Emerging Environmental Issues 2013

A COMPILATION OF GLOBAL ENVIRONMENTAL ALERT SERVICE BULLETINS

UNEP

ISBN: 978-92-807-3378-5

Job Number: DEW/1763/NA

United Nations Environment Programme
PO Box 30552, Nairobi 00100, Kenya
Tel: +254 20 7621234
Fax: +254 20 7623943/44
http://www.unep.org

For bibliographic and reference purposes this publication should be referred to as:

UNEP (2014), "Emerging Environmental Issues 2013"
Division of Early Warning and Assessment (DEWA)
United Nations Environment Programme (UNEP)
P.O. Box 30552
Nairobi 00100, Kenya

Cover (left to right)—*Top:* Karunakar Rayker/Flickr, Ari Moore/Flickr, Shayan/Flickr (Modified), Wikipedia, Walmart Stores/Flickr; ***Bottom:*** Net_Elek/Flickr, Erin Faulkner/Flickr, P. Casier (CGIAR)/Flickr, Abir Anwar/Flickr

UNEP
promotes environmentally sound
practices globally and in its own activities. This
publication is printed on 100 per cent chlorine free paper
from sustainably managed forests. Our distribution policy
aims to reduce UNEP's carbon footprint.

UNEP'S GLOBAL ENVIRONMENTAL ALERT SERVICE (GEAS)

GEAS is a mechanism for identifying and communicating early warning information on emerging issues in areas ranging from climate change and ecosystem management to environmental governance and resource efficiency. The Global Environmental Alert Service continuously scans the scientific literature, analyses results of earth observations and other data sources to produce alerts on policy relevant environmental hotspots, environmental science, and near real-time environmental hazards. GEAS are widely distributed, reaching up to 300,000 individuals by emails and social media. By taking the pulse of the planet, GEAS enhances UNEP's ability to provide regular, science based environmental updates to its Member States and the international community.

Public awareness on emerging environmental issues is recognized as a critical issue in the Future We Want, the outcome document of the 2012 United Nations Conference on Sustainable Development (Rio +20). However, the process of identifying emerging issues is not always straight forward. The very definition of an emerging issue is subjective. Different methods such as the Foresight process, Delphi method, and Horizon scanning tend to lead to different lists of emerging issues because of varying methodologies and different perspectives of participants.

For the purposes of GEAS, emerging issues are defined as issues that are:

- Critical to the environment. The issue can be either positive or negative but must be environmental in nature, or environmentally-related.
- Have a large impact. Issues should either be global, continental or 'universal' in nature (by 'universal' we mean an issue occurring in many places around the world).
- Recognized as 'emerging' based on newness, which can be the result of new scientific knowledge; new scales or accelerated rates of impact; heightened level of awareness; and, or, new ways to respond to the issue.

Production and Outreach Team

Michelle Anthony
Arshia Chander
Kim Giese
Tejaswi Giri
Lindsey Harriman
Reza Hussain
Erick Litswa
Theuri Mwangi
Charles Sebukeera
Ashbindu Singh
Anna Stabrawa
Zinta Zommers

UNEP Enviromental Themes

Climate Change | Disasters and Conflicts | Ecosystem Management | Environmental Governance | Harmful Substances and Waste | Resource Efficiency

TABLE OF CONTENTS

TABLE OF CONTENTS

WRITERS

Claire Bedelian
University College, London

Braedon Cashion
UNEP/DEWA/LAC- Panama

Ludgarde Coppens
UNEP/DEWA-Nairobi

Lindsey Harriman
UNEP/DEWA/GRID-Sioux Falls

Joseph Muhlhausen
CielMap

Naga Manohar Velpuri and Gabriel Senay
USGS

A. Rozenberg
UNEP/DEWA/GRID-Geneva

Mwangi Theuri
UNEP/DEWA-Nairobi

Martin Walter and Michelle Luebke
UNEP-RONA

ACKNOWLEDGEMENTS

UNEP/DEWA-Nairobi
Ludgarde Coppens
Peter Gilruth
Patrick M'mayi
Neeyati Patel
Ashbindu Singh
Anna Stabrawa
Frank Turyatunga
Kaisa Uusimaa

UNEP/DEWA/GRID-Geneva
Pascal Peduzzi
Ron Witt

UNEP/DTIE
Surya Chandak
Françoise D'Estais
Ben Janse Van Rensburg
Pia Jonsson
Llorenc Mila I Canals
David Piper
Mark Radka
Djaheezah Subratty
Marlyn Van Voore

University of Toronto, Munk School of Global Affairs
Shelley Robertson

UNEP/DEWA-LAC
Charles Davies
Silvia Giada
Andrea Salinas
Lucia Scodanibbio

University of Sheffield, UK
Edward Van-Asch

UNODC
Tim Steele
Joanna Wright

UNEP/ROAP
Thomas Enters
Justin Gosling
Kakuko Nagatani-Yoshid
Max Zieren

Institute of Geographic Sciences and Natural Resources Research, CAS
Dr. Juanle Wang

NASA/Goddard Space Flight Center
Dr. Ritesh Gautam

Chapman University
Dr. Ramesh Singh

UNEP/RONA, Northwestern University and the Institut d'Etudes Politiques de Paris
Justin Gosling
Dmitry Zhdankin

UNEP/DEPI
Tim Christophersen
David Jensen
Andrew Morton

UNEP/WCMC
Maxwell Gomera
Michael Hoffmann

CAB International-Nairobi
Arne Witt

UNEP/DELC
Robert Wabunoha

UNEP/DHI Centre
Peter Bjornsen

UNEP-ROLAC
Andrea Salinas

UNEP-Marine and Coastal Ecosystem Branch
Jacqueline Alder

UNEP/DEWA-ROLAC
Charles Davies
Isabel Martinez
Jordi Pon
Andrea Sabelli

Institut de Recherche pour le Développement (IRD), Bolivia
Bernard Francou

GEOESTUDIOS, Chile
Cedomir Marangunic

Instituto de Geologia y del Medio Ambiente, Universidad Mayor de San Andres, Bolivia
Alvaro Soruco

University of Hohenheim
Joseph Ogutu

Conservation Biologist, Kenya
Zeke Davidson

EXECUTIVE SUMMARY

UNEP's monthly Global Environmental Alert (GEAS) bulletins 'take the pulse of the planet' and widely distribute the findings about environmental events and trends to the public. The science about the state of the planet's health is presented in highly readable language, accompanied by clear graphics and stunning satellite imagery. The bulletins use sound scientific investigation to recognize important environmental trends and connect them to policy by uncovering the links to past human activity and the potential for future action.

This 2013 Emerging Environmental Issues publication presents the 12 monthly bulletins in a single document, allowing readers to note and assess significant environmental events that took place that year. UNEP's GEAS team carefully identified and selected these monthly issues by continuously scanning the scientific literature, focusing on policy relevant environmental hotspots, environmental science, and near real-time environmental hazards. They are organized around UNEP's five themes: environmental governance, harmful substances and hazardous wastes, ecosystem management, climate change, disasters and conflicts, and resource efficiency. Each bulletin acknowledges UNEP's team of authors and provides a full list of the scientific literature referenced.

The bulletins present the issues in an eminently understandable way by organizing the stories around four main questions: Why is this issue important? What are the findings? What are the implications for policy? and What can be done?

January's story is about Transnational Environmental Crime, which refers to a number of common but ill-controlled offences, including the illegal trade in wildlife; illegal logging and its associated timber trade; illegal, unreported and unregulated (IUU) fishing; illegal trade in controlled chemicals (including ozone-depleting substances); the illegal disposal of hazardous waste; and newer environmental crimes such as the illegal trading of carbon and unlawful water management. Globally, such environmental crimes rank among the top ten for their value in illicit markets and more needs to be done to control them.

In February, the bulletin looked at the need for a better way to forecast dust storms and broadcast early warnings to help prevent and mitigate future risks and impacts of these devastating events. This need became evident after a massive dust storm engulfed Sydney, Australia in September 2009. The bulletin presents facts about the harmful impacts of such events and the science behind their occurrence, illustrates the story with impressive satellite images of major recent dust storms, and suggests future steps to improve early-warning systems.

March's bulletin is an overview of the impact of corruption on environmental governance, focusing on emissions trading mechanisms. These regulatory frameworks were set up to achieve the goals to reduce greenhouse gas (GHG) emissions laid out in the 1992 United Nations Framework Convention on Climate Change (UNFCCC). The system quantifies and commodifies GHG emissions to allow them to be exchanged among economic actors. When corrupt actors prioritize private benefits (examples include reselling and misreporting used carbon offsets, theft from national carbon emission registries, and tax fraud) it jeopardizes mitigation efforts and reduces the effectiveness of environmental governance.

In April, the bulletin looked at the aggressive invasion of water hyacinth and how to control it. This plant, native to South America, is now a major weed in more than 50 countries in the world's tropical and subtropical regions and climate change may allow it to spread to higher latitudes. The bulletin shows its destructive impacts on biodiversity and other environmental services, and on humans and their economies. It warns of the need for more intense monitoring, mitigation, and management measures to keep it in check.

Although usually associated with military weapons or surveillance tools, drones can also be low-cost and low-impact ways to manage ecosystems. May's bulletin is about such 'eco-drones' or 'conservation drones'. Because they are very agile and have high-quality imaging abilities, they are being used effectively as mapping tools for monitoring environmental change and providing early warning. A number of challenges and concerns still need to be surmounted, however, including addressing technological capabilities and policy implications.

In June, the bulletin examined how to balance economic development in the transboundary Lake Turkana basin without harming the environment known as the cradle of mankind. The watershed extends into Ethiopia, Kenya, South Sudan, and Uganda. Development activities, such as dam building and irrigation schemes, bring economic opportunities but also affect water levels and distribution. Sharing water can be a cause of conflict, but can also provide opportunities for cooperation. Transboundary agreements or other international arrangements more commonly associated with much larger shared basins would benefit this region if more dams and irrigation schemes are planned.

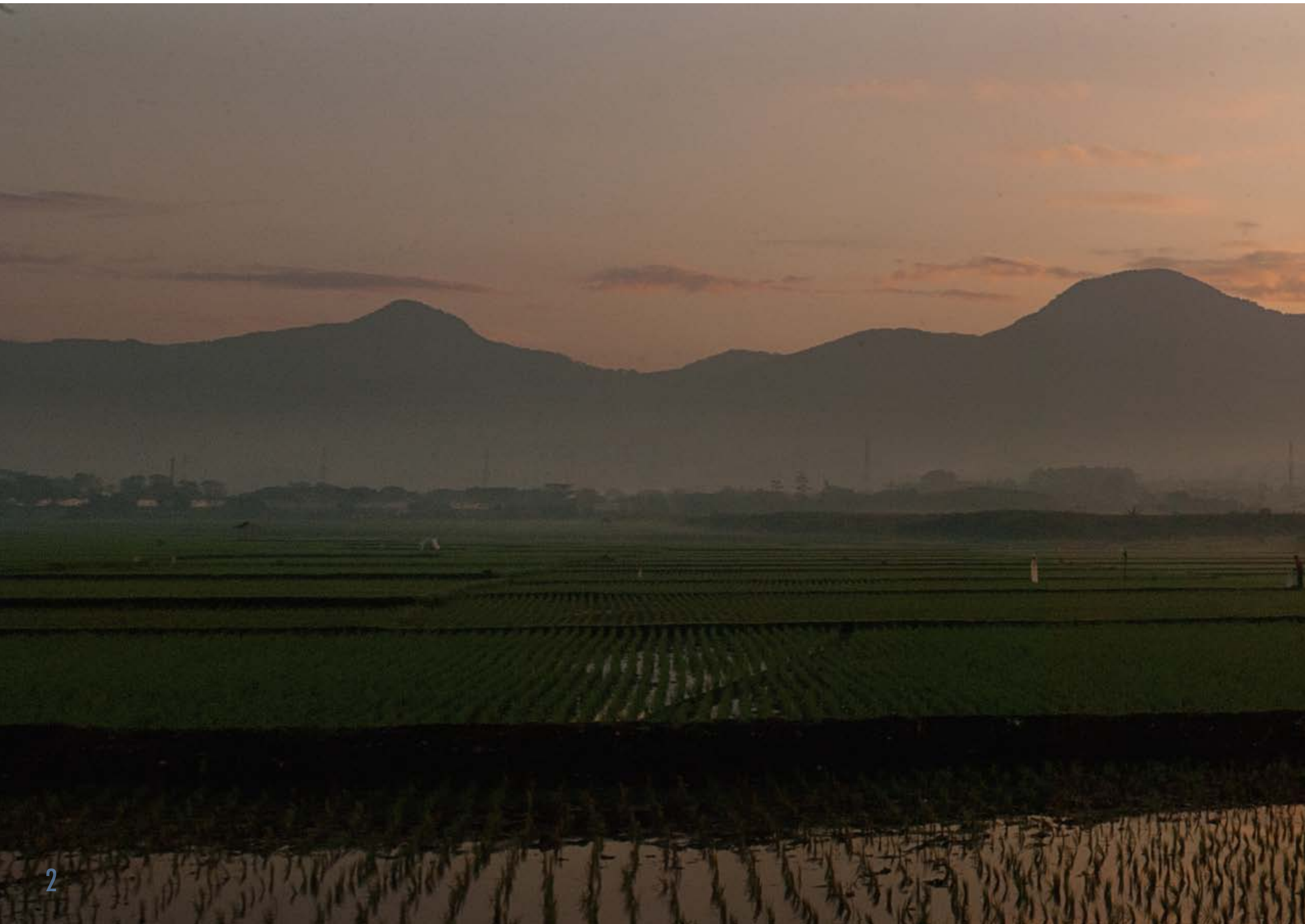
EXECUTIVE SUMMARY

The July issue discusses UNEP's ongoing use of paired satellite images to document environmental change and inform a large audience of its findings. By comparing past and present images of the same place on the planet, its series of Atlases of Our Changing Environment has identified more than 200 'hotspots' of dramatic large-scale environmental change, representing local places in more than 100 countries and on all seven continents. These 'change pairs' also identify 'hopespots', which refer to areas where actions have led to, or are now making positive changes to the local environment. Accompanied by a short storyline and ground photos, these images can ultimately function as a unique decision-support tool.

