pdf.

Sougnabé, P., 2013, La sédentarisation comme moyen d'adaptation aux baisses de la pluviométrie chez les éleveurs Peuls en Savane tchadienne: Vertigo-la revue électronique en sciences de l'environnement, v. 13, no. 1.

UICN/PACO, 2006, Parcs et Réserves du Tchad, Evaluation de l'Efficacité de la Gestion des Aires Protégées: Ouagadougou, Burkina Faso, UICN – Programme Afrique centrale et occidentale (PACO) at <https://portals.iucn.org/library/sites/library/files/documents/2008-034.pdf>.

Togo

African Cashew Alliance, 2013, Family of ACA Seal-Approved Processors Grows and Strengthens: at <http://www.africacashewalliance.com/en/news-and-info/newsletter/family-aca-seal-approved-processors-grows-and-strengthens>.

African Cashew Initiative (ACI), 2010, A value chain analysis of the cashew sector in Ghana: Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ), Eschborn, Germany.

Kokou, K., 2008, Remnant sacred forests of Togo: Their Role in Conservation Biology, at <http://international-programs.forestry.oregonstate.edu/sites/ip/files/seminars/KokouSacredForestsTogo.pdf>.

Kokou, K., Kamana, P., Tebonou, G., Dimizou, K.A., Tchakorom, O., Kombate, Y., Bindaoudou, I., Adjonou, K., and Fontodji, K., 2012, Evaluation des impacts des expériences positives dans le domaine de la Gestion des Ressources Naturelles en Afrique de l'Ouest, Hotspot Positif de la Zone de Tchamba au Togo, U.S. Agency for International Development.

Opoku-Ameyaw, K., Oppong, F., Amoah, F., Osei-Akoto, S., and Swatson, E., 2011, Growth and early yield of cashew intercropped with food crops in northern Ghana: *Journal of Tropical Agriculture*, v. 49, no. 1-2, p. 53-57.

Tandjiékpon, A.M., 2010, Analysis of the Benin cashew sector value chain: African cashew initiative (ACI).

Tchamie, T., 2000, Les problèmes environnementaux liés à la caféiculture sur les plateaux du sud-ouest du Togo: *Rev. CAMES*, v. 02, Serie B, p. 16, at <http://greenstone.lecames.org/collect/revu/import/B02/B-002-00-151-166.pdf>.

Temudo, M.P., and Abrantes, M., 2014, The cashew frontier in Guinea-Bissau, West Africa: changing landscapes and livelihoods: *Human ecology*, v. 42, no. 2, p. 217-230.

USAID, 2008, Togo: 118/119 Biodiversity and Forest Assessment, U.S. Agency for International Development at http://pdf.usaid.gov/pdf_docs/Pnadl905.pdf.

Acronyms and Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	PN	Parc National – National Park
CIESIN	Center for International Earth Science Information Network	PNGIM	<i>Programme National de Gestion de l'Information sur le Milieu</i> – National Program on habitat management information
CILSS	<i>Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel</i> – Permanent Interstate Committee for Drought Control in the Sahel	PREVINOBA	<i>Projet de Reboisement Villageois dans le Nord-Est du Bassin Arachidier</i> – Village Afforestation Project of the Northwest Peanut Basin
DNEF	<i>Direction Nationale des Eaux et Forêts de la République de Guinée</i> – Water and Forest National Office of Guinea	RCP	Relative Concentration Pathways
EROS	Earth Resources Observation and Science Center	RISE	Resilience in the Sahel Enhanced
FAO	Food and Agriculture Organization of the United Nations	RLCM	Rapid Land Cover Mapper
FMNR	Farmer Managed Natural Regeneration	sq km	square kilometers
GEF	Global Environment Fund	SDSU	South Dakota State University
GDP	Gross Domestic Product	UICN/PACO	<i>Programme Afrique Centrale et Occidentale de l'Union Internationale pour la Conservation de la Nature</i> – Western and central African programme of the international union for conservation of nature
GIS	Geographic Information System	UN	United Nations
IMF	International Monetary Fund	UNCCD	United Nations Convention to Combat Desertification
IPCC	Intergovernmental Panel on Climate Change	UNDP	United Nations Development Programme
ITCZ	Intertropical Convergence Zone	UNEP	United Nations Environment Programme
IUCN	International Union for Conservation of Nature	UNESCO	United Nations Educational, Scientific and Cultural Organization
km	kilometers	USAID	U.S. Agency for International Development
m	meters	USGS	U.S. Geological Survey
MAB	Man and the Biosphere	WAP	W-Arly-Pendjari
mm	millimeters	WCMC	World Conservation Monitoring Centre
MODIS	Moderate Resolution Imaging Spectroradiometer	WDPA	World Database on Protected Areas
NASA	National Aeronautics and Space Administration	WOCAT	World Overview of Conservation Approaches and Technologies
NDVI	Normalized Difference Vegetation Index	WRI	World Resources Institute
NIR	Near-Infrared		
NP	National Park		
OECD	Organization for Economic Co-operation and Development		
PGRN	<i>Projet Gestion des Ressources Naturelles</i> – Natural resources management project		

