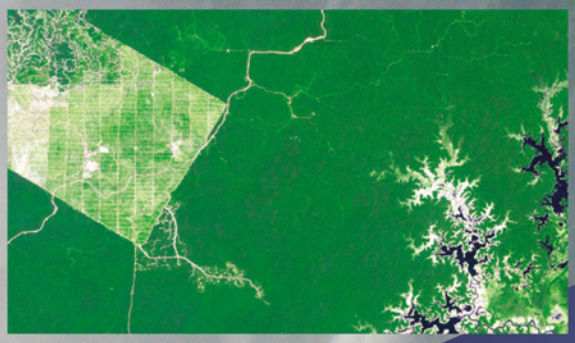
UNEP/DEWA/RS.04-5

UNEP



Analyzing Environmental Trends using Satellite Data: Selected Cases

Environment Change Analysis Series

Copyright 2004, United Nations Environment Programme
ISBN: 92-807-2513-0
Job No: DEW/0598/NA

This publication may be reproduced in whole or in part and in any form for educational or non-profit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. UNEP and the authors would appreciate receiving a copy of any publication that uses this report as a source.

No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from the United Nations Environment Programme.

United Nations Environment Programme
PO Box 30552, Nairobi 00100, Kenya
Tel: +254 20 621234
Fax: +254 20 623943/44

United Nations Environment Programme
Division of Early Warning and Assessment—North America
47914 252nd Street, EROS Data Center, Sioux Falls, SD 57198-0001 USA
Tel: 1-605-594-6117
Fax: 1-605-594-6119
info@na.unep.net

For bibliographic and reference purposes this publication should be referred to as:
Analyzing Environmental Trends Using Satellite Data: Selected Cases
Division of Early Warning and Assessment (DEWA)
United Nations Environment Programme (UNEP)
PO Box 30552, Nairobi 00100, Kenya

Itaip Dam and Iguaz River
This chapter was produced with generous support from the United States Geological Survey and the National Aeronautics and Space Administration. UNEP acknowledges the contributions of the following who made this publication possible: Robert Campbell, University of Kansas, author; with assistance from Eugene Fosnight, Mark Ernste, Kim Giese, Jane Smith, Ragna Godtland and Ashbindu Singh, UNEP GRID Sioux Falls; and Kaveh Zahedi, DEWALAC - UNEP/ROLAC.

Papua (Irian Jaya) and The Sundarbans
This chapter was produced with generous support from the United States Geological Survey and the National Aeronautics and Space Administration. UNEP acknowledges the contributions of the following who made this publication possible: Robert Campbell, University of Kansas, author; with assistance from Eugene Fosnight, Mark Ernste, Kim Giese, Jane Smith, Ragna Godtland and Ashbindu Singh, UNEP GRID Sioux Falls.

Images used in analysis can be acquired from the NASA Earth Science Information Partner Michigan State University at http://bsrsi.msu.edu/trfic/UNEP_GRID/.

Lake Chad
This chapter was produced with generous support from the United States Geological Survey and the National Aeronautics and Space Administration. UNEP acknowledges the contributions of the following who made this publication possible: Eugene Fosnight, author; with assistance from Robert Campbell, University of Kansas, Mark Ernste, Kim Giese, Jane Smith, Ragna Godtland and Ashbindu Singh, UNEP GRID Sioux Falls.

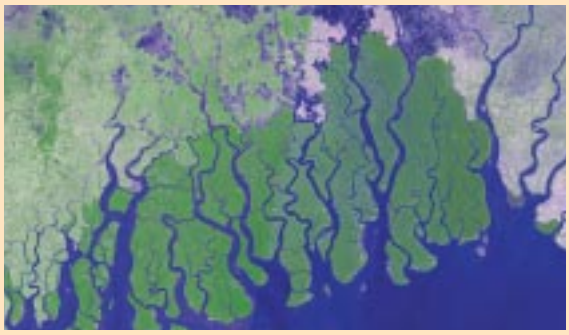
Atat rk Dam and Harran Plain
This chapter was produced with generous support from the United States Geological Survey and the National Aeronautics and Space Administration. UNEP acknowledges the contributions of the following who made this publication possible: Robert Campbell, University of Kansas, author; and Eugene Fosnight, Mark Ernste, Kim Giese, Jane Smith, Ragna Godtland and Ashbindu Singh, UNEP GRID Sioux Falls.

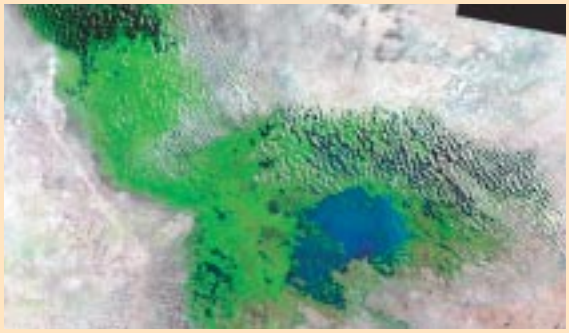
The Sundarbans
This chapter was produced with generous support from the United States Geological Survey and the National Aeronautics and Space Administration. UNEP acknowledges the contributions of the following who made this publication possible: Robert Campbell, University of Kansas; and Eugene Fosnight, Nazmul Hossain, Mark Ernste, Kim Giese, Jane Smith, Ragna Godtland, Abdullah Daud and Ashbindu Singh, UNEP GRID Sioux Falls.

DISCLAIMER
The views expressed in this publication are not necessarily those of the agencies cooperating in this project. The designations employed and the presentations do not imply the expression of any opinion whatsoever on the part of UNEP or cooperating agencies concerning the legal status of any country, territory, city, or area of its authorities, or the delineation of its frontiers or boundaries.

Mention of a commercial company or product in this report does not imply endorsement by the United Nations Environment Programme. The use of information from this publication concerning proprietary products for publicity or advertising is not permitted. Trademark names and symbols are used in an editorial fashion with no intention of infringement on trademark or copyright laws.

We regret any errors or omissions that may have been unwittingly made.





Analyzing Environmental Trends using Satellite Data: Selected Cases

B i gi g a i a oli

Contents

Foreword i

Itaip Dam and Iguaz River: Economic Development and Forest Survival 1

Location 2
Historical Isolation 3
Guair and Itaip 4
Itaip and Deforestation 5
Iguaz and Tourism 6
Ongoing Concerns 7
References 8

Papua (Irian Jaya): Tropical Forest and the Oil Palm Frontier 9

Papua (Irian Jaya) s Place in Indonesia 10
Environmental Impacts of Development 10
Ongoing Concerns 13
References 14

Lake Chad: Sustainable Use of Water and Land in the Sahel 15

Characteristics 16
Causes 18
Climate 18
Human Use 18
Ongoing Concerns 20
References 22

Atat rk Dam and Harran Plain: Re-Engineering the Cradle of Agriculture 23

The Physical Context 24
Ecology and Biodiversity 24
The Region s Peoples 25
Atat rk and Harran Plain: W ater Resources and Agricultural Change 28
Ongoing Concerns 29
References 30

The Sundarbans: Mangroves, Tigers and Shrimp Farms 31

Location and Conditions 32
Changes 33
Ongoing Concerns 35
References 36

Foreword

The world is a rapidly changing place. While this is stating the obvious, it is not always clear what the nature of these changes is. Many are the result of anthropogenic, or human, influences. Other changes may be the consequence of natural variation in the Earth s biophysical systems. Increasingly, we are able to identify and monitor these changes from space, using satellite observing systems. Five locations around the world were studied by the United Nations Environment Programme (UNEP) through their office in Sioux Falls, South Dakota (USA) and are highlighted in this publication. These locations are: Lake Chad in West Africa; the Sundarbans along the India-Bangladesh border; Papua (Irian Jaya) in Indonesia; the Paraneaense Forest near Itaip Dam and Iguaz Falls at the juncture of Argentina, Brazil and Paraguay; and the Atat rk Dam and the Harran Plain in southeastern Turkey.

Human population growth is often a major factor in environmental change. More people require more resources, with attendant environmental effects. The dramatic images of population growth and land use change near Iguaz Falls present visual evidence of this. But population growth is by no means the only factor. The internationalization of markets, resource exploitation due to a variety of reasons, and governance may play an important role. Development plans are too often designed to meet narrow, short-term objectives that may have unintended adverse consequences on the environment. There is more emphasis on promoting change than dealing with the consequences of this change. And there is often little concern for society or the environment when the emphasis is on political or technological factors.

Discussions over the past thirty years have focused on sustainable development and the need to consider the impact of our actions on human well-being. But as these images and case studies demonstrate, the unintended consequences of our actions can have dramatic effect on both humans and the natural environment. Analyzing these changes, by examining satellite data over various time periods, can provide scientific evidence and an early warning of the potential long-term consequences of our development decisions. UNEP is playing a major role in both environmental assessment and early warning, in an effort to promote actions to mitigate some of the unintended but negative impacts to people and their environment of development. This publication represents the first of a series of targeted assessments, and we look forward to your comments and reactions.

Steve Lonergan, Ph.D.
Director
Division of Early Warning and Assessment (DEWA)
United Nations Environment Programme

Itaipú Dam and Iguazú River

Economic Development and Forest Survival

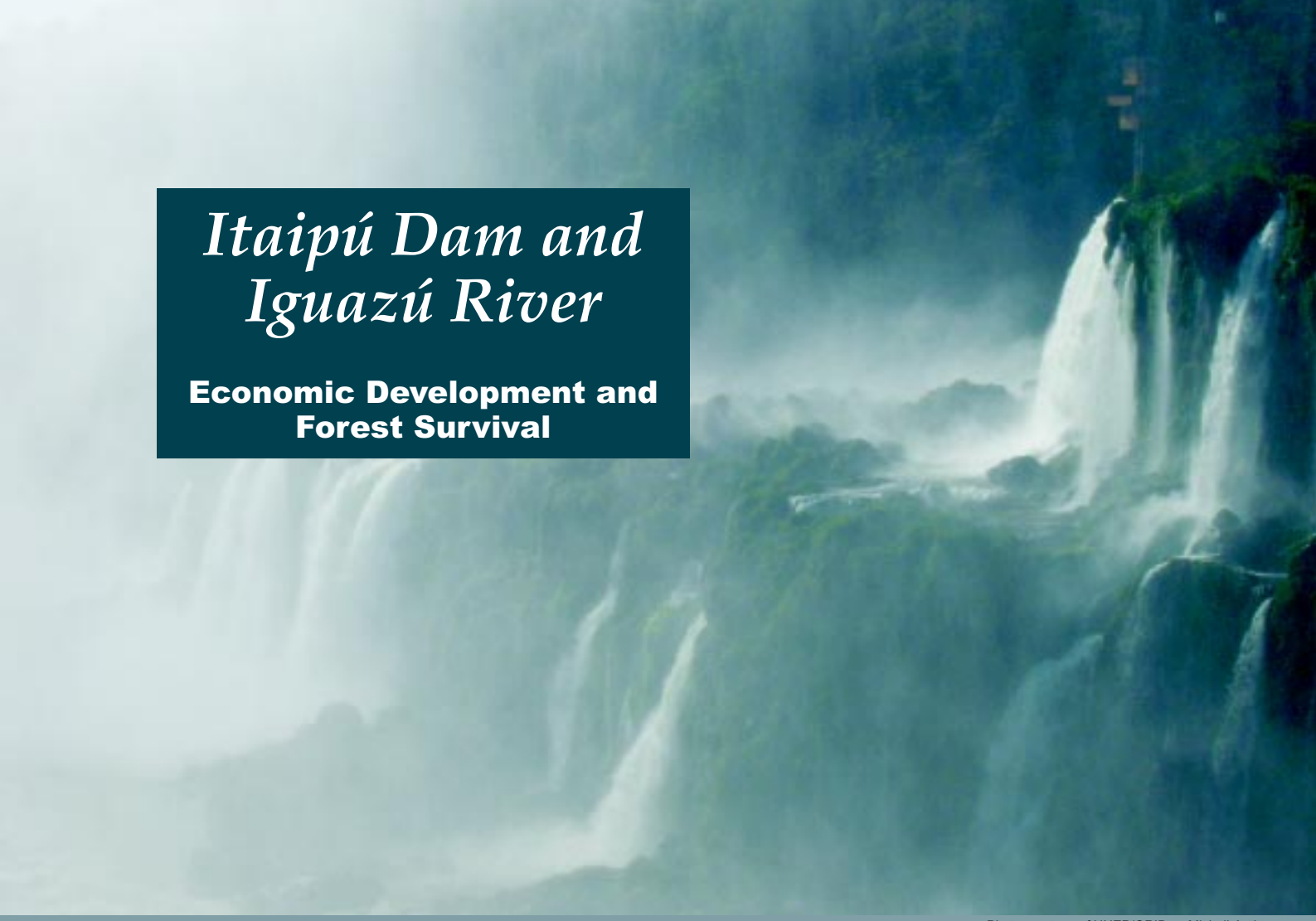


Photo courtesy of UNEP/GRID — MichelleAnthony.

Bras lia, the capital of Brazil, straddles South America s great hydrologic divide. North of this line lies the Amazon basin, the world s largest. South of this line lies South America s second great basin, the Paran , which is among the world s largest, but almost unknown outside the region. While the Amazon is only partially dammed and logged, the Paran River is being dammed top to bottom and the Paranaense forest is almost gone.

Isolated from other rainforests by natural barriers, the Paranaense forest developed into a distinct and highly diverse ecosystem with thousands of species which live nowhere else. Now less than 10% of it remains. The Paranaense forest in Brazil, for example, is the most threatened among all the forests of the Atlantic Forest biome, and has lost 92 percent of its 1.1 million square kilometres of original forest cover (World Bank, 2003).

The causes of its deforestation are many and some are common to forests everywhere. However, this case shows how national borders can preserve natural communities and how foreign capital crossing those borders can contribute to their destruction.

Courtesy of Blue Marble - http://rsd.gsfc.nasa.gov/rsd/bluemarble/ (20 Feb. 2004).

In this 1973 Landsat MSS image, small-scale clearing is visible west of Ciudad del Este in Paraguay.
Color key: Green - vegetation; Blue - water; White - developed areas/agriculture.

Location

The Paran River together with the Paraguay and Uruguay rivers form the La Plata Basin, which is one of the five largest water systems in the world. The La Plata Basin is shared by five countries: Argentina, Bolivia, Brasil, Paraguay and Uruguay.

These satellite images center on the mouth of the Iguaz River , a tributary of the Paran . The Iguaz flows west from the right

In this 2003 Landsat ETM image, clearing is widespread, the Itaip Dam is complete, and national park boundaries are sharply visible.

edge toward the middle of the images, where it empties into the Paran flowing south.

This study focuses on the meeting point of Brazil, Argentina, and Paraguay. From the mouth of the Iguaz , Brazil is northeast, Argentina is southeast, and Paraguay is west. Just upstream are the famous Iguaz Falls, where the Iguaz dips south and narrows; national parks flank the falls on both sides of the border. At the mouth of the Iguaz is the tri-city of Foz do Igua u (Mouth of the Iguaz) in Brazil, Puerto Iguaz (Iguaz Port) in Argentina, and Ciudad del Este (Eastern City) in Paraguay. North of the city, since the 1970s, lies the Itaip Dam, the world s largest hydroelectric plant.

Other much smaller reservoirs also appear in the later images amid agricultural fields and the few remaining patches of Paranaense forest.

Historical Isolation

In this study area, the Paran crosses the continent s cultural, linguistic, administrative, and economic border between the Spanish and Portuguese regions of South America. For most of its history, this area was more a quiet buffer than a busy crossroads.

For example, during most of the 1600s and 1700s, Jesuit missionaries organized this area into townships of armed Guaran Indians, defending themselves against Spanish settlers in the central core of Paraguay, and against Portuguese slave traders from Brazil. Misiones, the northward nger of Argentina, is named after this defensive buffer, whose surviving mission buildings are now tourist attractions.

Upon independence, Paraguay still isolated itself from Brazil and Argentina. Paraguay s dictatorial rst president sealed of f his country, bringing commerce almost to a halt. During the third presidency there was the calamitous War of the Triple Alliance (1864-1870), in which Paraguay suffered severe losses in terms of population and land base. Though much of its remaining land was bought by foreigners, Paraguay remained an isolated buffer state between its former enemies. It had a mixed-race population speaking Guaran , a subsistence economy, and a very poor transportation system. Paraguay normally tilted toward Argentina, especially because its commerce owed through the Paran and Buenos Aires (Hanratty and Meditz, 1990).