The August issue warns that despite their global importance, mangroves are being lost rapidly and action is urgently needed to protect them. Mangrove forests are uniquely adapted to the interface between the sea and land. Among their many attributes, they protect coastal areas from tidal waves and cyclones and are among the most carbon-rich forests in the tropics. Their ecosystem services and support for coastal livelihoods worldwide are worth at least US $1.6 billion a year. This bulletin shows the many ways in which these forests are being destroyed and degraded and highlights ongoing and new opportunities to protect them and the communities they support.

Like glaciers around the world, those in the tropical Andes are melting at an accelerated rate. The September bulletin looks at the evidence and impacts of the nexus of melting glaciers, dwindling water resources, and climate change in the region, with examples from Peru. It examines the scientific evidence of accelerated melting and discusses the causes, illustrated with numerous change-pair images. In addressing the issue, it examines the need for climate change modeling and policies, research, and actions towards adaptation and water rights.

The October issue asks: is municipal solid waste garbage or gold? With the world's growing population and increased



consumption, the health and environmental implications of rising volumes of solid waste have become global concerns. On the other hand, a growing solid-waste market, increasing resource scarcity, and the availability of new technologies are offering opportunities for turning waste into a resource. The bulletin provides examples of such solutions from the European Union. It underscores waste management opportunities that will benefit society and the environment, including new energy recovery technologies, and urges countries to make waste management a national priority.

November's issue analyzes early warning and timely actions before Cyclone Phailin in India and concludes that they saved lives when compared to the death toll from past catastrophic cyclones of similar strength. Cyclone Phailin, the strongest to hit India in 14 years, caused hundreds of millions of dollars in damage and affected the livelihoods of 13 million people; effective early warning systems put in place since the catastrophic Cyclone 05B 14 years earlier, however, led to the evacuation of more than a million people. As populations in cyclone-prone areas continue to increase, so does the magnitude of vulnerability to such disasters. The bulletin focuses on the lessons learned, suggesting that effective preparation could help to mitigate or even prevent future disasters.

The last bulletin of the year examines evidence of declining wildebeest populations in East Africa and discusses the issue of saving the phenomenon of the world's Great Migrations. High human population densities, increasing urbanization, expanding agriculture, and more fences are responsible for the loss of wildebeest dispersal areas and migratory corridors. In turn, their decline contributes to biodiversity loss and jeopardizes tourism and other ecosystem services. Urgent efforts are needed to ensure these great migrations persist in the future.

MORNING OVER RICE FIELDS - UANDERMAN / FOTER.COM / CC BY-NC

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
UNEP
Website: www.unep.org/geas E-mail: geas@unep.org

JANUARY 2013

Thematic Focus: Environmental governance

Transnational Environmental Crime: A common crime in need of better enforcement

Why is this issue important?

Environmental crime typically refers to any breach of a national or international environmental law or convention that exists to ensure the conservation and sustainability of the world's environment (Elliot, 2007). Five areas are considered to be of major importance: illegal trade in wildlife; illegal logging and its associated timber trade; illegal, unreported and unregulated (IUU) fishing; illegal trade in controlled chemicals (including ozone-depleting substances); and illegal disposal of hazardous waste. New types of environmental crime are also emerging, for example in carbon trade and water management (Interpol, 2012).

The impacts of illegal trade can be wide-ranging, varying between countries and sectors:

- Illegal logging contributes to deforestation, deprives forest communities of vital livelihoods, causes ecological problems such as flooding and is a major contributor to climate change.
- Illicit trade in ozone depleting substances contributes to a thinning ozone layer, which causes human health problems such as skin cancer and cataracts.
- Illegal fishing leads to direct losses (Gross national product (GNP), foregone revenue); indirect economic losses (income and employment in fisheries and other industries and activities in the supply chain); environmental impacts (unsustainable impacts on target species and the ecosystem itself); and socio-economic impacts (reduction in livelihood and food security) (MRAG, 2010).
- Soil and water contamination from illegal hazardous waste dumping can damage ecosystems and human health and illegal trade undermines the legitimate waste treatment and disposal industries.
- Poaching may have the greatest impact on species survival. For example, rhino, tiger and elephant populations are today threatened with extinction due to poaching and illegal trade driven by growing demand, in particular from Southeast Asia and China (OECD, 2012).


Sokwanele - Zimbabwe / Foter.com . CC BY-NC-SA

Some of the consequences of environmental crime are irreversible. The economic, environmental and health impacts of illegal trade can be sufficiently important to disrupt whole economies and ecosystems, undermining legal and environmentally sustainable activities and reducing future options for the use of resources. There can be spillover effects, with indirect consequences. For instance, in fragile states illegal trade can undermine the rule of law and can fuel armed conflict. Any serious attempt to tackle illegal trade in environmental goods would benefit from a systematic evaluation of the impacts (OECD, 2012).

Dimensions of environmental crime

Though data are scarce and experts are constantly debating the relative merits and weaknesses of every new study, the numbers reflect the potential for huge profits which is the fundamental driver of criminal trade (Haken, 2011). In its report 'Transnational Crime in the Developing World', the non-governmental research and advocacy body "Global Financial Integrity" made an estimate of the economic dimensions of

PHOTO LEFT: SEIZED IVORY SLATED FOR DESTRUCTION - USFWS MOUNTAIN PRAIRIE / FOTER.COM / CC BY

	Global Financial Integrity 2009 (USD)	Havocscope 2012 (USD)
Drugs	$320 billion	$323 billion
Counterfeiting Total	$250 billion	$540 billion
Humans	$31.6 billion	$32 billion
Oil	$10.8 billion	$53.64 billion (gas & oil)
Wildfire	$7.8 to $10 billion	$19 billion
Timber	$7 billion	$30 billion (illegal logging)
Fish	$4.2 to $9.5 billion	$23.5 billion (illegal fishing)
Waste Dumping	No data	$11 billion
Art and Cultural Property	$3.4 to $6.3 billion	$10 billion
Small Arms & Light Weapons	$0.3 to $1 billion	$1 billion

Table 1.1. Rankings for various illicit markets (Haken, 2011; Havocscope, 2012).

transnational crime (Haken, 2011). According to this report, illicit markets for wildlife, timber and fish ranked 5th, 6th and 7th respectively in 2009. Havocscope is a private website which collates information and data on black markets for a wide range of products from various open sources. While estimates between the two vary, as shown in Table 1.1, both have ranked environmental crime in the top ten.

Groups involved in environmental crime

Driven by perceptions of low risk and high profit, indications have emerged of environmental crime activities attracting the greater interest of organized crime groups. Organized criminal syndicates are moving poached or illegally harvested wildlife with the help of the same sophisticated techniques and networks used for illicit trafficking in persons, weapons, drugs and other contraband (Scanlon, 2012). Groups specializing in money laundering, financial crime, thefts and drug trafficking in European Union (EU) Member States are now engaged in environmental crime as well. In general, however, substantial intelligence gaps preclude a comprehensive assessment of organized crime activity in this area (Europol, 2011).

Many of the benefits of globalization, such as easier and faster communication, the movement of finances and international travel, are used by criminal groups to carry out criminal activities. The Internet is used with increasing sophistication to facilitate trade (Europol, 2011).

Results of a research conducted by the UN Office on Drugs and Crime (UNODC) on various forms of environmental crime in Southeast Asia suggest that the criminal networks responsible for wildlife and timber trafficking, as well as the

Left: Florida Fish and Wildlife CC BY-ND 2.0; Tyler Beeney / Flickr / CC BY-NC 2.0; Sokwanele - Zimbabwe/ Foter.com / CC BY-NC-SA. Right: hanje-anwat / Flickr / CC BY 2.0.

smuggling of e-waste and ozone depleting substances, use sophisticated techniques and operate between continents in order to connect cheap supply sources to wealthy markets (UNODC, 2012b).

UNODC, the Governments of Italy and Colombia and the International Criminal Police Organization (INTERPOL) decided in 2010 to jointly develop a Digest of Organized Crime Cases to provide States with a compilation of cases on organized crime accompanied by expert commentary and related good practices (UNODC, 2012a). In one Brazilian case concerning illicit logging in the Amazon Rainforest, the expert stated that the role of the corrupt officials and the professionals (e.g. engineers, topographic experts and other experts) who conspired in the issuance of the authorizations was not confined to mere facilitators in the fraudulent activities. On the contrary, since they were actively pursuing their own personal interests, they were one of the "motors" of the entire criminal scheme, promoting it just as much as the other participants, including the landowners, sawmill owners, transporters and licensed managers of the Forest Projects. The Brazilian expert also noted that environmental crimes are a significant new form of organized criminal activity alongside traditional activities such as drug trafficking.

The criminal conduct in the four cases on environmental crime mentioned in the study adheres to the same structure as in traditional organized crime cases, including a "business model" and the use of modern technologies. The groups' high level of organization requires law enforcement agencies to dedicate significant time and human, financial and technological resources to combat their criminal activities (UNODC, 2012a).

The specific Italian cases of illicit disposal of hazardous or normal waste mentioned in the 2009 report of the Italian National Anti-mafia Directorate involved fraudulent authorizations, which were frequently issued by corrupt officials (UNODC, 2012a). Europol (2011) found that illicit waste trafficking is often facilitated by cooperation with legitimate businesses, including those in the financial services, import/export and metal recycling sectors, and with specialists engaged in document forgery for the acquisition of permits. Lack of harmonization concerning the distinction between waste and second hand goods has resulted in e-waste (second-hand electrical and electronic equipment) and deregistered vehicles in particular being shipped to non- Organisation for Economic Co-operation and Development (OECD) and other states.

Illegal activities flourish when appropriate governance and regulation is lacking, including failures to determine or protect property rights (open access problems), inappropriate or weak regulation and corruption (OECD, 2012). A specific case in point is waste. In addition to the challenges of monitoring and detecting criminal conduct, there are varying definitions or understandings from country to country of what constitutes 'waste', 'hazardous waste' and 'illegal shipments' of hazardous waste. To make things even worse, most developing countries apparently lack an adequate legal framework enabling them to effectively define, prevent and combat illegal traffic (Secretariat Basel Convention, 2012).

BERT VAN DIJK / FLICKR / CC BY-NC-SA 2.0

In general, criminal penalties for environmental crimes are relatively light. Important offences risk being excluded from the categories of organized or serious crimes for which reinforced legal tools and law enforcement resources are usually provided (UNODC, 2012a). In international environmental law, little or no reference is made to sanctions themselves. In cases where provisions concern potential violations of norms or standards, a simple reference can be found to the obligation to punish. Only the Convention on the Law of the Sea prescribes, for a specific type of violation, the application of monetary penalties (ISISC, 2010).

What are the implications for policy?

In 2000 and 2003 respectively, UNODC adopted the UN Convention on Transnational Crime (UNTOC) and the United Nations Convention Against Corruption (UNCAC). These are two important instruments have started drawing attention to the link between environmental crime and corruption. However, resolutions adopted by these treaties only focus on wildlife, timber and forest products, with reference to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Biological Diversity (CBD). The resolutions are contained in the UN Economic and Social Council (ECOSOC) resolutions 2001/12, 2008/25, and 2011/36; and resolution 16/1 (2007) and resolution 20/5 (2011) of the Commission on Crime Prevention and Criminal Justice (CCPCJ).

The fact that wildlife and forest products are explicitly mentioned can be credited to the very active role of the CITES Secretariat to raise awareness of this issue at an international level, including through the creation of the International Consortium on Combating Wildlife Crime (ICCWC) – comprising CITES, INTERPOL, UNODC, the World Bank and the World Customs Organization (WCO).

The Financial Action Task Force (FATF) is an inter-governmental body established in 1989 by the Ministers of its Member jurisdictions. The objectives of the FATF are to set standards and promote effective implementation of legal, regulatory and operational measures for combating money laundering, terrorist financing and other related threats to the integrity of the international financial system. Under the FATF 40 Recommendations (FATF, 2003), the FATF has included environmental crime in the "Designated Categories of Offences" as a predicate offence to money laundering.

Cooperation is taking place between intergovernmental organizations such as UNEP, UNODC, INTERPOL, WCO, CITES and the World Bank, and through the International Consortium on Combating Wildlife Crime (ICCWC). Other partners and environmental Non-Governmental Organisations (NGOs) such as the International Network for Environmental Compliance and Enforcement (INECE), the Environmental Investigation Agency (EIA) and TRAFFIC are also assisting governments in combating environmental crime.

