The Eye of Mauritania

Also known as the Richat Structure, this prominent geographic feature in Mauritania's Sahara Desert was first thought to be the result of a meteorite impact because of its circular, crater-like pattern. However, Mauritania's "Eye" is actually a dome of layered sedimentary rock that, through time, has been eroded by wind and windblown sand. At 50 km wide, the Richat Structure can be seen from space by astronauts because it stands out so dramatically in the otherwise barren expanse of desert.

Source: NASA

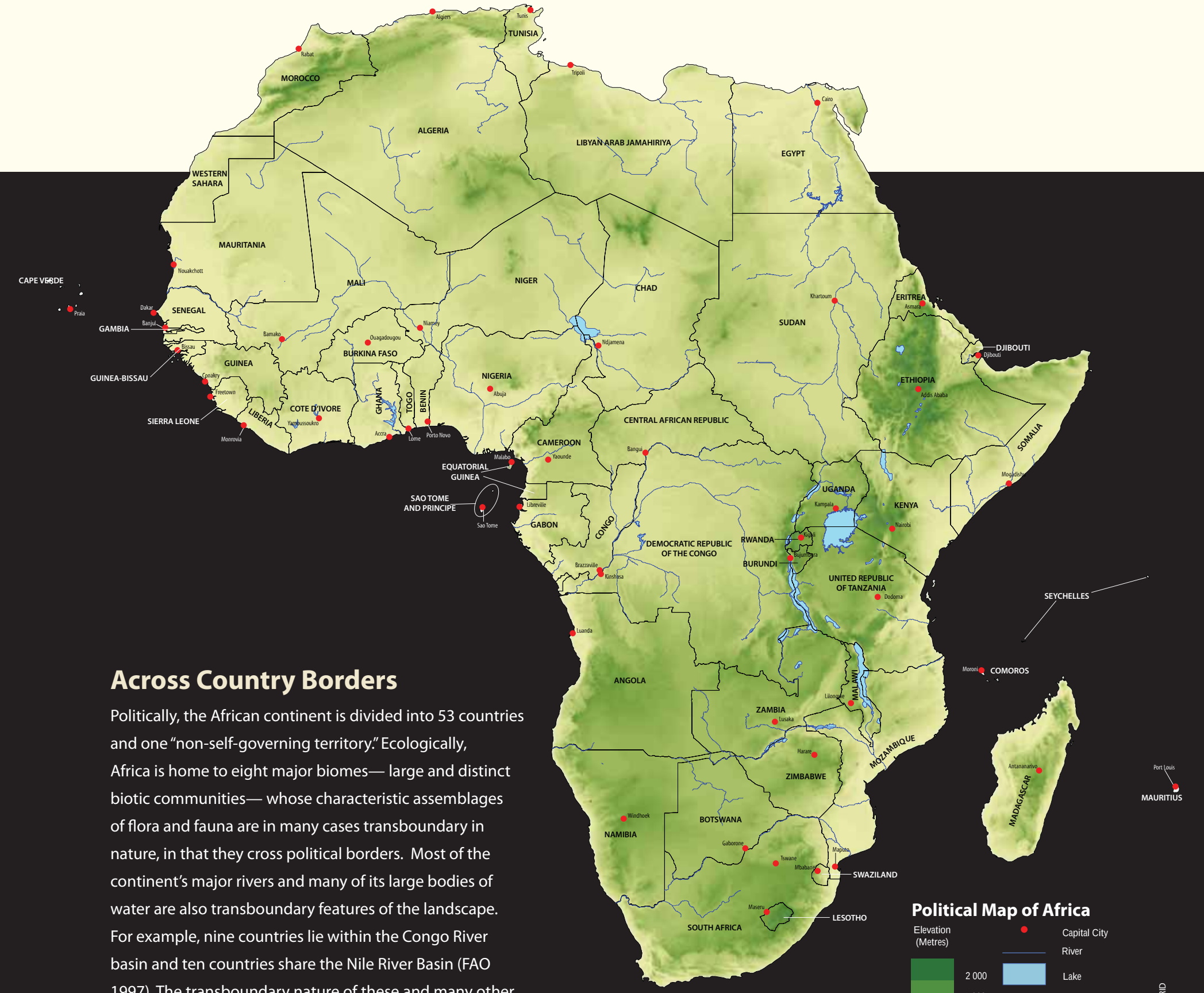
A man singing by himself on the Jemaa Fna Square, Morocco

Chapter 2

Transboundary Environmental Issues

Across Country Borders

Politically, the African continent is divided into 53 countries and one "non-self-governing territory." Ecologically, Africa is home to eight major biomes— large and distinct biotic communities— whose characteristic assemblages of flora and fauna are in many cases transboundary in nature, in that they cross political borders. Most of the continent's major rivers and many of its large bodies of water are also transboundary features of the landscape. For example, nine countries lie within the Congo River basin and ten countries share the Nile River Basin (FAO 1997). The transboundary nature of these and many other ecosystems, together with the natural resources they contain, is the source of diverse environmental issues and presents unique management challenges throughout Africa and, in some cases, beyond the continent itself.



Hippos in the Maasai Mara National Reserve, Kenya

Christian Lambrechts/UNEP

Given that transboundary environmental issues involve more than one nation, they are often addressed using varying political and management approaches that employ different laws and regulations (Gauthier and others 2003). The sustainable use of natural resources such as those derived from forest ecosystems and the monitoring, management, and conservation of flora and fauna shared by various countries, are problems of major concern in Africa. Efforts have been made to introduce management mechanisms that involve some international cooperation, especially in regard to transboundary waterways. But there are inadequacies in such mechanisms when it comes to dealing with many of Africa's other shared resources, such as forest belts and protected areas.

Environmental problems and the impact they have on people and their livelihoods are often similar among neighbouring countries. In many cases, regional approaches to these problems are advantageous. In some cases, cooperation across country borders is essential to solve specific problems. Examples of problems where a cooperative regional approach is vital and can benefit all parties include: the protection of crucial habitats shared by two or more countries; the protection and management of water resources that lie or flow across borders; and the integrated management of invasive, non-native species.

This chapter presents examples of four transboundary issues of importance to Africa:

1. Transboundary ecosystems and protected areas;
2. Transboundary water resources;
3. Transboundary movement of people; and
4. Transboundary movement of pollutants.

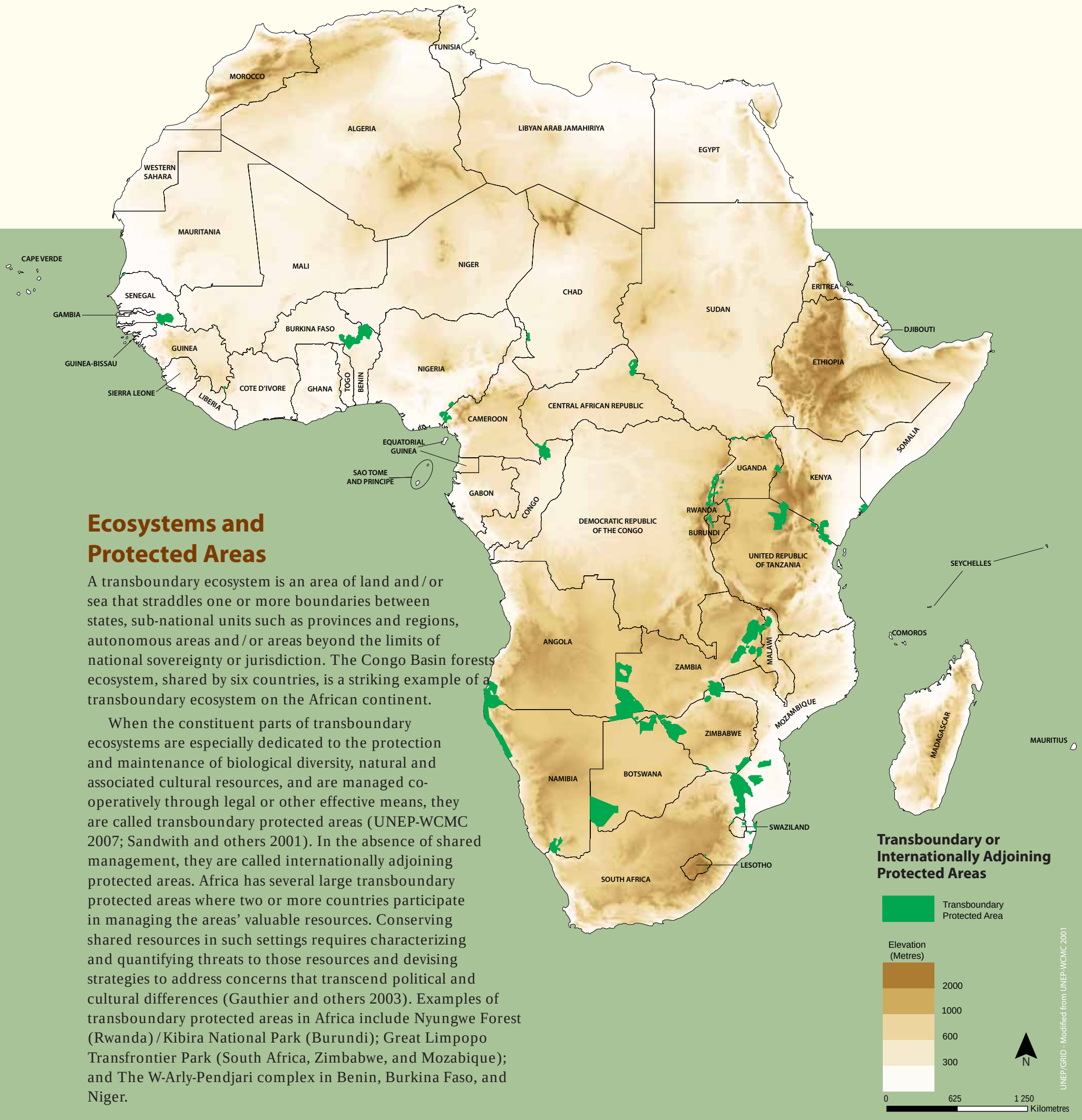
African landscape

Christian Lambrecht/UNEP

Ecosystems and Protected Areas

A transboundary ecosystem is an area of land and/or sea that straddles one or more boundaries between states, sub-national units such as provinces and regions, autonomous areas and/or areas beyond the limits of national sovereignty or jurisdiction. The Congo Basin forests ecosystem, shared by six countries, is a striking example of a transboundary ecosystem on the African continent.

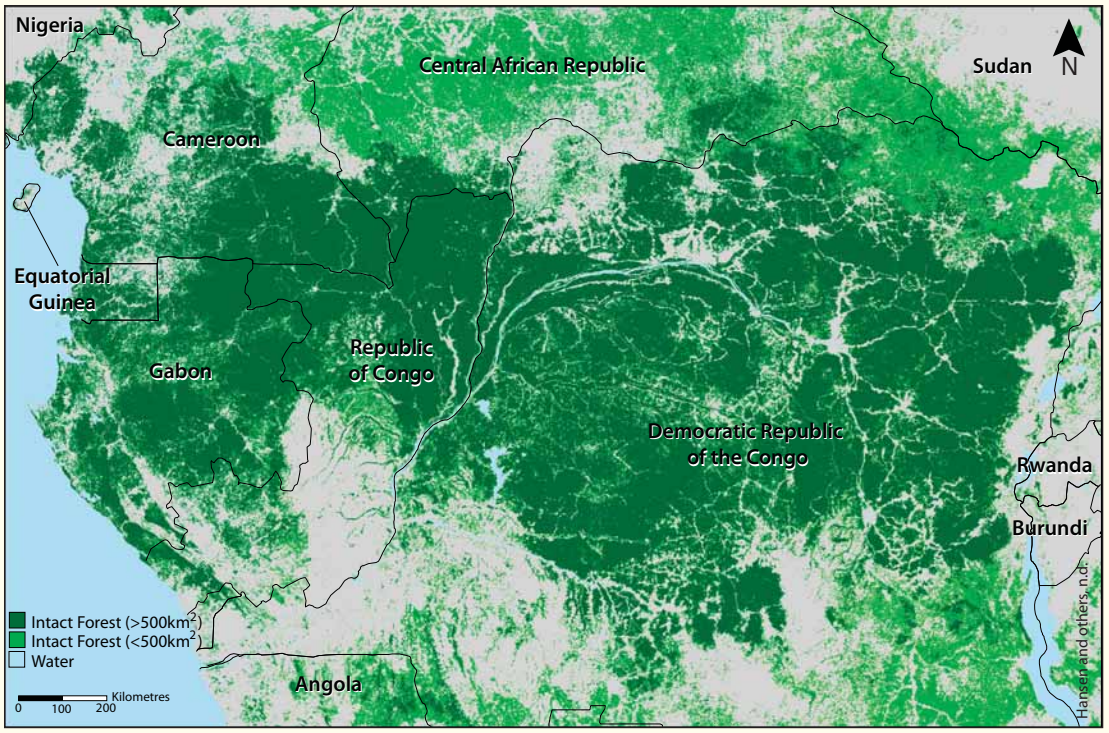
When the constituent parts of transboundary ecosystems are especially dedicated to the protection and maintenance of biological diversity, natural and associated cultural resources, and are managed co-operatively through legal or other effective means, they are called transboundary protected areas (UNEP-WCMC 2007; Sandwith and others 2001). In the absence of shared management, they are called internationally adjoining protected areas. Africa has several large transboundary protected areas where two or more countries participate in managing the areas' valuable resources. Conserving shared resources in such settings requires characterizing and quantifying threats to those resources and devising strategies to address concerns that transcend political and cultural differences (Gauthier and others 2003). Examples of transboundary protected areas in Africa include Nyungwe Forest (Rwanda)/Kibira National Park (Burundi); Great Limpopo Transfrontier Park (South Africa, Zimbabwe, and Mozabique); and The W-Arly-Pendjari complex in Benin, Burkina Faso, and Niger.



Transboundary Ecosystems

The Congo Basin Forests

After the Amazonian forests of South America, the forests of Africa's Congo Basin constitute the second largest area of dense tropical rain forest in the world. Congo Basin forests form a transboundary ecosystem shared by Cameroon, Central African Republic, Republic of Congo, Equatorial Guinea, Gabon, and Democratic Republic of the Congo. This immense, biologically diverse ecosystem ranges from the Gulf of Guinea in the west to the mountains of the Albertine Rift near the eastern border of Democratic Republic of the Congo and spans about seven degrees of latitude on either side of the equator. Congo Basin forests constitute over 80 per cent of the total area of the Guinea-Congo forest structure and include the Afromontane forests in western Cameroon and eastern Democratic Republic of the Congo (CARPE 2006). Table 2.1 compares forest area in each of the six countries that share the Congo Basin forests transboundary ecosystem.



Location of the Congo Basin forests

The dense rain forests of the Congo Basin were once among the most pristine on Earth. However, the relatively recent expansion of industrial logging and the networks of roads that accompany it are now threatening the future of this important and unique ecosystem.

About 60 per cent of the total forest area in the Congo Basin is considered to be industrially exploitable. The area allocated to logging has increased significantly in the last few years. In 2004, for example, the area allocated to logging throughout the Congo Basin forest ecosystem was 494 000 km² (CARPE 2006). By contrast, in 2007, more than 600 000 km² were under logging concessions (Laporte and others 2007).

Important impacts of logging in this transboundary ecosystem include alteration of ecosystem composition and biodiversity, the opening up of remote areas to poaching, and the modification of many other functional ecosystem attributes (Laporte and others 2007).

In addition to industrial timber harvesting, other activities or events are negatively impacting the Congo Basin forest ecosystem. These include the production of palm oil, immigration, population growth, commercial hunting, growing access to distant markets, and road construction. Together with logging, these activities have overwhelmed traditional systems of natural resource management (CARPE 2006).

Furthermore, the construction of railways and road networks for the extraction and removal of natural resources has strongly influenced the distribution of human populations within and around the Congo Basin forests. In many places, intensive permanent agriculture has replaced the forest ecosystem.

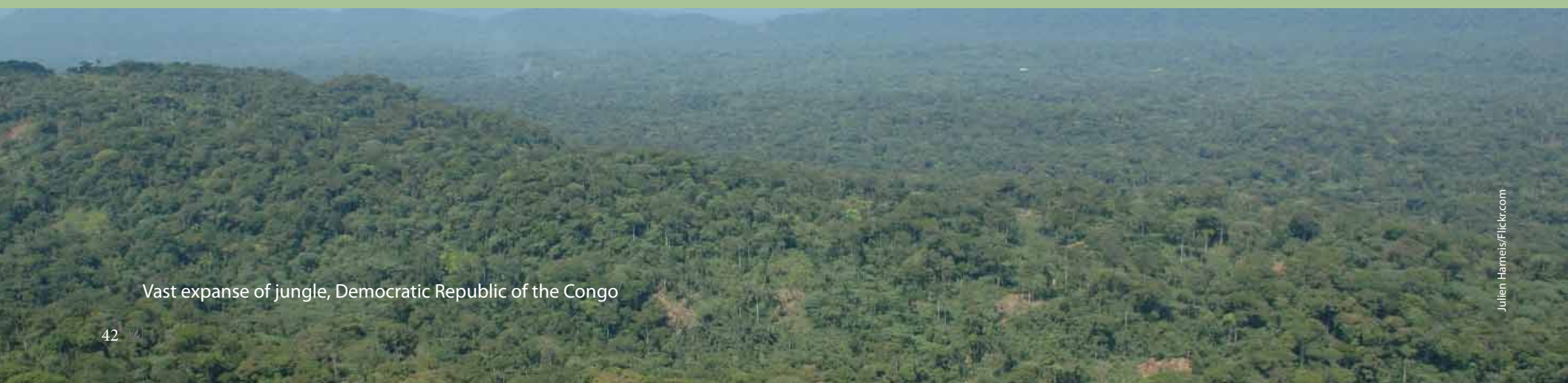
Although some vast, still-intact forest areas with no roads or navigable watercourses do remain in the Congo Basin, the pressure of human encroachment is increasing. The construction of villages along roads, for instance, creates rings, or halos of human impact in the forest. When these individual settlements converge, they form long strips of deforestation and degradation and result in fragmentation of remaining forested areas. The pattern in eastern Democratic Republic of the Congo is somewhat different. There, highland populations do not live in villages, but are more or less dispersed throughout the countryside where they practice intensive agriculture marked by short fallow periods. This lifestyle has created a pattern of high population density with local areas of overpopulation (CARPE 2006).

As various pressures on the forests of the Congo Basin increase, so does the need for appropriate management of this unique ecosystem. The transboundary nature of this ecosystem calls for a multinational approach for the conservation and sustainable use of its resources.

Table 2.1 – Forest area, by country, in the Congo Basin forest transboundary ecosystem

Country	Forest Status in 2005 (FAO) (1 000 hectare)
Cameroon	21 245
Central African Republic	22 755
Republic of Congo	22 471
Equatorial Guinea	1 632
Gabon	21 775
Democratic Republic of the Congo	133 610
Total	223 488

Source: FAO 2005, CARPE 2006


Vast expanse of jungle, Democratic Republic of the Congo

Julien Harneis/Flickr.com

Nyungwe Forest, Rwanda

Jon and Melanie Kots/Flickr.com

Transboundary Protected Areas

In total, Africa contains 3 044 protected areas (UNEP-WCMC 2007), including 198 Marine Protected Areas, 50 Biosphere Reserves, and 80 Wetlands of International Importance. For the purpose of this Atlas, the term transboundary protected areas describes protected areas shared by two or more countries, irrespective of the nature of collaboration.

The African continent is home to some of the richest and most biologically diverse habitats in the world. Africa's amazing animal populations are truly among the wonders of the world and from an ecological standpoint, endow the continent with special distinction. Yet these enormously rich natural resources are in jeopardy due to habitat destruction, poaching, burgeoning rural populations, urbanisation, and changes in land use. Thus, protected areas are extremely important for the safe-guarding and preservation of Africa's wildlife and the biodiversity of its ecosystems.