This changed in the 1940s and 1950s as Brazil s population and economy outpaced Argentina s. The same government which built Bras lia also started harnessing the Paran within its own territory, and sought to dam it along Paraguay s border as well.

Guairá and Itaipú

Brazil and Paraguay share about 175km of the Paran River , from the Iguaz up to Guair Falls. Guair Falls were formed by the Paran damming up to a width of almost 4km behind the Maracaj mountains, then breaking through and down into a tall, narrow canyon (Bonetto, 1994). Guair had the greatest volume of any waterfalls in the world, creating a roar heard miles away, a perpetual cloud of mist, and a constant stream of tourists. Paraguay and Brazil each claimed the falls (called by Brazil the Sete Quedas or Seven Falls) since the 1870s treaty, which placed the border at the falls but did not specify a precise point.

In the early 1960s Brazil considered diverting part of the Paran around Guair Falls for an

Itaip Dam on the Brazil/Paraguay border , taken by the IKONOS sensor.

Falls at Iguaz National Park.

all-Brazilian hydroelectric plant. Paraguay denounced the potential impact on its falls and eventually negotiated with Brazil, resulting in an agreement to dam the Paran in an equal partnership with each country receiving half of the produced electricity. In practice, Brazil built and nanced most of the dam, and Paraguay sold most of its excess electricity to Brazil at a low rate (da Rosa, 1983).

The Itaip hydro-electric plant, with its 1,350 km^2 reservoir (Itaip Binacional, 2004), was built between 1973 and 1982, near the mouth of the Iguaz , after the conclusion of complex diplomatic negotiations between Brazil and Paraguay (Souza, 2002). Almost 200m high, Guair Falls was buried under water . Farmland and riparian ecosystems were inundated and the seasonal ow of the river was further interrupted. But such direct effects were the tip of the iceberg, dwarfed by the economic and land cover changes that Itaip accelerated.

Itaipú and Deforestation

Since the Itaip construction, most of the deforestation shown in these images has taken place in eastern Paraguay. This is partly due to domestic pressures. Until recent decades, Paraguay s eastern quarter was sparsely settled; the population core was in central Paraguay. Many people there practiced shifting, subsistence agriculture as squatters on the fringes of large estates. During the 1960s, population pressure broke this system down as squatters and landowners clashed. In the so-called March to the East, thousands of rural families migrated to create farms in the forests of the Paran basin, encouraged by the Rural Welfare Institute, a resettlement agency created in 1963.

The search for pro ts in international markets rapidly changed this area s rivers and forests. In 1956, Paraguay and Brazil agreed to link central Paraguay to the Atlantic with roads, a bridge over the Paran , and a duty-free port on the Brazilian coast, thus breaking Paraguay s dependence on Argentina. In the 1973 satellite image, you can see this road running west from the Paran , with the classic shbone pattern of small elds along the side roads fanning out into the forest. Many of these new elds were cotton, a traditional Paraguayan crop, but most were soybeans, which exploded from almost zero production after the international price tripled in 1973 (Hanratty and Meditz, 1990).

The Itaip contributed to the acceleration of these changes, bringing more deforestation. Thousands of Paraguayans worked on the dam.

Photo courtesy of John Townshend, 2002, Global Land Cover Facility, University of Maryland.

Farmlands have replaced most of the forest in eastern Paraguay.

Photo courtesy of John Townshend, 2002, Global Land Cover Facility, University of Maryland.

This boomed the national economy, doubling the previous decade s growth and raising agricultural demand even as new lands were cleared. Much of this clearing was done by Brazilian farmers or agribusinesses who logged large areas and then either raised export crops or retailed the land to farmers, who were often Brazilians. Still more forest went to the three booming cities south of Itaip . Published deforestation statistics dif fer on the details of how much and when, but they agree on the trend: shrinking fast and accelerating in recent decades. One study from Landsat images indicated that in the 1990s, one third of eastern Paraguay s remaining forest was cleared (Ibarra and Nu ez, 1998; Altstatt et al., no date).

When the dam was completed and the construction boom over, thousands of workers found it hard to return to farming, as much of the land was taken. The new farmers were mechanized and modern; they used all their land, wanted fewer workers, and tolerated no squatters. One solution for the Paraguayan situation was for Itaip jobs to be replaced, directly or indirectly , by tourism.

In Brazil, hundreds of farms were expropriated for the construction of the Itaip reservoir and the farmer families were forced to migrate (Zaar, 2000). Some of them were resettled but others did not receive any compensation.

The differences between the countries in land use changes and deforestation owe much to environmental protection initiatives and policies passed in Brazil and Argentina to protect the Paranaense forest, not withstanding the huge area ooded for the Itaipu reservoir . Argentina created a national park (Parque Nacional Iguaz) in 1934, protecting 67,000ha (Argentina Parques Nacionales, 2004). In Brazil, the forest area was also protected by a national park (Parque Nacional do Igua u) created in 1939 and legally consolidated in 1981, covering 185,262ha (IBAMA, 2003). These two Parks are both World Heritage Sites (Bailby, 1995; UNEP-WCMC, 1995; UNEP-WCMC, 1997). They include over 2,000 plant species, jaguars, otters, anteaters, and hundreds of species of birds, including almost half of Argentina s bird species. Efforts are underway to preserve forests outside these parks.

Iguazú and Tourism

The Iguaz River is not held back by a standing barrier like Guair s mountains or Itaip s concrete; it is held up by an underlying plate of hard rock through which it eventually drops. The Iguaz Falls are famous for their breadth,

the beauty of 275 waterfalls dropping into a 3km long horseshoe canyon.

Iguaz Falls, like Itaip , is an economic development of the river s power. The real development is not the buildings, roads and catwalks, but the parks services, promotion, and protection. The Landsat images show the parks boundaries sharpening between 1973 and 2000, as Brazilian elds recede from within the park, while Argentine elds approach the park. The parks preserve one of the last fragments of intact Paranaense forest, a wonder of living diversity.

Tourism is now a large part of the local economy. Many tourists owing out of Foz do Igua do not visit the falls, the forest, or Itaip , but cross the Friendship Bridge to shop in Paraguay s tax free zone and bargain shops (Bailby, 1995). Trade is itself a major attraction for tourists to the region.

Ongoing Concerns

Proposals to further develop the immediate falls area with ood lighting, tower restaurants, or a tourist railroad have drawn concern and criticism. Broader threats to the park include understaf ng, poaching of palms, animals and sh, and a controversial road through the park which has been closed, reopened, and reclosed (Bailby, 1995).

On the heels of Itaip , Paraguay and Argentina agreed to build the Yacyret Dam. Politics stalled Yacyret for decades and proposed dams at Corpus, Itat -It -Cor , and other locations have generated ongoing controversy. In 1995, the former combatants in the War of the Triple Alliance formed a four-way common market, MERCOSUR. One subsequent proposal, called Hidrovia, would transform the Paran , Paraguay , and Uruguay rivers into a water highway carrying goods between the MERCOSUR partners. Hidrovia has already gone through several waves of controversy and revision (IRN, 2003). Whether the natural environment will fare better or worse under capitalist democracies, compared to the previous capitalist dictatorships, is still an open question.

The Paranaense Forest is an environmental asset which protects biodiversity and provides environmental services important at local, national, and global levels. The protection of this forest will require concerted efforts and joint actions by Argentina, Brazil, and Paraguay based on common objectives and a shared vision. The institutional basis for this joint action already exists in the form of the Environmental Framework Agreement of the MERCOSUR, approved by Argentina, Brazil, Paraguay, and Uruguay in 2001 (MERCOSUR, 2002).

The need to generate income and promote development, partially through international markets, rapidly changed this area s natural systems. The damming of the rivers for hydroelectricity had enormous ecological, economic, and social impacts on the region and its people. The exception is the lower Iguaz , which underwent a milder development process focusing on the promotion of tourism.

The satellite images capture the changing landscape. A wide-view image from 2003 shows how political borders still strongly affect development; Brazil and eastern Paraguay contrast sharply with the Misiones nger of Argentina where many conservation measures now focus. The story of the Itaip clearly shows that development can take different paths and that countries can achieve economic development with a lower cost to the environment and greater social bene ts for the local people.

Image courtesy of Blue Marble — http://rsd.gsfc.nasa.gov/rsd/bluemarble

Falls at Iguaz National Park. Photo courtesy of Parque Nacional del Iguazu.

Left: MODIS satellite image, 5 May 2003. Dark green indicates surviving forest in the nger of Argentina, as well as Brazil s Igua u National Park, in contrast to the light greens of agriculture. The white box indicates the Landsat images extent.
Above: Tourists at Iguaz National Park.

References

Argentina Parques Nacionales (2004) PN Iguaz , el parque. Available at www.par quesnacionales.gov.ar/ PN/pn_Iguazu/pn_Iguazu.htm on 6 February 2004.

Altstatt, Alice and others, (n.d.) Change in Subtropical Forest of Eastern Paraguay in the 1990s, unpublished poster. Global Land Cover Facility, University of Maryland, Greenbelt, Maryland. Available at www.glcf.umiacs.umd.edu/ library/pMaterials/posters/ on 11 February 2004.

Bailby, Edouard. (1995) The Igua u Falls: Cascading W onder of the Subtropical Forest. Unesco Courier. 1 Nov 1995. 40-43.

Bonetto, A.A. (1994) Austral Rivers of South America. Limnology Now: A Paradigm of Planetary Problems. R. Margalef, ed. Elsevier.

da Rosa, J. Eliseo (1983) Economics, Politics, and Hydroelectric Power: the Paran Basin. Latin American Research Review,18(3). 77-107.

Hanratty, Dennis M. and Meditz, Sandra W., eds. (1990) Paraguay: A Country Study. Library of Congress, Federal Research Division. General Printing Of ce, W ashington.

IBAMA (2003) Unidade: Parque Nacional do Igua u/PR, dic. 2003. Available at www2.ibama.gov.br/ unidades/parques/reuc/1002.htm on 6 February 2004.

Ibarra, Jos , and Nu ez, Fransisco (1998) Un estudio de caso en las Serranias sel Yvytyrusu, Paraguay. World Rainforest Movement. Available at wrm.org.uy on 23 November 2003.

IRN (2003) Paran -Paraguay River Basin, International Rivers Network. Available at www.irn.org/programs/ hidrovia on 23 November 2003.

Itaip Binacional (2004) Reservat rio. Available at www.itaipu.gov.br on 6 February 2004.

MERCOSUR, (2002) Medio Ambiente em el MERCOSUR. Montevideo, Uruguay: Secretar a Administrativa del MERCOSUR, Sector de Documentaci n y Divulgaci n, S rie tem tica a o 1 no. 3, julio 2002. Available at www.mercosur.org.uy on 6 February 2004.

Souza, Matilde (2002) guas Internacionais. 3o. Encontro da Associa o Brasileira de Ci ncia Pol tica, Niter i. Available at www.cienciapolitica.org.b r/encontro/relint7.3.doc on 06 Februray 2004.

UNEP-WCMC (1995) Igua u National Park, Brazil. Protected Areas Programme, World Heritage Sites. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK. Available at www.wcmc.org.uk:80/protected_areas/data/wh/iguazu.html on 23 November 2003.

UNEP-WCMC (1997) Iguaz National Park, Argentina. Protected Areas Programme. World Heritage Sites. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK. Available at www.wcmc.org.uk:80/protected_areas/data/wh/iguacu.html on 23 November 2003.

World Bank (2003) Brazil: Equitable, Competitive, Sustainable. Washington, D.C. World Bank.

Zaar, Miriam (2000) O processo migrat rio no extremo-oeste do Paran /Brasil com a constru o da Hidrel trica Binacional Itaipu, Scripta Nova - Revista Electr nica de Geograf a y Ciencias Sociales no. 69, 1…. agosto 2000Available at ub.es/geocrit/SN-69-47.htm on 6 February 2004.

Papua (Irian Jaya)

Tropical Forest and the Oil Palm Frontier

Top photo courtesy of NREL — SusanThorton.

Papua (Irian Jaya) stands out among Indonesia s provinces. It contains the highest point in Indonesia, at 5,000m above sea level. It is the largest province, covering the western half of New Guinea, the world s second-largest island at almost four times Britain s area. It has the most forest slated for logging, more than a quarter of the national total (Casson, 2000). It is the easternmost province, almost 3,000km from Jakarta, and until recently one of the least populated. It was among the last to be surrendered by the Netherlands, not nalized as an Indonesian province until 1969. Papua (Irian Jaya) has until recently escaped the large scale development that has decimated the forests of Sumatra, Borneo, Java and other more western islands. The Papua (Irian Jaya) frontier is experiencing increased transmigration from the eastern islands, increased deforestation, and increased introduction of monoculture oil palm plantations. Management of the forests is complicated by competing requirements of indigenous Irians populations that has created a strong separatist movement (Jakarta Post, 2003).

Harvested oil palm fruit. Photo courtesy of Mike Noonan — http://www.noonan.com (19 Feb. 2004).

Papua's (Irian Jaya's) Place in Indonesia

Indonesia is the old Dutch East Indies. Japan broke European colonialism here as it did in much of Asia by occupying the region in the Second World War. After the war, the Dutch tried unsuccessfully to reclaim their colonies, the one exception being what was then called West New Guinea, where they maintained control even after Indonesian independence. When this issue brought the Netherlands and Indonesia to war, the United Nations brokered a deal in which it administered the province brie y , handed it over to Indonesia in 1963, and oversaw a 1969 plebiscite for the Irians to decide whether to stay in Indonesia. This plebiscite was not a mass vote but a unanimous af rmation by about one thousand local leaders; it has been characterized variously as a traditional consensus-building process, or as a show for international opinion controlled by Jakarta.

Meanwhile, a complicated military coup had taken place in 1965-1966. The new regime was anticommunist, friendly to western nations, and eager to industrialize Indonesia s economy using outside investment. The military, long involved in civilian affairs, participated in many new development projects, as did the president s family (Frederick and Worden, 1993). Many of these investment schemes would affect the new province now called Papua (Irian Jaya).

Environmental Impacts of Development

Petroleum led Indonesia s industrialization, and Papua s (Irian Jaya s) market economy is now dominated by minerals as well, from oil in western Papua (Irian Jaya) to copper from the giant Freeport mine in the center. But these industries are not labor-intensive, and do not directly involve or enrich the majority of the population (Mathews, 1999). Though the area mined will continue to increase, mining tends to have a local rather than a wide-spread effect on land cover.

Transmigration, an of cial policy since Dutch colonial days, increased after 1965. Under this program, the central government moved more than a million families from overpopulated Java to new villages in the sparsely-populated outer islands, including Papua (Irian Jaya). The six-to-seven million sponsored migrants may have been accompanied by twice that many spontaneous migrants. Transmigration aimed to improve the economic well-being of migrants, to ease population pressure in sending regions, to secure national boundaries, and to provide a workforce for labor-intensive industries in places like Papua (Irian Jaya) with many natural resources (Frederick and Worden, 1993).

One of these labor-intensive industries is certainly logging. Indonesia remains three-quarters forested, including perhaps a tenth of the world s remaining primary tropical forest. Under the Indonesian constitution, the government owns all natural, or primary, forest and can sell or lease it in long-term leases known as concessions. Some concession holders are foreign companies, but most are controlled by Indonesians in part or full, often with ties to the government. In recent decades, the government has pushed for exports of processed wood products, rather than raw logs. Therefore, Papua s (Irian Jaya s) greatest export, besides copper, is plywood and other forms of constructed board (Baker, 1994; Mathews, 1999).

Instead of growing back into secondary forest, these logged primary forests are now often planted to oil palms (Wakker, 1999). This African tree grows bunches of fruit which produce plentiful

Dani tribesman at home. ' TopFoto Image Adrian Arbib.