The INTERPOL General Assembly Resolution, resolution AG-2010-RES-03, states that "there is a vital need for a global response to combating environmental crime and INTERPOL should play a leading role in supporting the international enforcement efforts" (INTERPOL General Assembly, 2010). INTERPOL projects offer an interesting perspective on the various areas where criminal law can intervene to protect the environment. These include Project Predator (wild tigers), Project Wisdom (elephants and rhinoceros), Project Leaf (illegal logging and other forest crime) led by INTERPOL and UNEP; and Project Clean (illegal discharge of waste from vessels). A project on Pollution Crime Forensics aims at creating a network of environmental technical and forensic experts, promoting best practices in environmental forensics and compiling them in a manual for distribution. A project on Global E-Waste is intended to design and execute an intelligence-led global analysis of the links between organized crime and the illegal export of e-waste. INTERPOL officially launched its National Environmental Security Task Force (NEST) initiative at the 21st INTERPOL Asian Regional Conference in September 2012. The initiative will establish a common platform and approach worldwide for national compliance and enforcement responses, so as to enhance both national and international efforts on ensuring current and future environmental security.

The World Customs Organization (WCO) continues to work closely with other international organizations involved in environmental issues such as the CITES Secretariat, the Basel Convention Secretariat and UNEP, which maximises joint efforts in the fight against environmental crime (WCO, 2009). Since 2001, the WCO has been an active partner in the Green Customs Initiatives, which is a series of collaborative activities by UNEP, WCO and a number of Multilateral Environmental Agreements (MEAs) to raise awareness to Customs officers about environment crime.

UNODC assists Governments to fight corruption, strengthen law enforcement and support sustainable livelihoods. Most of the initiatives, however, suffer from a lack of donor awareness regarding the magnitude of the problem, and consequently lack adequate funding (UNODC, 2012c).

The concept of intelligence-led enforcement, alongside preventative policing, is gradually being embraced and recent commitments in India and by the international community suggests that a new era of wildlife crime enforcement is being ushered in. The Wildlife Crime Control Bureau (WCCB) of India has collaborated with NGO specialists to deliver actionable intelligence to local forces resulting in seizures, arrests and the disruption of criminal networks at a domestic level (EIA, 2008).

There are signs that consumer markets are finally waking up to the role that demand plays in driving illegal logging. In May 2008, the US Congress amended the 1900 Lacey Act (for the protection of both plants and wildlife through civil and criminal penalties for a wide array of violations) and agreed on a landmark new law that allows prosecutions for violations of foreign law. The amendment makes it an offence to import or sell illegally-harvested timber and wood products in the USA. The European Parliament and European Council have approved a legislation reflected in the Forest Law Enforcement, Governance and Trade (FLEGT) Action Plan of the European Union. The legislation prohibits the sale of timber logged illegally under the rules of the country of origin. In addition, companies must use a system of 'due diligence' to ascertain that the timber they sell in the EU was harvested legally. The Illegal Logging Prohibition Act 2012 in Australia promotes the purchase and sale of legally logged timber products in Australia and gives consumers and businesses greater certainty about the legality of the timber products they buy.

The political declaration from the Twelfth United Nations Congress on Crime Prevention and Criminal Justice, referred to as "Salvador Declaration on Comprehensive Strategies for Global Challenges", acknowledged the challenge posed by emerging forms of crime that have a significant impact on the environment. It encourages Member States to strengthen their national crime prevention and criminal justice legislation, policies and practices in this area and to enhance international cooperation, technical assistance and the sharing of best practices.

What can be done?

In fighting environmental crimes, a strong regulatory regime and effective prevention mechanisms, including anti-corruption measures, may be just as important as criminal law tools. Environmental crime is a haven for corruption at all levels and unless corrupt officials are tackled efforts to combat environmental crime will be impeded - a fact that should be acknowledged within cross-cutting resolutions on environmental crime within the United Nations and within the UN Convention against Corruption (EIA, 2008).

Because of often thematic policy-making at international level, criminal accountability for environmental harms derives from a wide array of norms scattered among a diverse set of treaties that often impose differing, sometimes obscure, standards of protection. For environmental crimes, international criminal law conventions (or a single convention) could be conceived in order to have comparable obligations of criminalization and an extension of criminal jurisdictions ensuring that no safe havens remain for the offenders (ISISC, 2010).

More systematic accounting for the hidden costs of transnational environmental crime, for example loss of current and future revenue resulting from degradation of ecosystem services, or the social and economic costs of floods resulting from extensive illegal logging, as well as the increasingly organized nature of such illegal activities, would help to raise the criminal profile of transnational environmental crimes over their purely environmental dimension.

The EIA stresses the need to encourage the application of existing national criminal laws, proceeds of crime and seizure of assets legislation against environmental criminals in addition to "environmental specific" legislation (EIA, 2008). Administrative reform, particularly through the introduction of technology to remove direct human contact involved in areas such as trade in natural resources, would be another way to combat corruption (EIA, 2008).

International cooperation

Considering the possibility of establishing international jurisdiction for international environmental offences, it is important to reflect on the cooperation of States with the international bodies (ISISC, 2010). One way is to participate in existing international, national and regional environmental crime enforcement units and border liaison offices that would share intelligence with each other in order to develop investigations and operations targeting criminal networks (EIA, 2008). A more coordinated approach where all forms of environmental crime are considered on the same level of importance with, and are integrated in action plans on money laundering and organized transnational crime, is necessary in future.

Acknowledgement

Writer: Ludgarde Coppens[a]

Reviewers: Ron Witt[b] and Djaheezah Subratty[c]

Production and Outreach Team: Arshia Chander[d], Erick Litswa[a], Kim Giese[d], Michelle Anthony[d], Reza Hussain[d], Theuri Mwangi[a], Zinta Zommers[a]

Special thanks to Pia Jonsson[c], Ben Janse Van Rensburg[c], Edward Van-Asch[f], Tim Steele[g], Joanna Wright[g], Kakuko Nagatani-Yoshid[h], Justin Gosling[h] , and Pascal Peduzzi[b] for their valuable input

([a] UNEP/DEWA/Nairobi, [b] UNEP/DEWA/GRID-Geneva,, [c] UNEP/DTIE, [d] UNEP/DEWA/GRID-Sioux Falls, [e] Cites, [f] University of Sheffield, UK, [g] UNODC, [h] UNEP-ROAP)

References

Agnew, D., Pearce, J., Peatman, T., Pitcher, T., Ganapathiraju, P., 2008. The Global Extent of Illegal Fishing. Marine Resources Assessment Group, and Fisheries Ecosystems Restoration Research, Fisheries Centre, University of British Columbia. <http://www.mrag.co.uk/Documents/ExtentGlobalIllegalFishing.pdf> (accessed 23.12.2012).

Agnew, D.J., Walmsley, S.F., Leotte, F., Barnes, C., White, C., Good, S., 2010. West Africa Regional Fisheries Project, Estimation of the cost of illegal fishing in West Africa: Final Report. Marine Resources Assessment Group Ltd. <http://www.mrag.co.uk/Documents/Estimation_of_The_Cost_of_Illegal_Fishing_in_West_Africa_Final_report_20100513.pdf> (accessed 23.12.2012).

CCPCJ, 2007. International cooperation in preventing and combating illicit international trafficking in forest products, including timber, wildlife and other forest biological resources (resolution 16/1). United Nations Commission on Crime Prevention and Criminal Justice. <http://www.unodc.org/documents/commissions/CCPCJ/CCPCJ-ECOSOC/CCPCJ-ECOSOC-00/CCPCJ-ECOSOC-07/Resolution_16-1.pdf> (accessed 21.12.2012).

CCPCJ, 2011. Combating the problem of transnational organized crime committed at sea(resolution 20/5). United Nations Commission on Crime Prevention and Criminal Justice. <http://www.undoc.org /documents/WilflifeandFC/CCPCJ_2011_resolution_20-5_TOC_at_Sea.pdf> (accessed 21.12.2012).

ECOSOC, 2001. Illicit trafficking in protected species of wild flora and Fauna, (resolution 2001/12). United Nations Economic and Social Council, 40th plenary meeting. 24 July 2001. <https://www.unodc.org/documents/WilflifeandFC/ECOSOC_resolution_2001-12.pdf> (accessed 21.12.2012).

ECOSOC, 2008. International cooperation in preventing and combating illicit international trafficking in forest products, including timber, wildlife and other forest biological resources (resolution 2008/25). United Nations Economic and Social Council, 42nd plenary meeting. 24 July 2008. <http://www.unodc.org/documents/WilflifeandFC/resolution_2008-25.pdf> (accessed 21.12.2012).

ECOSOC, 2011. Crime prevention and criminal justice responses against illicit trafficking in endangered species of wild fauna and flora (resolution 2011/36). United Nations Economic and Social Council, 48th plenary meeting. 28 July 2011. <http://www.un.org/en/ecosoc/docs/2011/res%202011.36.pdf> (accessed 21.12.2012).

EIA, 2008. Environmental Crime: A threat to our future. Environmental Investigation Agency. Emmerson Press, UK. <http://www.unodc.org/documents/NGO/EIA_Ecocrime_report_0908_final_draft_low.pdf> (accessed 04.01.2013).

Elliott, L., 2007. Transnational Environmental Crime in the Asia-Pacific: an "un(der)securitized" security problem? The Pacific Review. 20(4), 499–522. <http://dx.doi.org/10.1080/09512740701671995> (accessed 03.01.2013).

Europol, 2011. EU Organised Crime Threat Assessment. Europol Police Office. Europol, The Hague. <https://www.europol.europa.eu/sites/default/files/publications/octa_2011.pdf> (accessed 27.12.2013).

FATF, 2003. Designated Categories of Offences. Financial Action Task Force. <http://www.fatf-gafi.org/media/fatf/documents/FATF%20Standards%20-%2040%20Recommendations%20rc.pdf> (accessed 20.12.2012).

Haken, J., 2011. Transnational Crime in the Developing World. Global Financial Integrity. <http://www.gfintegrity.org> (accessed 27.12.2012).

Havocscope, 2012. Global Black Market Information. Havocscope, LLC. <http://www.havocscope.com/products/ranking/> (accessed 03.01.2013).

ISISC, 2010. The Protection of the Environment through Criminal Law (A/CONF.213/NGO/10). In: Statement submitted by the International Institute of Higher Studies in Criminal Sciences (ISISC) and the International Association of Penal Law, a non-governmental organization in special consultative status with the Economic and Social Council, 12th United Nations Congress on Crime Prevention and Criminal Justice, 12-19 April 2010, Salvador, Brazil. <https://cms.unov.org/llsulinkbase/contenttree.aspx?nodeID=3406> (accessed 23.12.2012)

INTERPOL General Assembly, 2010. Resolution AG-2010-RES-03: Sustainable Environmental Crime Programme. International Criminal Police Organization – INTERPOL General Assembly, 79th Session. 11-18 November 2010, Doha. <http://www.interpol.int/content/download/4393/40084/version/4/file/AGN79RES03[1].pdf> (accessed 27.12.2012).

INTERPOL, 2012. Environmental Crime. International Criminal Police Organization - INTERPOL. <http://www.interpol.int/Crime-areas/Environmental-crime/Environmental-crime> (accessed 27.12.2012).

OECD, 2012. Illegal Trade in Environmentally Sensitive Goods. OECD Trade Policy Studies. <http://dx.doi.org/10.1787/9789264174238-en> (accessed 04.01.2013).

Scanlon, J., 2012. Ivory and Insecurity: The Global Implications of Poaching in Africa. CITES. http://www.cites.org/eng/news/SG/2012/20120525_SG_US-Senate_testimony.php (accessed 04.01.2013).

SBC, 2012. Vital Waste Graphics. Secretariat of the Basel Convention International Environment House. <http://archive.basel.int/pub/pub.html> (accessed 23.12.2012).

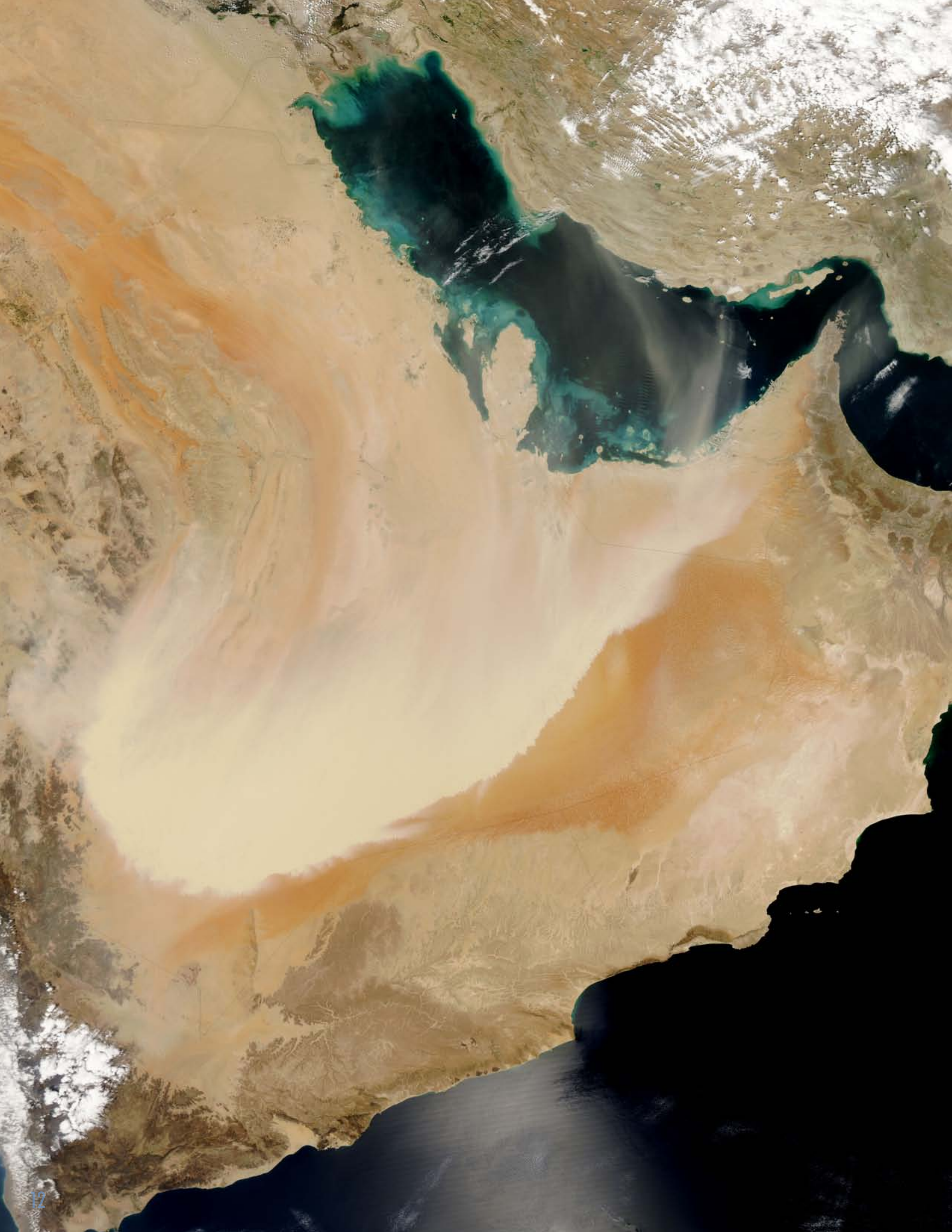
UN General Assembly, 2010. Salvador Declaration on Comprehensive Strategies for Global Challenges: Crime Prevention and Criminal Justice Systems and Their Development in a Changing World (A/RES/65/230). 21 December 2010. <http://www.unodc.org/documents/crime-congress/12th-Crime-Congress/Documents/Salvador_Declaration/Salvador_Declaration_E.pdf> (accessed 20.12.2012).