A

Abidjan 34, 63, 65
 Abuja 164
 Acacia 7, 70, 92, 149, 152, 155, 163, 179
Acacia nilotica 149, 152
Acacia senegal 155, 179
 Accra 62, 113, 114
 Aerial photography 26, 27, 29, 32, 56, 57, 64, 65, 70, 71, 87, 88, 89, 136, 153, 183
 Afforestation 71, 81, 90, 92, 94, 95, 131, 155, 179, 180, 214
 African elephant 16, 17, 23, 101, 196
 African lion 16, 17
 Agadez 11, 34
 Agriculture 8, 13, 21, 22, 23, 25, 26, 28, 29, 30, 32, 33, 34, 41, 42, 43, 54, 57, 58, 59, 60, 61, 62, 63, 66, 67, 68, 70, 71, 74, 75, 76, 77, 78, 79, 81, 82, 83, 84, 85, 86, 87, 89, 90, 91, 92, 93, 95, 97, 98, 99, 100, 102, 103, 104, 105, 106, 107, 108, 109, 110, 112, 113, 114, 115, 116, 120, 121, 122, 123, 124, 127, 128, 129, 133, 134, 135, 137, 140, 141, 142, 143, 149, 150, 151, 153, 156, 157, 158, 159, 162, 163, 165, 166, 167, 168, 170, 173, 174, 175, 176, 177, 180, 183, 184, 186, 187, 188, 193, 194, 195, 197, 199, 200, 201, 202, 203, 204, 205, 206, 207, 214
 Agriculture expansion 59, 60, 76, 100, 151, 158, 187
 Agroforestry 70, 71, 88, 90, 95, 123, 135, 159, 180
 Aïr mountains 4, 5, 11, 157
 Alluvial plain 119, 128, 141, 201
 Alluvial valley 3, 120, 157
 Andropogon 8
 Antelope 16, 23, 87, 191, 196, 198
 Aster 92, 206, 214
 Atacora Mountain 200, 201

B

Badlands 53, 57, 177
 Balayan Souroumba 125
 Bamako 4, 63
 Bamboo 57
 Banjul 104, 105, 106, 108
 Bare soil 30, 35, 38, 53, 57, 91, 150, 152, 177
 Benefits of re-greening 71
 Benin 16, 17, 20, 21, 22, 23, 33, 42, 57, 58, 59, 60, 62, 74, 75, 76, 77, 78, 80, 81
 Bijagos archipelago 68, 126, 127
 Bioclimatic regions 3, 7, 8, 59, 60, 83, 174, 200
 Biodiversity 16, 18, 20, 22, 23, 28, 29, 60, 61, 66, 67, 69, 70, 71, 74, 86, 94, 95, 102, 105, 110, 122, 123, 124, 131, 132, 136, 137, 148, 151, 164, 167, 171, 176, 179, 184, 189, 197, 202, 205, 207
 Biosphere Reserve 16, 18, 20, 22, 86, 122, 123, 125, 126, 137
 Bowé 52, 118, 119, 121, 127, 129
 Burkina Faso 6, 16, 17, 20, 21, 22, 29, 30, 32, 34, 41, 42, 56, 59, 60, 62, 63, 64, 70, 75, 82, 83, 84, 85, 88, 89, 97, 100, 116, 144, 153

C

Cabo Verde 59, 62, 63, 71, 90, 92, 93, 94, 95
 Carbon 13, 71, 207
 Casamance 62, 68, 69, 105, 175, 176, 182
 Cashew 59, 80, 81, 126, 207

Cassava 59, 104, 168, 207
 Central plateau 62, 82, 84, 88
 Chad 3, 5, 6, 7, 17, 24, 25, 32, 36, 42, 56, 59, 60, 62, 63, 157, 192, 193, 194, 195, 196, 198
 Charcoal 68, 174, 182, 183, 188, 197, 199
 Chimpanzee 16, 17, 19, 96, 101, 103, 122, 136, 173, 188, 189, 191
 Climate 3, 5, 6, 7, 13, 16, 30, 32, 33, 34, 35, 36, 37, 38, 39, 56, 59, 60, 69, 70, 71, 83, 86, 90, 91, 92, 94, 96, 110, 111, 116, 119, 131, 132, 138, 140, 144, 156, 162, 165, 178, 184, 192, 193, 194, 200, 214
 Climate change 13, 16, 35, 36, 37, 69, 70, 71, 116, 131, 144, 162, 214
 Climate variability 35, 37
 Climate zone 59, 60, 86, 119, 162, 192, 194
 Coastal 6, 17, 32, 33, 34, 37, 38, 43, 51, 62, 67, 68, 69, 74, 75, 104, 110, 111, 118, 119, 126, 127, 128, 129, 130, 131, 132, 133, 148, 154, 164, 165, 177, 180, 184, 185, 186, 200, 201, 203
 Coastal erosion 37, 104, 130, 131, 200
 Cocoa 59, 61, 65, 67, 96, 98, 102, 110, 112, 119, 168, 200, 204
 Coffee 61, 65, 96, 98, 119, 200, 204, 205
 Co-forest management 124, 125
 Community forest 19, 88, 89
 Comoé National Park 98, 100, 101
 Conservation 13, 16, 18, 19, 29, 30, 67, 68, 69, 78, 82, 85, 90, 92, 95, 100, 122, 123, 132, 137, 153, 171, 173, 189, 191, 214
 Conversion 28, 61, 67, 84, 90, 108, 150, 159, 172, 176, 205
 Corona 25, 28, 29, 108, 114, 138, 145, 155, 172, 180
 Cotton 21, 30, 59, 61, 63, 74, 79, 80, 82, 98, 140, 168, 174, 199, 200, 204, 207
 Crop 3, 21, 29, 30, 32, 33, 35, 37, 42, 54, 59, 60, 61, 71, 79, 80, 82, 83, 84, 85, 88, 98, 104, 107, 113, 117, 119, 144, 162, 165, 166, 170, 176, 180, 199, 200, 207
 Cropland 8, 29, 42, 43, 54, 59, 60, 64, 70, 74, 76, 77, 81, 82, 84, 85, 87, 89, 93, 96, 102, 111, 120, 142, 143, 144, 145, 151, 158, 162, 171, 176, 183, 184, 185, 186, 187, 188, 194, 197, 201, 202, 204
 Cropland and fallow with oil 43, 54, 60, 77