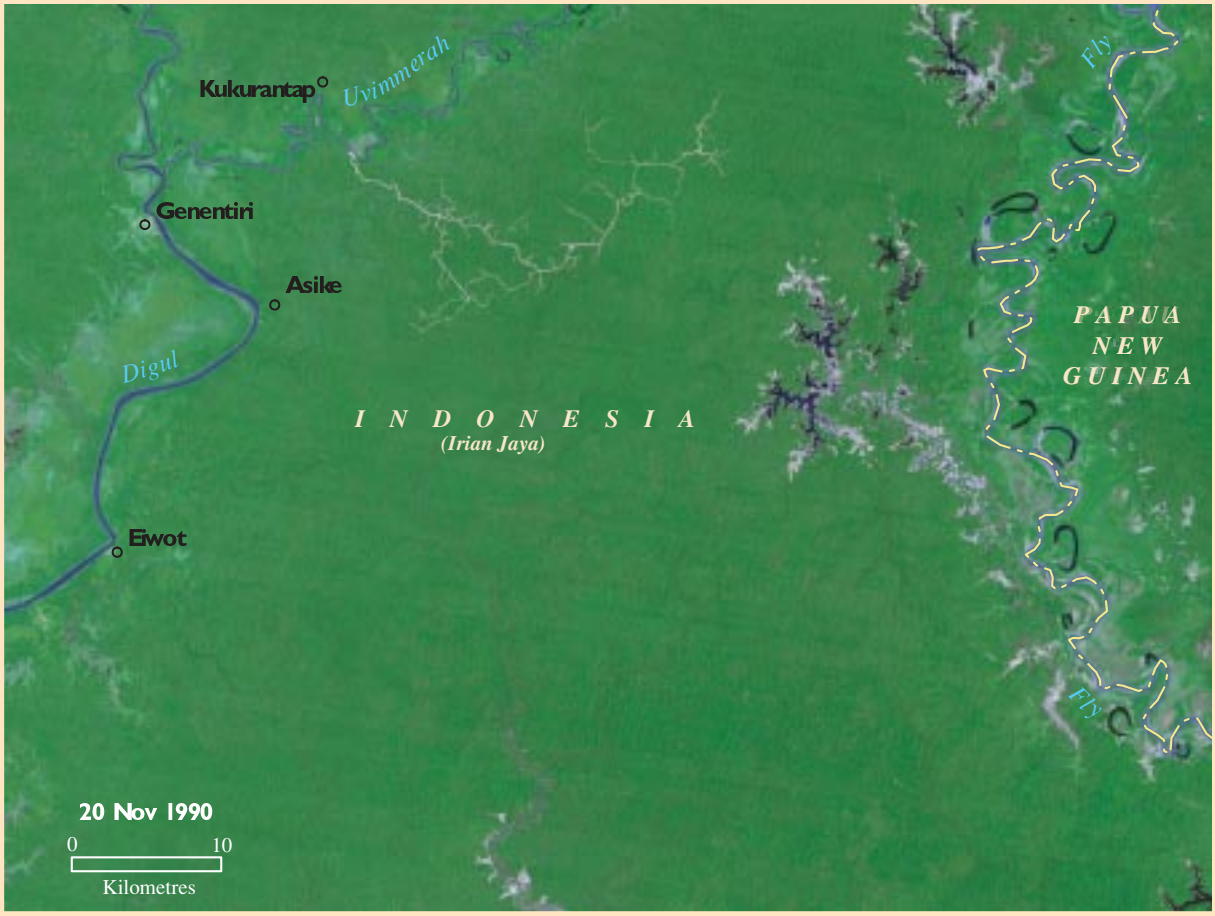
Image courtesy of http://rsd.gsfc.nasa.gov/rsd/bluemarble/ (19 Feb. 2004).

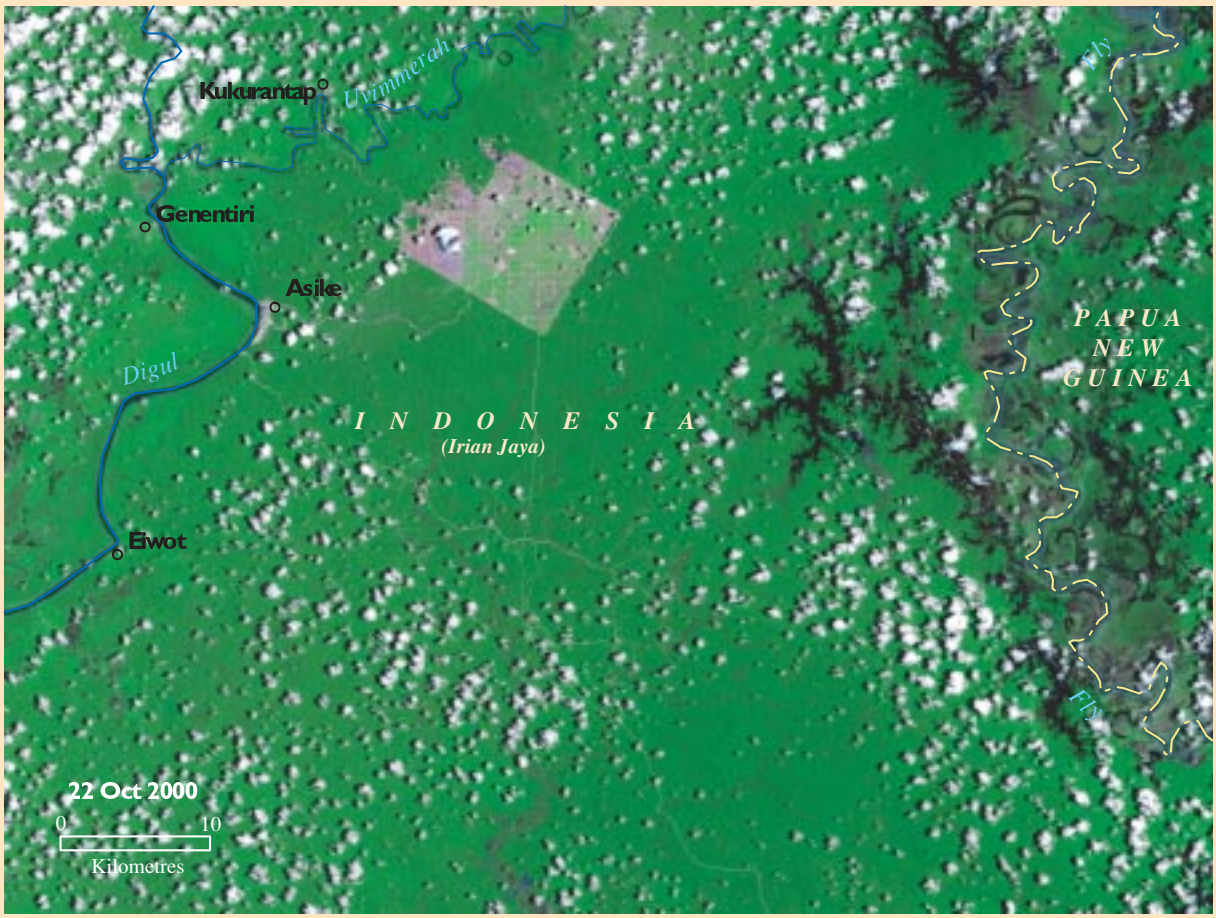
oil. It was initially used as a colorful, avorful cooking oil, later in inedibles like soap, and only recently re ned so as to be a bland, colorless food additive (Kiple and Ornelas, 2000). Oil palms were found to thrive in the wet, pestless heat of equatorial Asia, and today Malaysia and Indonesia have about 50% and 30% of world market share respectively, with Indonesia s share rising (Casson, 2000). Modern oil palm varieties are carefully bred, require high inputs such as fertilizer, and are always labor-intensive. The international market for their oil has ballooned since the 1960s.

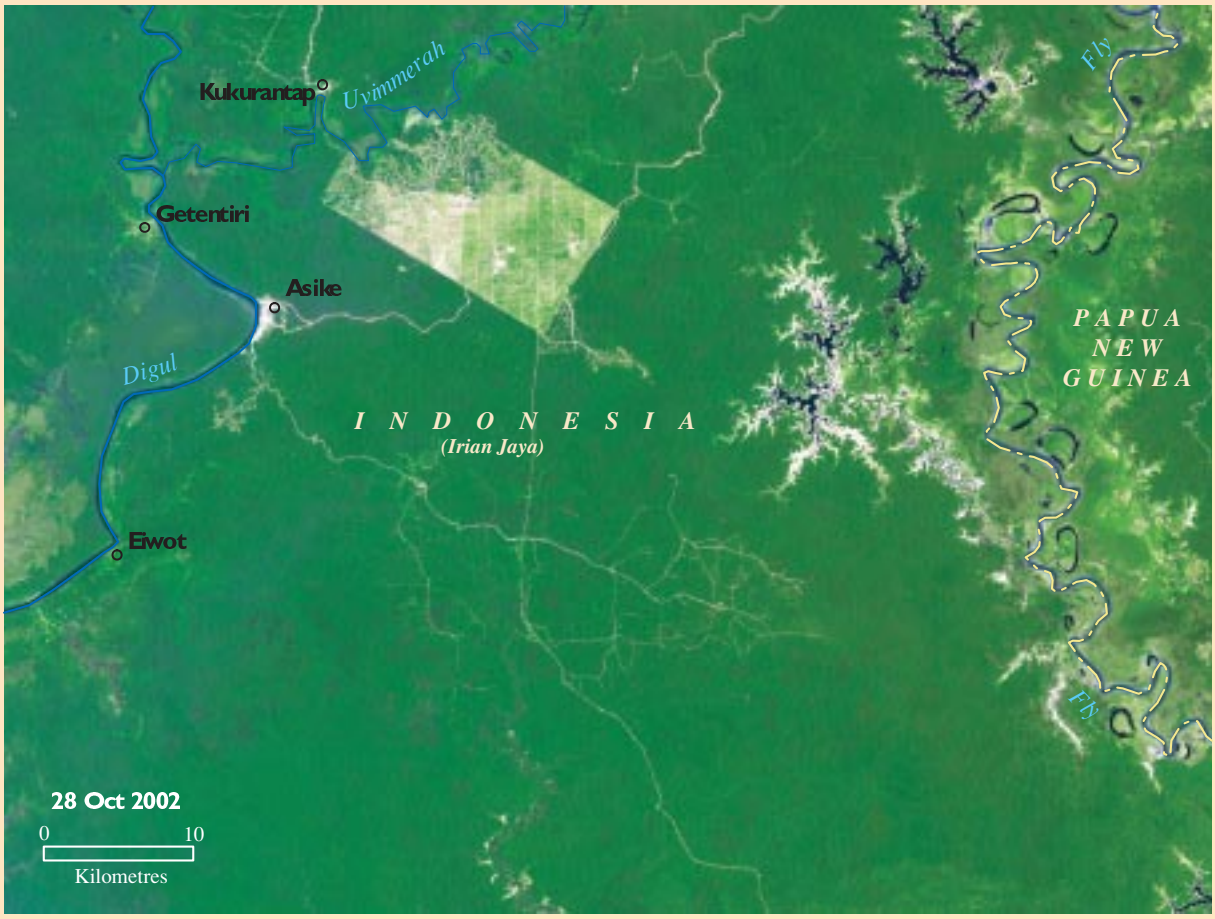
The satellite images on the next two pages show Indonesia s extreme frontier, not far from the border of Papua New Guinea. The tropical forest, inhabited by humans for thousands of years, is just starting to experience industrial-scale clearing. Oil and gas exploration are one cause, but the largest factor is logging. Rather than let the forest regrow, companies often plant the cleared lands to African oil palms, for greater, faster pro ts in the international market for edible fats. Indigenous residents often lose their lands to immigrants from central Indonesia, often sponsored by the government, who farm, process timber, or work the labor-intensive palms. Papua (Irian Jaya) is at a moment of sudden, fundamental transformation.

The satellite images demonstrate how transmigration, logging, and oil palms have affected Papua (Irian Jaya). The 1990 image shows jagged roads as the only breaks in the forest cover. The 2000 image shows (through popcorn clouds) a rectangle of cleared forest with roads gridded every 1,000 by 250 meters. It also shows a new road heading west to the river settlement of Asiki, which has been transformed

African oil palm tree. Photo courtesy of Mike Noonan —www.noonan.com (19 Feb. 2004).


Kukurantap
Uvimmerah
Genentiri
Asike
Digul
Ewot
I N D O N E S I A
(Irian Jaya)
PAPUA
NEW
GUINEA
Fly
Fly
20 Nov 1990
0
10
Kilometres


Kukurantap
Uvimmerah
Genentiri
Asike
Digul
Ewot
I N D O N E S I A
(Irian Jaya)
PAPUA
NEW
GUINEA
Fly
Fly
22 Oct 2000
0
10
Kilometres



These Landsat images show the creation of an oil palm plantation in Papua (Irian Jaya), near the border of Papua New Guinea. The white, irregular lines indicate road networks, transportation links to river systems.
Color key: Green - forested areas; Blue - water; Tan-white: non-forested areas.

into a factory and port town employing about 40 Koreans and 5,000 Indonesians, processing trees into plywood and other manufactured board. By 2002, the plantation of about 15,000ha was almost all cleared, and about half had been replanted with oil palms (Korindo Group, 2003).

Ongoing Concerns

In January 2001, a faction of the Free Papua Movement kidnapped 16 workers, including Indonesians and foreign employees, and demanded an end to logging in the area, withdrawal of troops protecting the logging and plantation, compensation for lost land, and a meeting with the Indonesian president to discuss independence for Papua (Irian Jaya). The incident ended in an apparent stalemate, with all hostages released peacefully (Embassy of Indonesia, 2001; Laksamana, 2001).

Later in 2001, three of the Netherlands largest banks, citing input from environmental organizations, released new criteria for their nancing of Indonesian oil palm plantations. These criteria combined social and environmental concerns, including respect for indigenous residents, compliance with applicable laws, sustainable practices, and preservation of primary forest. Non-complying plantations would be ineligible for nancing for three or ve years, depending on the bank (Rabobank, 2001; WRM, 2001).

Clearly, social and environmental issues in Papua (Irian Jaya) are tightly linked. Transmigrants come for natural resources. Indigenous Irians, who are physically and ethnically distinct from the transmigrants, sometimes resent transmigration as a deliberate Javanization or Asianization of their province, in which the bene ts of development go to outsiders. Logging inevitably clashes with the interests of indigenous forest dwellers, whose tending of trees and hunting of wild game create a weaker legal claim to land than does farming. Oil palm plantations, by replacing forest with monocrop farms, make these con icts long-term challenges.

References

Baker, Russ W. (1994) The Deforesting of Papua (Irian Jaya). *The Nation*. 7 February 1994. 258(5), 162-164.

Casson, Anne (2000) The Hesitant Boom: Indonesia s Oil Palm Sub-Sector in an Era of Economic Crisis and Political Change, Occasional Paper No. 29. Centre for International Forestry Research. Available at www.cifor.cgiar.org/publications/pdf_ les/ occpapers/op-029.pdf on 14 November 2003.

Embassy of Indonesia (2001) Last Three Hostages Freed by Leader of Free Papua Movement. *Indonesia Today - Daily News*. Embassy of Indonesia Ottawa - Canada.

Frederick, William H. and Worden, Robert L. eds. (1993) *Indonesia: A Country Study*. Library of Congress, Federal Research Division. General Printing Of ce, W ashington.

Kiple, Kenneth F. and Ornelas, Kriemhild eds. (2000) *Cambridge World History of Food*. Cambridge University Press.

Korindo Group. (2003) About Korindo. Available at www.korindo.co.id/eng/about/history.asp and http:// www.korindo.co.id/eng/af l/af _forest5.asp on 23 November 2003.

Laksamana. (2001) Irian Rebels Free Final 3 Hostages, Laksamana.net, 8 February 2001. Available at www.laksamana.net/ vnews.cfm?news_id=546 on 14 November 2003.

Mathews, Richard (1999) A Business Survival Guide to Eastern Indonesia (excert). Australian National University, North Australia Research Unit. Available at www.mybalivilla.comA%20Business%20 Survival%20Guide/bookhome.htm on 14 November 2003.

Rabobank, Utrecht (2001) The Rabobank in the Palm Oil Industry. Available at www.rabobank.com/report/ position/palmoilcode_ rabobank.pdf on 7 October 2001.

Jakarta Post (2003) Papua (Irian Jaya): The Rough Diamond of Indonesia. 15 November 2003. Available at www.thejakartapost.com/special/ os_08.asp on 14 November 2003.

Wakker, Eric (1999) Palm Oil Destroys Forests and People. *Inside Indonesia* 58, April-June 1999. Available at www.insideindonesia.org/ edit58/wakker.htm on 14 November 2003.