UNODC, 2012a. Digest of organised crime cases: A compilation of cases with commentaries and lessons learned. United Nations Office on Drugs and Crime, Vienna. <http://www.unodc.org/documents/organized-crime/EnglishDigest_Final301012_30102012.pdf> (accessed 20.12.2012).

UNODC, 2012b. Report of the Secretariat on technical assistance provided to States in the application of the United Nations Convention against Transnational Organized Crime to new forms and dimensions of transnational organized crime (CTOC/COP/2012/7). Conference of the Parties to the United Nations Convention against Transnational Organized Crime, 6th Session, 15-19 October 2012, Vienna, Austria. <http://www.unodc.org/unodc/treaties/CTOC/CTOC-COP-session6.html> (accessed 20.12.2012).

UNODC, 2012c. Report of the Secretariat on activities of the United Nations Office on Drugs and Crime to promote the implementation of the provisions on international cooperation in the United Nations Convention against Transnational Organized Crime (CTOC/COP/2012/9). Conference of the Parties to the United Nations Convention against Transnational Organized Crime, 6th Session, 15-19 October 2012, Vienna, Austria. <http://www.unodc.org/unodc/treaties/CTOC/CTOC-COP-session6.html> (accessed 20.12.2012).

WCO, 2009. Operation Demeter: tracking illegal shipments of hazardous waste, in: Maiano, D. (Ed.), WCO News Number 60. WCO, Brussels. pp. 11. <http://www.wcoomd.org/en/media/wco-news-magazine/~/media/34CD9FC5CE224094859848D108CB4EE3.ashx> (accessed 20.12.2012).



UNEP

FEBRUARY 2013

Thematic Focus: Harmful substances and hazardous wastes, Ecosystem management

Forecasting and early warning of dust storms

Why is this issue important?

Soon after a massive dust storm engulfed Sydney, Australia in September 2009, the worst the city had experienced since 1940 (Leys et al., 2011), a call was made for the development of more early warning systems to be able to predict these devastating events in the future (UN, 2009). The city was covered in dust for nine hours and suffered disruption to communications, daily activities, car and air traffic, and reduced visibility to 0.4 km (Leys et al., 2011). Impacts such as these can be quite common during a dust event and can result in great costs. Other impacts can include the deposition of foreign sediments causing cropland to suffer; compromised air quality and human health when dust particles remain suspended in the atmosphere; and reduced efficiency of renewable energy sources when dust interferes with their mechanics. Suspended dust particles can alter the atmospheric radiation balance and contribute to climatic variations (Du et al., 2002) such as alteration of regional monsoon patterns or the acceleration of glacial melt (Gautam et al., 2010). Dust storms can have high interannual, as well as annual and decadal, variability, thus it is important that more research is conducted over longer periods of time to analyze trends and associated storm severity (Ganor et al., 2010; Goudie, 2009). With increased information about long term trends, more accurate forecasts of dust storm movements can be developed, the appropriate efforts to mitigate damage can be put into place and effective early warning can be communicated.

What are the findings?

What causes a dust storm?

When high winds at a threshold speed (Table 2.1) blow over areas with minimal vegetation cover, soils that lack snow and/or soil moisture content (NRL, 2009), or soils that are vulnerable to surface disturbance (Wilcox, 2012) a dust storm has the potential to occur. Other types of areas that can also be vulnerable to a dust storms when threshold winds are present are areas in which soils have dried out and displaced after a flash flooding event (UCAR/COMET, 2010) or areas with dried out lakebed sediments.

WESTERN SAHARA PROJECT / FLICKR / CC BY-NC-ND 2.0

Desert soils are naturally resistant to wind erosion because they form a thin cohesive surface crust that helps to keep the soils intact. The crust is most prevalent in areas between plants because they help to stabilize and protect soil from wind and can trap suspended soil particles (Urban et al., 2009; Steenburgh et al., 2012; Wilcox, 2012). When the crust is disturbed or there is a reduction in vegetation cover, the risk of a dust storm occurrence is increased as the loosened

Wind speed thresholds for different desert environments	
Environment	Threshold wind speed
Fine to medium sand in areas with sand dunes	16 to 24.1 kmph
Sandy areas with poorly developed desert pavement	32.2 kmph
Fine material in desert flats	32.3 to 40.2 kmph
Dry lake beds and/or crusted salt flats	48.3 to 56.3 kmph
Well-developed desert pavement	64.4 kmph

Table 2.1. Wind speed thresholds for different desert environments. Wind speed threshold refers to the minimum wind speed required to lift suspended sediment in a certain environment (UCAR/COMET, 2010).

PHOTO LEFT: DUST STORM IN SAUDI ARABIA - NASA GODDARD PHOTO AND VIDEO / FOTER.COM / CC BY

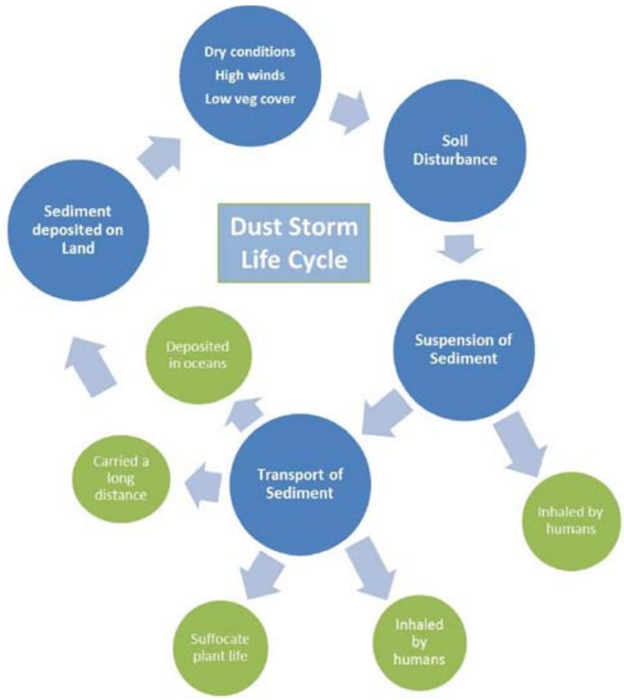


Figure 2.1. Dust Storm Life Cycle. This simplified diagram of the life cycle of a dust storm and its impacts illustrate how a dust storm can fuel itself.

sediments are free to be picked up by high winds. Land degrading events such as overgrazing of livestock and clearing of land for agricultural or infrastructure development are common sources of soil disturbance. Dust and sand from storm events can also bury crops blocking sunlight and damaging plant tissue, thus inhibiting future growth (Sivakumar, 2005). If crops do not recover from such an event, then the resulting barren field becomes fuel for the next dust storm. A brief life cycle of a dust storm, and how one can fuel itself, is described in Figure 2.1.

Where and when do dust storms occur?

The primary dust producing regions on earth are classified as some type of a desert with minimal saturation as indicated by a high erodible fraction value (Figure 2.2). These regions are the Sahara Desert, the Middle East (Figure 2.3), the Taklamakan Desert in northwest China, southwest Asia, central Australia, the Etosha and Mkgadikgadi basins of southern Africa, the Salar de Uyuni (Bolivia) and the Great Basin (USA) (NRL, 2009; Washington et al., 2003). Topographically, most of these regions encompass a large basin with an internal drainage system and are prone to high winds that facilitate dust mobilisation (Washington et al., 2003). Dust storms can occur on less than 40 days a year such as in the United States (NCDC/NOAA, 2012) or on more than 100 days a year such as in parts of Mongolia (Dagvadorj et al., 2009). Dust storms from around the world emit an estimated 1000 to 3000 teragrams per year (Tg/year) of dust into the atmosphere; the Sahara Desert region is the single largest contributing region with estimated dust emissions of 500 to 1000 Tg/yr (Goudie, 2009).

Some regions are continual dust producers year round, but dust intensity in other regions is influenced by seasonal

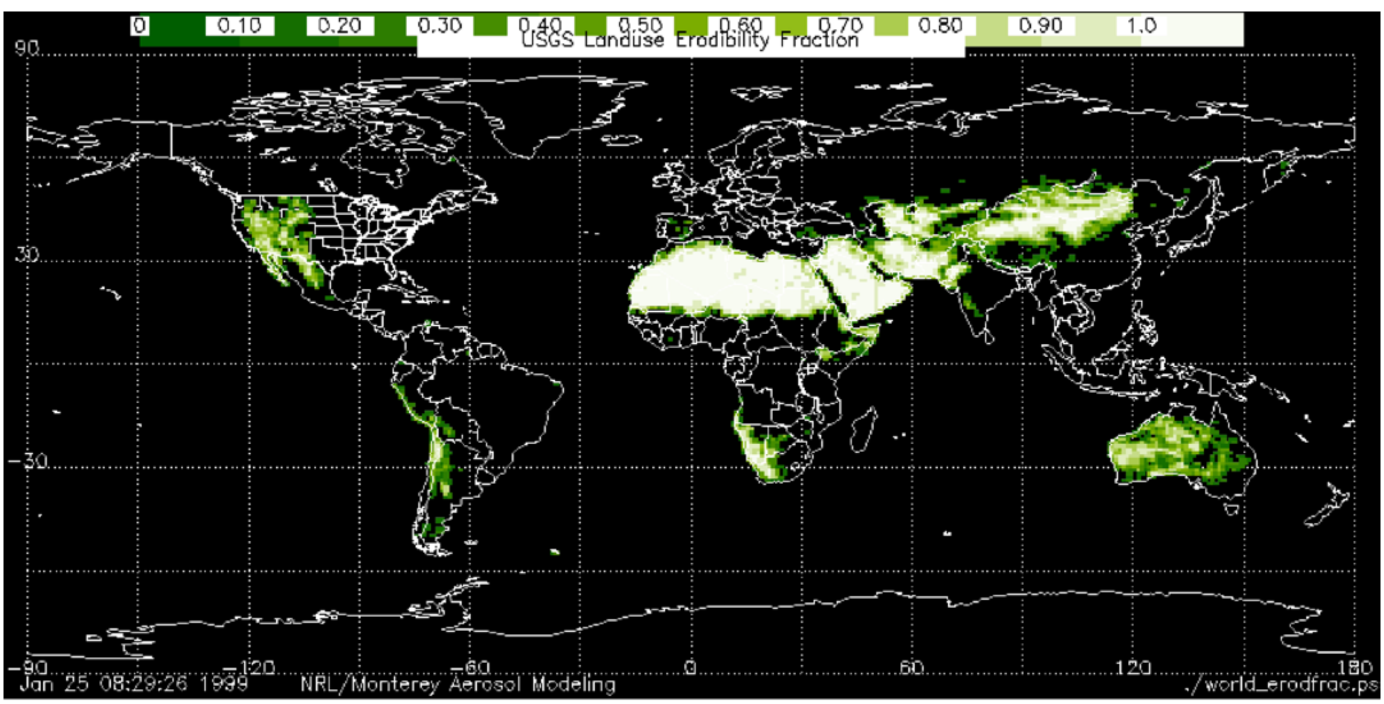


Figure 2.2. Historically regarded global dust producing regions (NRL 2009). Highlighted areas represent regions with a higher erodible fraction, a value that considers land cover type and the associated wetness value of the area.