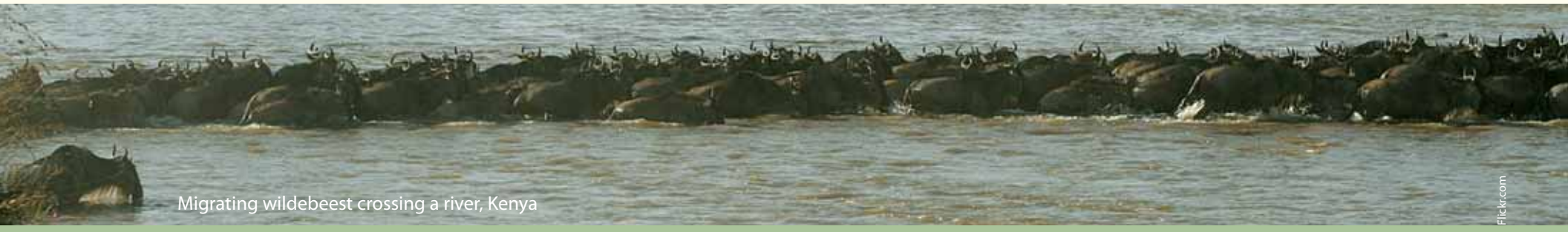
The importance of transboundary protected areas is especially obvious for migratory species. For example, thousands of bird species migrate across Africa performing a north-south, often cross-equatorial, seasonal migration between northern subtropical breeding grounds and southern homes. Thus, distinct and separate ecosystems can be linked by the migratory species that travel back and forth between them (UNEP 2006b).

Nyungwe Forest in Rwanda contains 980 km² of tropical montane forest, and is contiguous with the Kibira National Park in Burundi. Combined, these two protected areas form the largest block of forest in East Africa. It lies at an altitude between 1 500 and 2 300 m.

Migratory birds and other migratory animals are a significant component of transboundary environmental resources. The destruction or degradation of one or more of the ecosystems along a migration route can threaten the survival of migrating species. The map below illustrates global migratory bird routes and shows that Africa has the highest concentration of such routes. Where ecosystems along migration routes are formally protected, Africa's migratory birds have the greatest chance for survival.

Major migratory bird routes of the world

UNEP/GRID – Data Source: Perrins and Elphick 2003



Migrating wildebeest crossing a river, Kenya

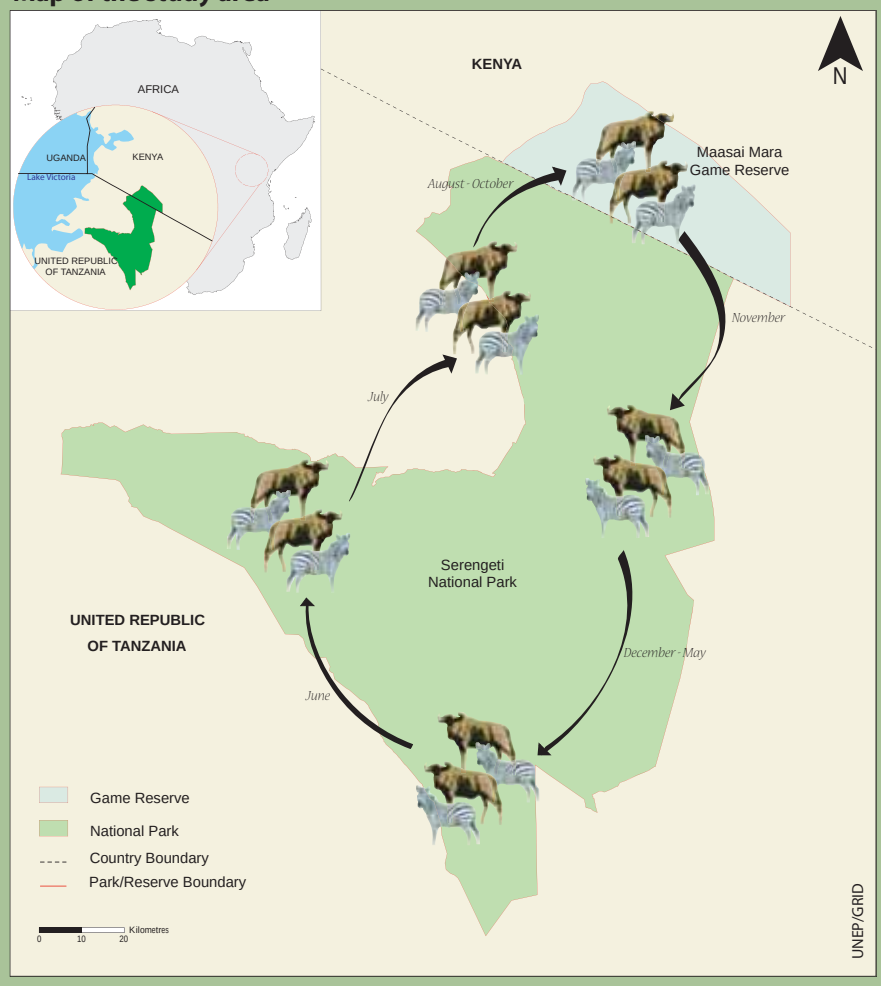
Flickr.com

Maasai Mara – Serengeti Protected Areas in East Africa

Kenya's Maasai Mara Game Reserve and United Republic of Tanzania's Serengeti National Park are two neighboring transboundary protected areas endowed with diverse fauna and flora, including vast herds of seasonally migrating wildebeest (*Connochaetes taurinus*). As the seasons progress in this East African savannah ecosystem, thousands of wildebeest, as well as other herbivores such as zebras (*Equus burchelli*), progressively migrate to greener pastures throughout the ecosystem. Predators follow the wildebeest migration closely, as the herds make their way into different territories. Timing of the wildebeest migration is linked to rainfall and other seasonal changes and is therefore slightly different from year to year (Douglas and others 2004). Generally, calving takes place in the eastern Serengeti between January and mid-March; by June the herds begin heading toward the western Serengeti and ultimately northward, toward Maasai Mara (Go2Africa 2003).

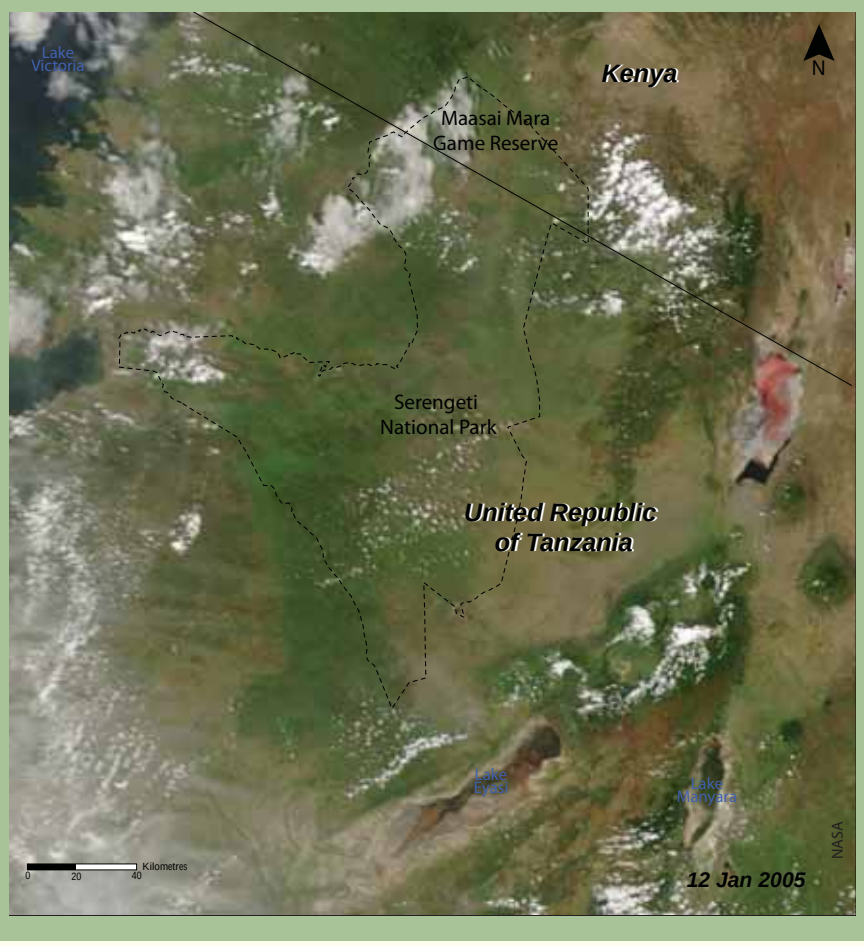
In January 2006, widespread drought in East Africa due to the late arrival of seasonal rains severely affected wildlife in the Serengeti and Maasai Mara protected areas. The drought partially disrupted the migration of more than 1.5 million wildebeest, zebras, and other herbivores from Maasai Mara to Serengeti (Ngowi 2006). In the pair of satellite images below, the contrast between the relatively lush vegetation of January 2005 and the barren, parched landscape of January 2006 reveals the intensity and extent of the drought. Lake Eyasi and Lake Manyara, visible in the lower right-hand corner of each image, were almost completely dry in 2006. The East African drought of 2006 underscored the need for cooperative natural resource management strategies between countries sharing transboundary-protected areas, which are home to migratory species.

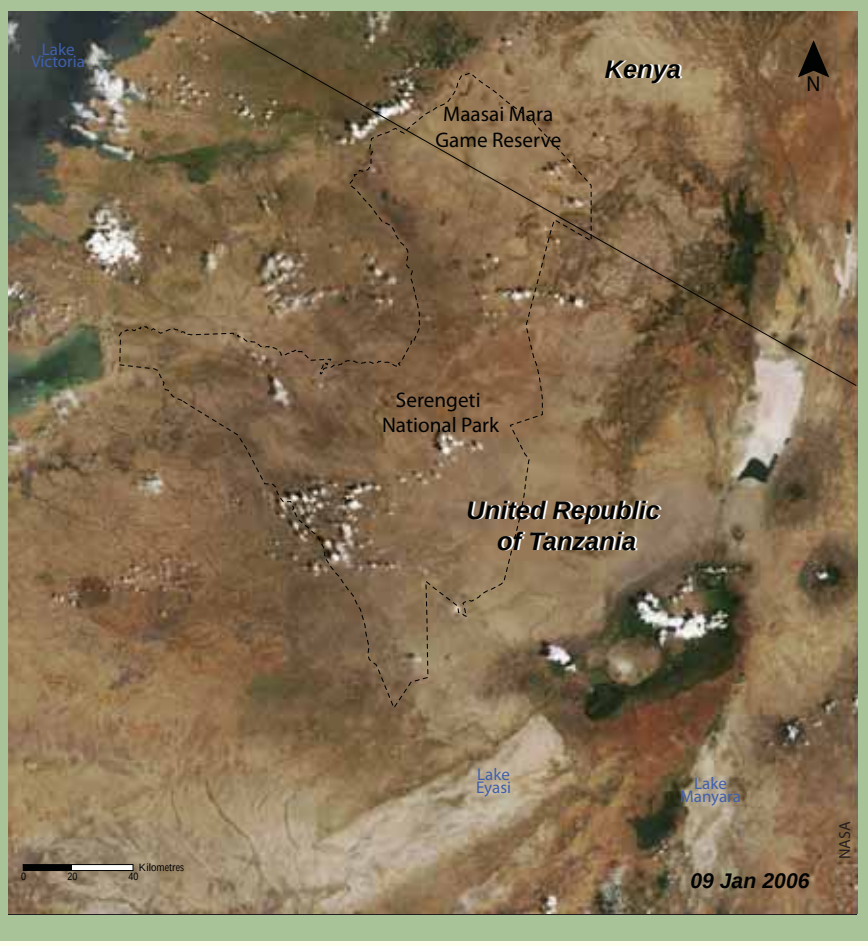
Map of the study area



Every year, herds of wildebeest, zebra, and other herbivores migrate in a clockwise fashion along a migratory route between the Serengeti National Park in United Republic of Tanzania and the Maasai Mara Game Reserve in Kenya.

A pair of images comparing green vegetation in 2005 to the parched, brown landscape in 2006 (NASA 2006a)





W-Arly-Pendjari Parks Complex

The W-Arly-Pendjari (WAP) Parks Complex straddles the countries of Benin, Burkina Faso, and Niger, and is one of the largest contiguous protected areas in Africa. The "W" portion of the Complex's name comes from the angular "W" path followed by the Niger River as it flows through the northern foothills of Benin's Atakora Mountains. The WAP Parks Complex is a mix of terrestrial, semi-aquatic, and aquatic ecosystems and home to more than half of West Africa's elephant population. Furthermore, WAP is the only natural refuge remaining for most of the vulnerable and/or threatened animal species in Benin, Burkina Faso, and Niger.

Land cover changes around the W-Arly-Pendjari Complex

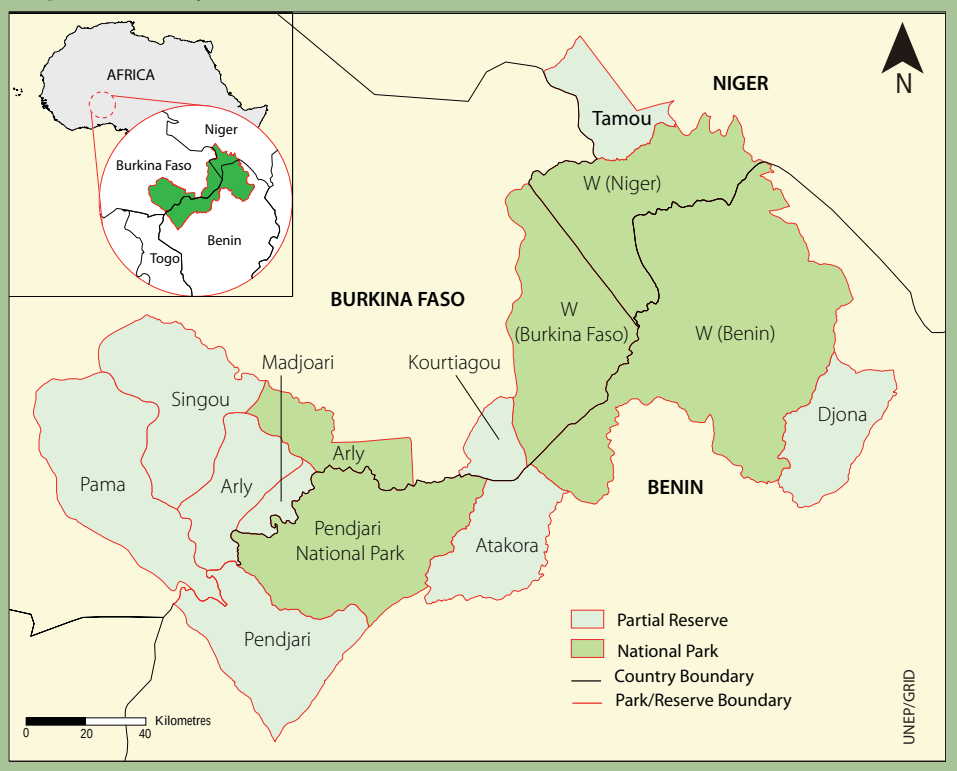
Areas surrounding parts of the WAP Complex are undergoing significant land-use and land-cover change. One of the most striking examples of change is in northern Benin, where the growth of the so-called "cotton belt" has markedly altered the natural vegetation over the last 20 years. During this time, protected lands of the Complex have become almost completely surrounded by agricultural lands, reducing biodiversity and increasing potential contact between humans and wildlife. As the availability of natural resources in non-protected areas dwindles, the protected areas, as the sole remaining repositories of fuelwood, forage, and bush meat in the region, increasingly are becoming a focus for poaching, illegal cattle grazing, and other human activities that impact the sustainability of this part of the WAP Complex (Eva and others 2006).

Table 2.2 – Land use/ land cover changes in the areas surrounding the parks (1975-2002)

	1975 (km²)	2002 (km²)	Increases (%)
Agriculture - Intensive	2 813	4 997	78
Agriculture - Mosaic	3 600	5 644	57
Degraded savannahs	3 281	4 264	30
Savannahs	10 059	4 924	-51

Source: Eva and others 2006

Map of the study area



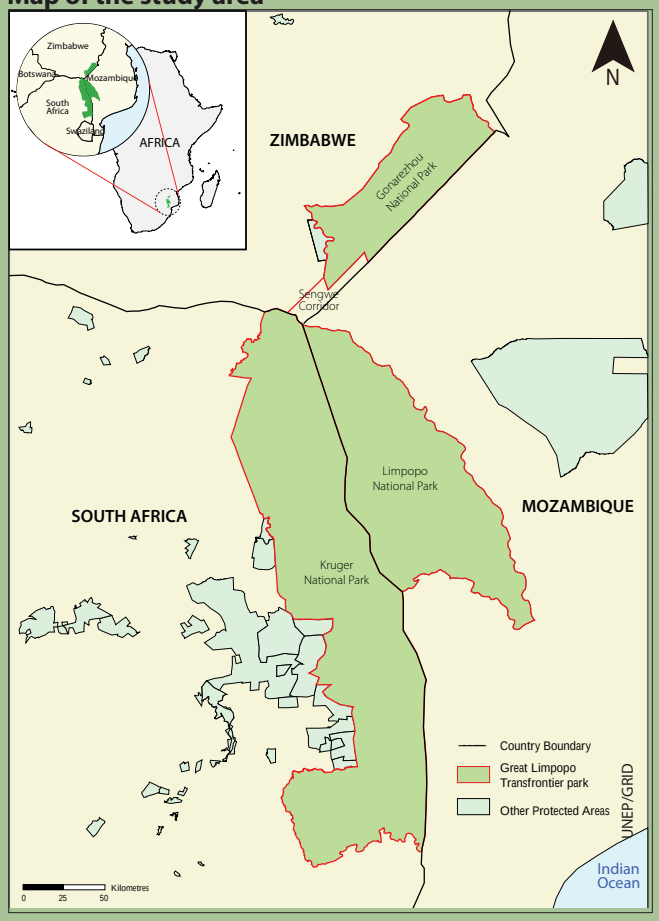
The Great Limpopo Transfrontier Park

The Great Limpopo Transfrontier Park (GLTP) is Africa's largest transboundary protected area. The GLTP is formed by South Africa's Kruger National Park, Mozambique's Limpopo National Park, and Zimbabwe's Gonarezhou National Park and is jointly managed by all three countries (AWF 2003). The GLTP covers 35 000 km² and is centred on the point where its three components meet along the Limpopo River.

Geographically, the main landscapes in the GLTP are: a lowland plains savannah ecosystem with a somewhat hilly granite plateau in the western portions; the Lebombo Mountains that rise to an average of only 500 m above sea level and follow the border between South Africa and Zimbabwe; and floodplains along the Save, Changane, Limpopo, Olifants, Shingwedzi, and Komati Rivers (SANParks 2007).

The GLTP brings together some of the best and most established protected areas for wildlife in southern Africa. It is home to important populations of endangered elephants, black rhinoceroses, and wild dogs, as well as vulnerable species such as lions, leopards, giraffes, buffaloes, and numerous types of antelope (MSN Encarta 2007). GLTP's wildlife population includes at least 147 mammal species, 116 reptile species, 49 species of fish, 34 frog species, and an extraordinary 500 or more species of birds. In addition, at least 2 000 plant species have been identified (SANParks 2007). The GLTP is an example of a recent success in establishing transboundary conservation and peace parks, and is characterized by a diverse array of natural resource management approaches (Rogers 2005).