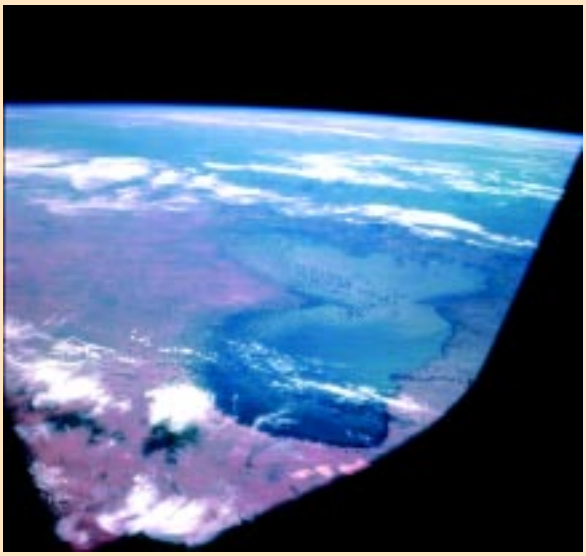
WRM (2001) Good News from Indonesia on Oil Palm! World Rainforest Movement Bulletin 52. November 2001. Available at www.wrm.org.uy/bulletin/52.html on 14 November 2003.

Lake Chad

Sustainable Use of Water and Land in the Sahel

Photo copyright ' 2000, University of Wisconsin System Board of Regents.

In the Sahelian transition zone between the Sahara Desert and the tropical rainforest lies Lake Chad and its drainage basin. In the 1960s Lake Chad was the sixth largest lake in the world, but in the past 35 years the lake s area has shrunk by 95%. Causes of lake level uctuation involve complex interactions among climate change, seasonal variability, changing human uses of water and the lake s shallowness. Under the climatic conditions of the past several thousand years, Lake Chad has balanced between being a shallow lake and a deep wetland. Recent studies suggest that Lake Chad is in danger of becoming a casualty of decreased precipitation and increased water loss from irrigation. Since water shortage spurs more irrigation attempts, these two factors interact to accelerate Lake Chad s decline. With continued climate change and increasing human population, the water level may continue to drop. Development in the Basin must take into account this fragile and highly variable ecosystem or we may witness the death of Lake Chad and the further degradation of livelihoods that depend on it.



In October 1968 an astronaut took this photograph of Lake Chad from a window of Apollo 7, looking southeast at a low angle. Photo courtesy of NASA (AS07-008-1932).

Characteristics

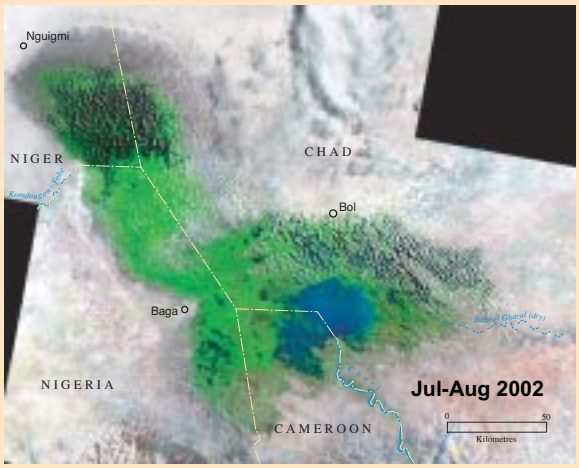
Lake Chad is extremely shallow. Seen from space, the lake can be recognized as a wetland with open water in two basins, divided by ancient sand dunes, which act as a swamp belt. Located at the southern edge of the Sahara desert, where temperatures can reach 40…C, the existence of Lake Chad seems like a fascinating enigma.

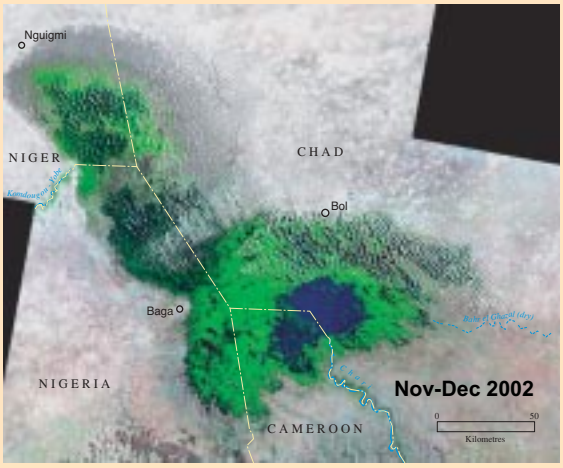
Even in normal periods, Lake Chad s maximum depth was no more than 5-8m (Schneider et al., 1985). As a result of the lake s shallowness, uctuations in volume result in substantial changes to surface area. The lakebed itself is not at, but lies on an ancient bed of fossilized sand dunes, many of which surface as islands when lake levels fall (Sikes, 2003). Submerged dunes form hidden anchorages for oating vegetation, which cover vast spaces of the lake.

The lake is given life from the wet south by runoff from one very large river and several smaller, intermittently owing rivers. About 95% of Lake Chad s water comes from the Chari-Logone River, entering the lake from the southeast, with its sources in the humid uplands of the Central African Republic. The Komadugu-Yobe River, which ows from Nigeria in the south, enters the lake in the northwest and historically has contributed about 5% of Lake Chad s water. The Yedseram and the Ngadda Rivers ow toward Lake Chad from northern Nigeria and Cameroon. Prior to entering Lake Chad, the Yedseram joins the Ngadda to form an 80km^2 swamp with no de nable watercourse to the lake.

The water is surprisingly fresh for a closed system, making the lake a valuable resource. As the second largest wetland in Africa after the Okavango, Lake Chad hosts biodiversity of global signi cance (Nami, 2002). The lake s unique mix of terrestrial and aquatic habitats forms a sanctuary for ora and fauna within the greater semi-arid Sahelian savanna. The wetlands of Lake Chad were home to many large mammal species such as gazelle, pataas monkey, hyena, cheetah, wild dog, otter, African elephant and hippopotamus. These species have been hunted to the point where some species no longer exist and others have severely reduced populations. The replacement of these large mammals with cattle has effectively degraded the wetlands ecosystem. Crocodiles and hippopotamus were particularly important agents for maintaining a healthy wetlands ecosystem (Mockrin and Thieme, 2001).

Within the lake itself, major wetland plant communities are (1) oating sudd communities, (2) permanent reed swamps, and (3) seasonal herbaceous swamps (Verhoeye and De Wulf, 2001). Grasslands dominate in areas that ood





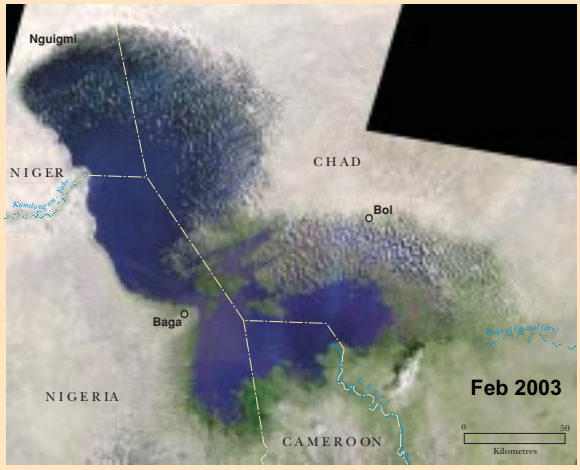
The within year lake level variation for Lake Chad is as great as the between year variation. The May-Oct rains, with up to 50% falling in August, reach Lake Chad by Oct-Nov. The Chari-Logone river systems rst ll the south basin. If the rain fall is suf cient as it was in 2002, then water from the south basin will breach the barrier between the basins along the west shore, as can be seen in the Nov-Dec 2002 image.

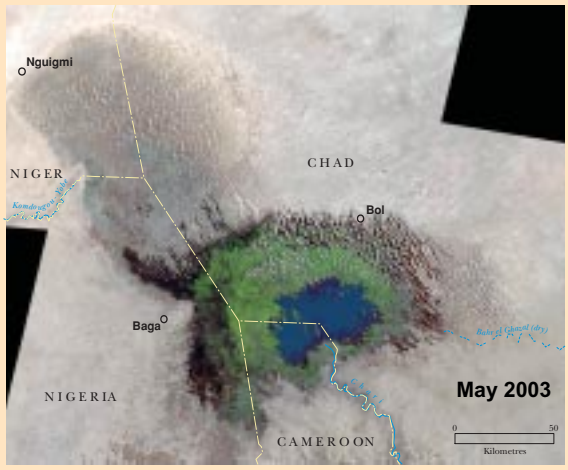
Four countries share Lake Chad s shores: Chad, Nigeria, Niger and Cameroon.

with Acacia woodlands growing interspersed with the grasslands. Dryland woodlands in sandy soils further from the lake include baobabs, desert date palms, African myrrh and Indian jujube (Mockrin and Thieme, 2001).

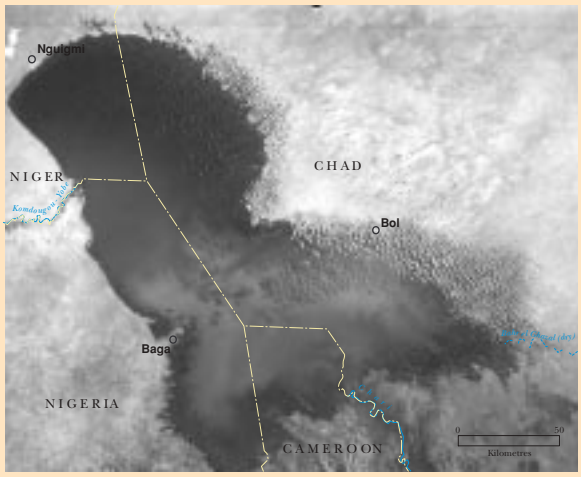
Lake Chad s level has varied greatly. Over 55,000 years ago Paleo-Chad formed a freshwater inland sea covering 1.95 million km^2. Lake levels decreased until, between 5,000 to 2,500 years ago, the lake assumed its current level with periodic oscillations. By 1908 lake levels were so low that the lake resembled a vast swamp with small northern and southern pools (Sikes, 2003). During the 1950s, water increased continuously, joining the southern and northern pools.

In 1963 the lake covered an area of approximately 22,902km^2. Thereafter, water levels again decreased. In October 1972 the lake covered 16,884km^2, a decrease of 5,018km^2 since 1963. The most dramatic reduction occurred during a 15-year period between 1972 and 1987 when the lake area decreased from

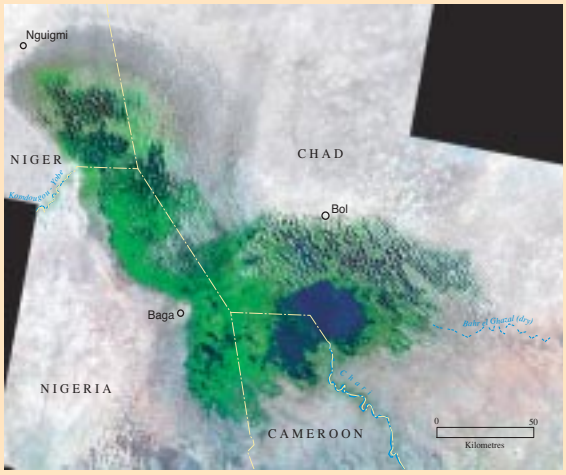




In extremely dry years the barrier is never breached. This water will join the limited discharge from the Komadugu-Yobe to ll the north basin, which is about 3 metres lower than the south basin (Dumont, 1992). By February, the lake level starts to recede to once again approach an annual low by May.
Color key: Blue - water; Green - vegetation; Tan - desert areas.



Argon photograph, 31 Oct 1963.



1972/1973 Landsat 1 MS mosaic: 25 Dec 1972, 31 Jan 1973.

16,884km^2 to 1,746km^2. Between the mid 1970s and the present, the seasonal cycles of the very shallow lake have become more extreme. Since 1974, the lake minimums have been consistently lower than any previous measured low. Between the mid 1980s and the mid 1990s, the north basin rarely held water at all. However, since the mid 1990s the lake levels have started to rise in response to increased rainfall. (FEWS, 2003).

Causes

The complex interaction between climate and human causes drives lake level uctuation. Interest is focused on the rapid decline since 1963. Recent modelling studies attempt to quantify the interplay of climate variability and water use. In summary, climate variability sets the parameters within which humans must operate. As the human impact on the local landscape becomes more severe, humans are in danger of changing these parameters through mismanagement of the water resource.

Climate

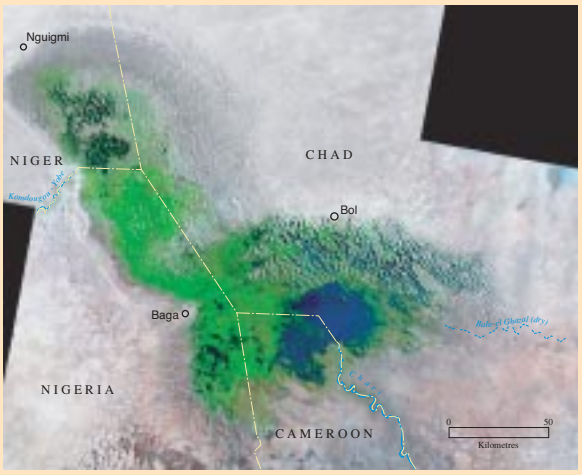
The climate near Lake Chad is hot and dry with highly variable annual average rainfall, ranging from a recorded high of 565mm in 1954 to a low of 94mm in 1984 (Olivry et al., 1996). However, lake level relies little on local precipitation with the Chari-Logone s sources receiving average rainfall of up to 1600mm. Precipitation in the basin varies geographically, with much more in the south than north. Rainfall also varies seasonally with about 90% of it falling from June to September (USGS, 2001). During the dry season, low humidity and high winds increase evaporation rates from the lake. Although evaporation is generally very high, salinity is not an issue since the heavier saline water leaves the lake through ssures in the lake oor . Water loss through the lake bed accounts for about 8% of the water out ow from the lake (Hughes and Hughes, 1992).

During the past 35 years, the climate around Lake Chad has changed. In the late 1960s the western Sahel appears to have undergone an abrupt hydro-climatic transition from a wetter to a drier rainfall state. In the mid-1960s, rainfall became intermittent, culminating in drought from 1972/1974 and 1983-1984. In the mid 1990s, rainfall again increased with several years of high rainfall occurring up to the present, but there are still no assurances that the drought is over. The size of the geographical region affected by this climactic change and the duration of this phenomenon is without precedent in hydro-climatic chronicles. Some authors speculated a climate rupture (Carbonnel and Hubert, 1985 in Nami, 2002).

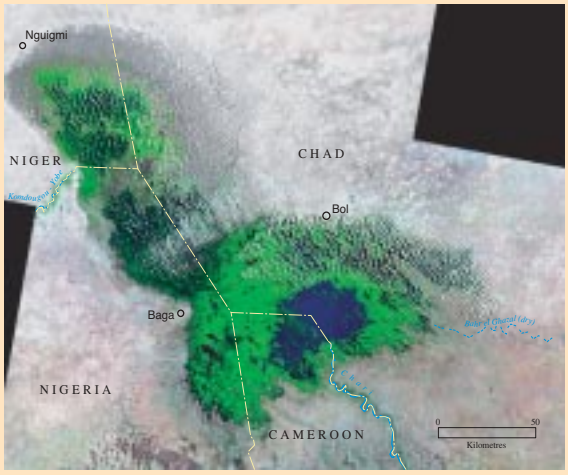
Human Use

During the 1960s, human demand for water resources near Lake Chad grew rapidly. In 1960, an estimated 13 million people lived within the catchment area. By 1990, the population had doubled to 26 million (UNEP, 1999). Pressure on water resources increases with increasing population density in the largely agricultural economy of the basin (Nami, 2002).

Agriculture is the main activity in 60% of the Lake Chad basin. Between 1983 and 1994, irrigation quadrupled (World Bank, 2002). At present, approximately 135,000 hectares of land are irrigated in the Lake Chad basin. The most extensive irrigation projects, totally over 100,000 hectares, have been developed in Nigeria, where the Southern Chad Irrigation Project alone had



1999/2000 Landsat 7 ETM mosaic: 16 Oct 1999, 23 Oct 1999, 9 Oct 2000, and 16 Oct 2000.