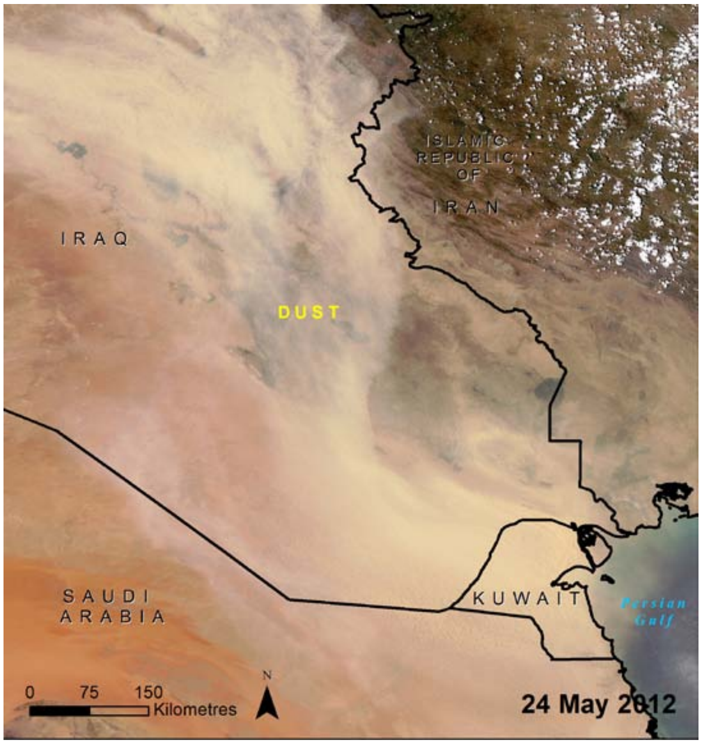


Figure 2.3. Dust blowing south from Syria over Iraq, Kuwait, and slightly clouding the Persian Gulf. Image acquired on 24 May 2012 by the Moderate Resolution Imaging Spectrometer (MODIS) on NASA'a Aqua satellite (image courtesy Jeff Schmaltz in Scott 2012b; visualisation by UNEP/DEWA/GRID-Sioux Falls).

changes. Large scale seasonal weather systems such as El Niño or La Niña or smaller regional patterns such as an influx of rainfall or excessive snowmelt can influence the severity of dust events. One way of identifying seasonal fluctuations in dust concentration is by looking at the global aerosol index (Figure 2.4). The aerosol index (AI) is a measurement of absorbing aerosol particles such as dust and smoke and is commonly used to identify dust source areas (NRL, 2009; Washington et al., 2003). The AI is obtained using NASA's Ozone Monitoring Instrument (OMI) on NASA's Earth Observing Satellite Aura (NASA, n.d). For example, the image from 1 April 2012 shows evidence that the aerosol index is much higher in India and East Asia during its spring season than in any other season.

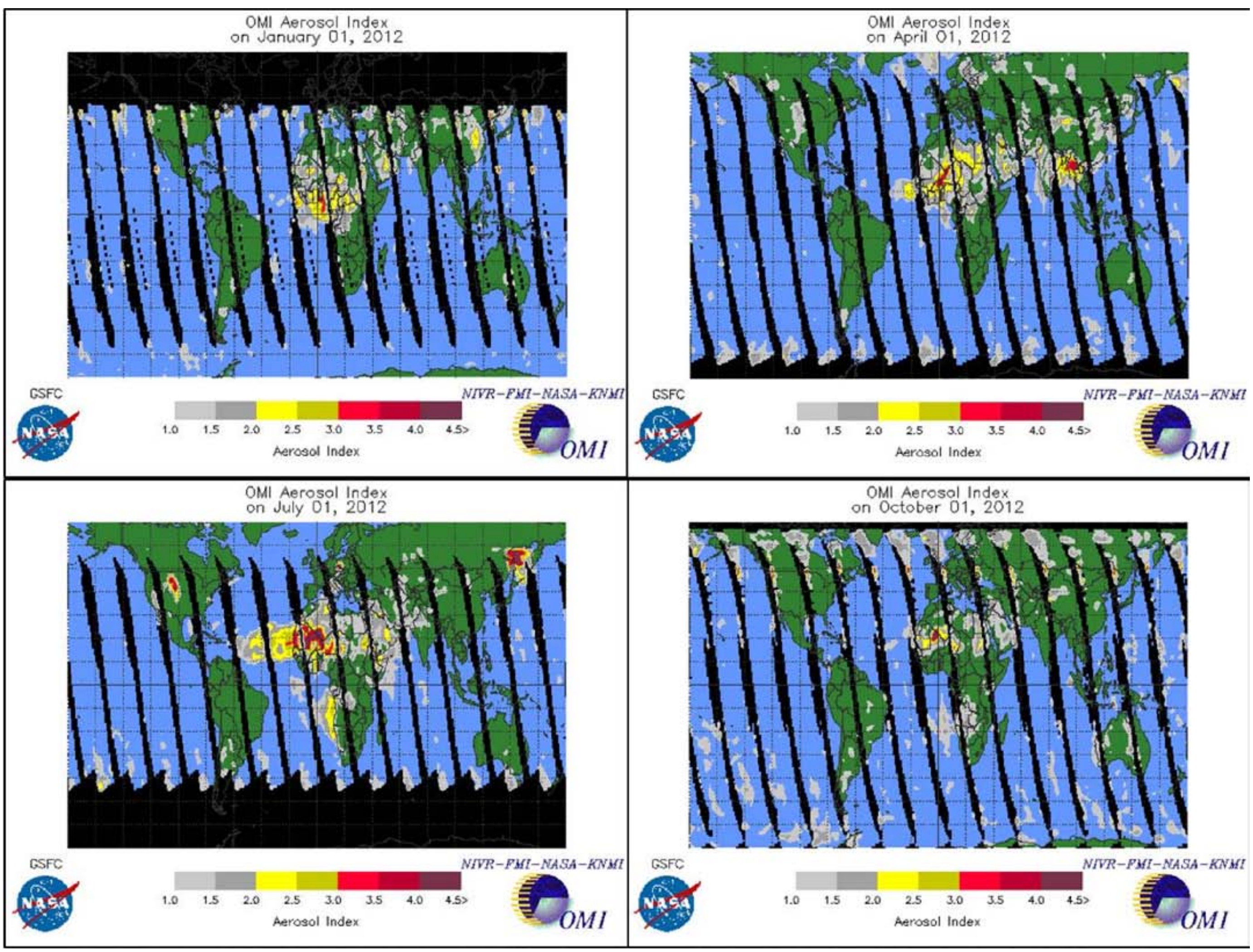


Figure 2.4. Global OMI Aerosol Index images from 1 January 2012, 1 April 2012, 1 July 2012 and 1 October 2012 (NASA, 2012b).

Intensity over India decreases by July, which coincides with its monsoon season that brings air-clearing rains (Gautam et al., 2012).

What are the implications for policy?

Travelling dust: a transboundary issue

A dust storm can not only impact the area surrounding its origin, but can also impact land and people a great distance away where the dust finally settles. Trade winds can carry dust originating in the Sahara Desert north to Spain and the United Kingdom as well as across the Atlantic Ocean to the east coast of the United States of America (USA), Central America, and South America. Several countries surrounding the Arabian Gulf transport dust across the Gulf at various times of the year (Figure 2.5). Dust originating in inner and southern Mongolia and northern China can be carried to Japan, the Democratic People's Republic of Korea (DPRK), the Republic of Korea and the Taiwan Province of China causing yellow sands and muddy rains (Lee and Liu, 2004; Kimura, 2012a; Kimura, 2012b). Dust storms originating in eastern Australian have been known to settle across the Tasman Sea in New Zealand (Marx et al., 2009). herefore, many countries or entire regions may be affected and this can cause difficulty when creating policies pertaining to dust storm mitigation (i.e. vegetation restoration efforts) or early warning communication. These transboundary movements can pose challenges when formulating policies pertaining to dust storm mitigation (i.e. vegetation restoration efforts) or early warning communication.

Long distance travel of dust from the Sahara Desert

A dust storm originating in the Sahara Desert blew over the Canary Islands and the Atlantic Ocean on 25 June 2012 (Figure 2.6). This dust storm persisted for several days and reportedly travelled as far north as the United Kingdom by 28 June where it covered cars and other surfaces with a thin layer of dust (Met Office, 2012). The corresponding global aerosol index image for 25 June 2012 (Figure 2.7) provides

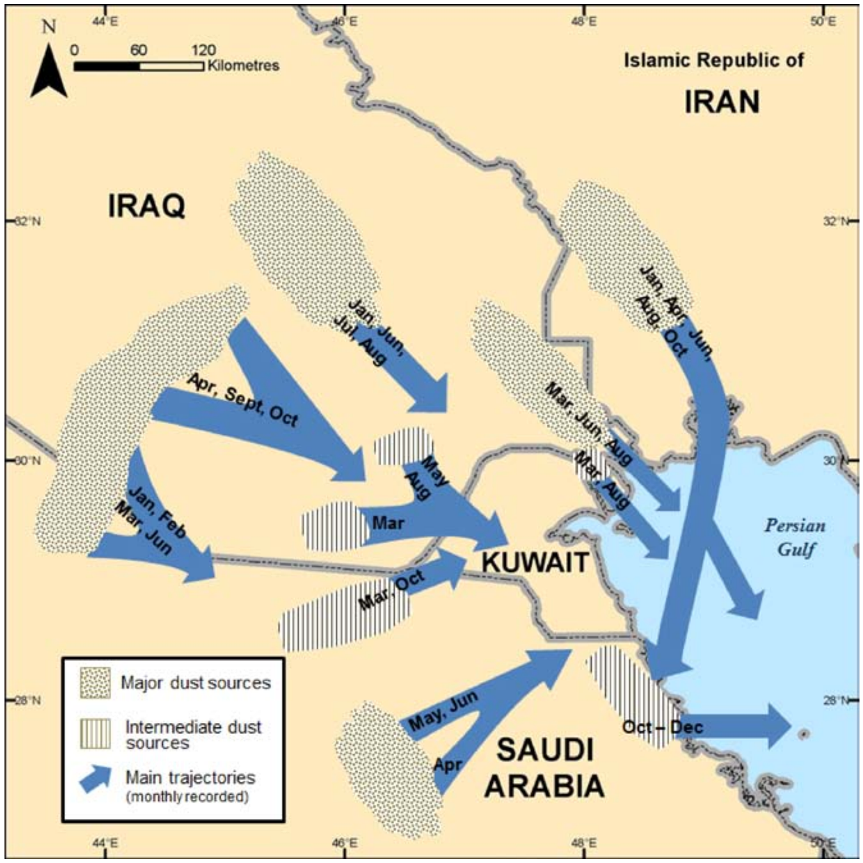


Figure 2.5. Major and intermediate sources of dust and their corresponding trajectories over areas northwest of the Arabian Gulf (Al-Dousari and Al-Awadhi, 2012).

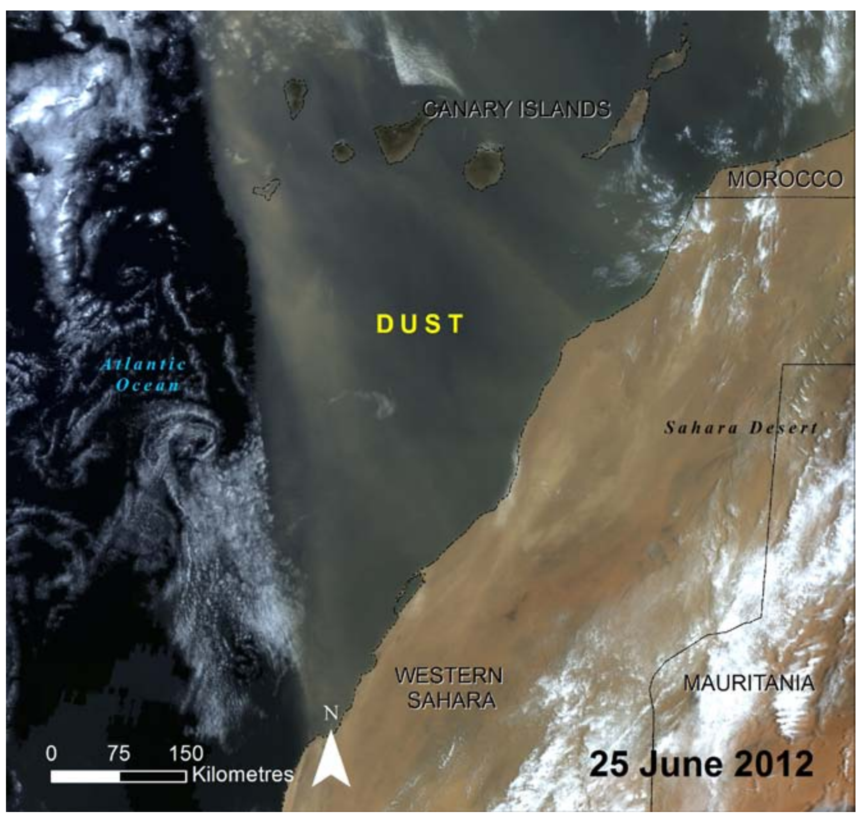


Figure 2.6. Dust from the Sahara Desert blowing over the Atlantic Ocean and the Canary Islands. Image acquired on 25 June 2012 by MODIS on NASA's Terra satellite (NASA image; visualisation by UNEP/DEWA/GRID-Sioux Falls).

insight as to how much of a wider region may also have been affected by dust in the atmosphere.