D

Dahomey gap 8, 66, 200, 204
 Dakar 4, 62, 63, 174, 176, 177
 Deforestation 57, 66, 67, 68, 69, 70, 74, 78, 79, 80, 81, 82, 96, 98, 99, 102, 103, 104, 110, 114, 115, 118, 121, 126, 128, 129, 132, 137, 144, 159, 160, 164, 173, 174, 184, 186, 189, 192, 194, 202, 204, 205, 206
 Degradation 34, 38, 56, 57, 61, 67, 69, 70, 71, 74, 77, 88, 94, 96, 99, 109, 110, 112, 124, 128, 140, 144, 154, 156, 159, 173, 179, 183, 195, 200, 204
 Degraded 42, 43, 50, 57, 61, 65, 66, 67, 70, 76, 77, 81, 88, 90, 92, 95, 96, 99, 102, 103, 107, 112, 113, 114, 115, 120, 124, 128, 133, 134, 135, 136, 162, 165, 167, 169, 174, 178, 186, 187, 188, 189, 202, 203, 204, 207
 Degraded forest 42, 43, 50, 65, 66, 67, 76, 77, 96, 99, 102, 103, 112, 113, 114, 115, 133, 134, 135, 165, 167, 186, 187, 188, 202, 203, 204
 Degraded land 57, 70, 81, 90, 92, 162, 178
 Desert 3, 7, 11, 17, 34, 42, 62, 91, 140, 141, 142, 148, 150, 154, 156, 157, 158, 163, 192, 194
 Desertification 57, 90, 95, 140, 143, 148, 150, 156, 159, 162, 164, 174, 192, 214
 Dogon 62, 142, 144
 Drought 28, 29, 30, 34, 35, 43, 56, 64, 70, 74, 82, 88, 94, 116, 144, 145, 147, 148, 151, 154, 156, 159, 162, 163, 174, 176, 177, 178, 180, 194, 197, 200, 203, 214

Dry 4, 6, 7, 8, 16, 28, 34, 39, 54, 59, 61, 82, 89, 90, 91, 104, 105, 111, 116, 117, 119, 146, 147, 148, 152, 171, 178, 179, 190, 191, 193, 200, 201, 205

Dune 7, 11, 29, 41, 53, 148, 149, 155, 157, 159, 177

E

East Nimba 132, 136, 137

Ecoregion 13, 14, 75, 76, 83, 84, 91, 97, 105, 111, 112, 119, 120, 127, 128, 129, 133, 141, 142, 143, 149, 157, 159, 165, 166, 175, 185, 186, 193, 194, 201

Ecosystems 3, 16, 18, 22, 23, 59, 61, 66, 67, 68, 71, 74, 77, 80, 86, 87, 95, 101, 122, 126, 129, 131, 136, 140, 167, 173, 176, 182, 186, 188, 196, 200, 202, 207

Ecosystem services 18, 61, 71, 202, 207

Ecotourism 87, 109, 110, 111, 115, 184, 191

Elephant 16, 17, 23, 87, 101, 102, 103, 122, 161, 172, 173, 188, 191, 196, 198

Endangered species 16, 19, 69, 102, 132, 173

Endemic species 66, 172

Environmental change 183

Ephemeral wetlands 152

Erosion 29, 30, 35, 37, 51, 57, 69, 70, 71, 79, 81, 86, 90, 92, 94, 95, 104, 116, 118, 119, 120, 130, 131, 143, 148, 159, 162, 177, 178, 179, 180, 189, 200

Expansion of agriculture 84, 98, 106, 142, 162, 166, 170, 176, 201

Extensification 61

F

Faidherbia albida 70, 71, 162, 163, 180

Farmer 29, 71, 88, 117, 162, 163, 180, 214

Farmer innovator 29, 88

Farmer-managed natural regeneration 29, 35, 70, 71, 140, 145, 162

Faunal Reserve 19, 20, 21, 22, 160

Fire 7, 8, 19, 27, 52, 53, 64, 78, 87, 117, 125, 161, 183, 190, 191, 197, 205

Flood 29, 86, 126, 146, 147, 153, 187, 189, 193

Floodplain 21, 55, 86, 128, 146, 147, 150, 160, 169, 176, 196, 203

Forest 3, 8, 16, 17, 19, 22, 25, 28, 29, 30, 38, 41, 42, 43, 50, 51, 56, 57, 59, 60, 61, 65, 66, 67, 68, 69, 70, 74, 76, 77, 78, 79, 80, 81, 84, 85, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 99, 100, 102, 103, 105, 107, 109, 110, 111, 112, 113, 114, 115, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 140, 143, 145, 149, 150, 151, 158, 159, 161, 164, 165, 166, 167, 168, 169, 170, 172, 173, 174, 175, 176, 177, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 214