2002 Landsat 7 ETM mosaic: 16 Nov 2002, 25 Nov 2002, 18 Dec2002, and 11 Feb 2003.

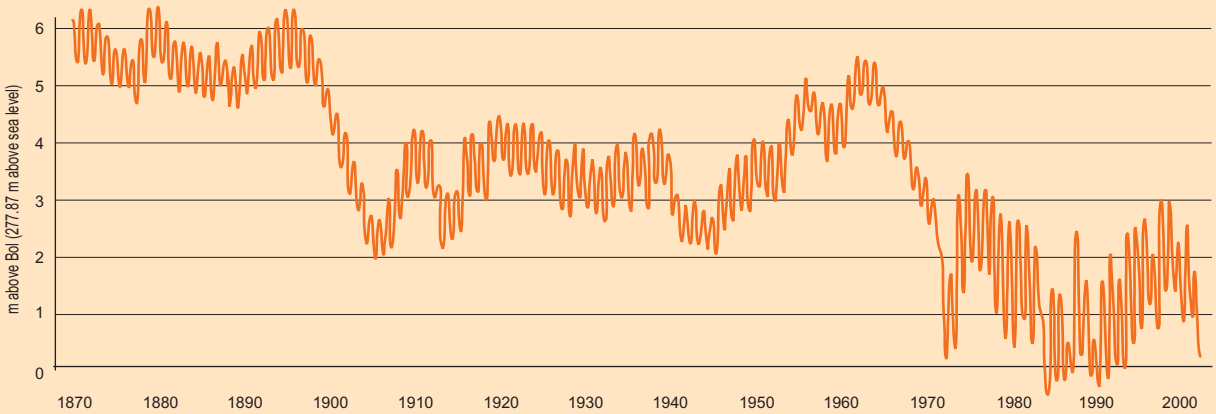
the goal of irrigating 67,000ha of land with an average cropping intensity of 130%, and resettling about 55,000 families onto the irrigated land (Sikes, 2003). Unfortunately, since the droughts of the early 1970s the water level of Lake Chad has not been high enough to reach the intake canals of the irrigation system (Sarch and Birkett, 2000).

In addition to irrigation, dams have in uenced rivers that feed Lake Chad. In the Kano and Hadejia basins, there are believed to be about 23 earth dams. The Komadugu-Yobe River system provides an example of the impact of human diversion. The upper basin used to contribute approximately 7km^3/yr to Lake Chad. Today, the bulk of this water is impounded in reservoirs within Kano province of Northern Nigeria, so that the system only provides 0.45 km^3/ yr. The likelihood of any sustained increase in water discharge down the Komadugu-Yobe is slim, since the demand for water for irrigation in the densely populated upper basin near Kano will not decrease.

Although the contribution from the Komadugu-Yobe drainage system was only 10% of the total contribution to Lake Chad, once the lake divided into a north and south basin its loss to the north basin became critical. The situation is critical in the north basin as good pastures for livestock become harder to nd (Sikes, 2003). The loss of water behind dams is further compounded by the increase in irrigation from wells and bore holes since the 1960s resulting in lower ground water (Sikes, 2003).

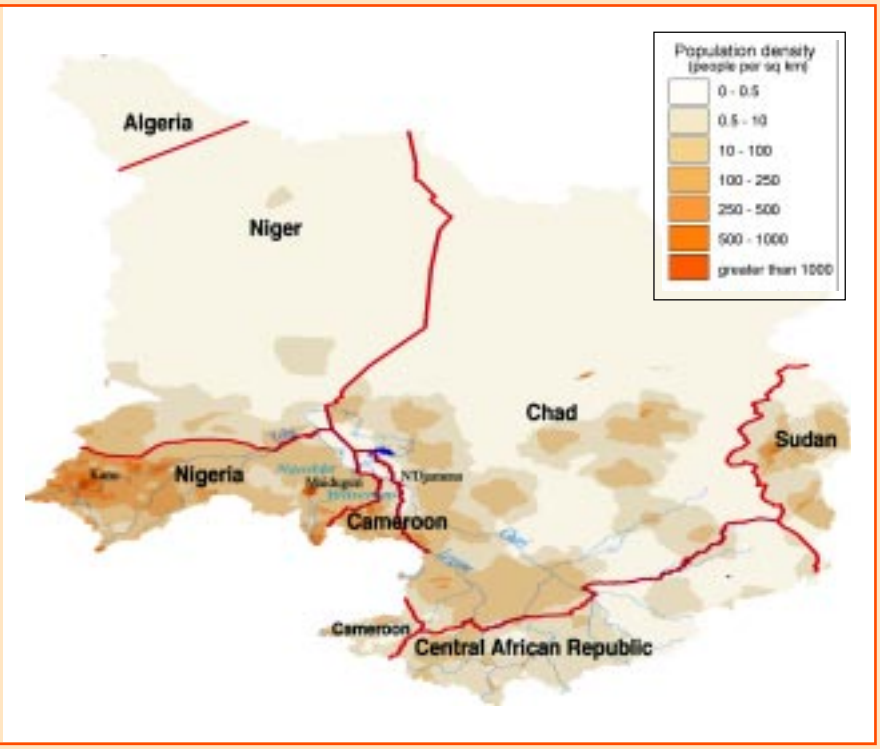
Research by Oyebande (2001) suggests that the impact of the change in the ow regime is caused by the dam construction in the upper Komadugu-Yobe river system. He suggests that the river course of the Komadugu-Yobe was heavily in uenced by the spring ooding prior to the construction of the dams, and that the levelling out of the ow would result in less water reaching downstream provinces and Lake Chad even if the ow volume was increased.

Input from the Chari-Logone river system that was once approximately 37.8km^3/yr decreased in the 1980s and 1990s (Olivry et al., 1996). Human consumptive uses are currently estimated at less than 5% of the basin yield [by Olivry] for the period 1953-1977 and were not thought to impact the Chari-Logone river system, except during times of low precipitation. Thus at this time, lower input is typically due to lower rainfall (Olivry et al., 1996).



Level of Lake Chad, redrawn from Olivry et al., 1996, USGS 2001, and USDA 2004.

Within the Lake Chad basin, the drainage basins of the Komadugu-Yobe and Yedseram-Ngadda, containing the cities Kano and Maiduguri respectively, have the greatest population density, placing a particularly high demand on these sources of water. The boundary of the early 1960s Lake Chad is shown with the open water in 1987 filled in.



Using an integrated biosphere model, run with and then without extraction for irrigation, Coe and Foley (2001) conclude that during the last 35 years, water level uctuations in Lake Chad were caused by both climate variability and water use. Since the 1970s, with marked population increases in the area, human activities have begun to play a signi cant role in lake decline. Human activities act in concert with climate variability to accelerate the decrease in lake levels. The onset of dry climatic conditions in the early 1970s induced people to dramatically increase irrigation activity, thereby almost doubling water loss from Lake Chad (Coe and Foley, 2001). The balance between lake and wetland has always been precarious, as inputs balance loss to ground water and to evaporation. The increased irrigation, which would be modest for many river systems, is very critical in a carefully balanced climatic-ecological system such as Lake Chad s.

Traditionally, shing and farming near Lake Chad have followed the rise and fall of the lake both seasonally and through the years. During dry seasons and dry years farmers move to the very rich soils of the newly exposed lake bottoms, and then sh during the oods (Sarch and Birkett, 2000). The cost to export surplus crops has also increased as cheap water transportation across the open lake is increasingly replaced by shipping via road or maintained canals. The introduction of irrigation and the movement of people to the lake, who only know the lake in its present state, shifts the perspective from water use to water management. In fact, a danger exists that if the water were to rise to 1960 levels, the longtime inhabitants of the basin may no longer be able to retreat from rising waters, as the land behind them may become increasingly exploited for irrigated agriculture as the water once again becomes available for irrigation.

Ongoing Concerns

As Lake Chad continues to shrink, its future as Africa s second largest wetland is uncertain. Plants that require water, or are adapted to changing water levels, are increasingly disadvantaged compared to plants that have adapted to water stress. Since little freshwater enters the north basin from the Komadugu-Yobe, the basin can quickly become saline if it is isolated for many years (Dumont, 1992). As productive perennial grasslands are replaced by annual grasses, biodiversity declines (Verhoeye and De Wulf , 2001). Declines in vegetation associated with lake ecosystems may result in increased erosion and ultimately in deserti cation. Anthropogenic emissions of greenhouse gases are altering world climate. The IPCC predicts reduced rainfall and run-off, and increased deserti cation, in the Sahelian belt near Lake Chad (IPCC, 2001).

The biodiversity of sh and birds in the Lake Chad ecoregion is also threatened. The drying up of water basins and ponds both directly and indirectly increases sh mortality . The Alestes naremoze, a sh species which once made up

approximately 80 per cent of the sheries catch, is now rare due to the disappearance of natural spawning beds. The life history of birds is also impacted as the lake shrinks. Lake Chad is an important resting place for migratory species crossing the Sahara, such as the European white stork. Without the unique refuge offered by this watering hole, migrations may be impossible to complete.

Diminishing water resources and continued ecosystem decline will also have severe health and economic impacts for human populations around Lake Chad. The northern states of Nigeria and Cameroon are among the poorest states in these two countries (World Bank, 1995a and 1995b). Sarch and Birkett (2000) report an annual sh catch in the Lake Chad basin between 1986 and 1989 of 56,000 tons, compared to an annual catch of 243,000 tons between 1970 and 1977. As sh decline, cultural loss may occur along with economic loss. The islands and swamps of Lake Chad are home to the Yedina, a unique ethnic group that is heavily dependent on shing (Sikes, 2003). Around the lake itself, domestic plant and animal production may become untenable due to increasing soil erosion and deserti cation. In the lower Yobe, dunes and layers of sand are already invading date palm plantations (Nami, 2002).

The drought has created a shortage of fresh drinking water, lower ows in the rivers have reduced their ability to assimilate wastes leading to an increase in diseases linked to poor sanitation, and irrigation related diseases, such as schistomiasis, have been introduced. Cases of meningitis, diarrhoea, cholera, and typhoid fever are already common throughout the basin (UNEP, 2004).

The future of Lake Chad looks bleak. With a high population growth rate, pressure on water resources in the Lake Chad basin will continue. While in the past Lake Chad has been able to rebound from low to high water levels, climate change and human water use may now act in concert against recovery.

The story is certainly not complete. Rainfall has again returned to the region, but for how long is unknown. As irrigated agriculture is developed along with the water structures, such as dams and levees, needed to support irrigated agriculture, how do these developments affect the environment and the livelihood of the inhabitants of the basin? The Lake Chad ecosystem requires a highly adaptive social and economic structure in which the nations sharing the basin work together to manage the resources of this unique ecosystem. Population growth and economic development that does not take into account the highly variable nature of the ecosytem could, in the end, doom the system.

Zebu cattle, typical to the region, are being herded through a marsh. Copyright ' 2000, University of Wisconsin System Board of Regents. Copyright ' 2000, University of Wisconsin System Board of Regents.

References

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*, v. 106 n. D4 p. 3349-3356.

Dumont, H.J. (1992) The regulation of plant and animal species and communities in African shallow lakes and wetlands. *Revue d Hydrobiologie Tropicale,* v. 25, pp. 303-346.

FEWS (2003) Rainfall estimates. Famine Early Warning System. Available at www.fews.org/ on 12 November 2003.

IPCC (2001) Climate Change 2001: Impacts, Vulnerability, and Adaptation. IPCC Working Group II, Geneva. Available at www.grida.no/climate/ipcc_tar/ on 13 November 2003.

Mockrin, Miranda and Thieme, Michelle (2001) Lake Chad ooded savanna (A T0904). World Wildlife Fund (WWF). Available at www.worldwildlife.org/ wildworld/pro les/terrestrial/at/at0904_full.html on 10 November 2003.

Nami B. (2002) Impacts of Environmental Change on Food Production in the Lake Chad Basin (unpublished).

Olivry, J.C., Chouret, A., Vuillaume, G., Lemoalle, J. and Bricquet, J.P. (1996) Hydrologie du Lac Tchad, ORSTOM, 266 pp., Monograph Hydrologie, v. 12, Paris, France.

Oyebande, Lekan (2001) Stream ow regime change and ecological response in the Lake Chad basin in Nigeria, Hydro-ecology: Linking Hydrology and Aquatic Ecology, Proceedings of Workshop HW2, Birmingham, UK, July 1999. IAHS Publication n. 26. pp. 101-111.

Sarch, Marie-Th r se and Birkett, Charon. (2000) Fishing and Farming at Lake Chad: Responses to Lake-level Fluctuations. *The Geographical Journal*, v. 166, n. 2, pp. 156-172.

Sikes, S. (2003) *Lake Chad versus the Sahara Desert*. Newbury: Mirage Newbury.

Schneider, Stanley R., McGinnis, David F., and Stephens, George (1985) Monitoring Africa s Lake Chad basin with LANDSAT and NOAA satellite data. International Journal of Remote Sensing, v. 6, n. 1, pp. 59-73.

UNEP (1999) Early Warning of Selected Emerging Environmental Issues in Africa: Change and Correlation from a Geographic Perspective. UNEP/ DEWA Environment Information and Assessment Technical Report, TR. 99-2, p. 42.

UNEP (2004) Fortnam, M. and J. Oguntola, Lake Chad Basin, GIWA Regional Assessment 43, University of Kalmar, Kalmar, Sweden

USDA (2004) Global Reservoir Monitoring. CropExplorer, Production Estimates and Crop Assessment Division, Foreign Agricultural Service, United States Agricultural Service. Available at www.pecad.fas.usda.gov/corpexplorer/ global_reservoir/ on 11 March 2004.

USGS (2001) Earthshots: Satellite Images of Environmental Change: Lake Chad, West Africa, United States Geological Survey. Available at earthshots.usgs.gov. on 14 November 2003.

Verhoeye, J. and De Wulf, R. (2001) Imaging radar for mapping and monitoring of wetland ecosystems in the Lake Chad basin, allserv.rug.ac.be/-educheyn/ projecten/lake_chad2001/StudyArea/ StudyArea.html.

World Bank (1995a) Nigeria: Poverty in the Midst of Plenty The Challenge of Growth with Inclusion. Report No. 14733-UNI. Available at poverty.worldbank.org/library/ on 14 November 2003.

World Bank (1995b) Cameroon: Diversity, Growth, and Poverty Reduction. Report No. 13167-CM Available at poverty.worldbank.org/library/ on 14 November 2003.

World Bank (2002) Reversal of Land and Water Degradation Trends in the Lake Chad Basin Ecosystem, Project Brief. Available at www.gefonline.org/projectDetails.cfm?projID=767 on 12 November 2003.

Atatürk Dam and Harran Plain

Re-Engineering the Cradle of Agriculture

Photo courtesy of Foriegn Agriculture Service.

The Atat rk Dam, the Sanliurfa Tunnel which connects the Atat rk reservoir to the Harran Plain, and other hydrologic projects have signi cantly changed the social, economic and environmental realities of southeast Turkey. In 1992, the Atat rk Dam was completed on the Euphrates (Firat) River in southeastern Turkey. The Atat rk Dam and its reservoir are key components of the very ambitious Southeastern Anatolian Project (GAP) that has the dual objectives of electric power production and the conversion of dryland agriculture regions to irrigated agriculture.

In 1975, the rst two of a series of major dams on the upper Euphrates, the Keban in Turkey and the Tabaqah in Syria, were built on the Euphrates River, allowing its ow to be controlled for the rst time (Beaumont, 1998). The primary motivations for these rst dams were ood control and hydroelectric power for industry. More dams followed, and control of the river became more complete with each one. The extreme swings from spring oods to nearly dry summers have been replaced by a nearly steady water ow.

Pool of Abraham in Sanliurfa, Turkey. Photo courtesy of Antoinette Wannebo.

Land use changes and utilization of water resources have been incremental in Upper Mesopotamia for centuries, if not millennia. But with the ow of the Euphrates controlled, agriculture, economics, and water resource management have undergone dramatic changes. The dams interrupt the natural ow of the river, submerge historical sites, disrupt the livelihoods of people living in the region, and raise issues regarding control of water resources. The hopes and plans are that the long-term bene ts will outweigh the social and environmental costs.

The Physical Context

The Euphrates River begins in the highlands northeast of the Anti-Taurus Mountains in Turkey. This region is tectonically very active, with major fault zones running throughout the Anti-Taurus Mountains. This raises concerns regarding the safety of large dams.

The Tigris-Euphrates Basin has a Mediterranean climate: mild, wet winters and long, hot, dry summers. The region is known for extreme temperatures, from —35C to over 38.C in the north, and from —9C to over 47.C in the south. Annual rainfall is 600mm in the highlands, dropping to 116mm along the Euphrates River in Syria. Snow covers the highlands for over 120 days per year, but the Harran Plain for only 7 to 10 days per year. Most of the precipitation falls in the mountains and highlands in winter and spring, and is released during the spring snowmelt.