Map of the study area



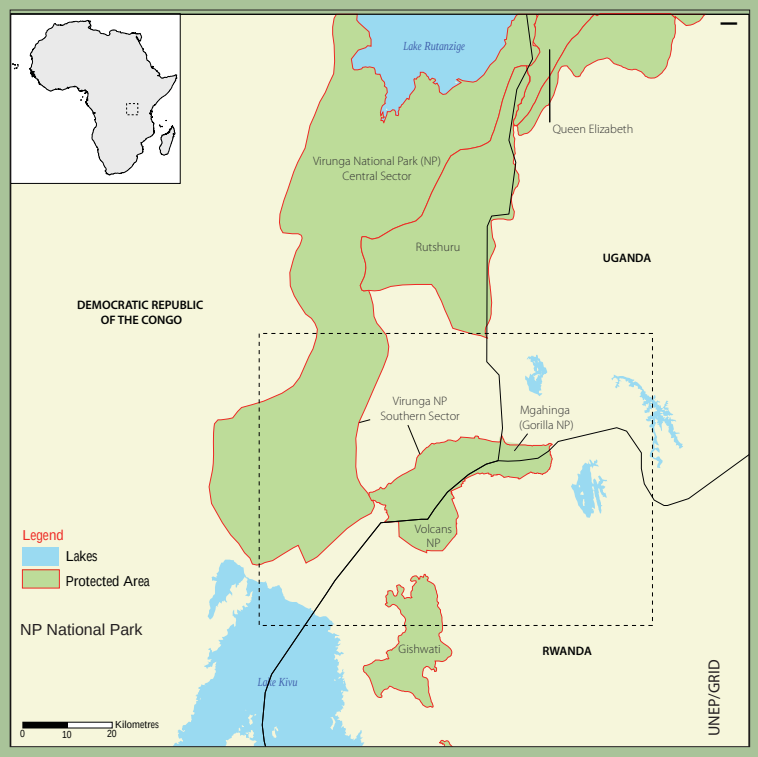
Mountain Gorilla Conservation in the Virunga Heartland

The Virunga Heartland in the central Albertine Rift region of east-central Africa spans the borders of Democratic Republic of the Congo, Rwanda, and Uganda. It includes the World Heritage site of Virunga National Park (Africa's oldest National Park) and supports lush Afromontane forests. Here, volcanic highland mountains shelter the last of the world's mountain gorillas (*Gorilla beringei beringei*). Chimpanzees, golden monkeys, forest elephants, and a rich variety of birds, reptiles, and amphibians also share this incredibly biodiverse ecosystem. Because Virunga Heartland encompasses parts of three countries, transboundary natural resource management is critical to maintaining landscape integrity. However, joint management efforts have suffered since 1990 due to war and political unrest in the region.

Historically, poaching, the spread of disease, and habitat loss from population pressures and civil unrest have threatened mountain gorillas in Virunga's forests. However, due to anti-poaching efforts and a unique gorilla-based ecotourism scheme, the Virunga gorilla population increased by 17 per cent between 1988 and 2003. Together with the 320 gorillas living in the Bwindi Impenetrable National Park in Uganda, the total number of mountain gorillas is now approximately 700.

Nevertheless, despite reasons for optimism, death and extinction are constant threats to the mountain gorillas. In 2007, seven mountain gorillas were killed; four of these deaths occurred in the Virunga region. The continued slaughter of these critically endangered primates demonstrates the challenges faced by gorilla preservation programmes and the urgent need to improve transboundary park management in this region of Africa.

Map of the study area



Sources: McCrummen 2007, MSNBC 2007, WWF 2007

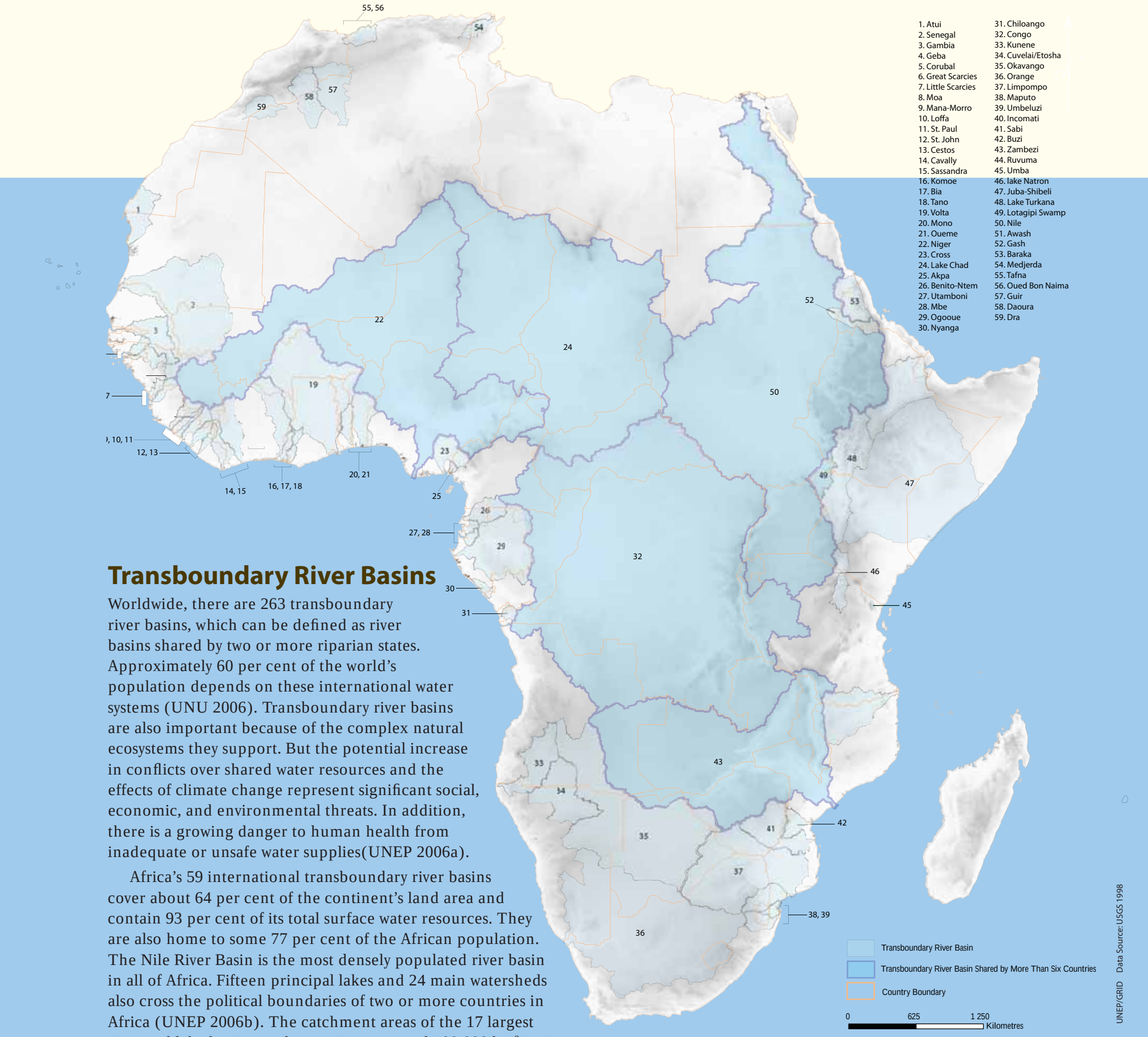
Southern Sudan: A Survival Surprise

Southern Sudan covers an area of 582 759 km^2 and sits between the Sahara Desert and Africa's belt of tropical forests. Wildlife biologists have long recognized that grasslands, woodlands, and swamps in southern Sudan are home to elephants, zebras, giraffes, and other animals.

Before the civil war (1983-2005), a 1982 survey showed an estimated 900 000 white-eared kob (*Kobus kob*)—a kind of antelope—migrating to southern Sudan from bordering areas. Recently, the first aerial survey of southern Sudan in 25 years revealed that vast migrating herds have managed to survive over 20 years of civil war. In this new survey, biologists estimated 1.3 million kob, tiang, and gazelle in their research area, a number that may even surpass the Serengeti's herds of wildebeest, long considered to be the world's biggest migration of mammals. Estimates include 250 000 Mongalla gazelle, 160 000 tiang, 13 000 reedbuck, 8 900 buffalo, and 2 800 ostrich. Other animals such as elephants, ostriches, lions, leopards, hippos, and buffalo are also thriving in parts of southern Sudan. In addition several East African oryx (*Oryx beisa*), a species thought to be extinct in this region, were seen here. On the other hand, some species in southern Sudan are faring badly. For example, the recent survey revealed no zebras in Boma National Park and only a few elsewhere in the region, compared to the estimated 20 000 in Boma tallied during the 1982 survey.

Map of the study area

Source: WCS 2007, Pilkington 2007, Mongabay 2007



Transboundary River Basins

Worldwide, there are 263 transboundary river basins, which can be defined as river basins shared by two or more riparian states. Approximately 60 per cent of the world's population depends on these international water systems (UNU 2006). Transboundary river basins are also important because of the complex natural ecosystems they support. But the potential increase in conflicts over shared water resources and the effects of climate change represent significant social, economic, and environmental threats. In addition, there is a growing danger to human health from inadequate or unsafe water supplies(UNEP 2006a).

Africa's 59 international transboundary river basins cover about 64 per cent of the continent's land area and contain 93 per cent of its total surface water resources. They are also home to some 77 per cent of the African population. The Nile River Basin is the most densely populated river basin in all of Africa. Fifteen principal lakes and 24 main watersheds also cross the political boundaries of two or more countries in Africa (UNEP 2006b). The catchment areas of the 17 largest river and lake basins on the continent exceed 100 000 km^2 in size (UNU 2006). Africa also has 38 transboundary aquifer systems, about which little is known.

Most Africans live in rural areas and are still heavily dependent on agriculture for their livelihoods, making water a vital economic and social commodity. Along with a growing population, the extreme variability of rainfall on Africa's landscapes—from arid northern and southern regions to the continent's belt of tropical forests—poses many challenges to providing safe drinking water and sanitation for millions of people. Consequently, transboundary water resource management requires an enabling environment that encourages cooperation on numerous fronts.

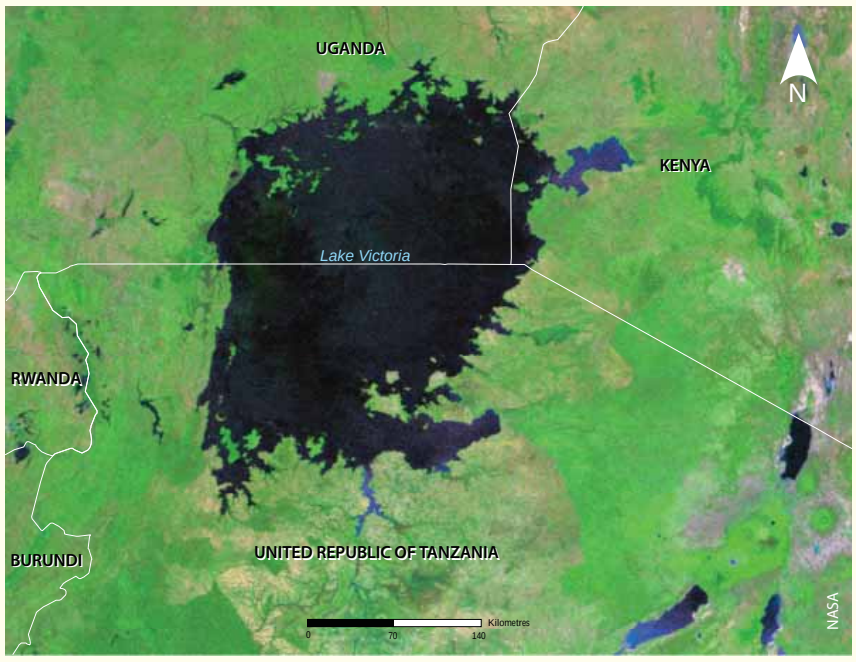

Water hyacinth growing near a dock, Lake Victoria, Kenya

Flickr.com

Lake Victoria: Africa's Largest Freshwater Lake

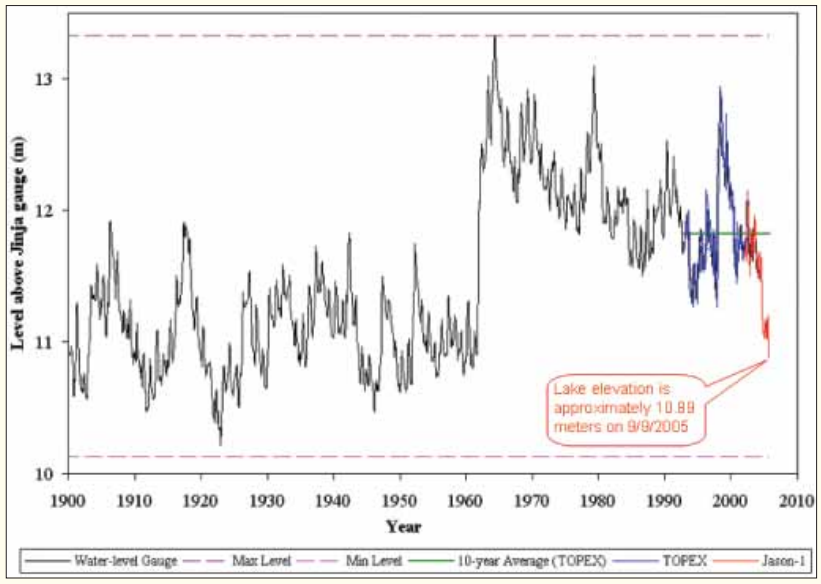
Lake Victoria is Africa's largest, and the world's second-largest, freshwater lake. It has a total catchment of about 250 000 km², of which 68 870 km² is the actual lake surface (URT 2001). Located in the upper reaches of the Nile River Basin in East Africa, the waters of Lake Victoria are shared by Kenya, Uganda, and United Republic of Tanzania. Lake Victoria faces myriad environmental problems, including invasive species, water quality, and fluctuating water levels.

In the 105-year history of accurate water-level measurements on Lake Victoria (measured at Jinja, Uganda), levels have fluctuated widely. In 1961 and 1962, for example, heavy rains drove water levels up by an astounding two metres. Since then, levels have been generally declining over time. In December



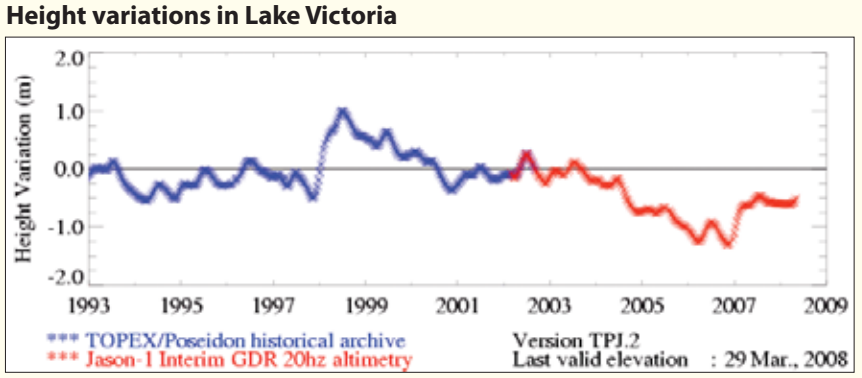
2005, water levels dropped to an all-time low of 10.89 m (NASA 2006a), a figure confirmed by satellite measurements of the lake's elevation. In the past few years, water levels have increased slightly.

Historical water level elevations of Lake Victoria

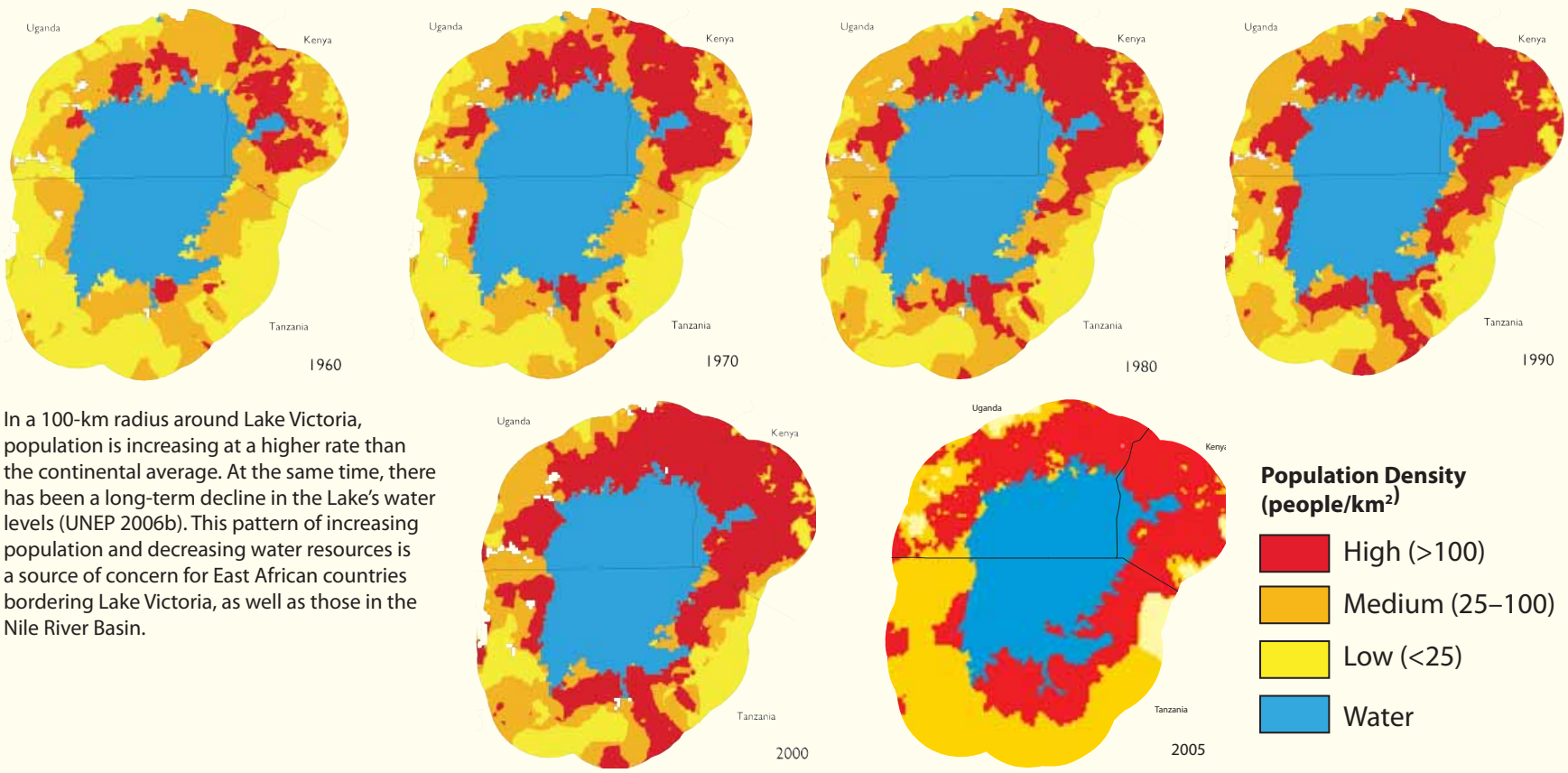


USDA 2005

Height variations in Lake Victoria

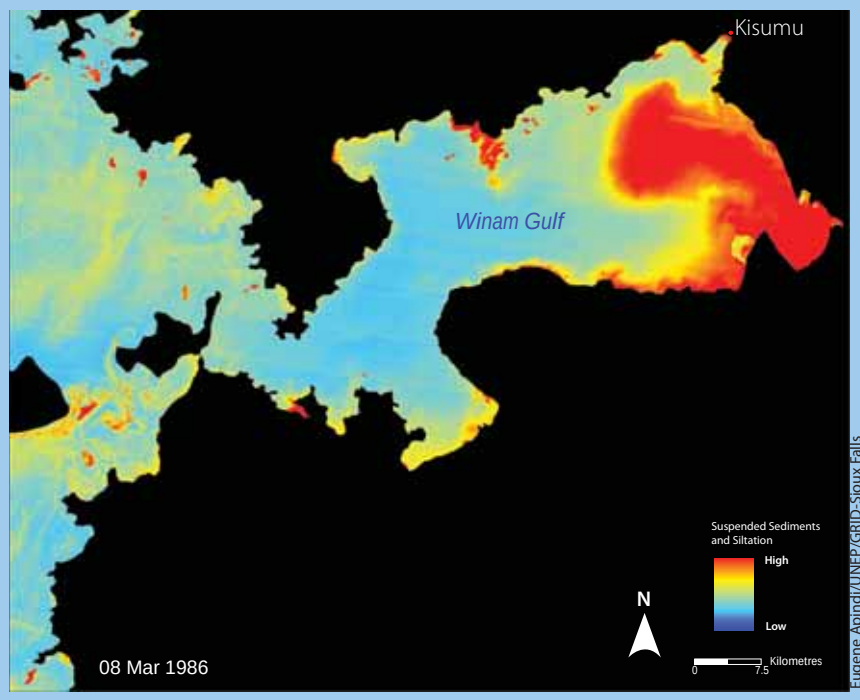


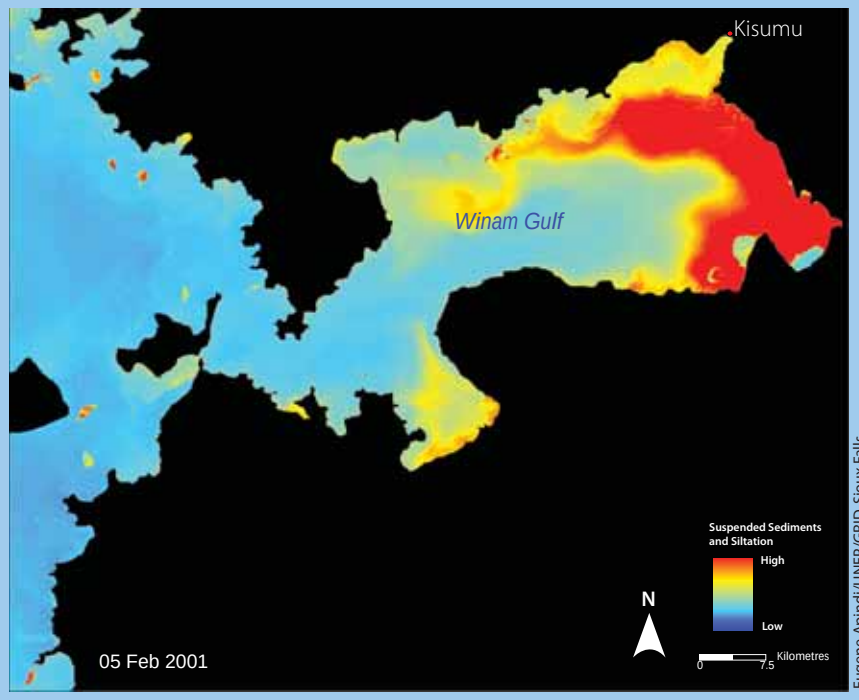
High population growth around Lake Victoria



In a 100-km radius around Lake Victoria, population is increasing at a higher rate than the continental average. At the same time, there has been a long-term decline in the Lake's water levels (UNEP 2006b). This pattern of increasing population and decreasing water resources is a source of concern for East African countries bordering Lake Victoria, as well as those in the Nile River Basin.