Forest islands 57, 120

Forest loss 30, 67, 135, 186, 206

Forest Reserve 16, 19, 78, 79, 81, 114, 115, 122, 124, 125, 132, 137, 170, 172, 173, 182, 183, 185, 188, 189, 196, 197, 198, 199

Fouta Djallon 4, 5, 97, 104, 119, 120, 124, 127

Freetown 184, 185

G

Gâat Mahmoudé 152, 153

Gallery forest 8, 22, 43, 50, 60, 67, 74, 77, 79, 84, 85, 87, 99, 100, 102, 103, 105, 107, 113, 118, 119, 121, 128, 129, 134, 143, 150, 151, 158, 159, 161, 167, 175, 176, 177, 182, 186, 187, 190, 194, 195, 198, 201, 202, 203, 204, 205, 206

Gambia (The) 5, 6, 17, 59, 62, 68, 104, 105, 107, 108, 109, 118, 124, 175, 182, 183

Gambia River 104, 105, 124, 182

Geographic information system 27, 214

Geology 3, 4, 13, 30, 56

Geomorphology 13, 56, 111

Ghana 3, 6, 33, 41, 42, 43, 44, 59, 60, 61, 62, 65, 66, 67, 68, 110, 111, 112, 113, 114, 115, 116, 140, 166

Giraffe 23, 198

Global warming 37

Gold 62, 82, 110, 118, 140, 184, 189, 192

Gold mining 140, 189

Google Earth 25, 27

Gourcy 88, 89

Groundnut 59, 61, 80, 105, 107, 199

Guéra Mountains 192, 193

Guinea 3, 4, 5, 6, 17, 34, 38, 39, 42, 43, 52, 57, 59, 62, 66, 68, 69, 96, 97, 104, 105, 111, 118, 119, 120, 121, 122, 124, 125, 126, 127, 129, 130, 133, 136, 137, 164, 185, 190, 214

Guinea-Bissau 3, 19, 68, 126, 127, 128, 129, 130

Guinea highlands 5, 34, 97, 122, 146, 164, 185

Guinean region 8, 59, 70, 111, 122, 127, 174, 182

Guineo-Congolian region 7, 8, 9, 59, 60, 96, 110, 204

Gulf of Guinea 6, 34, 38, 39, 62, 69, 96, 164

H

Harmattan 6, 34, 148, 163, 200

Harvested area 59, 61, 130, 147, 188

Herbaceous savanna 52, 107, 127, 195

High-resolution 23, 27, 28, 69, 92, 95, 144, 155, 162, 179, 180, 191, 206

Hippopotamus 23, 86, 87, 122, 126, 161, 191, 196

Hotspot 66, 123, 132, 148, 151, 164, 167

I

Ibadan 62, 168, 169

Inland Niger Delta 6, 7, 140, 141, 143, 146, 147

K

Kainji Lake National Park 17, 170

Kamb 178, 179

Kangari Hills 123, 188, 189

Kédougou 42

Kumasi 33, 41, 62, 113, 114, 115

L

Lake Chad 5, 6, 7, 24, 192, 193, 194, 195

Lake Fitri 25, 194, 195

Lake Volta 6, 111

Land cover 13, 22, 25, 26, 27, 28, 29, 30, 33, 35, 37, 38, 39, 42, 43, 44, 46, 48, 50, 52, 56, 57, 59, 60, 73, 76, 77, 79, 80, 84, 85, 91, 92, 93, 98, 99, 103, 106, 107, 109, 112, 113, 114, 120, 121, 128, 129, 134, 135, 138, 142, 143, 150, 151, 158, 159, 166, 167, 168, 176, 177, 180, 186, 187, 194, 195, 197, 202, 203, 204, 206, 207, 214

Land cover classes 26, 27, 37, 38, 39, 42, 43, 50, 56, 57, 76, 84, 85, 91, 93, 112, 113, 128, 129, 134, 135, 142, 143, 150, 151, 158, 166, 167, 186, 194

Land cover conversion 28, 159

Land cover modification 28, 29, 159

Land degradation 38, 57, 71, 74, 77, 94, 96, 110, 144, 156, 159

Land management 41, 70, 82, 88, 197

Land productivity 38, 39, 40, 41, 143

Landsat 11, 13, 24, 25, 26, 27, 79, 80, 103, 114, 115, 123, 138, 144, 146, 152, 161, 170, 173, 182, 183, 188, 191, 205

Landscape restoration 29, 70, 71, 94

Land use 3, 13, 16, 26, 27, 28, 30, 33, 35, 37, 38, 42, 44, 46, 48, 50, 52, 56, 57, 62, 73, 76, 78, 84, 92, 95, 98, 106, 108, 109, 112, 117, 120, 128, 134, 135, 142, 150, 158, 159, 166, 170, 171, 176, 181, 186, 194, 202

Land use and land cover 13, 26, 27, 28, 30, 33, 35, 38, 42, 44, 46, 48, 50, 56, 73, 92, 98, 109, 134, 142, 150, 159, 194

Laterite 52, 88, 89, 105, 118, 119, 121, 127, 129, 175

Liberia 6, 17, 42, 43, 59, 62, 63, 66, 67, 68, 97, 120, 132, 134, 136, 137, 138, 139

Logging 16, 28, 50, 67, 99, 107, 112, 120, 126, 128, 132, 135, 137, 172, 173, 183, 186, 188