Yellow Sands in Japan

Each spring Japan is plagued with "yellow sands" as a result of dust storms that originate in northeast Asia, notably the Taklamakan Desert and Loess Plateau in China and the Gobi Desert in southern Mongolia, and Inner Mongolia (Lee and Liu, 2004; NASA, 2012a; Kimura, 2012b; Onishi et al., 2012). Evidence of dust being carried over the Sea of Japan is presented in Figure 2.8. Yellow sand dust storms create an array of problems for Japan such as decreased visibility, presence of soil-derived and anthropogenic metals when transported with dust (Onishi et al., 2012), and decreased agricultural activity conducted in glass houses since dust prevents adequate UV light from reaching crops and plants (Taylor, 2002; Kimura, 2012b). These storms have also been reportedly responsible for worsened symptoms in asthmatics, heightened cases of respiratory issues and meningitis, instances of skin irritation, and widespread distribution of fungi (Otani et al., 2011; Shi et al., 2005; Zhou et al., 2008).

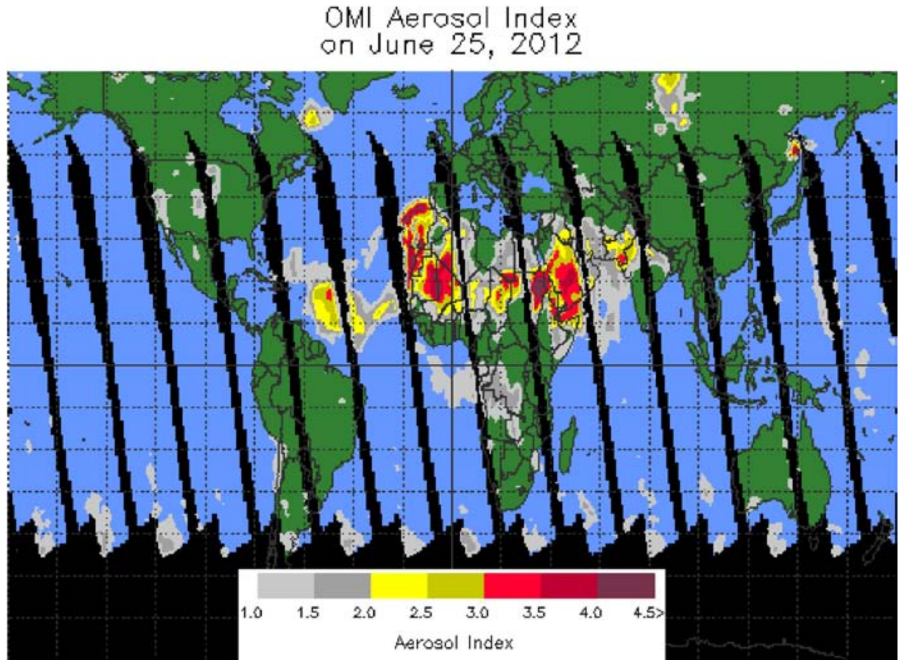


Figure 2.7. Global OMI Aerosol Index Image from 25 June 2012 (NASA, 2012b).

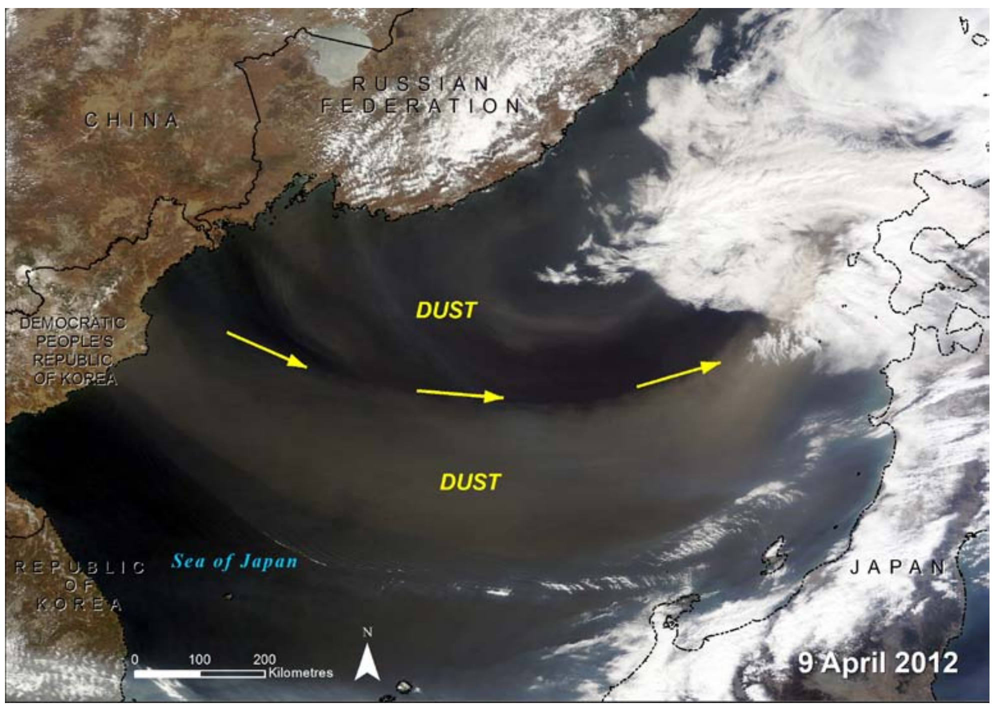


Figure 2.8. Fine yellow dust from Inner Mongolia blew over China, the Democratic People's Republic of Korea, the Russian Federation, Japan and blanketed the Sea of Japan (NASA, 2012a). Image acquired on 9 April 2012 by MODIS on NASA's Terra satellite (image courtesy Jeff Schmaltz (NASA, 2012a); visualisation by UNEP/DEWA/GRID-Sioux Falls).

What can be done?

Early warning systems create the opportunity to not only communicate a severe event, but also its anticipated impact, cost of impact and the overall level of uncertainty. With early warning people could better prepare for a dust storm by taking cover, sealing doors and windows, vacating the streets thus preventing car accidents and securing outdoor assets such as vehicles and manufacturing equipment. Farmers would be able to bring in livestock, farm equipment and, depending on how early the warning is provided, they could harvest all or a portion of a crop before the onset of a storm (Stefanski and Sivakumar, 2009). In the long term, farmers can decide if preventative physical structures such as shelterbelts and windbreaks would be beneficial for their farms.

A significant part of early warning is an accurate and thorough forecast. Forecasts enable scientists and others to observe how dust storms are forming and moving over space and time. Policymakers can also use this information to determine whether or not disease outbreaks were the result of transported sand and dust or the result of human transport when taking action against health risks (Stefanski and Sivakumar, 2009; UN, 2009). A sampling of institutions and organisations from around the world that offer some forecast or warning support are listed in Table 2.2. Most of these organisations or institutions provide free access to the forecasts via their websites, but others charge for access.

The use of forecasting networks

Due to the highly mobile nature of dust, global networks of forecasting systems are necessary to help predict the onset, duration and path of a dust storm for the protection of both humans and the environment. Since 2007, the World Meteorological Organisation (WMO) has operated a collaborative network of 15 organisations with several different forecasting models for comparison and analysis called the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS). Dust forecasting resources are available for four regions divided into two nodes: one node for Africa, the Middle East, and Europe and another node for Asia. The SDS-WAS has enabled WMO associated scientists and partner organisations to better understand dust processes and develop a societal benefit of early warning for dust storms (WMO, n.d.). A collaborative network creates a central resource location for scientists, the public and other interested parties.

Institutions and organisations with dust forecasting programmes		
Name	Location	Coverage
Japan Meteorological Society	Japan	East Asia, Central Pacific
Met Office, UK	UK	Global
The Meteorological State Agency of Spain (AEMET) and Barcelona Supercomputing Centre	Spain	North Africa, Midle East, Europe, Asia
Centre for Atmosphere Watch and Services (CAWAS), Chinese Meteorological Agency	China	East Asia, Central Pacific
University of Athens	Greece	Middle East, Mediterranean, Europe, North Africa and Atlantic Ocean; Saudi Arabia for Arabian Peninsula, North Africa, Middle East and SW Asia
Korean Meteorological Administration	Republic of Korea	East Asia
University of Tel Aviv	Israel	North Africa, Middle East, Europe
Naval Research Laboratory	Monterey, California, USA	Global
Research Institute for Applied Mechanics, Kyushu University in cooperation with the National Institute for Environmental Studies (NIES)	Japan	East Asia, Central Pacific
Laboratoire de Météorologie Dynamique	Paris, France	Africa, Europe, Atlantic, Central Asia
European Center for Medium range Weather Forecasting (ECMWF)	UK	Global
World Meteorological Organization (WMO)	Switzerland	Global network of regional models

Table 2.2. Institutions and Organisations with Dust Forecasting Programmes (WMO, 2011). Please note that this is not a comprehensive list. Find more information here: http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Organizations_delivering_SDS_forecasts.pdf.

Regional forecasting model: CUACE/Dust

China has been monitoring dust storm events since the 1950's as a part of routine weather monitoring (Wang et al., 2008). The CUACE/Dust (Chinese Unified Atmospheric Chemistry Environment for Dust) model is an integral part of a real-time mesoscale sand and dust storm forecasting system for eastern Asia. The system is capable of producing 24-hour, 48-hour, and 72-hour forecasts from the model. In addition to meteorological data and dust aerosol conditions, the CUACE/Dust model also incorporates information about the distribution of deserts and semi-deserts, soil grain size, soil moisture content, snow cover, land use and surface roughness length (Zhou et al., 2008). Identifying and analysing these factors allows scientists to make more educated assumptions about how land will be affected if a dust storm were to occur. In addition, the aerosol module that is used with CUACE/Dust can differentiate the size of suspended particles (Zhou et al., 2008). From this information analysts are able to make inferences about transport distance; fine particles remain suspended in the atmosphere longer and can travel farther than coarse particles. The CUACE/Dust model has been acknowledged as a suitable model for sand and dust storm events in East Asia (Wang et al., 2008) and is included as forecast model in the Asia node of the WMO SDS-WAS.

Global forecasting model: BSC-DREAM8b

Forecasting models with near global coverage such as the Barcelona Supercomputing Centre–Dust REgional Atmospheric Model 8b v2.0 (BSC-DREAM8b) are able to provide forecasts of the atmospheric life cycle of dust particles originating from deserts (BSC, 2012). This particular model has the ability to offer animated cycles of forecasts in six hour intervals from real time to 72 hours in the future, for four substantial dust producing regions in the world (Figure 2.9). Forecasts such as BSC-DREAM8b help to not only identify a storm in a local area, but also help to project movement of the storm across large geographic expanses over a period of several days.

Early Warning Systems: how is the information delivered?

A forecast contributes to early warning, but can only provide a real "warning" if it is properly communicated. As with most other severe weather or natural hazard events, dust storm warnings appear to be most widely provided via national or regional weather services (Davidson et al., 2003), spreading the word through television, internet, radio, and newspapers. Both the Korea Meteorological Administration (KMA) and the National Weather Service (NWS) in the USA provide dust storm warning information to some cell phone providers which then communicate the information to subscribers via text message (NEMA, 2006; NOAA, 2012). The KMA has provided text message alerts since at least 2006 and the USA just began this system in the summer of 2012 as a part of severe weather alert initiative. Although a text message alert system may not work in every nation as the wireless network would have to be quite robust, it is a good model for how to quickly distribute easy to understand information to a large population. Another example of an early warning platform that updates frequently is a website hosted by the National Centre of Meteorology and Seismology in the United Arab Emirates. The website updates warnings every three hours providing information about dust conditions and visibility to the public and local media sources (NCMS, 2013). The website cautions citizens to be aware, prepared, or to take action depending on the severity of the conditions. While early warning systems such as these exist, there appears to be a lack of literature or research gauging the depth and effectiveness of such systems.

Where do we go from here?

Many studies report that continued research using meteorological data, satellite imagery, and remote sensing information is needed to further examine the following aspects concerning dust storms and forecasting (Stefanski and Sivakumar, 2009; Urban et al., 2009; Kimura, 2012b):

- Increase the accuracy and length of forecasts through improved models and ground station monitoring
- Determine and refine seasonal and climatic trends including implications of climate change
- Refine dust source areas by considering geomorphological characteristics of the land such as topography, glacial presence and particle composition (Wang et al., 2008)
- Determine the effectiveness of re-vegetation projects in reducing the occurrence of a dust storm (i.e. Grain to Green Program in China) (Kimura, 2012a)
- Increase quantity and geographical spread of air quality monitoring stations to improve the ability to determine where a dust storm originates (Leys et al., 2011; Wang et al., 2008)
- Continue studies evaluating dust implications on health, especially in West Africa and the Middle East where studies are scarce (de Longueville et al., 2013; Thalib and Al-Taiar, 2012)

In addition to continued and enhanced research, a mechanism for creating, supporting and operating successful early warning systems is necessary to communicate research findings. While the current early warning networks and systems have a wealth of information to provide, it may not be easily understood by a wide variety of audiences. There is a demonstrated need in the following areas:

- Increased education and awareness to promote the information and forecasts that are publically and freely available
- Establishment of appropriate communication channels for the dissemination of interpreted dust forecasts at a frequency that enables preparedness (i.e. through weather news networks, text message alerts)
- Development of policies and practices regarding land use, development, desertification and any other risk increasing activity to attempt to mitigate the inception of a dust storm
- A metric for measuring and evaluating aid and risk reduction activities so future improvements can be made if warranted

In conclusion, as changes in land cover and the global climate continue to occur, early detection and warning of dust storms in conjunction with effective and widespread information broadcasts will be essential to the prevention and mitigation of future risks and impacts.