UNEP/GRID





Images showing increased siltation and suspended sediments

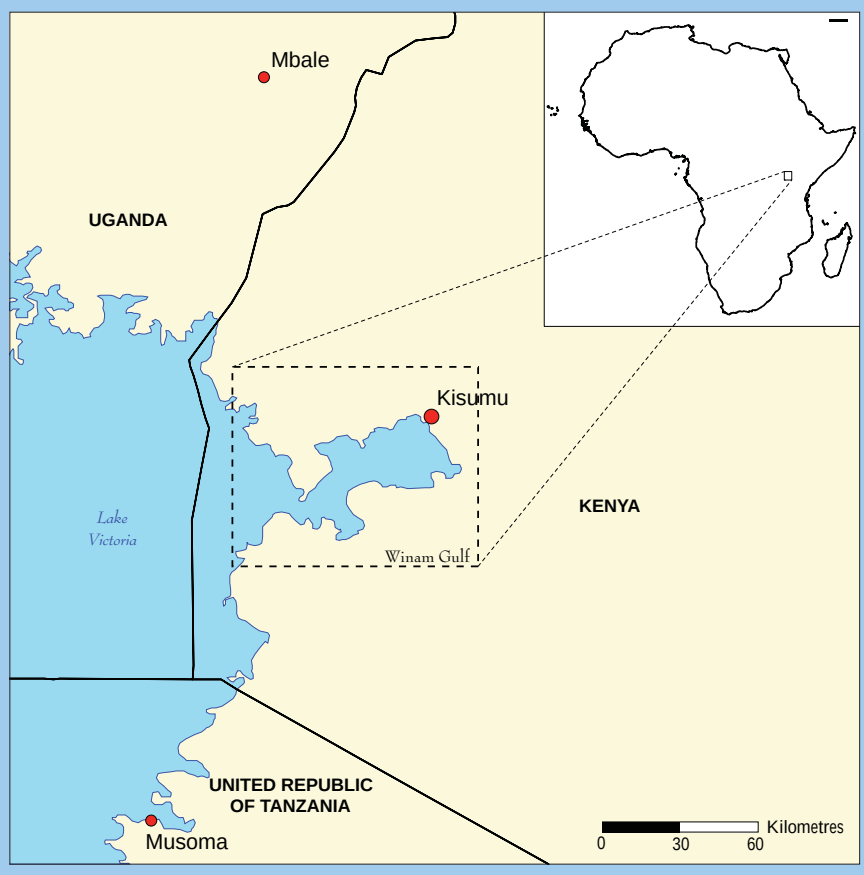
Lake Victoria's Winam Gulf

Winam Gulf is a large arm of Lake Victoria that extends east into Kenya. The Gulf is roughly 100 km from east to west and 50 km from north to south, with a shoreline measuring about 550 km. The Gulf is relatively shallow, with a recorded average depth of six metres (Osumo 2001).

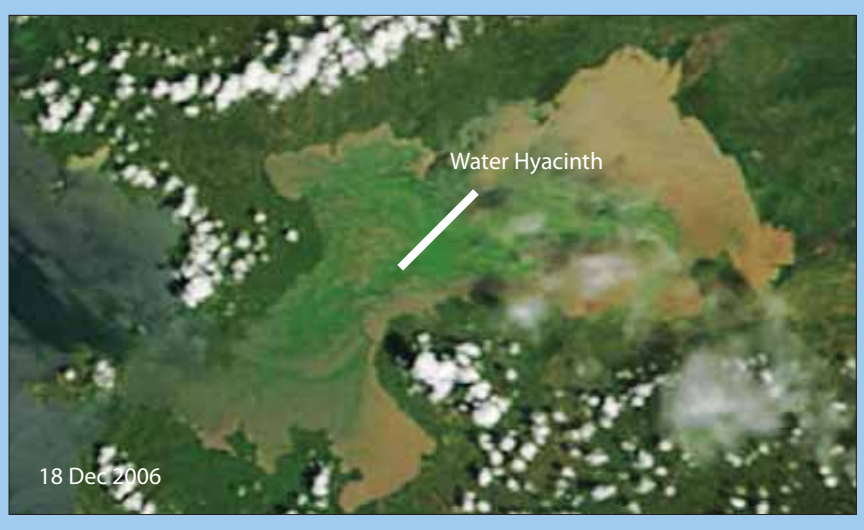
Like Lake Victoria of which it is part, Winam Gulf faces numerous environmental challenges. These include, but are not limited to, siltation, sedimentation, toxic contamination, and eutrophication. The underlying force of change is explosive population growth in the lake's basin, along with associated farming practices and urbanisation. Four major rivers—Sondu-Miriu, Kibos, Nyando, and Kisat—discharge an average of 231 m^3 of water per second into the Gulf (Osumo 2001). Untreated sewage and wastewater from surrounding towns and organic and inorganic nutrients washed down from cultivated areas flow first into these rivers, and then into the Gulf. In addition, excessive soil erosion in parts of the lake's catchment has led to heavy siltation and sedimentation in certain areas, especially in the Winam Gulf. The above images show increased siltation and suspended sediments in the Winam Gulf waters between 8 March 1986 (upper left) and 5 February 2001 (upper right). Highly affected areas appear in red while least affected areas are blue.

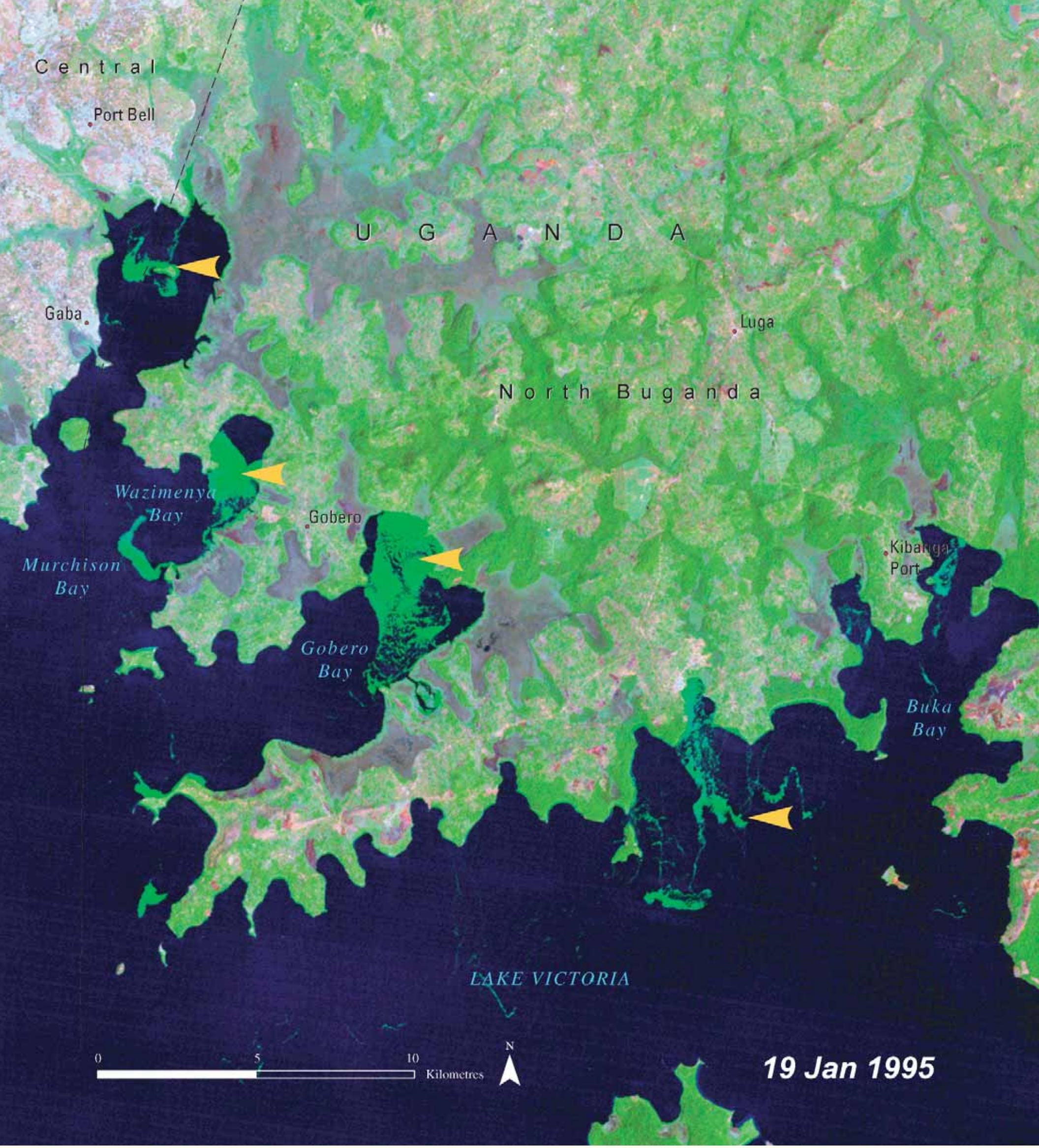
When water hyacinth *(Eichhornia crassipes)* invaded Lake Victoria in the 1990s, Winam Gulf was one of the most severely affected regions. As much as 17 231 hectares of the Gulf's surface were covered by the plant. By 2000, however, the area invaded by water hyacinth had been reduced by control measures to about 500 hectares. Five years later, as the December 2005 satellite image (below left) shows, the Gulf appeared to be essentially free of the plant. Approximately one year later, however, unusually heavy rains flooded the rivers that flow into the Gulf, which in turn raised Gulf water levels and contributed nutrient-rich sediment to the aquatic environment. As a result, water hyacinth quickly reinvaded the Gulf, as the 2006 satellite image (below right) shows.

Map of the study area



Images showing water hyacinth choked bays





Water Hyacinth in Lake Victoria, 1995-2001

In the 1990s, Lake Victoria suffered an infestation of water hyacinth (yellow arrows), an introduced species that thrives on the nutrients running into the lake from increased fertilizer applications on adjacent agricultural lands. The plants disrupted transportation and fishing, clogged water intake pipes for municipal water, and created habitat for disease-causing mosquitoes and other insects. To address the problem, a Lake Victoria Environmental Management Project began in 1994. The Project's focus was to combat water hyacinth infestations on the Lake, particularly in the region bordered by Uganda, which was one of the most severely affected areas.

The 1995 satellite image shows water hyacinth infestations in or near Murchison, Wazimenya, Gobero, and Buka bays (yellow arrows). Initially, the plants were manually removed from the Lake, but they quickly re-grew. Later, natural insect predators of water hyacinth were introduced as a control measure, with better results. By late 2001, essentially all of the floating weeds had disappeared from the aforementioned locations.

Vendor selling wares, Chad

Permission Pending/Flickr.com

Lake Chad: Africa's Shrinking Lake

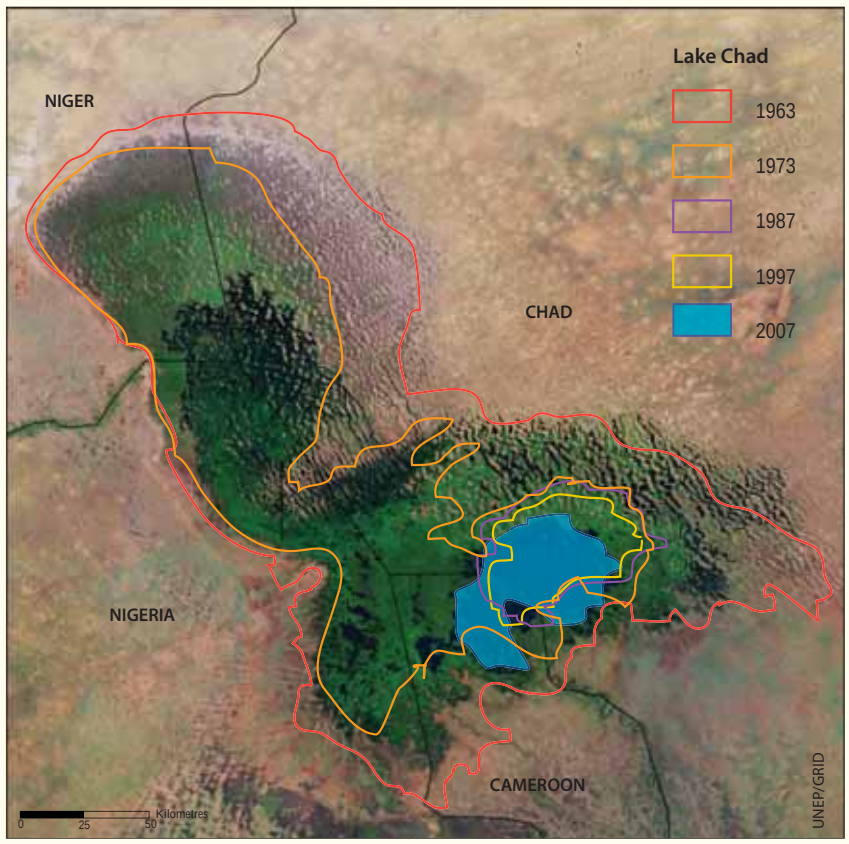
Located at the southern edge of the Sahara Desert, Lake Chad is bordered by Nigeria, Niger, Chad, and Cameroon. The lake was once the second-largest wetland in Africa, supporting a rich diversity of endemic animals and plant life.

The Lake Chad drainage basin, a 2 500 000 km² hydrologically closed catchment, extends to eight countries: Algeria, Libyan Arab Jamahiriya, Niger, Chad, Sudan, Central African Republic, Cameroon, and Nigeria. It is home to over 20 million people who derive direct or indirect livelihoods from the lake. Most of the region's rainfall occurs in the southern one-third of the Lake Chad drainage basin, contributing about 90 per cent of the basin's runoff. The northern two-thirds, however, are dominated by arid conditions (Coe and Foley 2001).

Climate variability and increased water consumption by the area's inhabitants have changed the water balance within the Lake Chad drainage basin, and continue to do so. Since the early 1960's, rainfall over the basin decreased significantly while irrigation increased dramatically over the same period (Coe and Foley 2001). The lake is especially susceptible to climatic variability as it is rather shallow, with an average depth of 4.11 m (NASA 2001a). As a result of decreased rainfall and increased water usage, the extent of Lake Chad decreased by 95 per cent over roughly 35 years. More recently, water levels in Lake Chad have increased slightly. But the lake still remains a remnant of its former self.

Lake Chad drainage basin

Shrinking of Lake Chad



Nguigmi

NIGER

CHAD

Bol

Baga

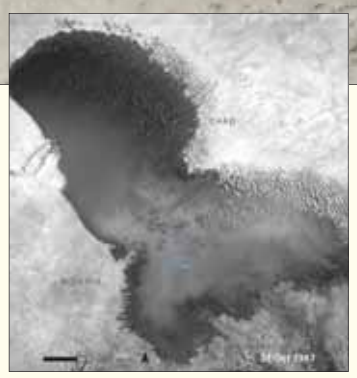
NIGERIA

CAMEROON

0 25 50 Kilometres

Makari

1972



Declining Water Levels in Lake Chad, 1972-2007

Lake Chad, located at the junction of Nigeria, Niger, Chad, and Cameroon, was once the sixth-largest lake in the world and the second-largest wetland in Africa. The lake was highly productive, and supported a great diversity of wildlife.

Persistent droughts and increased agricultural irrigation have reduced the lake's extent in the past 35 years to one-tenth of its former size. Despite the lake's large drainage basin, almost no water flows in from the dry north. Ninety per cent of the lake's water flows in from the Chari River.

Nguigmi

NIGER

CHAD

Bol

Baga

NIGERIA

CAMEROON

0 25 50 Kilometres

Makari

1987

With a flat and shallow lakebed, Lake Chad is very responsive to changes in rainfall. When rainfall decreases, water levels in the lake drop rapidly. Diversion of water by human activities from the lake and from the Chari River may be significant at times of low flow, but rainfall is still the determining factor in water levels and the lake's extent. As these

satellite images from 1972, 1987, and 2007 show, the surface area of the lake has declined dramatically over time. The 2007 image shows significant improvement over previous years, but the extent of Lake Chad is still far smaller than it was three to four decades ago.