Lomé 204, 206

M

Mali 6, 17, 26, 42, 43, 56, 59, 62, 63, 70, 97, 116, 140, 141, 142, 143, 144, 145, 146, 153

Manda National Park 196, 197

Mangrove 43, 51, 68, 69, 105, 107, 109, 110, 119, 126, 127, 128, 129, 130, 131, 133, 138, 164, 165, 167, 184, 185

Maradi 63, 145, 157, 162, 163

Marahoué National Park 102, 103

Mare aux hippopotames 86, 87

Mauritania 4, 7, 16, 17, 35, 42, 43, 56, 59, 60, 62, 63, 68, 70, 148, 149, 150, 151, 152, 154

Mbar diop 180, 181

Millet 29, 59, 61, 70, 83, 89, 104, 105, 117, 199, 207

MODIS 25, 40, 206, 214

Monrovia 138, 139

Mossi 6, 83

Mountain 3, 4, 5, 7, 11, 17, 24, 34, 74, 75, 90, 91, 92, 93, 94, 95, 97, 111, 118, 119, 120, 122, 133, 136, 137, 184, 185, 192, 193, 200, 201, 204

N

National Forest 19, 120

National Park 11, 16, 17, 19, 20, 21, 22, 23, 54, 67, 74, 86, 96, 98, 100, 101, 102, 103, 109, 126, 132, 160, 170, 173, 174, 185, 190, 191, 196, 197, 198, 201, 202, 214

Natural Forest 99, 172, 201

Natural landscapes 42, 59, 61, 70, 82, 84, 85, 100, 105, 106, 108, 176, 194, 200, 202, 205, 206

Natural regeneration 29, 35, 70, 71, 88, 140, 145, 157, 162, 214

NDVI 25, 38, 40, 214

Niamey 6, 13, 32

Niger 3, 5, 6, 7, 11, 12, 13, 16, 17, 20, 21, 22, 26, 29, 30, 31, 32, 33, 34, 36, 42, 43, 54, 56, 59, 61, 62, 63, 68, 70, 71, 74, 75, 83, 116, 118, 119, 120, 124, 140, 141, 142, 143, 145, 146, 147, 153, 156, 157, 158, 159, 160, 162, 163, 164, 165, 166, 167, 170, 171

Nigeria 3, 6, 17, 33, 34, 42, 43, 59, 60, 62, 65, 68, 85, 164, 166, 168, 169, 170, 171, 172

Niger River 6, 21, 32, 119, 140, 143, 146, 147, 156, 158, 160, 165

Niokolo-Koba National Park 17, 174

Nouakchott 63, 148, 154, 155

N'Djamena 63, 192, 194, 196

O

Oasis 7, 11, 149, 193

Okomu Forest Reserve 172, 173

On-farm trees 70, 71, 159, 162, 163

Open mine 55, 121, 167

Ouaddaï 193, 194

Ouagadougou 4, 34, 63, 64

Ouénou Bénou Forest Reserve 78, 79

Outamba-Kilimi National Park 17, 190, 191

P

Palm trees 11, 43, 54, 59, 60, 61, 67, 74, 75, 76, 77, 98, 115, 126, 127, 168, 173, 201

Pastoral 3, 11, 30, 59, 70, 93, 141, 156, 157, 158, 159, 171, 174, 175, 177, 178, 195

Pata Forest Reserve 182, 183

Peanut Basin 32, 42, 59, 62, 175, 176, 180, 214

Peanuts 30, 104, 174, 176, 207

Pendjari National Park 20, 22, 74

Plantation 43, 51, 60, 61, 65, 66, 67, 76, 77, 80, 81, 92, 93, 95, 96, 97, 98, 99, 102, 103, 113, 116, 134, 135, 167, 172, 173, 178, 179, 201, 203, 207

Plateau 3, 5, 6, 7, 29, 34, 52, 56, 62, 70, 74, 75, 76, 82, 83, 84, 88, 91, 97, 105, 107, 111, 118, 119, 120, 121, 122, 126, 129, 133, 136, 141, 142, 144, 149, 156, 157, 158, 162, 165, 175, 184, 185, 186, 187, 193, 201, 204, 205

Plateaus Region of Togo 204, 205

Poaching 100, 103, 132, 161, 173, 191, 197, 199

Pollution 67, 110, 132, 164, 181

Population 16, 17, 19, 21, 22, 23, 30, 31, 32, 33, 42, 43, 57, 59, 62, 63, 67, 68, 70, 74, 77, 78, 79, 80, 81, 82, 83, 84, 86, 88, 90, 91, 92, 95, 96, 98, 99, 102, 104, 108, 109, 110, 111, 113, 114, 116, 118, 120, 123, 124, 126, 131, 132, 136, 137, 138, 139, 140, 142, 143, 144, 146, 147, 148, 150, 153, 155, 156, 158, 161, 162, 163, 164, 166, 167, 168, 171, 172, 173, 174, 175, 177, 179, 180, 181, 183, 184, 187, 188, 191, 192, 194, 195, 196, 197, 199, 200, 202, 203, 206, 207

Population density 32, 33, 62, 83, 88, 111, 116, 150, 162, 175

Population growth 30, 31, 33, 43, 59, 62, 63, 77, 80, 82, 98, 113, 114, 120, 123, 137, 139, 158, 171, 187, 194, 202