Acknowledgement

Writer: Lindsey Harriman[a]

Reviewers: Arshia Chander[a], Ron Witt[b], Ashbindu Singh[a,c], Neeyati Patel[c], Theuri Mwangi[c], Zinta Zommers[c]

Special thanks to Dr. Juanle Wang[d], Dr. Ali Al-Dousari[e], Dr. Ritesh Gautam[f], and Dr. Ramesh Singh[g] for comments and reference suggestions

Production and Outreach Team: Erick Litswa[c], Kim Giese[a], Michelle Anthony[a], Reza Hussain[a], Theuri Mwangi[c],

([a] UNEP/DEWA/GRID-Sioux Falls, [b] UNEP/DEWA/GRID-Geneva, [c] UNEP/DEWA Nairobi, [d] Institute of Geographic Sciences and Natural Resources Research, CAS, [e] Kuwait Institute for Scientific Research, [f] NASA/Goddard Space Flight Center, [g] Chapman University)

References

Al-Dousari, A. M , Al-Awadhi, J., 2012. Dust fallout characteristics within global dust storms major trajectories. Arabian Journal of Geosciences, doi:10.1007/s1257-012-0644-0.

BSC, 2012. BSC-DREAM8b v2.0 Atmospheric Dust Forecast System. Barcelona Supercomputing Center Earth Sciences. http://www.bsc.es/projects/earthscience/BSC-DREAM/ (accessed 01.11.12).

Dagvadorj, D., Natsagdorj, L., Dorjpurev, J., Namkhainyam, B., Gomboluudev, P., Batimaa, P., Jugder, D., Mijiddorj, R., Davaa, G., Erdenetsetseg, B., Khaulenbek, 2009. Climate Change Observation and Research in Mongolia, in: D. Dagvadorj, B. Khuldorj, R. Aldover (Eds.), Mongolia Assessment Report on Climate Change 2009. Ministry of Environment, Nature and Tourism, Mongolia, Ulaanbaatar, pp. 32 – 57.

Davidson, J., Lam, H., Lam, C.Y., Wass, S., Dupuy, C., Chavaux, F., 2003. Guidelines on Cross-Border Exchange of Warnings, H. Kootval (Ed.). World Meteorological Organization, Available at: http://www.wmo.int/pages/prog/amp/pwsp/pdf/TD-1179.pdf.

de Longueville, F., Ozer, P., Doumbia, S., Henry, S., 2013. Desert dust impacts on human health: An alarming worldwide reality and a need for studies in West Africa. International Journal of Biometeorology 57(1), 1 – 19.

Du, M., Seiichiro, Y., Shen, Z., Shen, Y., Wang, W., and Maki, T., 2002. Wind Erosion Processes during Dust Storm in Dunhuang, China. In the Editorial Committee (Ed.d), Proceedings 12th International Soil Conservation Organization Conference – Dynamic Monitoring, Forecasting and Evaluation of Soil Erosion Watershed Management and Development Desertification Control. Tsinghua University, China, pp. 624 – 629.

Ganor, E. Osetinksy, I., Stupp, A., Pinhas, A., 2010. Increasing trend of African dust, over 49 years, in the eastern Mediterranean. Journal of Geophysical Research: Atmospheres, 115, D07201, doi:10.1029/2009JD012500.

Gautam, R., Hsu, N.C., Lau, K-M., 2010. Premonsoon aerosol characterization and radiative effects over the Indo-Gangetic Plains: Implications for regional climate warming. Journal of Geophysical Research. 115, D17208.

Goudie, A.S., 2009. Dust storms: Recent Developments. Journal of Environmental Management. 90, 89 – 94.

Kimura, R., 2012a. Effect of the Strong Wind and Land Cover in Dust Source Regions on the Asian Dust Event over Japan from 2000 to 2011. Scientific Online Letters on the Atmosphere. 8, 77 – 80.

Kimura, R., 2012b. Factors contributing to dust storms in source regions producing the yellow-sand phenomena observed in Japan from 1993 to 2002. Journal of Arid Environments. 80, 40 – 44.

Lee, H., Liu, C., 2004. Coping with Dust Storm Events: Information, Impacts, and Policymaking in Taiwan. TAO, 15(5).

Leys, J., Heidenreich, S.K., Strong, C.L., McTainsh, G.H., Quigley, S., 2011. PM10 concentrations and mass transport during "Red Dawn" – Sydney 23 September 2009. Aeolian Research. 3, 327 – 342.

Marx, S.K., McGowan, H.A., Balz, K.S., 2009. Long-range dust transport from eastern Australia: A proxy for Holocene aridity and ENSO-type climate variability. Earth and Planetary Science Letters. 282, 167 – 177.

Met Office, 2012. Dust storm brings Saharan sand to the UK. Met Office News Blog. 28 June 2012. http://metofficenews.wordpress.com/2012/06/28/dust-storm-brings-saharan-sand-to-the-uk/ (accessed 25.01.13).

NASA, n.d. OMI Ozone Monitoring Instrument. National Aeronautics and Space Administration. http://aura.gsfc.nasa.gov/instruments/omi.html (accessed 31.01.13).

NASA, 2012a. Dust over the Sea of Japan. NASA Earth Observatory. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=77665 (accessed 22.10.12).

NASA, 2012b. OMI Aerosol Images 2012. National Aeronautics and Space Administration. http://ozoneaq.gsfc.nasa.gov/datadis.md?year=2012&instr=omi&prod=aerosol&patt=IM_aersl_omi (accessed 24.10.12).

NCMS, 2013. Warnings. National Centre of Meteorology and Seismology. http://www.ncms.ae/warning/warning3.htm (accessed 31.01.13).

NEMA, 2006. International cooperation key to combating dust storms. National Emergency Management Agency News. 22 April 2006. http://eng.nema.go.kr/sub/cms5/view.asp?c_no=75&c_step=0&c_relation=2&c_relation2=1&page=5 (accessed 05.02.13).

NCDC/ NOAA, 2012. Storm Events Database. National Oceanic and Atmospheric Administration National Climatic Data Center. http://www.ncdc.noaa.gov/stormevents/listevents.jsp?beginDate_mm=01&beginDate_dd=01&beginDate_yyyy=2006&endDate_mm=12&endDate_dd=31&endDate_yyyy=2012&eventType=Dust+Storm&submitbutton=Search&statefips=-999%2CALL (accessed 04.02.13).

NOAA, 2012. Mobile weather warnings on the way! National Oceanic and Atmospheric Administration. http://www.noaa.gov/features/03_protecting/wireless_emergency_alerts.html (accessed 31.01.13).

NRL, 2009. Description of NAAPS (Navy Aerosol Analysis and Prediction System) Global Aerosol Model. Naval Research Laboratory. http://www.nrlmry.navy.mil/aerosol/Docs/globaer_model.html (accessed 24.10.12).

Onishi, K., Kurosaki, Y., Otani, S., Yoshida, A., Sugimoto, N., Kurozawa, Y., 2012. Atmospheric transport route determines components of Asian dust and health effects in Japan. Atmospheric Environment. 49, 94 – 102.

Otani, S., Onishi, K., Mu, H., Kurozawa, Y., 2011. The effect of Asian dust events on the daily symptoms in Yonago, Japan: A pilot study on healthy subjects. Archives of Environmental and Occupational Health 66(1), 43 – 46.

Scott, M., 2012a. Dust Storm over the Gobi Desert. NASA Earth Observatory. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79746 (accessed 03.12.12).

Scott, M., 2012b. Dust Storm over Iraq. NASA Earth Observatory. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=78087 (accessed 24.01.13).

Shi, P.J., Shimizu, H., Wang, J.A., Liu, L. Y., Li, X.Y., Fan, Y.D., Yu, Y.J., Jia, H.K., Zhao, Y., Wang, L., and Song, Y., 2005. Land degradation and blown-sand disaster in China, in: K. Omasa, I. Nouchi, and L.J. De Kok (Eds.), Plant Responses to Air Pollution and Global Change. Springer-Verlag, Tokyo, pp. 261-269.

Sivakumar, M.V.K., 2005. Impacts of Sand/Dust Storms on Agriculture, in: M.V.K. Sivakumar, R.P. Motha, and H.P. Das (Eds.), Natural Disasters and Extreme Events in Agriculture. Springer-Verlag, Berlin, pp. 150-177.

Stefanski, R and Sivakumar, M.V.K., 2009. Impacts of Sand and Dust Storms on Agriculture and Potential Agricultural Applications of a SDSWS. IOP Conference Series: Earth and Environmental Science. 7, 012016.

Steenburgh, W.J., Massey, J.D., Painter, T., 2012. Episodic Dust Events of Utah's Wasatch Front and Adjoining Region. Journal of Applied Meteorology and Climatology 5(9), 1654-1669.

Taylor, D., 2002. Dust in the Wind. Environmental Health Perspectives 110(2), A80-A87.

Thalib, L. and Al-Taiar, A., 2012. Dust storms and the risk of asthma admissions to hospitals in Kuwait. Science of the Total Environment. 433, 347 – 351.

UCAR/COMET, 2010. Atmospheric Dust. The COMET Program and University Corporation for Atmospheric Research sponsored in part through cooperative agreement(s) with the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC). ©1997-2011 University Corporation for Atmospheric Research. All Rights Reserved." https://www.meted.ucar.edu/training_module.php?id=820 (accessed 17.10.12).

UN, 2009. UN experts call for early warning system to deal with rising number of sand, dust storms. United Nations News Centre. 25 September 2009. http://www.un.org/apps/news/story.asp?NewsID=32255&Cr=&Cr1 (accessed 26.10.12).

Urban, F.E., Reynolds, R.L., Fulton, R., 2009. The Dynamic Interaction of Climate, Vegetation, and Dust Emission, Mojave Desert, USA, in: A. Fernandez-Bernal and M.A. De La Rosa (Eds.), Arid Environments and Wind Erosion. Nova Science Publishers, Inc., New York. pp. 1 – 25.

Wang, X., Xia, D., Wang, T., Xue, X., Li, J., 2008. Dust sources in arid and semiarid China and Southern Mongolia: Impacts of geomorphological setting and surface materials. Geomorphology. 97, 583 – 600.

Washington, R., Todd, M., Middleton, N. J., Goudie, A. S., 2003. Dust-Storm Source Areas Determined by the Total Ozone Monitoring Spectrometer and Surface Observations. Annals of the Association of American Geographers 93(2), 297 – 313.

Wilcox, B., 2012. Dust Storms Roll Across America. United States Geological Survey Science Features. http://www.usgs.gov/blogs/features/usgs_top_story/dust-storms-roll-across-arizona-2/ (accessed 17.10.12).

WMO, 2011. Organizations delivering SDS forecasts. World Meteorology Organization. http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Organizations_delivering_SDS_forecasts.pdf (accessed 24.10.12).

WMO, n.d. Sand and Dust Storm Warning Advisory and Assessment System. World Meteorology Organization. http://www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html. (accessed 17.10.12).

Zhou, C. H., Gong, S. L., Zhang, X. Y., Wang, Y. Q., Niu, T., Liu, H. L., Zhao, T. L., Yang, Y. Q., and Hou, Q., 2008. Development and evaluation of an operation SDS forecasting system for East Asia: CUACE/Dust. Atmospheric Chemistry and Physics. 8, 787-798.

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

MARCH 2013

Thematic Focus: Environmental governance, Climate change

The impact of corruption on climate change: threatening emissions trading mechanisms?

This bulletin provides an overview of recent discussions about the impact of corruption on environmental governance, with a focus on emissions trading. It reviews new definitions and the latest corruption assessment methodologies in order to illuminate the broader challenges faced by GHG trading mechanisms and climate finance.

Why is this issue important?

The trading of greenhouse gas (GHG) emissions has recently emerged as one of the most dynamic and promising areas of global environmental governance. According to the latest assessment by the International Panel on Climate Change (IPCC, 2007), global GHG emissions must peak, if not decline, by 2015 in order to limit global mean temperature increases to 2°C above pre-industrial levels. The Panel predicted that without a reduction of GHG emissions, the globe would experience an overall temperature rise of 6.4°C by the end of this century, which is a catastrophic scenario.

Emissions trading mechanisms are regulatory frameworks for the quantification and commoditisation of the greenhouse gas emissions allowing the exchange of those emissions among economic actors as financial instruments. Under these frameworks, emissions are converted into financial instruments which include, depending on the particularities of the system, tradable units, credits and certificates for the reduction of emissions. Conceived in the years preceding the signature of the Kyoto Protocol of 1997 as means to achieve the goals outlined in the United Nations Framework Convention on Climate Change of 1992 (UNFCCC), these markets currently mobilise approximately US$167 billion (Kossoy and Guignon, 2012). Emissions trading systems are often hailed as a powerful and cost-efficient approach to dealing with the multi-faceted challenges posed by climate change (Kossoy and Guignon, 2012). The UNFCCC estimates that these systems will contribute a significant portion of

MONICA MCGIVERN / FOTER / CC BY-ND

the funds necessary for climate change mitigation (UNFCCC, 2007). The Organization for Economic Co-operation and Development (OECD) member countries have already pledged up to US$100 billion by 2020 and agreed to contribute up to US$30 billion in 'fast-track finance' between 2010 and 2012 for the funding of adaptation and mitigation actions (UNEP, 2008; Nakhooda et al., 2012; UNFCCC, 2007). Much of these financial resources are expected to be mobilised through the implementation and expansion of emissions trading mechanisms.