Mark Knobil/Flickr.com

Aerial view of the Okavango Delta

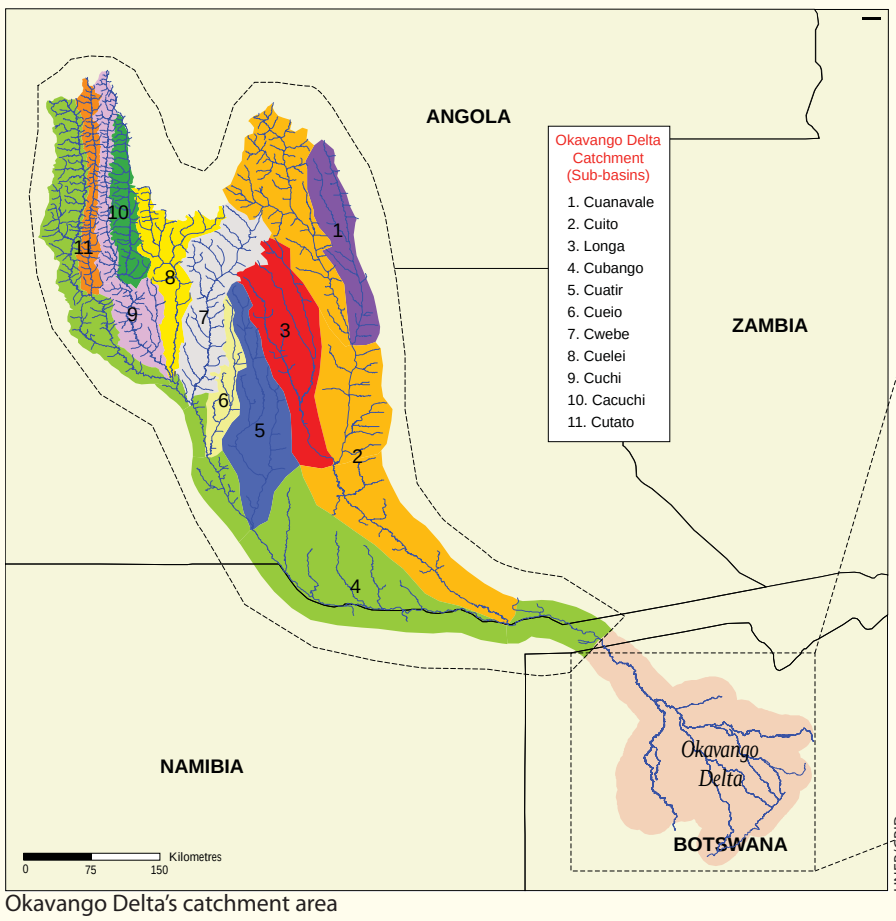
Justin Hall/Flickr.com

Okavango: The World's Largest Inland Delta

The Okavango Delta (or Okavango Swamp), a globally renowned Ramsar Wetland Site, is the world's largest inland delta. Angola, Namibia, and Botswana share the Okavango River catchment area that feeds the Okavango Delta. Spanning approximately 15 000 km², the Delta is a rich and varied freshwater habitat for diverse flora and fauna. It is home to 2 000 to 3 000 plant species, over 162 arachnid species, more than 20 species of large herbivores, over 450 bird species (Monna 1999), and approximately 70 species of fish (Kolding 1996). The area was once a part of Lake Makgadikgadi, an ancient lake that dried up some 10 000 years ago. Today, the Okavango River has no outlet to the sea. Instead, it flows out onto the sands of the Kalahari (Kgalagadi) Desert, watering 15 000 km² of that arid landscape. Each year some 11 km³ of water reach and sustain the Okavango Delta.

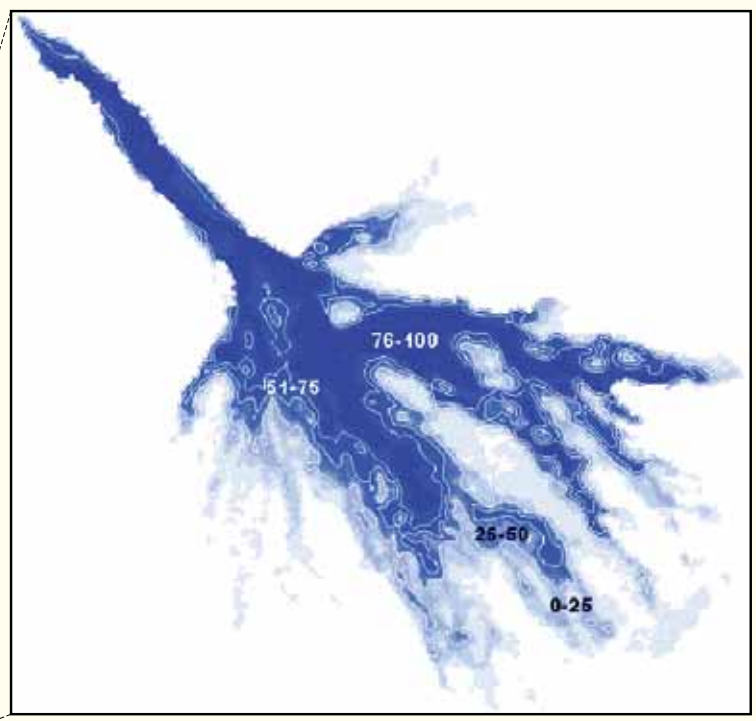
The inundated area of the Okavango Delta changes annually and seasonally, depending on the regional precipitation over the catchment area in the Angolan highlands (McCarthy and others 2003). The Delta's flooding begins about mid-summer in the north and six months later in the south. Water entering the Delta passes through the sand aquifers of numerous islands and evaporates, leaving behind enormous quantities of salt. The vegetation disappears in the centre of the islands and thick salt crusts form around their edges. Islands can disappear completely during the times of peak flooding, and reappear at the end of the season as waters recede. Constantly changing water levels have huge environmental and social implications since the Delta enjoys rich biodiversity and is a major source of livelihoods for local communities. The map below shows the percentage of time between 1985 and 2000 that areas of the delta were inundated. Dark blue areas indicate permanently inundated regions while lighter blue to white areas represent less inundation time (McCarthy and others 2003). The Delta's inundation has always varied from year to year. A study by McCarthy and others (2003) showed that the wetland area varied in extent from 2 450 km² to 11 400 km² between 1972 and 2000.

Map of the catchment area of the Okavango Delta



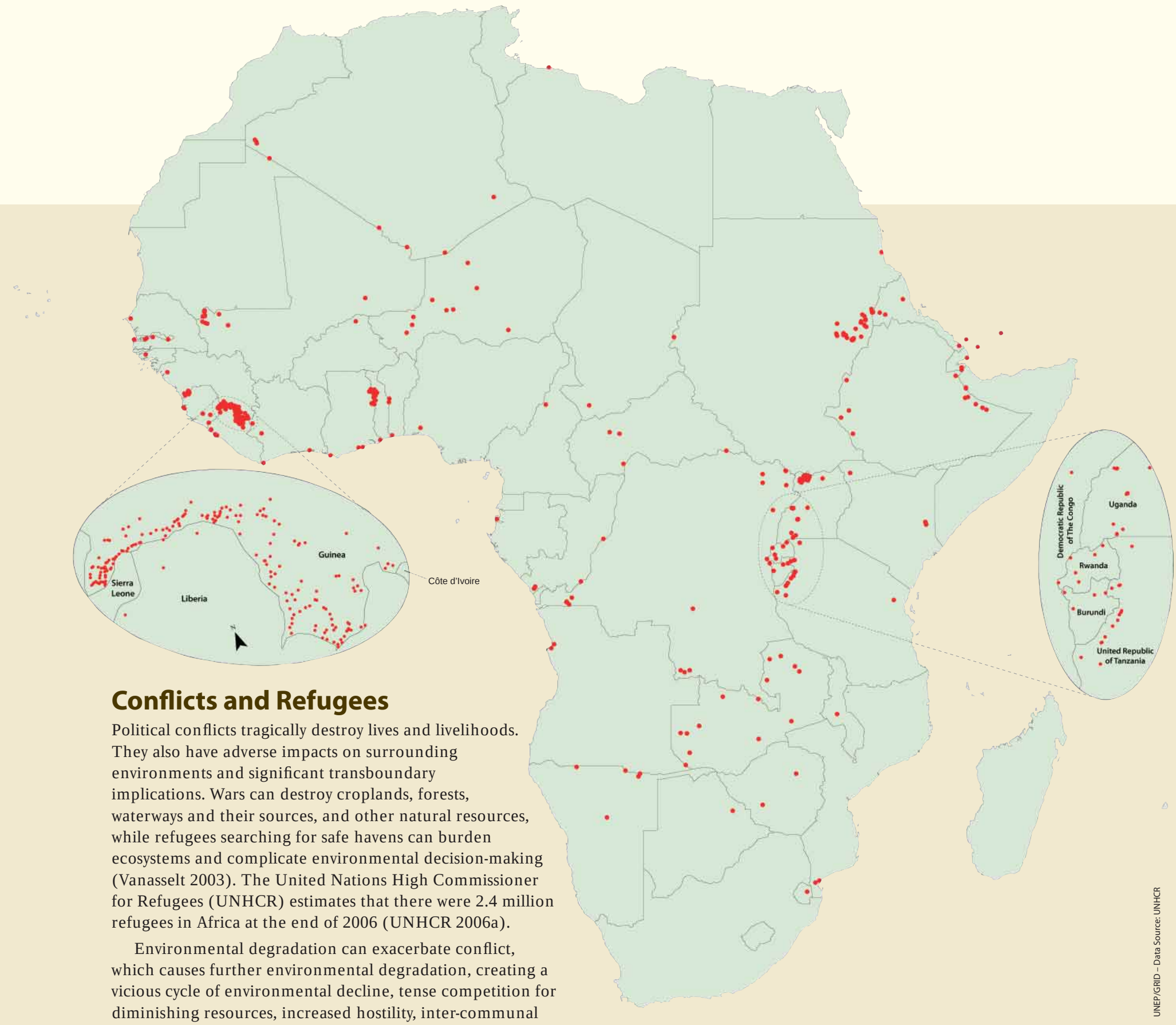
Okavango Delta's catchment area

UNEP/GRID



McCarthy and others 2003

Some parts of Okavango Delta remain inundated year round even in dry years, however, much of the delta is inundated only seasonally or in wet years. This image shows the percentage of time various areas of the delta were inundated between 1985 and 2000.

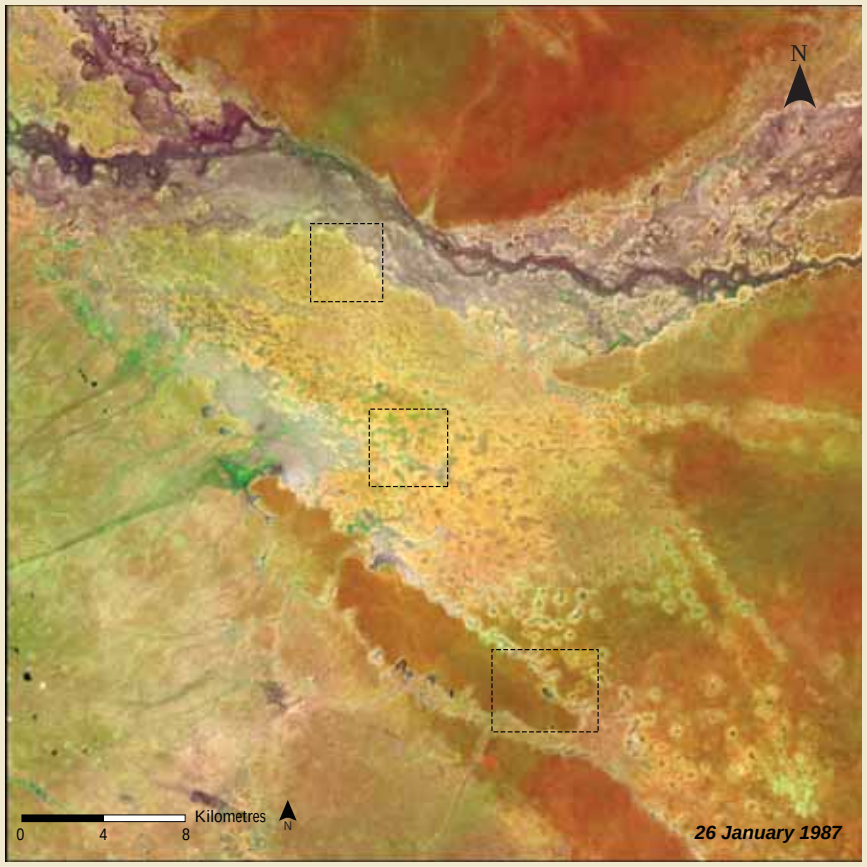


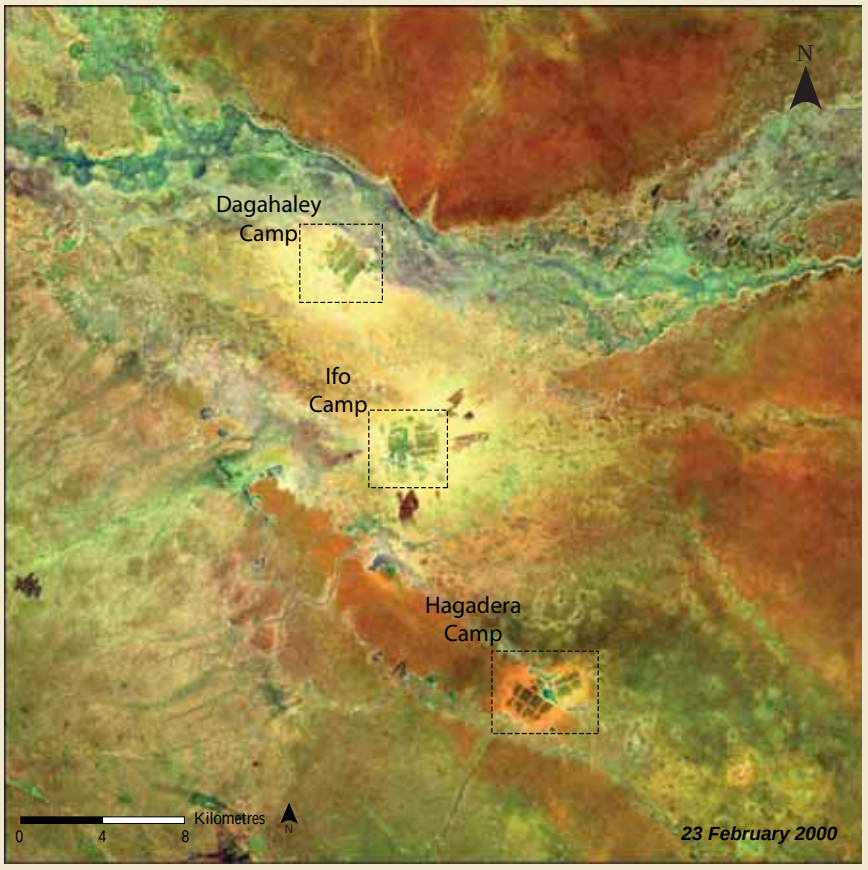
Conflicts and Refugees

Political conflicts tragically destroy lives and livelihoods. They also have adverse impacts on surrounding environments and significant transboundary implications. Wars can destroy croplands, forests, waterways and their sources, and other natural resources, while refugees searching for safe havens can burden ecosystems and complicate environmental decision-making (Vanasselt 2003). The United Nations High Commissioner for Refugees (UNHCR) estimates that there were 2.4 million refugees in Africa at the end of 2006 (UNHCR 2006a).

Environmental degradation can exacerbate conflict, which causes further environmental degradation, creating a vicious cycle of environmental decline, tense competition for diminishing resources, increased hostility, inter-communal fighting, and ultimately social and political breakdown. Ecological warning signs related to conflict and its impacts include limited habitable space, decrease in production of goods, and a heavy human "footprint" (Wolf 2007).

Changes to the landscape in and around the Dadaab Refugee Camp between 1987 and 2000



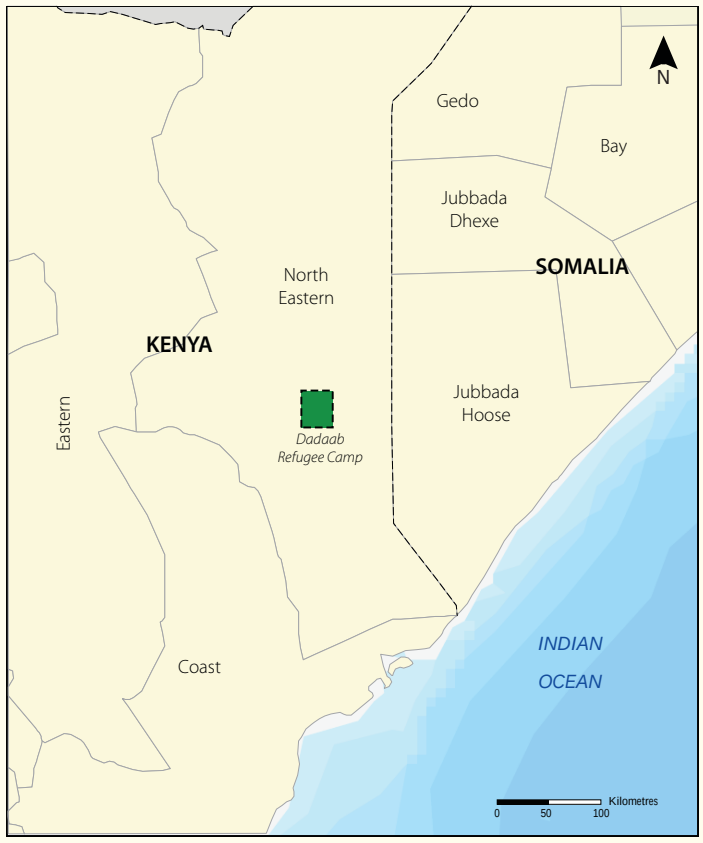


Dadaab Refugee Camp

Ifo, Dagahaley, and Hagadera refugee camps are located in Dadaab town in the North Eastern Province of Kenya, near the border with Somalia. The camps date back to 1991 when civil wars erupted on a large scale in Somalia. The conflicts, along with prolonged drought, forced more than 400 000 people from Somalia to flee to Kenya and another 500 000 to other neighbouring countries.

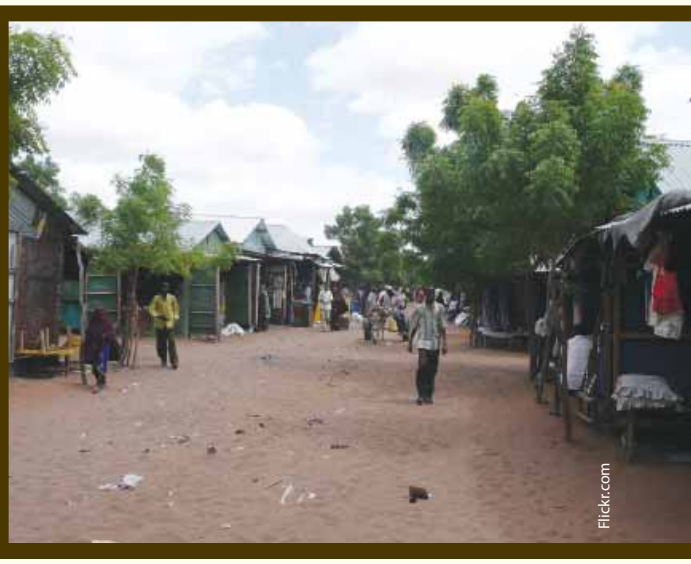
The 1987 satellite image above shows a fairly intact landscape dominated by shrub vegetation that is characteristic of the semi-arid area. In the 2000 image, the Ifo, Dagahaley, and Hagadera refugee camps stand out distinctly, revealing the presence and impact of a high concentration of over 100 000 refugees on the environment. Shrublands have been reduced largely to bare spots with sparse and stunted shrubs and grasses while riverine vegetation has also suffered loss and degradation.

Map of study area



UNEP/GRID

In the refugee camps, most households have several buildings—sleeping rooms, a kitchen, maybe a storage area—and lots of outside communal space where families can cook, socialize, clean, do laundry and other activities. It is not uncommon for families to keep goats, donkeys, or chickens within the household area.