Practices 29, 67, 70, 71, 79, 82, 89, 92, 95, 120, 159, 162, 173

Precambrian 3, 4, 11, 120

Precipitation 34, 36, 91, 122, 152

Preservation 20, 82, 86, 109, 124, 137, 207

Primates 16, 102, 172, 188, 191, 196

Prosopis juliflora 92, 155

Protected area 16, 17, 18, 19, 21, 23, 42, 61, 67, 68, 74, 76, 84, 85, 99, 102, 116, 122, 126, 132, 166, 167, 170, 174, 179, 196, 214

Protected forest 22, 78, 79, 80, 120, 204

R

Rain 3, 17, 35, 66, 96, 102, 111, 112, 132, 133, 135, 140, 172, 178, 185

Rainfall 5, 6, 7, 8, 29, 34, 35, 36, 37, 38, 39, 40, 54, 66, 82, 83, 84, 86, 88, 90, 94, 95, 96, 98, 110, 111, 116, 119, 132, 144, 145, 147, 148, 152, 162, 176, 178, 180, 183, 184, 185, 189, 190, 192, 194, 195, 196, 198, 200

Rainfall anomalies 35

Rainfed agriculture 60, 76, 81, 84, 85, 97, 107, 111, 151, 166, 176

Ramsar 18, 22, 69, 86

Rapid Land Cover Mapper 27, 214

Recessional agriculture 187

Reforestation 68, 69, 95, 99, 172, 173, 177, 205

Regeneration 29, 35, 70, 71, 88, 89, 107, 125, 140, 145, 157, 162, 214

Re-greening 70, 71, 145, 156, 159, 162, 178, 179

Relief 3, 4, 5, 75, 83, 91, 97, 105, 111, 119, 127, 133, 141, 149, 156, 157, 165, 175, 185, 190, 193, 201

Remote sensing 13, 25, 57

Reservoir 74, 82, 116, 117, 132
Resilience 16, 70, 144, 162
Ribeiras 92, 93
Rice 32, 59, 71, 98, 104, 107, 117, 120, 126, 128, 129, 140, 146, 147, 171, 175, 207
Riparian forest 50, 107, 169
River 5, 6, 16, 21, 29, 32, 54, 68, 77, 86, 99, 104, 105, 107, 119, 138, 140, 143, 146, 147, 148, 149, 151, 156, 158, 160, 164, 165, 169, 172, 182, 191, 194, 196, 197, 201, 203
River basins 5, 148
RLCM 27, 214
Roan antelope 23, 87, 196
Rock lines 29, 88, 89, 120
Rocky land 53, 84, 150
Rubber 59, 61, 67, 98, 119, 134, 168, 173
Runoff 29, 88, 152, 153
Rural 32, 33, 59, 62, 64, 65, 71, 79, 81, 88, 95, 116, 122, 123, 139, 150, 154, 160, 163, 168, 175, 204
Rural population 32, 81, 88, 116, 150

S

Sahara Desert 6, 7, 9, 11, 16, 17, 34, 42, 62, 91, 140, 141, 148, 149, 155, 156, 157, 192
Saharan Region 7
Sahel 3, 6, 7, 8, 9, 16, 26, 29, 30, 34, 35, 39, 43, 56, 57, 59, 62, 63, 68, 70, 82, 83, 84, 88, 89, 141, 143, 144, 148, 149, 152, 157, 162, 174, 175, 178, 192, 194, 195, 214
Sahelian Region 7, 52, 59, 156, 162
Sahelian short grass savanna 20, 42, 43, 52, 59, 85, 142, 143, 149, 150, 151, 152, 158, 159, 164, 167, 177, 194, 195
Sandy area 43, 53, 142, 143, 150, 151, 159, 177, 194, 195
Sandy soil 41, 43, 105, 153, 158, 165, 178
Santiago 91, 92, 93, 94, 95
Santo Antão 71, 91, 92, 93, 94, 95
Satellite 13, 21, 25, 26, 27, 28, 57, 87, 88, 89, 94, 95, 114, 125, 136, 138, 147, 155, 163, 172, 178, 180, 197, 198, 199, 204, 206
Savanna 7, 8, 11, 16, 20, 21, 22, 23, 25, 28, 32, 33, 38, 39, 41, 42, 43, 52, 56, 57, 58, 59, 60, 61, 64, 65, 66, 67, 70, 74, 76, 77, 78, 79, 80, 83, 84, 85, 87, 96, 97, 98, 99, 100, 102, 103, 105, 106, 107, 108, 109, 111, 112, 113, 114, 116, 119, 120, 121, 122, 123, 127, 128, 129, 133, 134, 135, 136, 142, 143, 144, 145, 149, 150, 151, 152, 156, 157, 158, 159, 160, 164, 166, 167, 168, 169, 170, 174, 175, 176, 177, 178, 179, 180, 184, 185, 186, 187, 188, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 206, 207
Scaling up 71
Scenery 11, 148, 149, 156, 164
Secondary cities 62, 63
Secondary forest 8, 115
Selective logging 107, 135, 183
Semiarid 3, 7, 30, 34, 35, 39, 42, 56, 57, 70, 74, 82, 92, 93, 94, 96, 141, 143, 156, 165, 166, 174, 175
Senegal 3, 4, 5, 6, 7, 16, 17, 26, 28, 29, 32, 39, 41, 42, 56, 57, 59, 60, 61, 62, 63, 68, 69, 70, 71, 104, 105, 107, 118, 124, 148, 149, 151, 155, 174, 175, 176, 177, 178, 179, 180, 182, 183
Seno plain 144, 145
Settlement growth 62, 63
Settlements 32, 42, 43, 53, 59, 62, 63, 65, 77, 85, 93, 98, 99, 107, 113, 121, 129, 135, 137, 143, 149, 151, 154, 159, 161, 167, 173, 177, 181, 183, 187, 191, 195, 202, 203, 204
Shifting agriculture 114, 170, 187
Shoreline 110, 118, 126, 130, 185