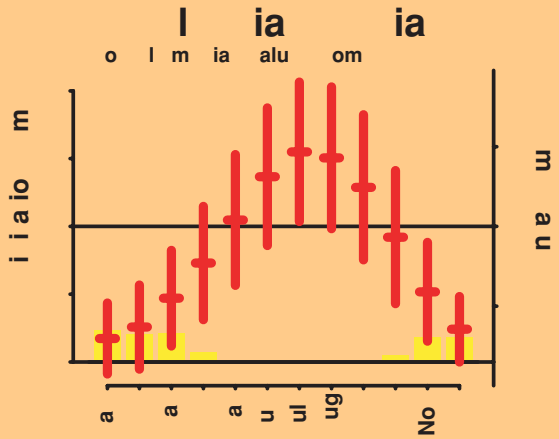
The porous limestone underlying the Euphrates basin absorbs signi cant portions of the snow and rain runoff into the ground water and releases it gradually over a six-month period. As a result, ground water is an important source of water in southeastern Turkey and northern Syria. Among the perennial streams in the Euphrates basin is the Balikh River, originating at springs in the limestone uplands south of the Anti-Taurus Mountains, and owing into the Euphrates in Syria. The diversion of water for irrigation has in recent times made these rivers intermittent. However, in the case of the Balikh, irrigation runoff has actually increased the ow.

Ecology and Biodiversity

The natural ecosystem is dominated by dryland shrubs and grasses. Oak woodlands can be found at higher elevations and riparian woodlands can be found along the streams. Wetlands and agricultural elds create an important area of bird diversity along the migratory route from northern Asia to the Upper Rift Valley in Africa (Zeydanli, 2001). More importantly, the landforms and Mediterranean climate in southwest Asia forms an area of mega-diversity of important food, pasture, and medicinal species (Jaradat, 1998).

Diamond (1997) presents a clear discussion of the domestication of plants and animals throughout the world, and the characteristics that make this region critically important. In essence, the Mediterranean climate promoted the evolution of many critical grass and legume annuals, and the extreme variation in climate due to landform allowed these grasses and legumes to mature at different times during the growing season and to survive high local variability in temperature and rainfall from one year to the next. The wet winters and dry summers promoted the evolution of large fruits and seeds that could survive the dry season. These traits proved to be invaluable for feeding settled human populations.

Protecting the biodiversity of our foods genetic ancestors is critical to the long-term



On the Harran Plain at Tel-Abiad near the Turkey-Syria border, median maximum temperatures approach 30.C in the summer and the median minimum temperature approaches 0.C in the winter. Little or no rain falls between May and September. Even in the wet winter, median precipitation rarely reaches 3cm/month. This is a classic Mediterranean climate. As you go north and upstream on the Euphrates the winter lows become lower and the winter precipitation becomes greater with more snow, but the temperature and precipitation pattern remains the same.

Image courtesy of http://rsd.gsfc.nasa.gov/rsd/bluemarble/.

NASA Blue Marble Image available from http://rsd.gsfc.nasa.gov/rsd/bluemarble/

viability of their genetic strains. Bioengineering and mass distribution of commercial seed stocks can signi cantly increase yield and provide resistance to speci c threats. However , they also compete with wild relatives and with old cultivars, which provide the biodiversity necessary to survive global climate changes and new crop and animal diseases that may evolve (Tan, 1996). This region s early development of civilization was due to the incredibly rich biodiversity of plants and animals from which many of our existing food products derive. Old cultivars developed in the region and their wild relatives have adapted to survive the wide ranges of daily and annual weather conditions that exist throughout the region and continue to provide valuable alternate seed stocks. New crops relying on irrigation and introduced varieties of existing crops compete with and reduce the diversity of the locally evolved old cultivars.

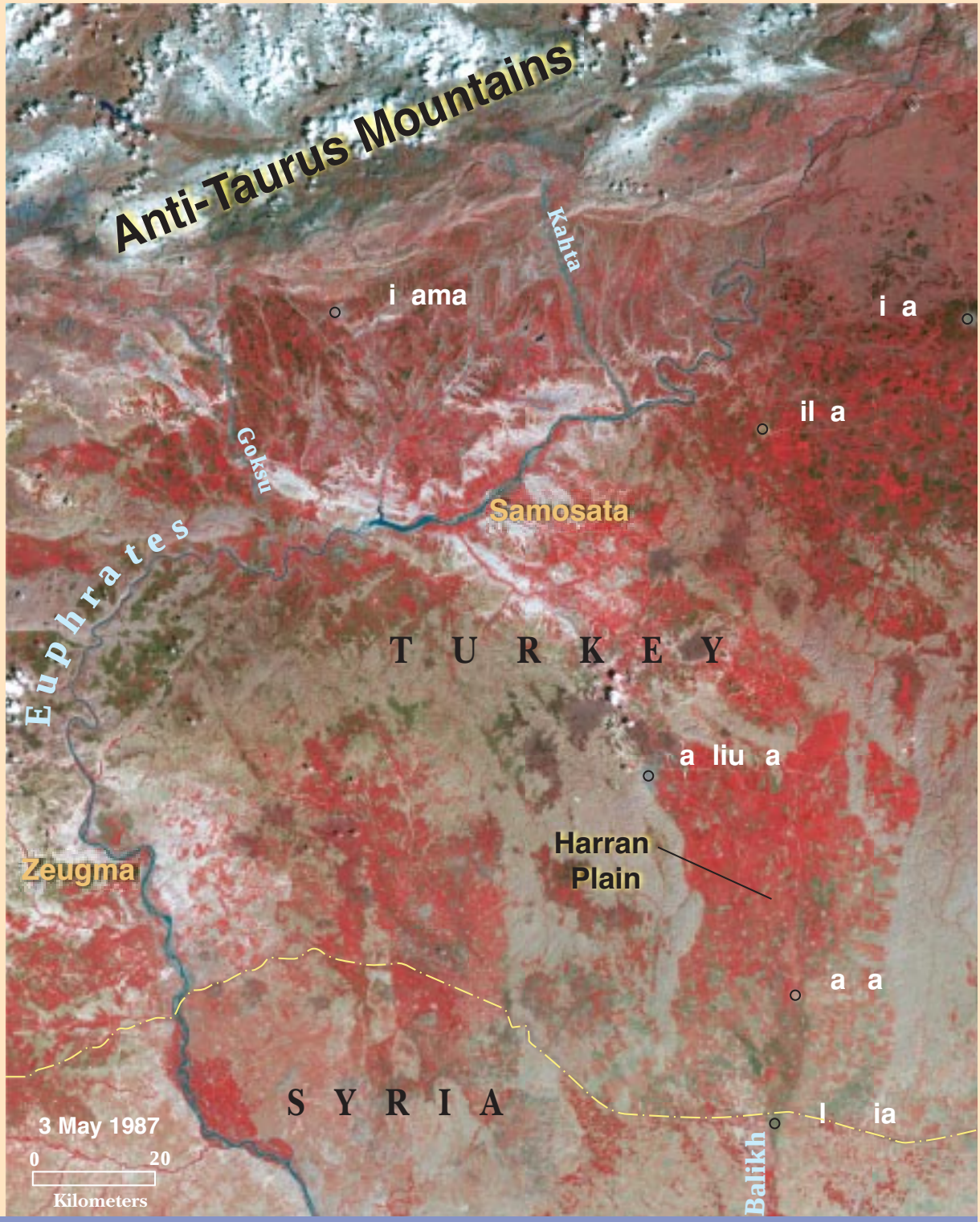
In this climate, most dryland agriculture relies on springtime harvest of crops planted in the fall. The southern part of this region is too hot and dry for dryland agriculture (de Brichambaut and Wall n, 1968). If irrigation water is available, then crops are planted in the spring for a fall harvest.

The Region's Peoples

With these favorable climates, grains, and animals, the Tigris-Euphrates basin developed the very earliest human civilizations. Great civilizations ourished here: the Hittite, Assyrian, Medes, Babylonian, Persian, Hellenistic, Roman, Arab, and Ottoman. The Euphrates, with its unreliable ow , has never been a major transportation route. Major cities grew where trade routes crossed the river, rather than at its ports. Sanliurfa and Harran on the Harran Plain lie where trade routes connect Mesopotamia Asia to Asia Minor and the Mediterranean. The road from the Harran Plain to Asia Minor crossed the Euphrates at Samosata and the road to Damascus and the Mediterranean crossed the Euphrates at Zeugma (Kennedy, 1998; Ward, 1990). Both of these ancient cities have now disappeared beneath the surfaces of reservoirs.

The present countries in the Tigris-Euphrates Basin resulted from political maneuverings following the breakup of the Ottoman Empire after the First World War. During much of recorded history the region has been dominated by ethnically mixed societies. The partition of the Ottoman Empire into small states split a large multiethnic state into small multiethnic states. More importantly, ethnic groups that were once largely contained within one state became split among many states. In southeastern Turkey the major ethnic groups are the Turks, Arabs and Kurds.

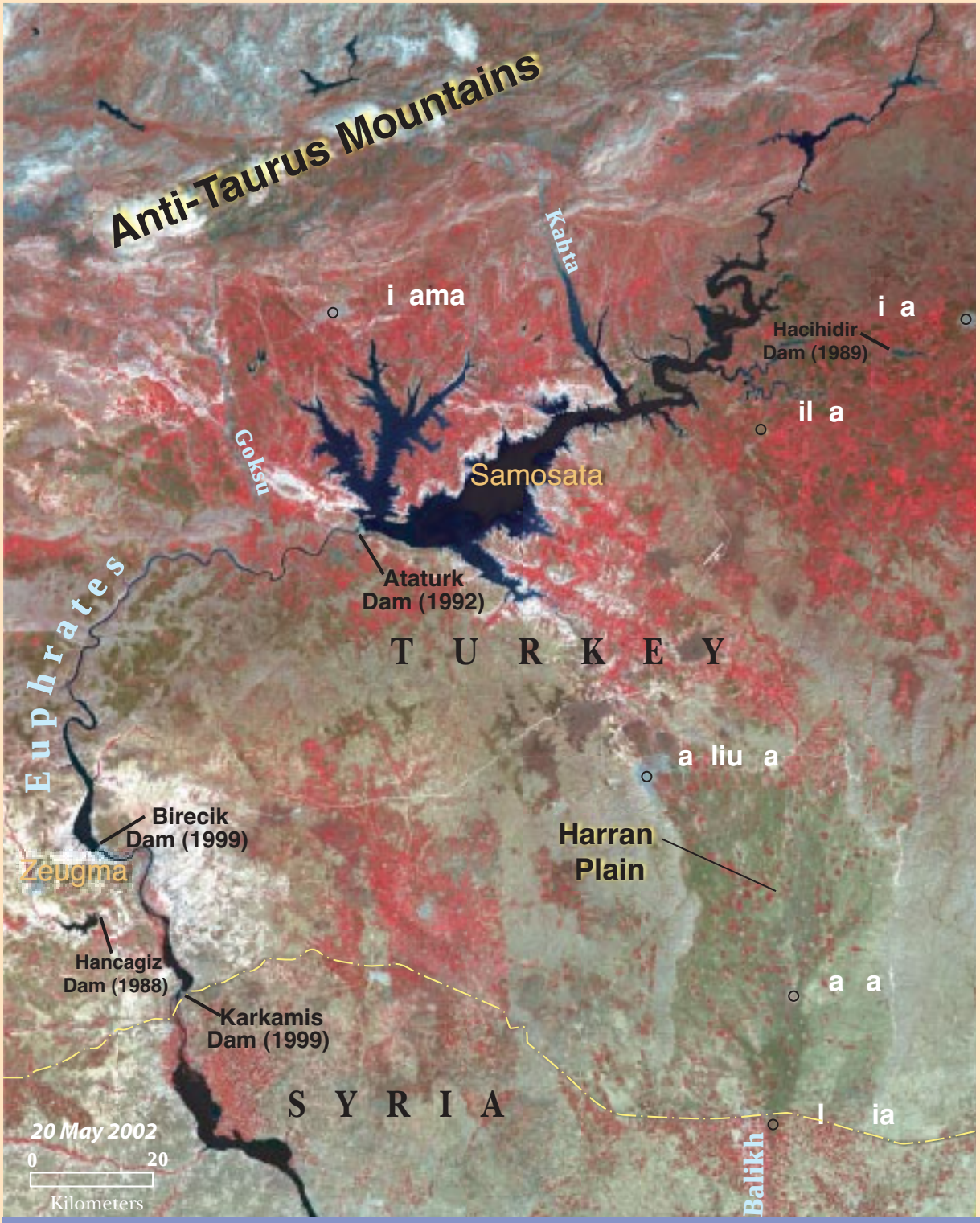
Development in Upper Mesopotamia has been driven by the availability of water for irrigation and energy, and fertile soils. All countries in the basin seek to increase agricultural and energy production, and to reduce ooding and poverty . By effectively utilizing water resources the governments in the region hope to radically improve the standard of living, and in the process



This Landsat image shows the area before the Atat rk Dam was built.
Color key: Red - vegetation; Blue - water; Tan - barren land.

lessen competition for resources among ethnic groups within each country.

But the nationalistic competition for resources should be moderated to ensure a fair share of resources for each country. The 1966 Helsinki Rules provide guidance for allocating water resources in an equitable and reasonable manner among countries sharing a drainage basin. Allocation of the waters of the basin should be a function of (1) precipitation, (2) historic use, (3) effective use, and (4) control. Precipitation is a simple measure of water wealth. Historic use is a function of a largely symbolic ancestral use and the very real needs of existing populations. Effective use is a function of climate and landform, and should consider cost versus bene t of future developments. Control in the simplest form should ensure that



This Landsat image shows the area after the Atat rk Dam was built.

existing populations are not unduly compromised, but in the nationalistic sense too often can be reduced to a struggle for power (Akmansoy, 1996).

Southeastern and eastern Turkey are among the country s more impoverished regions. The region has signi cant out-migration, partly from con icts and unrest in the region, but much of it from lack of economic opportunities and high population growth. Unemployment is around 20 percent in the cities and is especially high among the unskilled (Aksit et al., 1996). Strong tribal structures still exist with southeastern Turkey, which compete with the national government for authority. These tribal structures can inhibit agricultural, social and economic change (Nestor, 1995). Increased economic opportunities provided by electricity for industry and water for irrigation should slow out-migration and create jobs.

Atatürk and Harran Plain: Water Resources and Agricultural Change

Construction of the Atat rk Dam started in 1981 and was completed in 1992. The ow of the Euphrates River was partially interrupted for one month in January 1990, during the lling of the reservoir, causing heighted tension with Syria and Iraq (Kaya 1998). The two Sanliurfa Tunnels, 7.62m in diameter and 26.4km long, are the longest irrigation tunnels in the world. The tunnels rst delivered water in April 1995. One of the tunnels empties into the irrigation canals delivering water throughout the Harran Plain. The second tunnel empties into a canal that carries the water further east to the Mardin-Ceylanpinar plains.

Comparing the 1987 and 2002 images, the most noticeable changes created by the dam are the Atat rk Reservoir and the intensively cultivated Harran Plain. To the north and east of Lake Atat rk, irrigated agriculture is replacing traditional dryland agricultural methods. With the shift in agricultural methods comes a change in the predominant crops, from wheat, barley, pistachios, and caparis, to more water-intensive crops such as cotton, corn, and soybeans.

In the May 1987 image, most agricultural elds were nearly ready for harvest. Certain elds were left fallow while others had dryland agricultural crops. Crops in these elds appear bright red, indicating the high re ectivity of near-infrared light. By 2002, the Harran Plain had been largely converted to irrigated summer crops and no longer had crops ready for harvest in the spring.