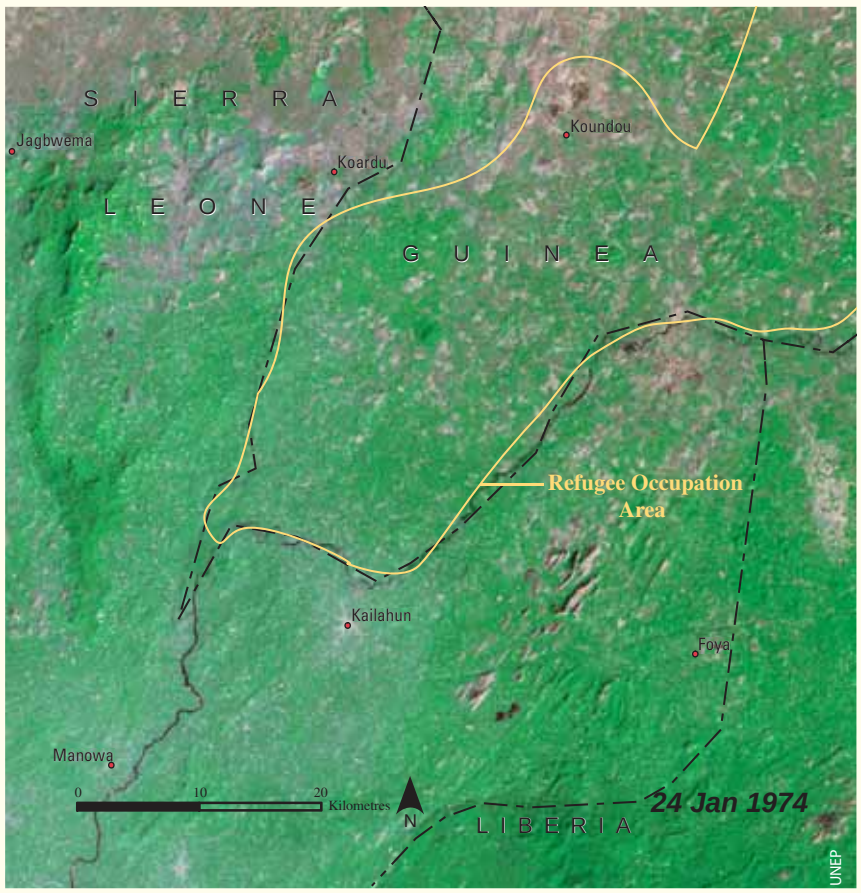
A street scene in Guinea

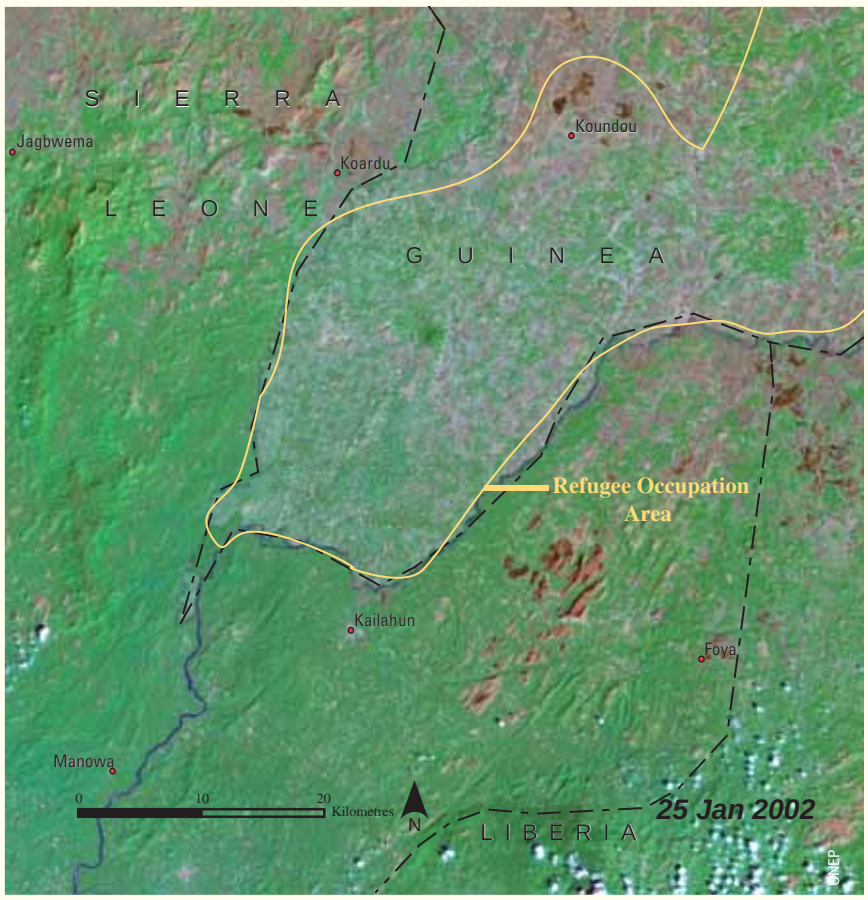
Courtney/Flickr.com

The Parrot's Beak Region

"Parrot's Beak" is a small strip of land belonging to Guinea, situated between Sierra Leone and Liberia. In the 1990s, civil wars in Sierra Leone and Liberia forced hundreds of thousands of people to seek the relative safety of Guinea. Many of these refugees settled in the Parrot's Beak region. The impact on the region can be seen in the two satellite images below. In the 1974 image, prior to the influx of refugees, small flecks of light green scattered throughout the deep-green forest of the Parrot's Beak region represent compounds of villages surrounded by agricultural plots. Contrast this with the light green colour of the 2002 image. This is the result of deforestation where refugees have settled. Many of the refugees integrated into local villages, converting forest into family agricultural plots to such an extent that the Parrot's Beak was largely denuded of trees. In early 2003, the United Nations High Commissioner for Refugees (UNHCR) helped 16 500 Sierra Leonean refugees living in Guinea return to their homeland; roughly half of these returning refugees traveled through the Parrot's Beak region.

Changes in the Parrot's Beak region between 1974 and 2002





Darfur Conflict

The Darfur conflict is a complex crisis in the Darfur region of western Sudan. The combination of decades of drought, desertification, and overpopulation are among the contributing factors that led nomads searching for water to drive their livestock south into regions mainly occupied by farming communities. Eventually, tensions between the two groups escalated into conflict. The United Nations estimates that as many as 450 000 people have died from violence and disease and about 2.5 million are thought to have been displaced as of October 2006 (UNHCR 2006b).

On 16 June 2007, United Nations Secretary General Ban Ki-moon released a statement in which he proposed that the impact of climate change is directly related to the Darfur conflict, as desertification has added significantly to the stress on the livelihoods of pastoralist societies, forcing them to move south to find pasture (Ban Ki-moon 2007). Apart from the millions internally displaced, more than 200 000 refugees are currently hosted in 12 UNHCR-run camps across the border in Chad (UNHCR 2006b). Their presence is a transboundary environmental problem, since the need for fuelwood has led refugees to destroy forests around the camps and dig new bore holes for water, which are depleting aquifers.

Bir Kedouas is a two square kilometre settlement within Chad, just west of Sudan's Darfur region (see below). On 16 December 2005, Janjawid nomadic fighters attacked the village settlement, burning at least 60 homes and causing widespread destruction (Amnesty International 2006).

Map of study area

Changes in Bir Kedouas, Chad, between 2004 and 2006

Before and after the 2005 attack (images from Quickbird/Digital Globe)

Dust Storms and Fires

Dust storms and biomass burning are two significant sources of transboundary air pollution in Africa. Desertification—a major environmental issue—contributes to dust storms, while biomass burning releases unhealthy particulates into the air, causing air pollution that in turn leads to respiratory illnesses, allergies, and other health problems.

Dust storm in Cairo, Egypt

Keith and Gabriela Fultonne/Flickr.com

Dust Storms

Dust storms are severe weather hazards. They are characterized by strong winds and dust-filled air over an extensive area, often drifting from one country to another. They are common in arid and semi-arid regions. The dust in such storms is either natural in origin, from volcanic eruptions or from soil eroded by wind, or the result of human activities, such as mining and various industries.

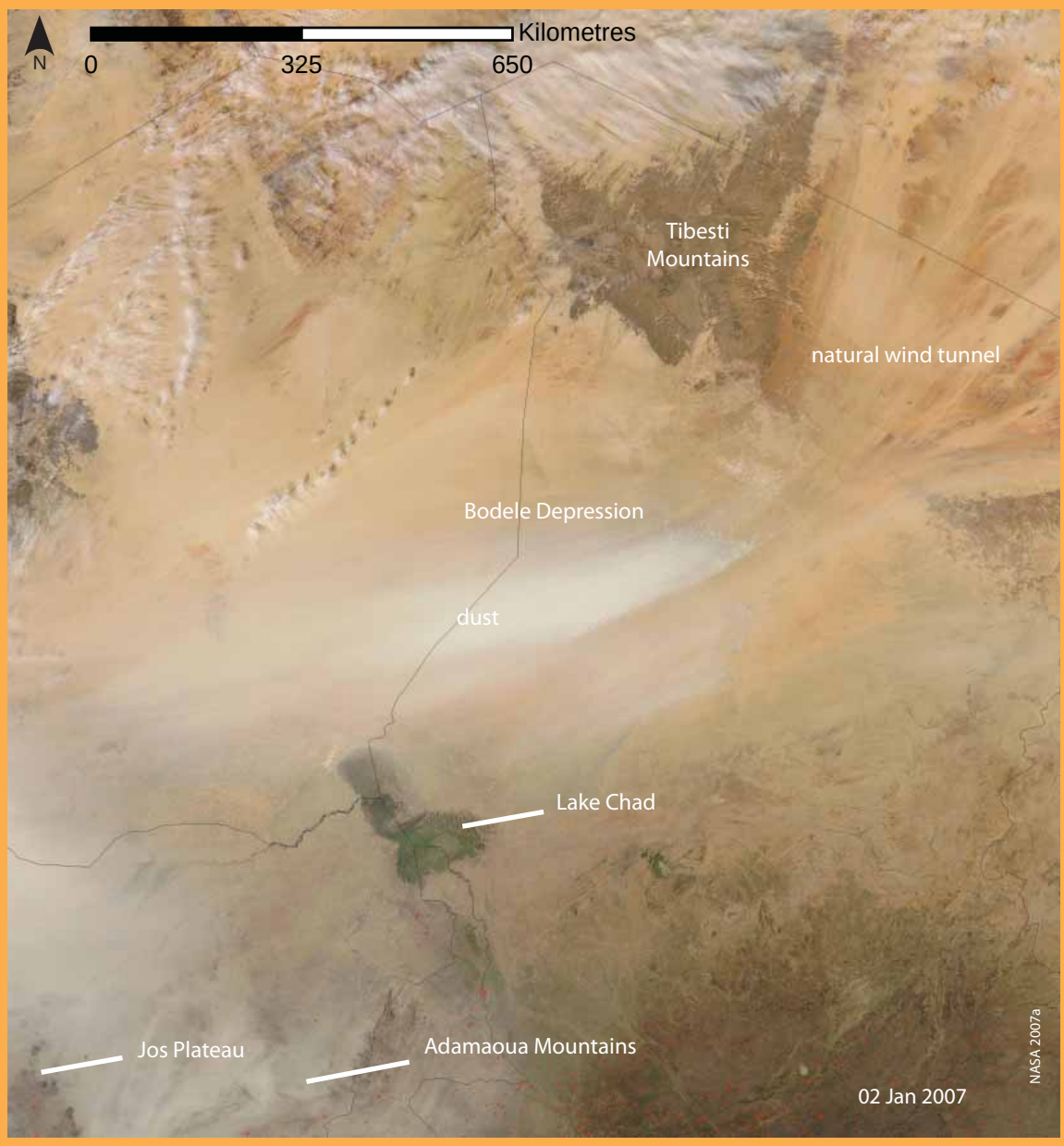
Africa is one of the largest dust-producing regions in the world (Washington and others 2006a). Niger, Chad, Mauritania, northern Nigeria, and Burkina Faso are among the countries most affected by the loss of top soil by wind erosion. Saharan dust storms were once relatively rare, but in the past half-century they have increased ten-fold. In Mauritania, the number of dust storms rose from two per year in the early 1960s to 80 per year in more recent times (Brown 2007).

Transboundary transport of African dust-—across continents and even oceans—can result in a number of environmental hazards such as eutrophication (decreased oxygen) in estuaries and lung infections in humans. The loss of fine soil particles through erosion and dust storms deprives the land of fertility as well as biological productivity (Brown 2007), and can affect the weather by reflecting the sun's rays back into space (NASA 2004a). Dust storms are thus increasingly viewed as a key component of change in some terrestrial and marine ecosystems and as a potentially significant source of pathogens and contaminants (Ila 2006).

Dust Storm in the Bodele Depression

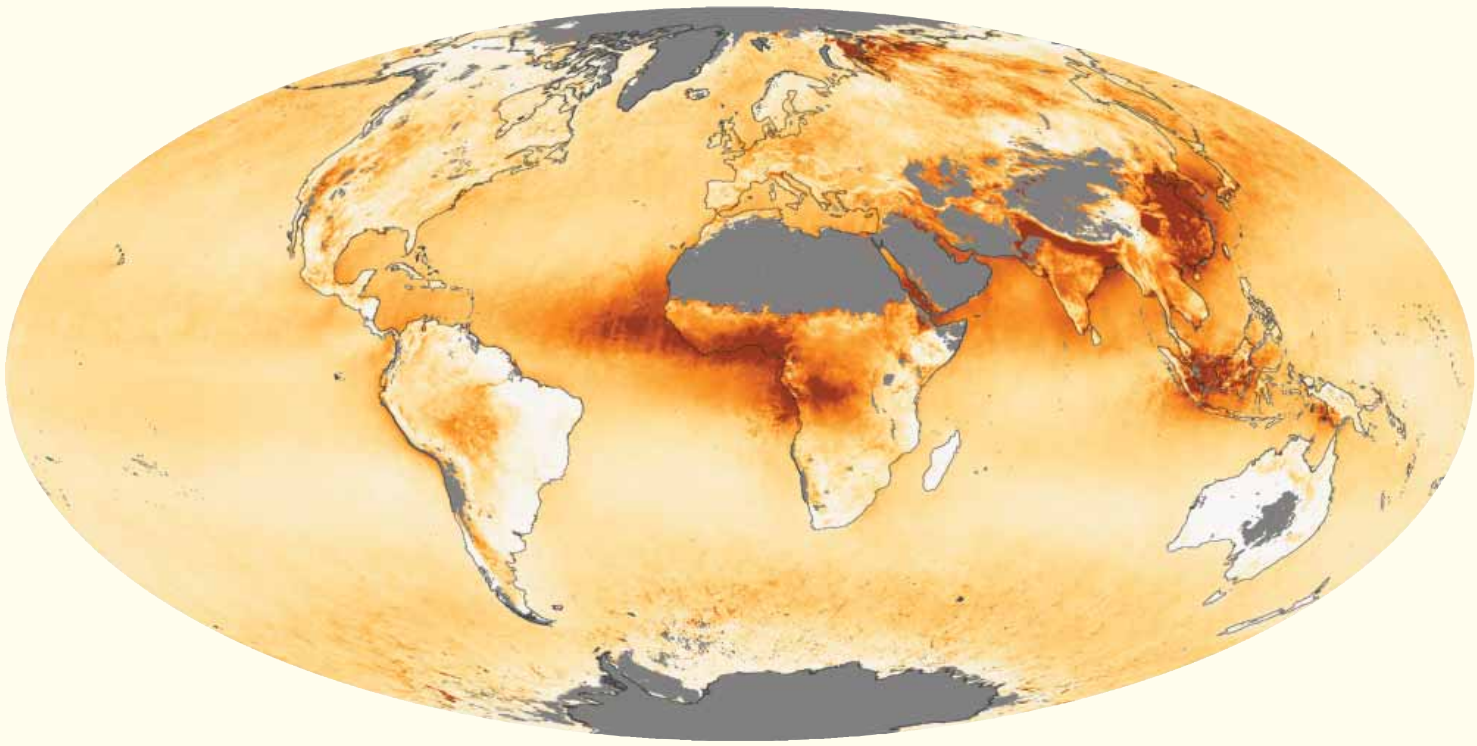
The Bodele Depression, located at the southern edge of the Sahara Desert in north-central Africa, is one of the largest sources of airborne dust in the world. Nested between two mountain ranges in Chad and downwind from a natural wind tunnel, the Bodele Depression provides a steady supply of Saharan dust plumes. This January 2007 satellite image (right), shows a dust storm brewing in the Bodele Depression. Clearly visible is a bright streak of dust that arcs southwest across the Depression toward Lake Chad. During winter in the Northern Hemisphere, northeasterly winds routinely blow across this part of northern Africa. The dust spreads westward across the Atlantic Ocean on the easterly trade winds. Eventually, the dust reaches the Amazon River Basin in South America, where it replenishes mineral nutrients that are continually depleted from the soil by heavy, tropical rains. About half of the 40 million metric tonnes of dust that are swept across the Atlantic from the Sahara to the Amazon each year come from the Bodele Depression, an area that accounts for only 0.2 per cent of the Sahara (NASA 2007a).

Based on satellite data and computer models, scientists estimate that Saharan dust storms generate an average of about 0.7 million metric tonnes of dust during winter days.

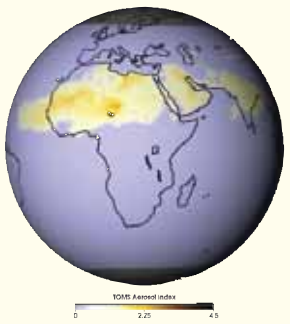


Dust storm, Bodele Depression

Richard Washingtonne/BodEx



This image shows the annual mean aerosol optical depth for 2006. Optical depth is the degree to which aerosols prevent incoming sunlight from reaching the Earth's surface. High aerosol concentrations were observed over western and central Africa due to dust from the Sahara and smoke from biomass burning. Gray zones on the map represent areas were aerosol data could not be collected (NASA 2006c).



This April 2000 image of Africa shows dust blowing from the Sahara Desert into the Atlantic Ocean, represented as areas where aerosols absorb ultraviolet radiation. High concentrations of aerosols are indicated in brown and lower concentrations in yellow (NASA 2000).

Aerosols

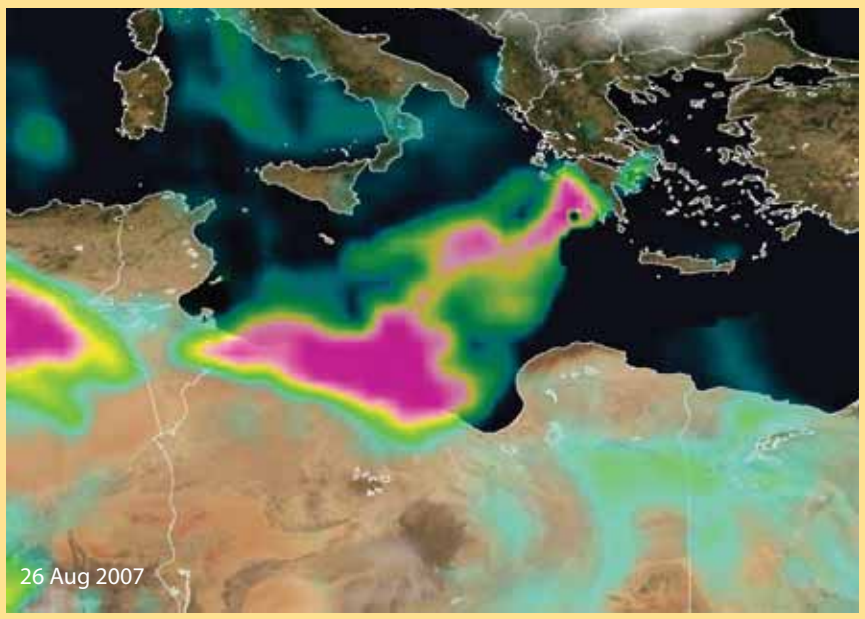
Aerosols are tiny particles suspended in the air. They tend to have a cooling effect on the Earth's surface by reflecting some of the sun's rays back into space. Aerosols also absorb ultraviolet radiation.