Shrubland 93
Sierra Leone 11, 17, 43, 59, 61, 62, 63, 66, 68, 97, 120, 123, 184, 185, 186, 187, 188, 190, 191
Slash-and-burn agriculture 8, 61, 67, 112, 120, 124, 135, 137, 186
Soil and water conservation 29, 30, 82, 90, 92
Soil degradation 140, 200
Soil erosion 35, 79, 81, 90, 92, 94, 118, 120, 148, 177, 179, 180, 189
Sorghum 59, 61, 79, 83, 89, 104, 199, 207
Spotted bush 56
Steppe 7, 41, 42, 43, 53, 56, 61, 83, 84, 85, 90, 91, 93, 95, 141, 142, 143, 149, 150, 151, 156, 157, 158, 159, 177, 194, 195
Streams 50, 85, 93, 107
Subsistence 62, 77, 79, 98, 123, 193, 199, 204
Sudan 7, 8, 9, 39, 52, 82, 84, 111, 112, 192, 194
Sudanian Region 7, 8, 42, 57, 59, 60, 83, 96, 99, 127, 141, 174, 193, 194, 198, 199
Suitability 37, 93, 112, 189, 205
Surface water 55, 153, 194
Sustainable 19, 70, 79, 108, 109, 117, 124, 125, 152, 173, 180, 206, 207
Swamp forest 43, 51, 77, 143, 150, 164, 167

T

Tamou Total Faunal Reserve 21, 160
Tchad 59
Tchamba prefecture 206, 207
Tchaourou 80
Temperature 6, 34, 35, 36, 37, 71, 162, 183
Termite mounds 56, 119
Terraces 70, 105, 107, 137, 157, 158
Thicket 43, 51, 102, 103, 134, 135, 186
Threatened species 136
Tibesti Mountains 4, 24, 193
Tiger bush 56, 157
Timbuktu 6, 140, 146
Togo 3, 6, 17, 42, 43, 59, 60, 62, 66, 67, 68, 111, 200, 201, 202, 203, 204, 205, 206
Toumaï skull 192
Tourism 16, 101, 104, 126, 131, 140, 191, 205
Transboundary 16, 17, 20, 21, 22, 105, 136, 160
Tree 7, 8, 16, 28, 29, 50, 51, 52, 53, 56, 57, 59, 70, 71, 76, 77, 79, 81, 84, 85, 87, 88, 89, 92, 93, 95, 98, 105, 106, 107, 111, 115, 116, 117, 122, 125, 126, 128, 130, 144, 145, 156, 157, 159, 161, 162, 163, 166, 172, 173, 179, 180, 183, 198, 205, 206, 207
Tree cover 28, 51, 81, 85, 125, 144, 145, 159, 163, 180
Tree density 28, 117, 125, 145, 162, 163, 180
Tree mortality 28
Tree savanna 7, 8, 28, 52, 76, 105, 106, 111, 144
Trends 35, 36, 42, 61, 68, 73, 76, 84, 92, 96, 98, 106, 112, 120, 125, 128, 134, 142, 148, 150, 158, 159, 166, 176, 177, 180, 186, 194, 202, 206, 207
Tropical climate 110, 132, 138, 184
Tropical forest 16, 96, 99, 102, 111, 133, 135, 137, 172, 185, 200, 202
Tuareg 11

U

Unproductive 41, 88, 177
Unsustainable 113, 207
Upper East region 116
Upper Guinean countries 16, 66, 67
Upper Guinean forest 16, 28, 66, 67, 102, 119, 186, 188, 200, 204

Urban 30, 32, 33, 59, 62, 63, 64, 65, 68, 77, 82, 106, 108, 109, 113, 114, 138, 139, 154, 164, 168, 169, 174, 195, 202
Urban agglomerations 32
Urban area 30, 59, 62, 65, 82, 113, 114, 155, 168, 195, 202
Urban centers 62, 65
Urban expansion 62, 68, 169
Urbanization 33, 43, 62, 63, 64, 65, 67, 100, 104, 114, 148, 154
Urban sprawl 106, 108, 168

V

Valuable timber 16, 70, 183, 188
Varela 130, 131
Vegetation cover 7, 13, 28, 37, 39, 53, 56, 57, 60, 70, 95, 111, 137, 140, 142, 150, 156, 159, 177, 194, 197, 201
Vegetation index 25, 38, 214
Village 11, 21, 53, 57, 62, 63, 77, 88, 89, 102, 107, 108, 120, 123, 125, 130, 140, 144, 145, 152, 160, 161, 163, 170, 177, 179, 180, 181, 183, 188, 189, 199, 214
Volta 6, 82, 83, 86, 111
Voodoo 74
Vulnerability to drought 82, 148
Vulnerability to erosion 120, 131