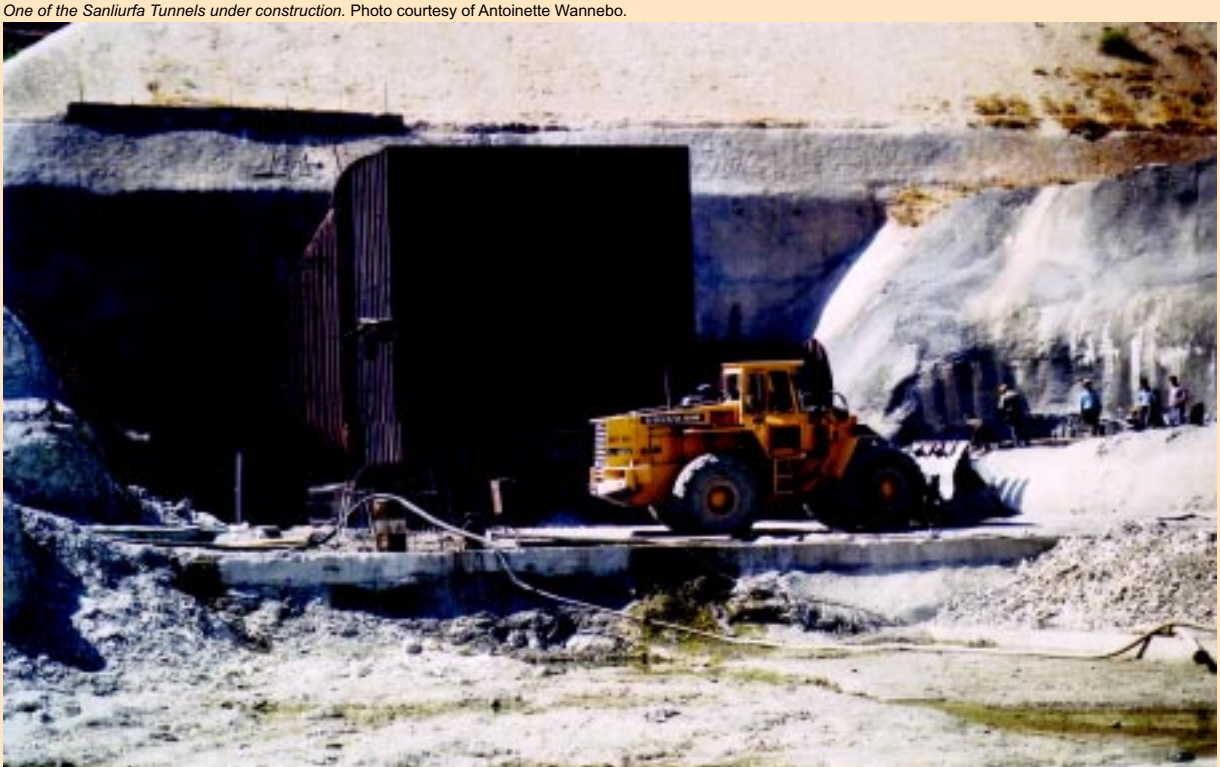
Agricultural statistics show that by 1998, the regions surrounding the Atat rk Dam produced signi cantly more agricultural output. According to government of cials, the region produced 41.6% of the country s cotton needs, and approximately 12% of the country s grains and vegetable requirements. Cotton, a popular cash crop, has had the largest increase in overall productivity since the introduction of the dam. The conversion to growing cotton for the export market links the fate of the farmer to the market s long-term stability (Aksit and Ak ay , 1997).

Turkey s plan is not to increase the area under cultivation, but by irrigating, change from dryland crops such as wheat and barley to water-demanding crops such as cotton and corn, and to reduce the amount of time that a eld must lie fallow (Beaumont, 1996). Cropping patterns have changed from one crop every two years to potentially multiple crops every year.

The cities and provinces containing Atat rk and the Harran Plain have grown in population. According to of cial statistics, from 1990 to 2000 the population of Sanliurfa grew 33%, from 276,528 to 383,870. In the same years Adiyaman grew 58%, from 100,045 to 178,538. The provinces of Sanliurfa and Adiyaman grew 36% and 20% respectively, compared to the national average of 18%.

Agricultural areas downstream depend on fresh water from the Euphrates and from spring-fed streams. Increased irrigation upstream raises concerns about increased soil salinization. Agricultural runoff from the Harran Plain, high in salt content, drains through Syria to the Euphrates

One of the Sanliurfa Tunnels under construction. Photo courtesy of Antoinette Wannebo.



A siphon offtake irrigating a eld in the Harran Plain. Photo courtesy of the United States Foreign Agriculture Service.

by way of the Balikh River. It is estimated that the ow of the Balikh may be 3.5 times as great as before the diversion of water to the Harran Plain. The runoff from irrigation will contain signi cant amounts of pesticides, herbicides and nutrients, whose effects on downstream water quality are yet to be determined (Beaumont, 1998). Most of the irrigation projects have low ef ciency , with wide use of ood irrigation, but education should bring higher ef ciency (Bayazit and Avci, 1997), which in turn should result in less salinization and contamination of the ground and surface water (Kolars and Mitchell, 1991).

There is not enough water in the Atat rk reservoir to both operate the turbines at full capacity and meet the need for irrigation water (Beaumont, 1998). In the future this will require consideration of tradeoffs between irrigated land and power production. These tradeoffs will become dif cult with the shift to a cash-crop economy, and could easily result in decisions pitting electric power requirements in western Turkey against agricultural requirements in eastern Turkey. It could also require more-ef cient irrigation or a return to dryland farming. As in most of the world, access to water is considered a right and the amount a user is charged does not cover the cost of delivering water (Beaumont, 1998). The method of charging for water resources may need to change as the resource becomes fully utilized, and a long-term costing structure needs to acknowledge water s value to the natural environment, and the long-term cost of losing cultural treasures.

There are seasonal tradeoffs as well. The need for electricity production is greatest in winter, so the maximum discharge down the Euphrates may shift from spring to winter, when it is least needed for downstream agriculture. Effective downstream storage structures would then become critical for irrigation (Beaumont, 1998). Changing the discharge patterns completely changes the downstream riparian and marshland ecosystems. These ecosystems have evolved to rely on the large variation inherent on a wild river, with spring oods followed by low water. The ecological impacts of changing the discharge regime can not be overestimated. These may be considered acceptable consequences, but they are nonetheless consequences of controlling the river.

Ongoing Concerns

This part of Turkey in many ways has been left behind, as early development efforts focused on western Turkey. The per-capita gross national product of southeastern Turkey is less than half the national average (Bayazit and Avci, 1977). The Atat rk Reservoir is only part of the huge Southeastern Anatolia Project designed to reduce reliance on imported sources of energy, to increase agricultural production, and to develop southeastern Turkey. Thorough planning and implementation is needed to ensure that all peoples in the region bene t and that damage to cultural and ecological resources are minimized.

References

Aksit, B., Mutlu, K., Nalbantoglu, H. ., Ak ay , A. A., & Sen, M. (1996) Population Movements in Southeastern Anatolia: some ndings of an empirical research in 1993. *New Perspectives on Turkey*, 14, 53-74.

Aksit, B., & Ak ay , A. A. (1997) Sociocultural Aspects of Irrigation Practices in Southeastern Turkey. *Water Resources Development*, 13(4), 523-540.

Akmansoy, S. (1996) Southeastern Anatolian Project. Available from www.ce.utexas.edu/prof/maidment/ grad/akmansoy/gap/ paper.html on 14 November 2003.

Bayazit, M., & Avci, I. (1997) Water Resources of Turkey: Potential, Planning, Development and Management. *Water Resources Development*, 13(4), 443-452.

Beaumont, P. (1996) Agricultural and Environmental Changes in the Upper Euphrates Catchment of Turkey and Syria and their Political and Economic Implications. *Applied Geography*, 16(2), 137-57.

Beaumont, P. (1998) Restructuring of Water Usage in the Tigris-Euphrates Basin: The Impact of Modern Water Management Policies. from www.yale.edu/environment/publications/bulletin/ 103pdfs/ 103beaumont.pdf on 19 October 2003.

de Brichambaut, G. P., & Wall n, C. C. (1968) A Study of Agroclimatology in Semi-Arid and Arid Zones of the Near East. World Meteorological Organization. Geneva, Switzerland.

Diamond, J. (1997) *Guns, Germs and Steel: The Fates of Human Societies.* New York: W.W. Norton & Company.

Jaradat, A. A. (1998) Biodiversity and Sustainable Agriculture in the Fertile Crescent. Available from www.yale.edu/environment/ publications/bulletin/103pdfs/103jaradat.pdf on 19 October 2003.

Kennedy, D. (1998) Drowned Cities of the Upper Euphrates. *Aramco World*, 49(5), 20-27.

Kaya, Ibrahim (1998) The Euphrates-Tigris basin: An overview and opportunities for cooperation under international law. Arid Lands Newsletter, No. 44, Fall/Winter 1998. Available at ag.arizona.edu/ OALS/ALN/aln44/kaya.html on 20 October 2003.

Kolars, J. F., & Mitchell, W. A. (1991) *The Euphrates River and the Southeast Anatolia Development Project*. Carbondale: Southern Illinois University Press.

Nestor, C. E. (1995) Dimensions of Turkey s Kurdish Question and the Potential Impact of the Southeast Anatolian Project (GAP): Part I. *The International Journal of Kurdish Studies*, 8(1-2), 33-78.

Tan, A. (1996) *Turkey: Country Report to the FAO International Technical Conference on Plant Genetic Resource.* Available from www.fao.org/ WAICENT/FaoInfo/Agricult/ AGP/AGPS/pgrfa/pdf/turkey.pdf on 19 October 2003.

Ward, D. R. (1990) In Anatolia, a massive dam project drowns traces of an ancient past. *Smithsonian*, 21(5), 28-40.

Zeydanli, U. (2001) Eastern Mediterranean conifer-sclerophyllous-broadleaf forests. Available from http://www.worldwildlife.org/ wildworld/pro les/terrestrial/pa/pa1207_full.html on 20 October 2003.

The Sundarbans

Mangroves, Tigers and Shrimp Farms

A resting Bengal tiger. Photo courtesy of TopFoto —Anant Vijay Singh

The Sundarbans, a tide-washed mangrove forest in India and Bangladesh inhospitable to human settlement, has survived the pressures of exploitation including shing, logging, poaching and recently shrimp farming from the impoverished human population crowded directly around it. What remains to be seen is whether it can be saved from hydrologic changes including river diversion and sea-level rise caused by people far away.

Photo courtesy of the Institute of Water Modeling.

A young boy enters the Sundarbans mangrove forest, Bangladesh, for a week to collect shrimp fry for shrimp farms in the area. Photo courtesy of FAO Photo/G. Grepin.

Location and Conditions

The Sundarbans (also known as the Sunderbans or Sunderbunds) is one of the largest mangrove forests in the world, about 10,000km^2. It lies along the Indian Ocean, about 60% in southwestern Bangladesh and 40% in India.

This forest is drenched in water from three sides. First, it stands on the delta of the Ganges River, broken into strips by its many distributaries. These rivers bring fresh water as well as silt, which gives the mangroves nutrients and new soil to colonize, but can also ll channels and smother plants. Second, the Sundarbans is ooded twice daily by ocean tides, whose saltwater the mangroves also need. The funnel-shaped coast focuses ocean energy on Bangladesh, which is mostly within 10m of sea level, so the Sundarbans help protect inland areas from disastrous cyclones. Third, the Sundarbans receives about 250cm of rain annually. Most of this is during the monsoon season, followed by a dry winter (Heitzman and Worden, 1988).

The Sundarbans is richly populated with plants and animals, including a number threatened with extinction. Its name is likely derived from forest of Sundari, one of the 60 species of mangroves which grow here (Ghosh, 2003). Mangroves thrive in the tidal zone where they alternate between wet and dry, saltwater and freshwater. The mangroves character is in their roots: a broad, shallow fan which buttresses the trunk against tidal forces. These prop roots are in the air at low tide and breathe for the tree. Mangrove roots also build and hold the land together and are habitat for marine life, while their branches are for bird life. Their roots can also absorb a considerable amount of pollutants.

The marquee animal species here is clearly the man-eating Bengal tiger. Though they do not systematically prey on humans and rarely eat them when killed, these tigers do kill people, and defend their habitat by scaring people away (Chaudhuri, 2002). Other animals here include estuarine crocodiles, spotted deer, dolphins, marine turtles, monkeys, clawless otters, and Indian pythons. Species formerly living here included the one-horned Indian rhino, the Javan rhino, and a species of river dolphin (UNEP-WCMC, 1987a and 1987b).

People have long moved deeper into the transitional area north of the forest; one study estimated that 5,000km^2 of mangrove have been cleared in the last two centuries (Ghosh, 2003). These agricultural areas produce rice, shrimp, sugarcane, and betel nuts. While the Sundarbans itself is essentially unpopulated, 35,000 people are estimated to work there in any given year, including 25,000 in shing, 5,000 in timber and 1,500 in honey collection (UNEP-WCMC, 1987a and 1987b). These resources are very valuable for the area s impoverished population. Annual per-capita GDP in Bangladesh (as a whole, in

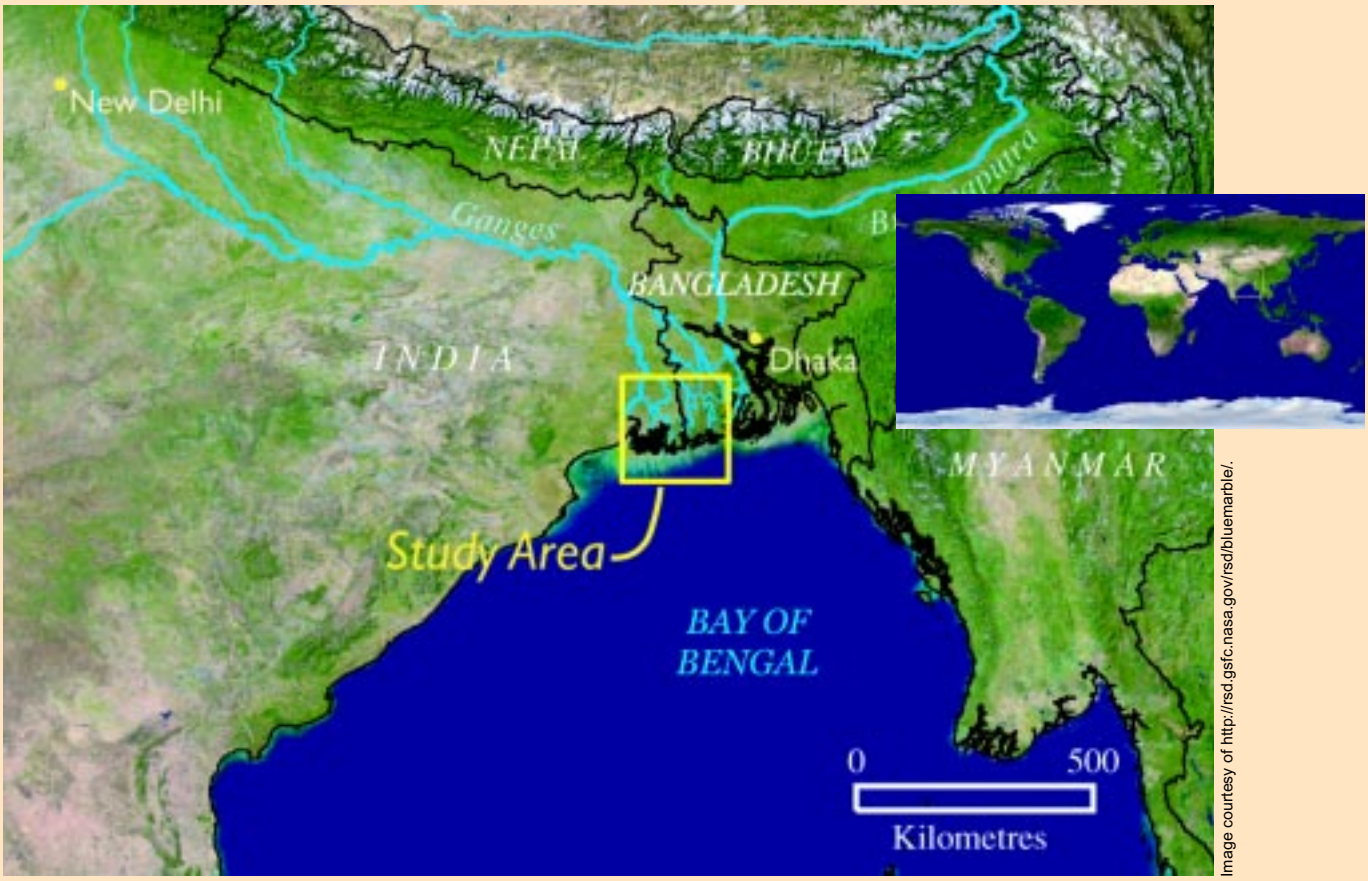


Image courtesy of http://rsd.gsfc.nasa.gov/rsd/bluemarble/.