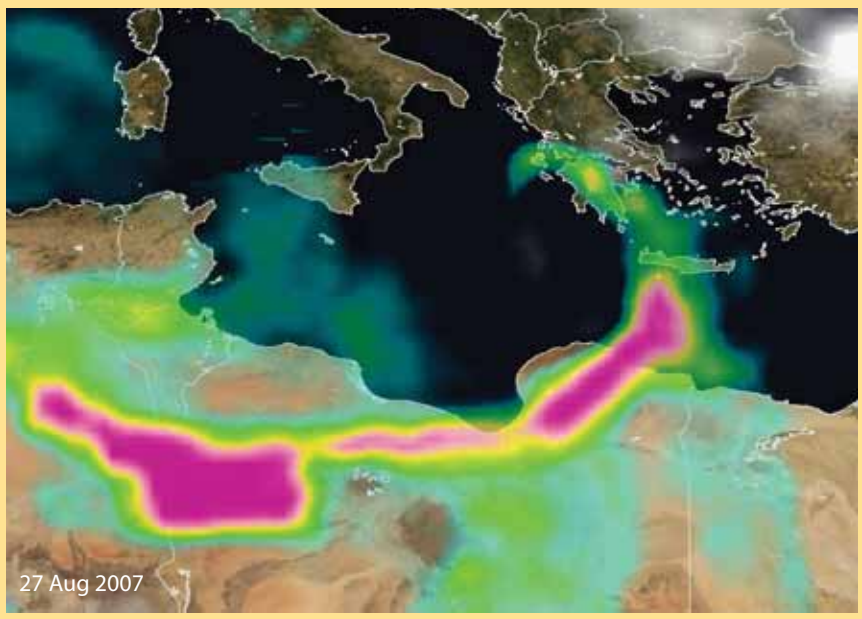
Aerosols can originate from natural sources such as volcanoes, forest fires, and dust storms, or from anthropogenic sources such as the burning of fossil fuels. Averaged over the globe, aerosols resulting from human activities currently account for about 10 per cent of the total amount of aerosols in the atmosphere (Hardin and Kahn n.d.). Most of that 10 per cent is concentrated in the Northern Hemisphere, especially over industrial sites, agricultural regions, areas where slash-and-burn agriculture is practised, and overgrazed grasslands.

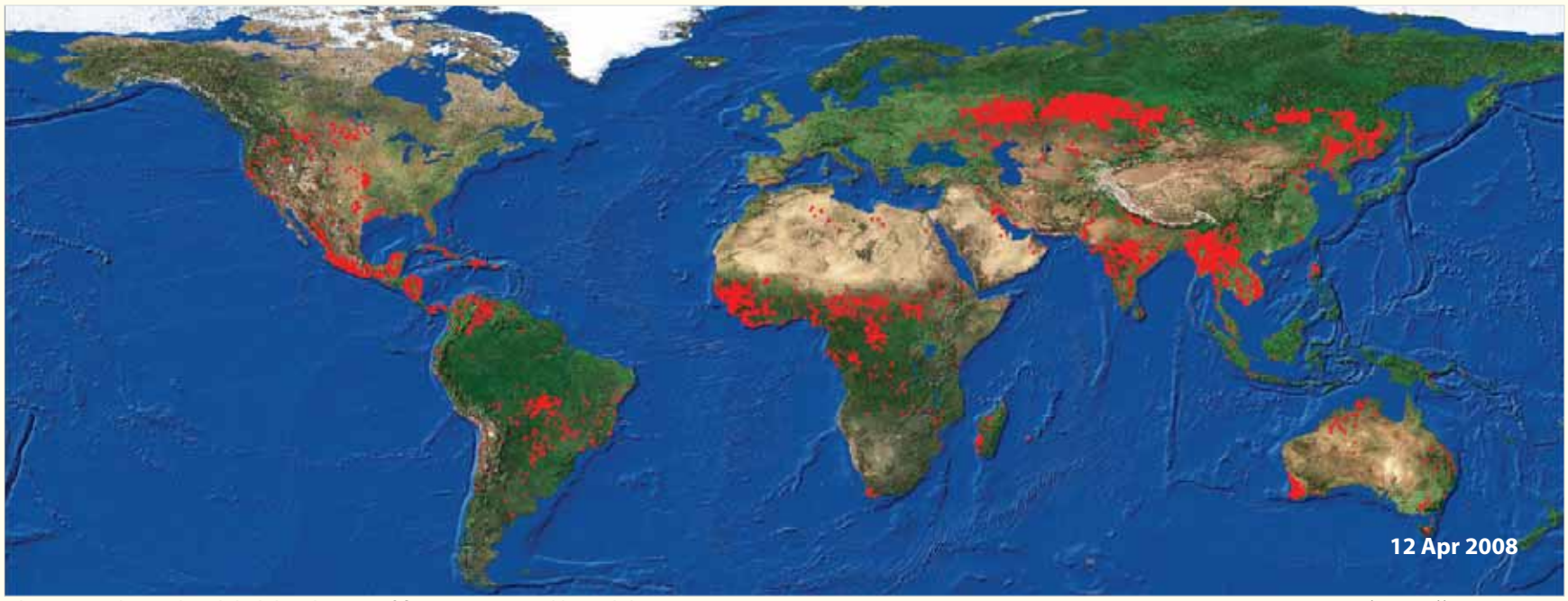
This 2007 image shows actively burning fires in red—a line of fires stretches along the western coast of Greece's Peloponnesus Peninsula. To the northeast, a single fire casts a plume of smoke over the Greek capital of Athens.

Smoke Spreading From Greece to Africa

Fires burning in southwestern Greece in August 2007 released aerosols that winds carried to Africa. On 26 August 2007, aerosols from the fires took a fairly direct route across the Mediterranean Sea to collect on the western part of the Libyan Arab Jamahiriya coast. On 27 August 2007, the aerosols took a different path, spreading southward in a clockwise direction from Greece, across the island of Crete, and ultimately concentrating over eastern Libyan Arab Jamahiriya. In these images, the highest aerosol concentrations are represented in pink, with lower concentrations in yellow and green; relatively clear air is transparent (NASA 2007c).







This image shows the global distribution of fires, represented by red dots. Fire distribution in Africa indicates the highest biomass burning in the world (images based on night-time measurements).

Image Credit: NASA n.d.b; Data Source: GLCF

Fires

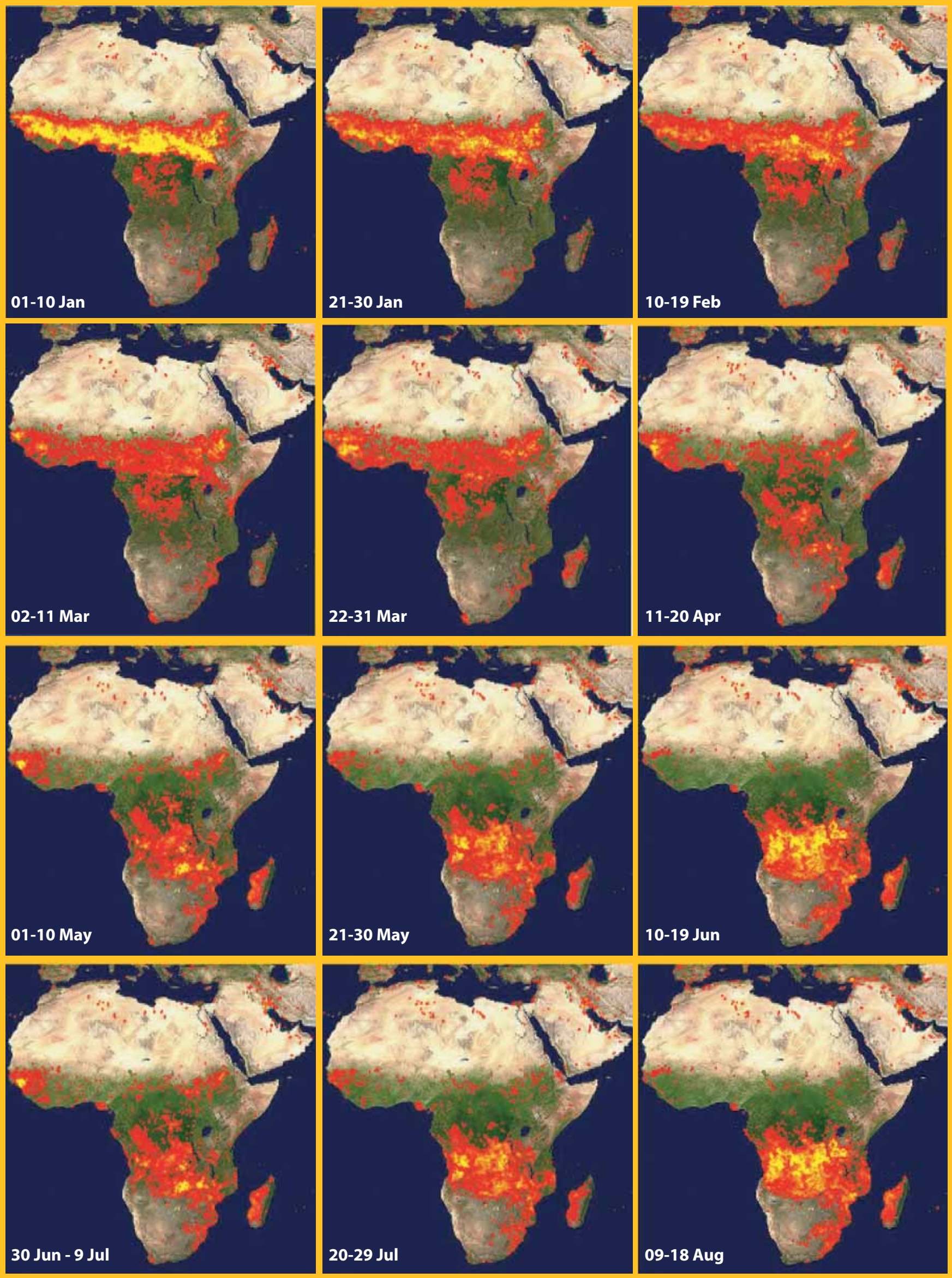
The frequent and large-scale burning of grasslands in Africa contributes to transboundary air pollution through the release of airborne particles (aerosols) and gases into the atmosphere, many of which can have an impact on climate and human health. For example, fires also release carbon monoxide, hydrocarbons, and nitrogen oxides. When exposed to sunlight, some of these substances react chemically to create ground-level ozone. Unlike the ozone in the stratosphere, which absorbs dangerous ultraviolet light, ozone near the Earth's surface is a harmful air pollutant that can lead to respiratory illnesses and allergies in people. While urban and industrial contributions to pollution go on year round, wildfires can add to global pollution levels in intense seasonal bursts. Fires contribute as much as 35 per cent of ground-level ozone formation in Africa.

Biomass Burning in Africa

Biomass burning is the burning of living and dead vegetation and includes the burning of forests, savannahs, and agricultural lands. Wildfires are responsible for half of the biomass burning that occurs in Africa, while shifting cultivation accounts for 24 per cent, deforestation for ten per cent, domestic burning for 11 per cent, and the burning of agricultural waste for five per cent (UNEP 2005b). Studies show that biomass burning has increased on a global scale over the last 100 years. Savannahs in Africa experience the most extensive biomass burning in the world (NASA 2001b). Because two-thirds of the Earth's savannahs are located in Africa, the continent is now recognized as the "burn centre" of the planet (Levine and others 1995).

Burning brush in Kenya

Christian Lambrechts/UNEP



Seasonal Pattern of Wildland Fires

This series of images shows the seasonal pattern of wildland fires in Africa during 2005. Fires appear as red, orange, or yellow dots, with yellow indicating the greatest number of fires. Some of the highest levels of biomass burning in the world occur in southern Africa. For thousands of years farmers and herders south of the Sahara Desert have used fire to clear land for farming or renew grazing land. Fire locations shift with the seasons. The burning of tropical savannahs is estimated to release nearly three times as much carbon (as carbon dioxide) into the atmosphere as the burning of tropical forests. Extensive biomass burning in Africa not only releases carbon dioxide, the principle greenhouse gas, into the atmosphere but also contributes carbon monoxide. Furthermore, if burned vegetation does not regenerate, it can no longer act as a carbon sink. Denuded landscapes also hasten desertification.

Biomass burning results in carbon monoxide pollution

Christian Lambrechts/UNEP

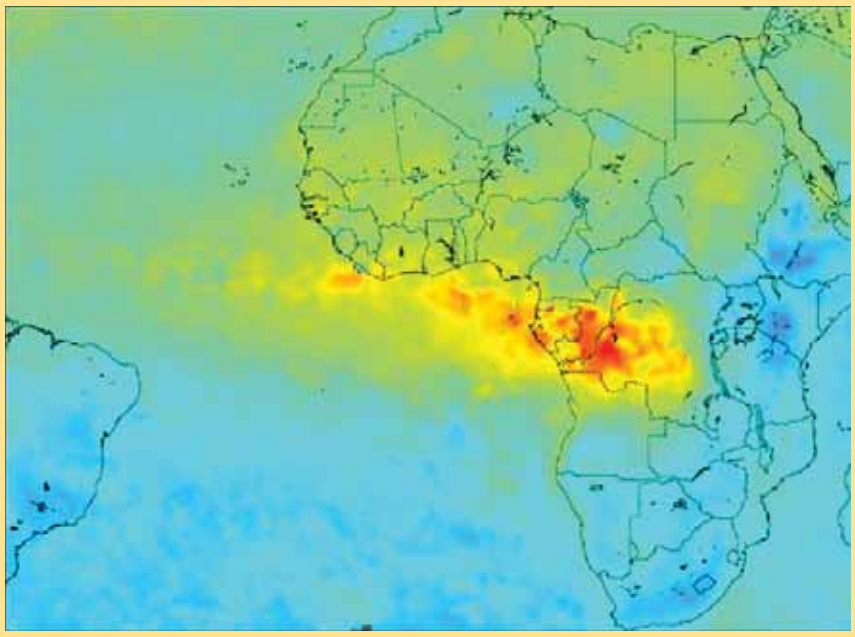
Carbon Monoxide Pollution: A Result of Biomass Burning

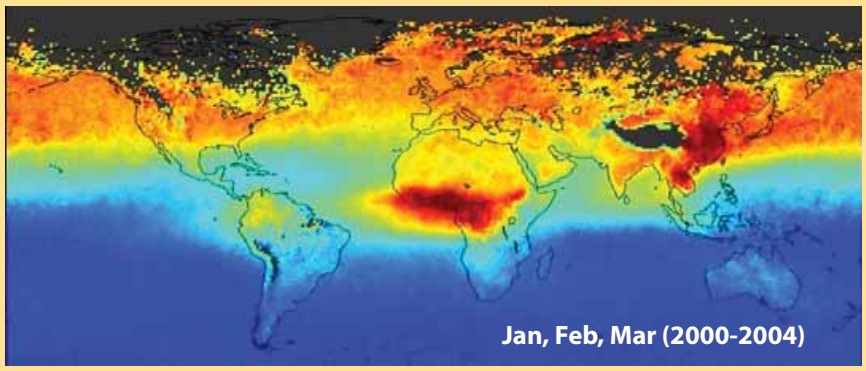
A colourless, odourless, and poisonous gas, carbon monoxide (CO) is a by-product of the burning of fossil fuels in industry and automobiles, as well as the burning of forests and grasslands. A major air pollutant, carbon monoxide is created when carbon-based fuels—like fossil fuels or fuelwoods—do not burn completely or efficiently. High levels of CO pollution are found in many parts of the world, and they result from different types of burning in different locations. In central Africa, high levels of atmospheric CO are linked to widespread fire activity from agricultural burning and wildfires. Carbon monoxide molecules can last from a few weeks to several months in the atmosphere and can travel across national boundaries. Because of its transboundary movement, CO can affect air quality in regions far from its original source (NASA 2000-2004).

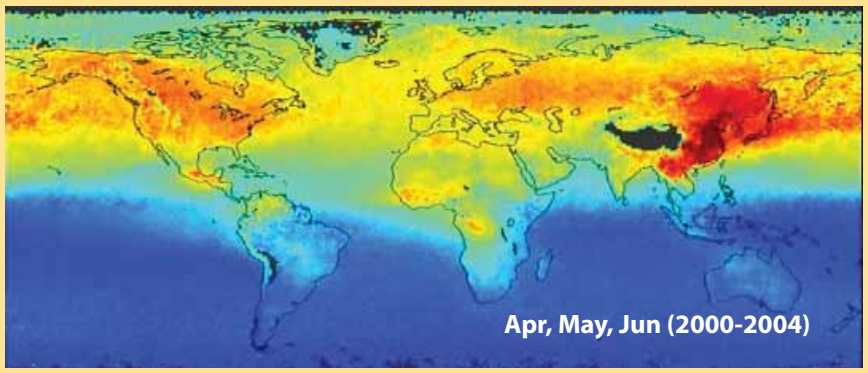
Widespread fires release high levels of CO

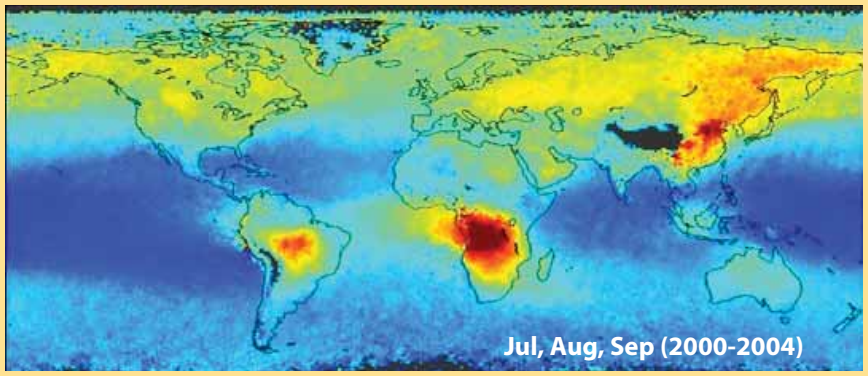
This vertical series of images (right) shows a record of global CO production from March 2000 through February 2004. Blue areas have little or no atmospheric CO, while progressively higher CO levels are shown in green, yellow, orange, and red. In January through March, carbon monoxide levels are in the "red zone"—more than 200 parts per 1 000 million—across much of the Northern Hemisphere. They are even present as far north as the Arctic and extending out over the Atlantic and Pacific Oceans because of transboundary movement (NASA 2000-2004). CO levels are especially high over central Africa for much of the year.

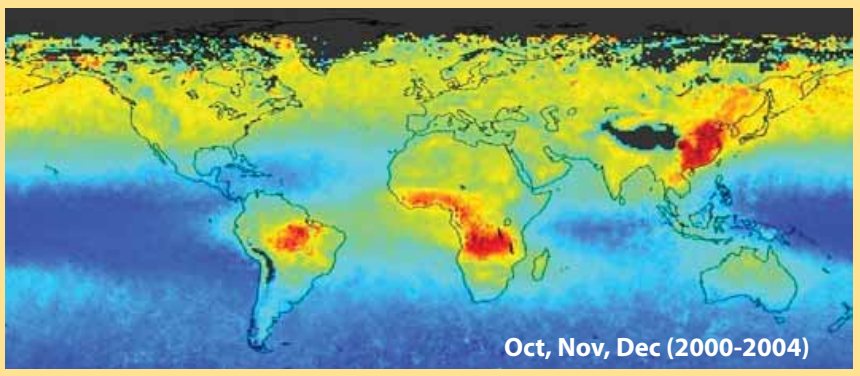
In this June 2004 image, red and yellow indicate high carbon monoxide levels, while light- and dark-blue hues represent low values (NASA 2004b). A vast plume of carbon monoxide extends from Africa over the Atlantic Ocean.