W

W National Park 22, 23, 54, 160
Wadis 7, 157
W-Arly-Pendjari 16, 17, 20, 21, 22, 23, 185, 214
Water 7, 16, 29, 30, 32, 33, 37, 50, 51, 54, 55, 56, 57, 67, 68, 70, 74, 82, 86, 88, 89, 90, 92, 94, 104, 105, 107, 110, 116, 117, 118, 121, 124, 136, 143, 146, 147, 152, 153, 159, 160, 165, 169, 175, 179, 187, 192, 194, 195, 214
Water bodies 30, 55, 86, 146, 159, 195
Water conservation 29, 30, 82, 90, 92
Water erosion 51, 57, 70, 143
Water pollution 110
Wetland 7, 18, 19, 22, 43, 55, 56, 59, 61, 68, 69, 86, 100, 107, 109, 128, 146, 147, 148, 150, 151, 152, 153, 169, 175, 176, 177, 187, 195, 198, 203
White-throated monkeys 172, 173
Wilderness 42, 172
Wildfires 112, 197
Wildlife 19, 67, 86, 102, 103, 111, 112, 143, 146, 151, 153, 167, 171, 173, 188, 189, 190, 196, 197, 205
Wildlife Reserve 19, 102
Wildlife Sanctuary 19, 67, 173
Windbreaks 180
Wind erosion 71, 159, 162, 178
Winterthorn 70, 71, 163
Wolof 104, 183
Wooded landscapes 105, 200
Wooded savana 7, 8, 22, 28, 39, 42, 52, 57, 58, 59, 61, 76, 78, 79, 80, 84, 105, 106, 109, 111, 127, 128, 160, 170, 174, 175, 178, 179, 192, 196, 206
Woodland 7, 8, 16, 28, 39, 42, 43, 51, 59, 60, 74, 77, 80, 85, 89, 90, 92, 93, 95, 98, 99, 100, 105, 108, 112, 120, 121, 122, 123, 124, 127, 128, 129, 133, 135, 160, 167, 174, 175, 176, 177, 182, 183, 184, 185, 186, 187, 188, 190, 192, 193, 194, 195, 196, 197, 200, 202, 203, 206
World 1, 3, 5, 7, 9, 11, 13, 15, 17, 18, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41,

43, 45, 47, 49, 51, 53, 55, 57, 59, 61, 63, 65, 67, 69, 70, 71, 73, 75, 77, 79, 81, 83, 85, 87, 89, 91, 93, 95, 96, 97, 99, 100, 101, 103, 104, 105, 107, 109, 110, 111, 113, 115, 117, 118, 119, 121, 123, 125, 127, 129, 131, 133, 135, 137, 139, 140, 141, 143, 145, 147, 149, 151, 153, 155, 156, 157, 159, 161, 163, 164, 165, 167, 169, 171, 173, 175, 177, 179, 181, 183, 185, 187, 189, 191, 193, 195, 197, 199, 201, 203, 205, 207, 214

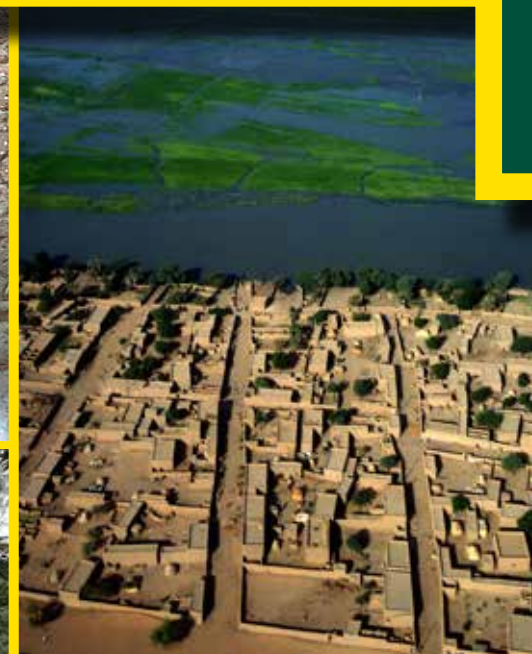
World heritage site 100, 140

Z

Zai 89
Ziama Massif Biosphere Reserve 122, 123, 125
Zinder 71, 145, 158, 162

Landscapes of West Africa, A Window on a Changing World presents a vivid picture of the changing natural environment of West Africa. Using images collected by satellites orbiting hundreds of miles above the Earth, a story of four decades of accelerating environmental change is told. Widely varied landscapes — some changing and some unchanged — are revealing the interdependence and interactions between the people of West Africa and the land that sustains them. Some sections of this atlas raise cause for concern, of landscapes being taxed beyond sustainable limits. Others offer glimpses of resilient and resourceful responses to the environmental challenges that every country in West Africa faces. At the center of all of these stories are the roughly 335 million people who coexist in this environment; about three times the number of people that lived in the same space nearly four decades ago.

This rapid growth of West Africa's population has driven dramatic loss of savanna, woodlands, forests and steppe. Most of this transformation has been to agriculture. The cropped area doubled between 1975 and 2013. Much of that agriculture feeds a growing rural population, but an increasing fraction goes to cities like Lagos, Ouagadougou, Dakar and Accra as the proportion of West Africans living in cities has risen from 8.3 percent in 1950 to nearly 44 percent in 2015. The people of West Africa and their leaders must navigate an increasingly complex path, to meet the immediate needs of a growing population while protecting the environment that will sustain it into the future. This atlas contributes quantifiable information and meaningful perspective that can help guide West Africa and its people to a more sustainable future.



USAID
FROM THE AMERICAN PEOPLE



USGS
science for a changing world