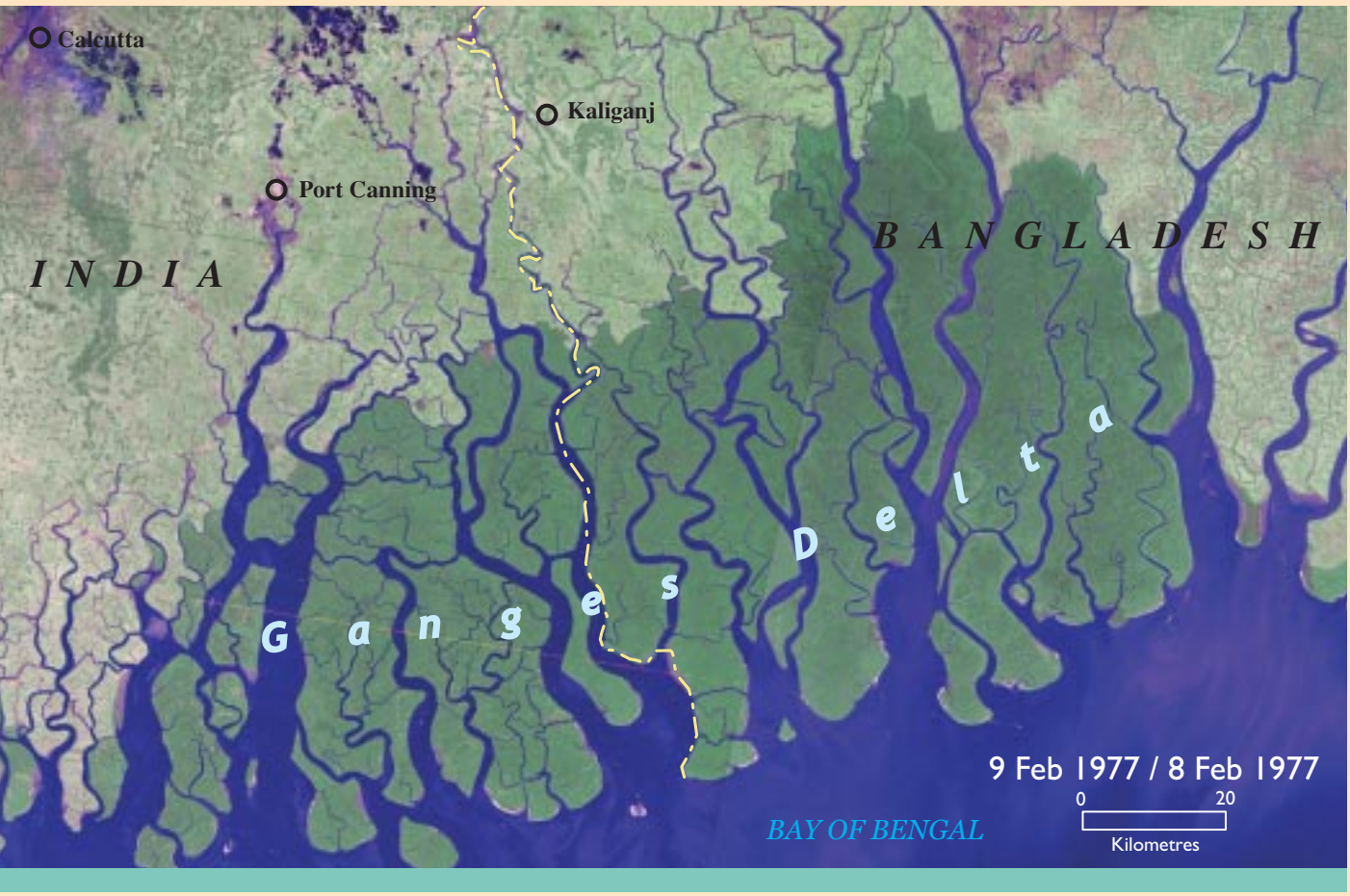
1999) was $370, and the population is very rural, crowded, and only 54% literate (World Bank, 2000).

This forest has both economic and ecological signi cance. In the 1870s, it was designated as forest reserve; in the 1970s portions were made wildlife sanctuaries; in the 1980s the Indian side was recognized as a National Park and a World Heritage Site; and in the 1990s the Bangladesh side was likewise recognized as another World Heritage Site (UNEP-WCMC, 1987a and 1987b). People press in on the parks borders, but this preservation appears to be a success story. As these satellite images show, rapid deforestation and habitat loss are not an issue here as they are in many developing areas. The tiger population, for example, is by different accounts either growing or holding even, as is their major prey species of deer and boar. But the Sundarbans is in a precarious position, subject to many dangers which are easily apparent, even if their present and future effects are still unclear.

Changes

Population pressure threatens to increase whatever illegal poaching occurs now, the amount of which is debated. Bangladesh s population, already crowded at about 130 million, is projected by the World Bank to rise to 218 million by 2050. The mangroves themselves are the subject of most attention, especially as they support the rest of the ecosystem. The Sundarbans is the largest forest in the country, and especially prominent in the almost deforested, but densely settled, delta. Wood serves as the main home fuel on both sides of the border, and mangroves also serve as utility poles, pulp for the paper industry, and even as thatch for roofs (Heitzman and Worden, 1989). There are also reports of tiger poaching, though at

One of the many sea inlets into the Sunderbans that, with a mixture of salt and fresh water, mangroves thrive in. Photo courtesy of Institute of Water Modeling.



The 1977 Landsat image clearly shows the borders of the Sundarbans forest.
Color key: Blue - water; Light green - developed areas; Dark green - undeveloped areas.

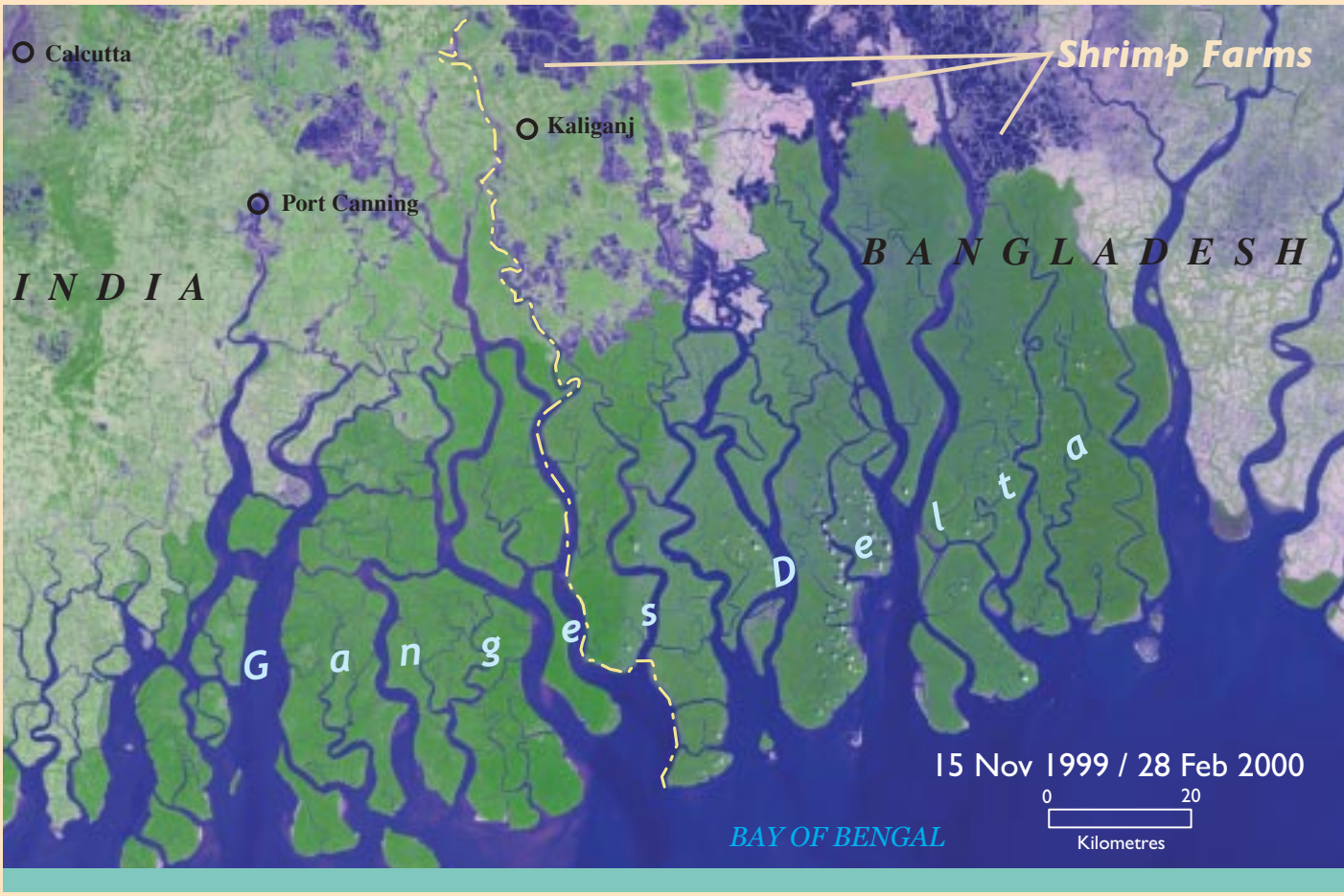
least some of the tiger deaths are certainly from surprise run-ins with villagers on the forest s edge, or with workers in the forest itself. These protected areas are certainly open to poaching, but the amount of poaching is unclear.

Shrimp farming has clearly expanded rapidly. Outside capital from the World Bank, the Asian Development Bank, and others funded this enterprise starting in the 1980s as a way to generate more income for local farmers (Heitzman and Worden, 1989). The growth in shrimp ponds can be seen in the 1999/2000 satellite image, accounting for much of the blue areas north of the Sundarbans.

One recent analysis of satellite images estimated there were about 1,500km^2 of shrimp farms in the area by 2002, up from zero in 1977 (Hossain, 2003). Shrimp farms affect water quality and naturally compete with mangroves for the same spaces, but low-tech, low-capital methods have caused additional problems as well. The Sundarbans is the main nursery for shrimp in the region, and people collect shrimp eggs by dragging nets along its riverbanks; this catches some shrimp eggs, but also many eggs and seeds of other species, disrupting the food chain. It also kills mangrove seedlings, interfering with forest regeneration (Chattopadhyay, 2002).

Global warming threatens to unbalance the Sundarbans water forces from two directions. Air temperature has been measured as rising 0.02…C per year, and most computer models predict more rain for this area in the future. Some models also predict this rainfall will be even more concentrated in the monsoon season, leaving a drier winter. More serious for this at and crowded land is the threat of sea level rise, currently measured at 3.24mm per year. The problem is not a steadily creeping waterline, but changes in a dynamic energy system, which already bring periodic catastrophies. Lands erode, banks collapse, and siltation is affected. Various studies have already found 85km^2 over 20 years and 200km^2 of land lost over 70 years. Scientists from Jadavpur University have projected nearly 500,000 people will be homeless from coastal erosion in this area by 2020 (Chattopadhyay, 2002; Mukhopadhyay, 2003; World Bank, 2000).

River diversion, in contrast, is already allowing less water to reach the Sundarbans, and it couples with sea level rise to increase salinity. Some of this is natural; deltas are dynamic, and this area s underlying geology has been tilting



The 1999/2000 Landsat image shows very little change to the Sundarbans since 1977. New shrimp farms north of the Sundarbans appear as dark blue.

slightly eastward in recent centuries, leading the Ganges water into its more eastern distributaries. This has cut freshwater ow to the western Sundarbans, to the extent that Indian of cials are acting to stem the loss of the Sundari trees for which the forest is named (Siddiqui, 2003). Since the 1970s, arti cial diversion has accelerated this problem. Siltation in the Hugli River (west of the Sundarbans) was interfering with shipping in Calcutta (visible in the northwest of the satellite images), so the Indian government built the Farakka Barrage, or dam, to divert part of the Ganges into the Hugli. The delta was left with less fresh water and more saltwater intrusion from the sea during the dry season. The dam went into operation in 1975 over objections from Bangladesh, including a protest to the United Nations. Binational negotiations led to an agreement in 1977 to share dry-season water, but Farakka has remained a contentious issue (Beach et al, 2000). India has proposed much larger diversion plans, to link rivers in both Bangladesh and India with giant canals which dwarf the scale of Farakka. Because India lies upstream and surrounds Bangladesh, India controls the freshwater owing into Bangladesh. Impoundment of wet -season water can mitigate dry-season water shortages, but Bangladesh is too at for ef fective reservoirs leaving them dependent on upstream states (Heitzman and Worden, 1989). Bangladesh and India continue negotiating their shared water resources.

Ongoing Concerns

For the Sundarbans, more analysis of the forest as an ecological unit, rather than by legal divisions, may create a clearer picture of its condition. There is an unusual amount of factual confusion and contradiction for this area. Tourism will likely play an increasing role for the Sundarbans and for the Bengal tiger, encouraging local residents away from poaching and toward pro ts from preservation. On the other hand, one of the proposed solutions for the Port of Calcutta is to create a new shipping channel through the Sundarbans, and the natural channels already carry increasing concentrations of industrial wastes. The Sundarbans has been a conservation success; many factors will determine whether this success will continue.

References

Beach, H.L., Hamner, J., Hewitt, J.J., Kaufman, E.,Kurki, A., Oppenheimer, J.A., and Wolf, A.T. (2000) *Transboundary Freshwater Dispute Resolution: Theory, Practice, and Annotated References.* United Nations University Press.

Chattopadhyay, Suhrid Sankar (2002) Sundarbans: An Ecosystem in Peril. India: *Frontline* 19(3) 2-15 February 2002. Available from www.frontlineonnet.com on 22 November 2003.

Chaudhuri, Kisor (2002) The Vanishing Tiger. *The Statesman*, 13 October 2002. West Bengal. Available at www.thestatesman.net/ on 23 November 2003.

Ghosh, Kaushik (2003) Deforestation Plays Havoc with Sunderbans Mangrove. *The Statesman*, 22 April 2003. West Bengal. Available at www.thestatesman.net/ on 23 November 2003.

Heitzman, James and Worden, Robert L. ed. (1989) *Bangladesh: A Country Study*. Library of Congress, Federal Research Division. General Printing Of ce, W ashington.

Hossain, Sheikh M. Nazmul (2003) Assessing Biodiversity Threat in Sundarban Biosphere Reserve Using GIS and Satellite Imagery. Presentation for the ESRI International User Conference, 7-11 July 2003. San Diego, California.

Mukhopadhyay, Sougata (2003) Ecologists Concerned Over Sunderbans Erosion. *The Statesman*, 3 October 2003. West Bengal. Available at www.thestatesman.net/ on 23 November 2003.

Siddiqui, Imran Ahmed (2003) Attempt to Salvage Green Pride in Sunderbans. *The Statesman*, 24 July 2003. West Bengal. Available at www.thestatesman.net/ on 23 November 2003.

World Bank (2000) *Bangladesh: Climate Change and Sustainable Development*. Report No. 21104 BD. South Asia Rural Development Team, World Bank Of ce, Dhaka. Available at wbln0018.worldbank.org/lo+web+sites/bangladesh+Web.nsf/All/ 6DE0A774ACF0365185256A7E006AE31A?OpenDocument on 22 November 2003.

UNEP-WCMC (1987a) Factsheet on Bangladesh s Sundarbans protected areas. Last revised 1990. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK. Available at www.unep-wcmc.org on 23 November 2003.

UNEP-WCMC (1987b) Factsheet on Indian Sundarbans protected areas. Last revised 1990. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK. Available at www.unep-wcmc.org on 23 November 2003.

www.unep.org

United Nations Environment Programme
P.O. Box 30552, Nairobi 00100, Kenya
Tel: (+254) 20 621234
Fax: (+254) 20 623927
E-mail: cpiinfo@unep.org
Web: www.unep.org

UNEP

An analysis of recent and historical satellite imagery collected over the past forty years was carried out for Lake Chad in West Africa, the Sundarbans along the India-Bangladesh border, Papua in Indonesia, the Paranaense Forest around Itaipú Dam and Iguazú Falls at the juncture of Argentina, Brazil and Paraguay, and the Atatürk Dam and the Harran Plain in southeastern Turkey to provide scientific evidence of environmental change taking place in these ecologically significant regions of the world.

While it can be difficult to pinpoint exact causes of change to the environment, the report documents environmental impacts of development, tourism, globalisation, human uses, engineering, climate change and a host of other factors. An analysis of change can provide warnings of potential long-term consequences and suggest what the environment may be in the future. UNEP plays a major role in both environmental assessment and early warning in an effort to promote actions to mitigate some of the unintended consequences to people and their environment.

For further information

Division of Early Warning and Assessment
United Nations Environment Programme
P.O. Box 30552, Nairobi 00100, Kenya
Tel: (+254) 20 624028 Fax: (+254) 20 623943 Email: dewa.director@unep.org
Web: www.unep.org

Job No: DEW/0598/NA