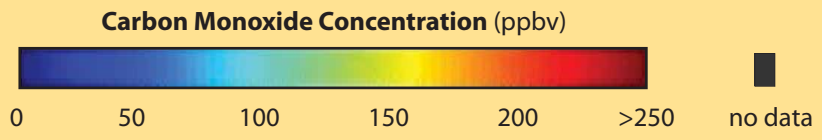










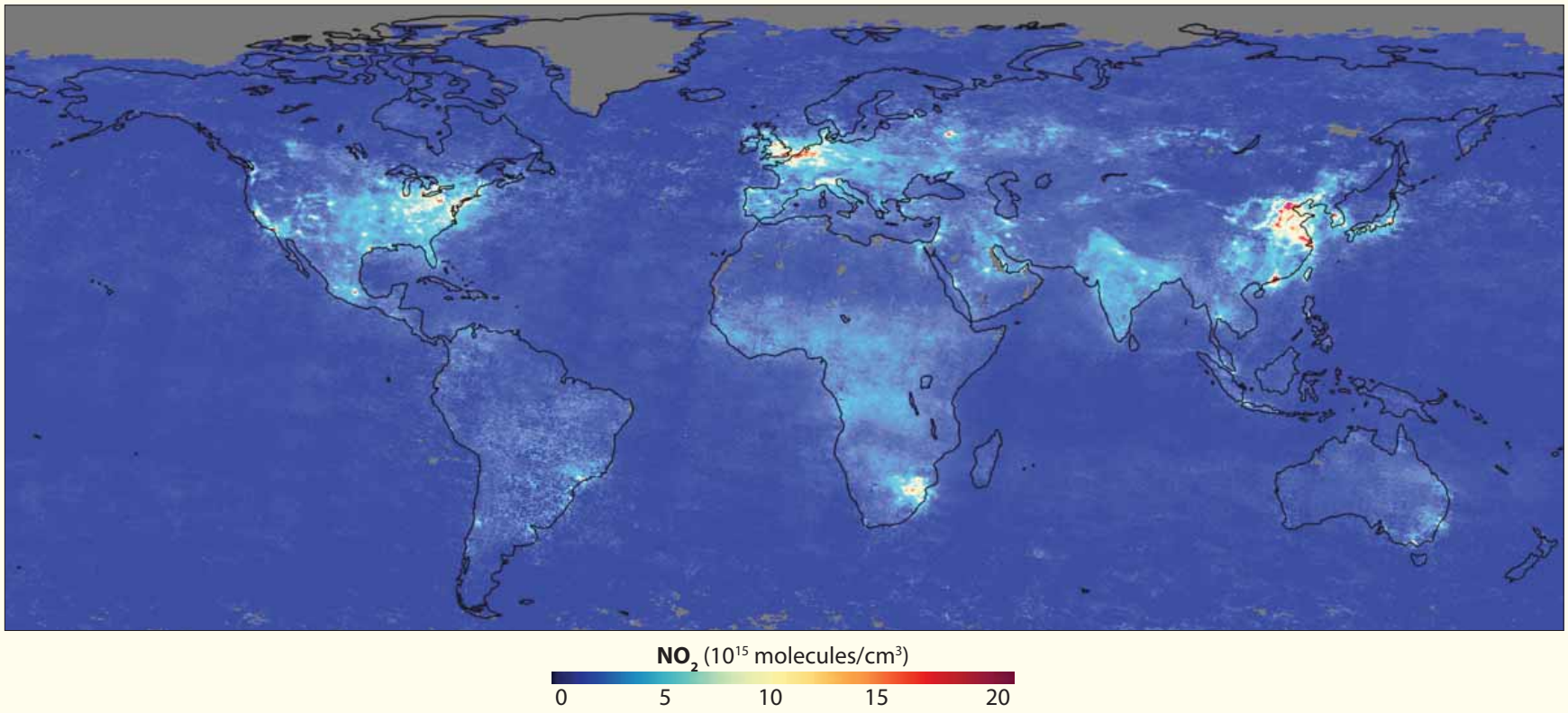


Southern Africa: Hotspot for Nitrogen Dioxide (NO_2)

Nitrogen oxides are created from lightning, soil microbial activity, both natural and anthropogenic fires, automobile exhaust, the burning of fossil fuels and biomass, and the photo-degradation of nitrous oxide (N_2O) in the stratosphere. Nitrogen oxides in the atmosphere eventually form acid rain that damages plants and agricultural crops (EPA 2002). Nitrogen dioxide can impact human health, causing lung damage and respiratory problems. It also contributes to urban pollution, since it is a reactant in the production of ground-level ozone.

A global map of nitrogen dioxide (NO_2) in the troposphere in 2003

This 2003 image shows the locations of high levels of nitrogen dioxide worldwide. High concentrations of NO_2 tend to be associated with large urban or industrial areas. In Africa, NO_2 concentrations are particularly high over coal-fired power stations in South Africa. Lower, but widespread, concentrations of the gas—produced by biomass burning—are visible across much of the African continent (NASA 2003).



2.5 Conclusion

The illustrated case studies and examples in this chapter have underscored how Africa's ecosystems and their plant and animal inhabitants are not confined by political jurisdictions, but are often shared by many countries. Furthermore, the impact of human activities can often be felt far beyond the borders of the countries in which the activities take place. For these reasons, common approaches and complementary actions by neighbouring countries and entire regions are needed to effectively conserve Africa's biodiversity and the natural resources its people depend upon for their livelihoods.

Taking wood to market

Christian Lambrechts/UNEP

References

AWF (2003). African Wildlife Foundation, Africa launches the Great Limpopo Transfrontier Park, 13 January 2003, Available at: http://www.awf.org/content/headline/detail/1174 [Accessed 13 September 2007]

Ban Ki-moon (2007). A climate culprit in Darfur, The Washington Post, 16 June 2007, pp. A15. Available at: http://www.washingtonpost.com/wp-dyn/content/article/2007/06/15/AR2007061501857.html [Accessed 16 June 2007]

Brown, L. R. (2007). Losing soil. Adapted from Chapter 5, "Natural Systems Under Stress," in Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble, New York: W.W. Norton & Company, 2006. Earth Policy Institute, New York, Available at: http://www.earth-policy.org/Books/Seg/PB2ch05_ss3.htm [Accessed 04 July 2007]

CARPE (2006). Central African Regional Project for the Environment, The Forests of the Congo Basin: State of the Forest 2006. The Congo Basin Forest Partnership (CBFP), http://carpe.umd.edu/resources/Documents/THE_FORESTS_OF_THE_CONGO_BASIN_State_of_the_Forest_2006.pdf/view [Accessed 21 July 2007]

Coe, M. T. and Foley, J. A. (2001). Human and natural impacts on the water research of the Lake Chad Basin. Journal of Geophysical Research, 106 (D4) pp. 3349-3356.

Douglas E. M., Sanga-Ngoie K. (2004). Simulating the East African wildebeest migration patterns using GIS and remote sensing, African Journal of Ecology, v. 42, n.4, pp. 355–362.

EPA (2002). Greenhouse Gases and Global Warming Potential Values. Excerpt from the inventory of U.S. greenhouse emissions and sinks: 1990-2000, United States Environmental Protection Agency, Available at: http://www.epa.gov/climatechange/emissions/downloads/ghg_gwp.pdf [Accessed 13 May 2007]

Eva, H. D., Brink, A. and Simonetti, D. (2006). Monitoring land cover dynamics in Sub-Saharan Africa. EUR 22498 EN. Institute for Environment and Sustainability, Joint Research Centre European Commission, Luxembourg. Available at: http://ies.jrc.cec.eu.int/fileadmin/Documentation/Reports/Global_Vegetation_Monitoring/EUR_2006-2007/EUR_22498_EN.pdf [Accessed 11 October 2007]

FAO (1997). Irrigation potential in Africa: A basin approach – The Nile Basin and The Congo/Zaire River basin. Available at: http://www.fao.org/docrep/W4347E/w4347e0k.htm#the%20nile%20basin and http://www.fao.org/docrep/W4347E/w4347e0n.htm#the%20congozaire%20river%20basin [Accessed 23 January 2007]

FAO (2005). State of the World's Forests 2005. Food and Agriculture Organization of the United Nations, Rome, ftp://ftp.fao.org/docrep/fao/007/y5574e/y5574e00.pdf [Accessed 28 April 2007]

Gauthier, D. A., Lafon, A., Tooms, T. P., Hoth, J. and Wiken, E. (2003). Grasslands: Toward a North American Conservation Strategy. Commission for Environmental Cooperation, Montreal and Canadian Plains Research Center, University of Regina, Canada,

Go2Africa (2003). The Wildebeest Migration, http://www.safari.go2africa.com/africa-features/wildebeest-migration.asp [Accessed 25 September 2007]

Hansen, M.C.,Roy, D., Lindquist, E., Adusei, B., Justice, C.O., and Altstatt, A. (n.d.). A method for integrating MODIS and Landsat data for systematic monitoring of forest cover and change in the Congo Basin, Remote Sensing of Environment, in press.

Hardin, M. and Kahn, R. (n.d.). Aerosols and climate change. Available at: http://earthobservatory.nasa.gov/Library/Aerosols/aerosol.html [Accessed 24 September 2007]

Ila, P. (2006). Medical geology/geochemistry: an exposure. Massachusetts Institute of Technology, Cambridge MA, USA. Available at: http://ocw.mit.edu/NR/rdonlyres/Earth--Atmospheric--and-Planetary-Sciences/12-091January--IAP--2006/B8E16620-F020-48EC-A11D-0BC2EB06246D/0/session5.pdf [Accessed 18 June 2007]

Kolding, J. (1996). Feasibility Study and Appraisal of Fish Stock Management Plan in Okavango,

University of Bergen, Norway

Levine, J. S., Cofer, W. R., Cahoon, D. R. and Winstead, E. L. (1995). Biomass burning: a driver for global change, Environmental Science and Technology, 29 (3) 120A-125A, Available at: http://science.larc.nasa.gov/biomass_burn/pdfdocs/BioMassBurning--Factsheet.pdf [Accessed 24 September 2007]

Laporte, N. T., Stabach, J. A., Grosch, R., Lin, T. S. and Goetz, S. J. (2007). Expansion of industrial logging in Central Africa, Science, 316 (5830) 1451.

McCarthy, J. M., Gumbricht, T., McCarthy, T., Frost, P., Wessels, K. and Seidel, F. (2003). Flooding patterns of the Okavango Wetland in Botswana between 1972-2000. Ambio, 32 (7) 453-457,

Available at: http://www.bioone.org/archive/0044-7447/32/7/pdf/i0044-7447-32-7-453.pdf [Accessed 24 September 2007]

McCrummen, S. (2007). In an Eastern Congo oasis, blood amid the greenery. The Washington Post, 22 July 2007, 130 (229) pp. A1, A10 [Accessed 22 July 2007]

Miller, R. L. and Tegen, I. (1998). Climate response to soil dust aerosols. Journal of Climate. 11: pp 3247 – 3267.

Mongabay (2007). Massive wildlife population discovered in Southern Sudan, 12 June 2007, Available at: http://news.mongabay.com/2007/0612-sudan.html [Accessed 24 September 2007]

Monna, S. C. (1999). A Framework for International Cooperation for the Management of the Okavango Basin and Delta. Ramsar COP7 DOC.205. The Ramsar Convention on Wetlands.

MSNBC (2007). Four endangered gorillas found shot dead, MSNBC News, 26 July 2007. Available at: http://www.msnbc.msn.com/id/19974474/ [Accessed 26 July 2007]

MSN Encarta (2007). Great Limpopo Transfrontier Park. MSN Encarta Enciclopedia, Available at: http://encarta.msn-ppe.com:443/encyclopedia_701639180/Great_Limpopo_Transfrontier_Park.html [Accessed 24 September 2007]

Musiega, D. E., and Kazadi, S-N (2004). Simulating the East African wildebeest migration patterns using GIS and remote sensing. African Journal of Ecology 42 (4) 355–362, Available at: http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2028.2004.00538.x?journalCode=aje [Accessed 24 September 2007]

NASA (2000). TOMS Aerosol Index, Earth Observatory News, 2000, Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4540 [Accessed 24 September 2007]

NASA (2000-2004). Seasonal carbon monoxide measurements, Earth Observatory News. Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16550 [Accessed 26 September 2007]

NASA (2001a). Africa's Lake Chad shrinks by 20 times due to irrigation demands, climate change, Goddard Space Flight Center, Release No: 01-17, 27, February 2001, Available at: http://www.gsfc.nasa.gov/news-release/releases/2001/01-17.htm [Accessed 8 June 2007]

NASA (2001b). Biomass burning: a hot issue in global change, Fact Sheet, Langley Research Center, Available at: http://science.larc.nasa.gov/biomass_burn/pdfdocs/BioMassBurning--Factsheet.pdf [Accessed 24 September 2007]

NASA (2003). 2003 Global NO2, Earth Observatory News, 2003. Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16654 [Accessed 24 September 2007]

NASA (2004a). 2004 Earth Feature Story – Special: Africa to Atlantic, Dust to Dust, Goddard Space Flight Center, 10 February 2004, Available at: http://www.gsfc.nasa.gov/feature/2004/0116dust.html [Accessed 24 September 2007]

NASA (2004b). Carbon monoxide from African fires, Earth Observatory News, June 2004, Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16598 [Accessed 24 September 2007]

NASA (2005). 2005 Fire patterns across Africa, Earth Observatory News, 2005, Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17016 [Accessed 24 September 2007]

NASA (2006a). Drought on the Serengeti Plain. Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17163 [Accessed 14 September 2007]

NASA (2006b). Lake Victoria's falling waters. Available at: http://earthobservatory.nasa.gov/Study/Victoria/victoria.html [Accessed 09 June 2007]

NASA (2006c). Water Hyacinth Re-invades Lake Victoria. Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17560 [Accessed 09 June 2007]

NASA (2006d). Aerosol optical depth in 2006, Earth Observatory News, 2006. Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17575 [Accessed 09 June 2007]

NASA (2007a). Bodele Depression dust storm, Earth Observatory and Natural Hazards, January 2007, Available at: http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=14061 [Accessed 24 September 2007]

NASA (2007b). Deadly fires in Greece, Earth Observatory News, August 2007, Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17753 [Accessed 24 September 2007]

NASA (2007c). Smoke spreading from Greece to Africa, Earth Observatory News, August 2007, Available at: http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17755 [Accessed 24 September 2007]

NASA (2007d). Hurricanes: Did Dust Bust the 2006 Hurricane Season Forecasts? 28 March 2007. Available at: http://www.nasa.gov/mission_pages/hurricanes/archives/2007/hurricane_dust.html [Accessed on 27 December 2007

Ngowi, R. (2006). Drought threatens East Africa's wildlife. Mail and Guardian Online, 19 February 2007, http://www.mg.co.za/articlePage.aspx?articleid=264684&area=/breaking_news/breaking_news__africa/ [Accessed 25 September 2007]

Osumo, W. M. (2001). Effects of Water Hyacinth on Water Quality of Winam Gulf, Lake Victoria. The United Nations University, Reykjavik, Iceland, Available at: http://www.unuftp.is/proj01/OsumoPRF.pdf [Accessed 9 October 2007]

Perrins, C. M., and Elphick, J. (2003). The Complete Encyclopedia of Birds and Bird Migration, Chartwell Books, Edison, New Jersey, USA

Pilkington, E. (2007). Sudan's breathtaking migration. Guardian Unlimited, 13 June 2007, Available at: http://www.guardian.co.uk/environment/gallery/2007/jun/13/sudan.internationalnews?picture=330018155 [Accessed 25 September 2007]

Rogers, P. J. (2005). The Great Limpopo Transfrontier Conservation Area as governance mosaic, Paper presented at the annual meeting of the International Studies Association, Hilton Hawaiian Village, Honolulu, Hawaii, http://www.allacademic.com/meta/p69557_index.html [Accessed 12 October 2007]

SANParks (2007). South African National Parks, Conservation: Great Limpopo Frontier Park, 2001-2007, Available at: http://www.sanparks.org/conservation/transfrontier/great_limpopo.php [Accessed 14 September 2007]

Sandwith, T., Shine, C., Hamilton, L. and Sheppard, D. (2001). Introduction and definitions. In Transboundary Protected Areas for Peace and Co-operation. IUCN - The World Conservation Union and World Commission on Protected Areas (WCPA), http://www.iucn.org/bookstore/HTML-books/BP7-transboundary_protected_areas/cover.html [Accessed 17 September 2007]

Schollaert, S.E. and Merrill, J.T. (1998). Cooler sea surface west of the Sahara desert Correlated to dust events. Geophysical research letters: 25 - 18, pp. 3529-3532.

UNDP-GEF (2005). Project Executive Summary: GEF Council Intersessional Work Program Submission. Available at: http://www.gefweb.org/Documents/work_programs/IWP%20July05/1%20-%20BD%20-%20Regional-Enhancing%20Effectiveness-W-Arly-Pendjari-ExecSumm.pdf [Accessed 21 January 2007]

UNEP (2005a). One Planet Many People: Atlas of Our Changing Environment, United Nations Environment Programme, Nairobi, Kenya, pp. 14-15,

UNEP (2005b). Report on atmosphere and air pollution. In African Regional Implementation Review for the 14th Session of the Commission on Sustainable Development (CSD-14), United Nations Environment Programme, Nairobi, Kenya, http://www.uneca.org/csd/CSD4_Report_of_African_Atmosphere_and_Air_Pollution.htm [Accessed 10 July 2007]

UNEP (2006a). Global Deserts Outlook, United Nations Environment Programme, Nairobi, Kenya

UNEP (2006b). Africa's Lakes: Atlas of Our Changing Environment, United Nations Environment Programme, Nairobi, Kenya, pp. 28-29, http://www.na.unep.net/AfricaLakes/ [Accessed 25 September 2007]

UNEP (2007). Sudan Post-Conflict Environmental Assessment: Synthesis Report, United Nations Environment Programme, Nairobi, Kenya, Available at: http://sudanreport.unep.ch/UNEP_Sudan_synthesis_E.pdf [Accessed 4 July 2007]

UNEP-WCMC (2007). Protected Areas and World Heritage, United Nations Environment Programme and World Conservation Monitoring Centre, Available at: http://www.unep-wcmc.org/protected_areas/index.html [Accessed 17 September 2007]

UNHCR (2006a). UNHCR Global Report 2006, UNHCR, The UN Refugee Agency, Available at: http://www.unhcr.org/gr06/index.html [Accessed 07 September 2007]

UNHCR (2006b). Worsening Darfur crisis threatens entire region, Guterres warns, UNHCR Press Releases, 8 September 2006, Available at: http://www.unhcr.org/news/NEWS/45012ab52.html [Accessed 24 September 2007]

UNU (2006). International Rivers and Lake Basin Management, United Nations University, Available at: http://www.unu.edu/env/water/transboundary-water.html [Accessed 24 September 2007]

URT (2001). United Republic of Tanzania, Statistics 2001

Vanasselt, W. (2003). EarthTrends Featured Topic: Armed Conflict, Refugees, and the Environment, Available at: http://earthtrends.wri.org/pdf_library/feature/gov_fea_conflict.pdf [Accessed 07 September 2007]

USDA (2005). United States Department of Agriculture, Production Estimates and Crop Assessment Division, Low Water Levels Observed on Lake Victoria, Foreign Agriculture Service, 26 September 2005, Available at: http://www.fas.usda.gov/pecad/highlights/2005/09/uganda_26sep2005/ [Accessed 26 September 2007]

USDA (2007). United States Department of Agriculture, Crop Explorer, Lake Victoria (0314) Height Variations from TOPEX/POSEIDON and Jason-1 Altimetry, Foreign Agriculture Service, 3 September 2007, Available at: http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.cfm?regionid=eafrica&region=&reservoir_name=Victoria&gfo_data=1 [Accessed 26 September 2007]

USGS (1998). United States Geological Survery, HYDRO1k Elevation Derivative Database, USGS EROS Data Center, Sioux Falls, South Dakota, USA. Available at: http://eros.usgs.gov/products/elevation/gtopo30/hydro/index.html [Accessed 26 November 2007]

WCS (2007). Wildlife Conservation Society, Southern Sudan Program, 2007, Available at: http://www.wcs.org/international/Africa/sudanprogram?preview=&psid=&ph=class%2525252525252525253DAWC-14877272 [Accessed 25 September 2007]

Washington, R., Todd, M. C., Lizcano, G., Tegen, I., Flamant, C., Koren, I., Ginoux, P., Engelstaedter, S., Goudie, A. S., Zender, C. S., Bristow, C. and Prospero, J. (2006). Links between topography, wind, deflation, lakes and dust: The case of the Bodélé depression, Chad, Geophys. Res. Lett., 33, (L09401)

Wolf, R. (2007). Environment, globalization, and genocide. Thomas Paine's Corner, 24 April, Available at: http://civillibertarian.blogspot.com/2007/04/environment-globalization-and-genocide.html [Accessed 24 September 2007]

WWF (2007). Endangered mountain gorillas killed in Congo; population at risk, WWF Newsroom, 26 July, Available at: http://www.panda.org/news_facts/newsroom/index.cfm?uNewsID=109801 [Accessed 24 September 2007].