Corruption impacts the success of emissions trading schemes by reducing the overall reliability and effectiveness of GHG markets. The implementation of cap-and-trade systems in both developed and developing countries has been recurrently tainted by cases of fraud and bribery, abuses of power, and other conventional forms of corruption. Corruption in this sector has also taken more original forms, such as the strategic exploitation of 'bad science' and scientific uncertainties for profit, the manipulation of GHG market prices, and anti-systemic speculation (Lohmann, 2007; TI, 2012a; Wara, 2007). The challenge that corruption poses to climate finance also contributes to broader debates about the impact of corruption in environmental governance. Over the past two decades,

PHOTO LEFT: MOUNT KILIMANJARO, TANZANIA - NASA'S MARSHALL SPACE FLIGHT CENTER / FOTER.COM / CC BY-NC

GUY GOREK / FOTER / CC BY-NC-SA

domestic and international anti-corruption initiatives have proliferated, with the process being largely driven by the increasing recognition of the impact of corruption on the quality of environmental governance.

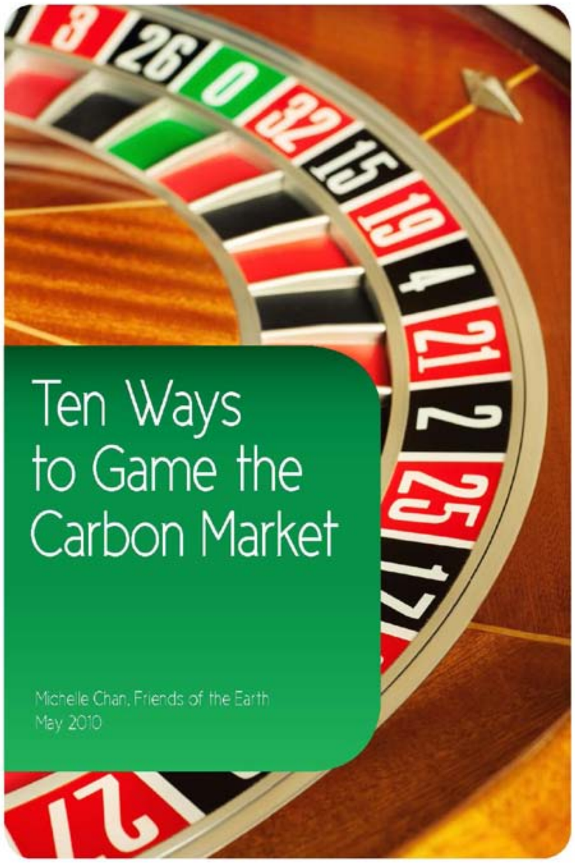
For the first time, the participants in the 2012 United Nations Conference on Sustainable Development (or the Rio+20 Conference) explicitly recognised that corruption is an impediment to effective environmental stewardship: paragraph 266 of the Outcome Declaration - The Future We Want - proclaimed that corruption must be addressed for the successful allocation and effectiveness of international aid. Governments stressed the links between transparency and accountability and the quality of governance, noting that corruption is a serious barrier to effective resource mobilisation and allocation and diverts resources away from activities that are vital for poverty eradication, the fight against hunger and sustainable development. They recognised the need to take urgent and decisive steps to continue to combat corruption in all its manifestations (UN, 2012). This attention to the issue of corruption in the Rio+20 Declaration echoes the debates that have taken place during the past decade in conferences and policy initiatives organised and implemented by the United Nations Office on Drugs and Crime (UNODC), the European Union, the Association of Southeast Asian Nations (ASEAN), the G20, and other multilateral organisations. In the face of challenges, while some critics have begun questioning the validity of the fundamental tenets of emissions trading schemes, supporters of the approach have responded by beginning to mainstream anti-corruption strategies into their frameworks and paying more attention to the consequences of corruption on the overall efficiency of the system.

What are the findings?

Measurements of corruption are inevitably imperfect

The features of corrupt behaviour may seem intuitively straightforward. In practice, however, attempts to exhaustively define corruption invariably encounter legal, criminological, and, in many countries, political problems (Foster et al., 2012; Heinrich and Hodess, 2012; Sampford et al., 2006; Sequeira, 2011). Over the past few decades, definitions of corruption have evolved from expressions of culture, which were prevalent until the late 1980s, to having been progressively replaced by others crafted to directly support the implementation of anti-corruption strategies. Today, corruption is generally understood as the abuse of public roles or resources for private benefit (Johnston, 1997; Klitgaard, 1988); it denotes not just the actions of public officials, but also those of agents of non-government organizations and for-profit businesses. New formulations of the concept anchor it in a set of behaviours that erode economic, political, and institutional development, which include bribery, nepotism, cronyism, embezzlement, fraud, and the misappropriation of resources (UNODC, 2010 and 2012).

Along with new definitions, several methodologies for the quantitative assessment of corruption have emerged over the past two decades. They include those employed by the World Bank's Worldwide Governance Indicators (WGI), Transparency International's (TI) Corruption Perceptions Index (CPI), and the Political Risk Services Group's (PRSG) International Corruption Risk Index (ICR), as well as a newer generation of measurements like the Ibrahim Index of African Governance, the Global Integrity Report and the Global Integrity Index.



FRIENDS OF THE EARTH

These measurements generally rely on three basic sources of information: 1) Surveys on the perception of corruption and the payment of bribes; 2) Institutional performance analyses, which examine the reach and effectiveness of administrative operations and management rules; and 3) Project audits, which analyse divergences between the expected results and the reported outcomes of specific projects and activities (Kaufmann et al., 2009; Urra, 2007). These measurements seek to specify the "quantity" of corruption, in order to increase awareness about the issue and monitor the success of anti-corruption initiatives.

While measures of corruption based on observed and reported acts of corruption inexorably tend to miss the actions of "successful" corrupt agents, assessments based on stakeholder perception provide information unfit for comparisons over time and across geographies (Urra, 2007; UNODC, 2010). In order to tackle the limitations of particular indicators, experts have developed aggregation methods through which it is possible to compensate for the biases, errors and limits of point-sources of information (Heinrich and Hodess, 2012; Sampford et al., 2006). Thus, the most widely employed measurements of corruption are composite indices, which provide country-level overviews that help raise awareness about the issue, encourage the entry of corruption topics into the political agenda and add legitimacy to anti-corruption initiatives (McDervitt, 2012; TI, 2012b). The aggregated approach is useful because composite indices convey information succinctly and communicate ideas more efficiently than multiple indicators. Critics note, however, that the selection of any discrete set of indicators for measuring governance quality and corruption levels is inevitably prone to biases - favouring particular ideological, cultural and normative ideals - which often breeds socio-political resistance to measurement initiatives and reduces the actionability of the information (Kotkin and Sajó, 2002; Sampford et al., 2006; Sik, 2002). Existing methodologies for the measurement of corruption are imperfect and, in spite of their constant improvement, are likely to remain so. This is basically because corrupt behaviours, by definition, tend to avoid scrutiny and prosecution. It is also due to the fact that corruption tends to both manifest itself in different forms and to take on different meanings in different contexts. In other words, corruption reflects the particular declination of contextual and sectoral challenges (Campos and Pradhan, 2007; UNODC, 2010 and 2012).

Corruption reduces the quality of environmental governance and the effectiveness of emissions trading

Corruption induces socially sub-optimal environmental governance. It reduces environmental regulatory stringency and undermines the effectiveness of management systems (Aidt, 2003; Dinda, 2004); this is because corruption reduces the social and/or economic cost of breaking established rules. In a corrupt environment, actors prioritise private benefits at the expense of socially optimal outcomes (Fredriksson et al., 2004; Olken and Pande, 2012; Welsh, 2004). Conversely, lower corruption levels translate into stricter and more effectively enforced environmental policies (Pellegrini and Gerlagh, 2004; Rehman et al., 2012; Zugravu et al., 2008). This proposition is generally supported by empirical research that correlates corruption levels and deforestation (Kishor and Damania, 2007; Yilmaz and Koyuncu, 2009), air pollution levels (Leitão, 2010; Lopez and Mitra, 2000), access to safe drinking water (Stålgren, 2006) and biodiversity (Smith et al., 2003). Research highlights that dysfunctional environmental governance systems - due to corruption - generally contribute to the extinction of species, the over-exploitation of natural resources, the pollution and degradation of ecosystems and wildlife habitats, the spread of diseases and invasive species, and the deprivation of local stakeholders reliant on wildlife and plants for subsistence. Not unlike other sectors of environmental governance, mitigation and adaptation strategies necessary to offset the impact of climate change are also vulnerable to the actions of corrupt actors. In fact, as mitigation and adaptation actions become more pressing, the negative impact of corruption in the different industries and political actors is likely to increase. This is because the increasing economic value of climate governance decisions and initiatives simultaneously fosters the perverse economic incentives that drive corruption.

Known as cap-and-trade systems, emissions trading schemes seek to reduce the production of greenhouse gases (GHG) through economic incentives which progressively increases the cost of emitting these gases and fostering the economic competitiveness of low carbon footprint alternatives. At least in theory, these "market-based" instruments are more efficient than "command and control" approaches for the control of GHG emissions. Actors can deal with their unique emission abatement challenges with limited government intervention and minimal regulatory disruption.

There are two basic types of emissions trading: compliance schemes and voluntary programs. Markets in a compliance scheme are created and controlled by national, regional or international GHG reduction regulatory frameworks. They operate on the basis of pre-determined annual limits for the emissions of certain greenhouse gases, and they create economic constraints for the production of GHG by economic actors — i.e. factories, power-production facilities, and other installations. Depending on the volume of GHG emitted each year, actors obtain emission allowances that they can sell when they emit GHGs below the permitted "cap" or they can buy from other actors in the marketplace when they are in need. Each year, actors failing to surrender sufficient allowances to cover their emissions face fines, while those that reduce emissions can either keep spare allowances to cover future needs or profit from their sale to other actors that have exceeded their respective annual quotas. Conversely, actors operating in the context of voluntary programs deal outside compliance markets. Voluntary schemes enable businesses, governments, NGOs, and individuals to offset the GHG emissions to voluntary buyers — i.e. corporations, institutions and individuals. Voluntary transactions are often employed to test new procedures, methodologies and technologies. They can be implemented with fewer transaction costs than those taking place in the context of mandatory markets.

The practical implementation of emissions trading schemes has produced promising, yet not entirely satisfactory results. Reports of widespread corruption in their implementation have raised concerns about the ability of these mechanisms to effectively and reliably ensure reductions in the emission of GHG. The Kyoto Protocol to the UNFCCC established a global GHG governance system that imposed caps on the emissions of the developed countries ratifying the Protocol. The framework assigned emissions targets and allowances. On average, the system sought the reduction of average GHG emissions by 5.2 per cent below their 1990 baseline between 2008 and 2012 (UNEP, 2008; Reyes and Gilbertson, 2009). Countries could meet their targets by reducing GHG emissions and/or by trading allowances with other countries.

Examples - EU emissions trading schemes, domestic cap-and-trade systems, and the REDD+ mechanism

The 15 original member states of the European Union have created the EU Emissions Trading Scheme (EU ETS). The EU ETS came into force in 2005 and is the largest operational mandatory cap-and-trade scheme to date. Currently, the EU ETS sets a cap for GHG emissions and distributes "carbon credits" among more than 11,000 participating factories, power plants, and other such installations across 30 countries (comprising all 27 EU member states, as well as Iceland, Liechtenstein, and Norway). The EU ETS has not operated exactly as predicted. Although emissions in the EU ETS are slated to be 21 per cent lower by 2020 than they were in 2005, during the first phase of the program (2005-2007), emission permits were over-allocated, which resulted in a 2.1 per cent increase in emissions from levels existing before the scheme began (Elges, 2011; Reyes and Gilbertson, 2009). In addition to problems linked to the design of the system, the EU ETS has also suffered from the impact of corruption.

In the European Union's US$134 billion emissions trading scheme (Kossoy and Guignon, 2012), corruption has enabled and facilitated the re-sale and misreporting of used carbon offsets, sophisticated computer hacking schemes for the theft from national carbon emission registries, and continuing value-added tax fraud (Elges, 2011; Lohmann, 2007; TI, 2012b). In 2010, European authorities uncovered several cases of "carousel fraud" in the trading of emissions, which amounted to an estimated US$6.45 billion in lost revenues across at least 11 countries (Gilbertson, 2010). Carousel fraud is a form of missing trader fraud, wherein the trader facilitating the carbon credit exchange keeps the value-added tax (VAT), rather than paying it to the tax authorities and government treasuries. Made possible by cross-national trading not subject to VAT, emission credits were initially purchased without adding the VAT, but then sold with the VAT added. The discovery of fraudulent activities prompted the rapid introduction of changes to the tax law and improvements in the security of the trading system by the European Commission, but also led to the deflation of the European carbon market by approximately 90 per cent and forced the momentary suspensions of credit-trading activities (Corporate Watch, 2010; Kossoy and Guignon, 2012). In January 2011, lax security facilitated the theft of over US$3 million in carbon credits (about 2 billion are issued each year), valued at about US$62 million in the open market (The Economist, 2011); cases were reported in Austria, the Czech Republic, Germany, Greece, Italy, and Romania (Kossoy and Guignon, 2012). Together, these problems raised concerns about not only the fate of the EU ETS, but also the increasing number of domestic cap-and-trade systems being implemented across the globe.

In time, similar climate governance schemes operating at the regional and domestic level are expected to form the backbone of a global marketplace, which will facilitate the integration of adaptation and mitigation strategies. The integrity of these trading schemes will be crucial for the success of global climate governance. In 2012 alone, Australia approved the implementation of an emissions trading market, which is expected to cover approximately 60 per cent of the country's annual GHG emissions by 2015. Similar initiatives are slated to enter into effect in the state of California — covering 85 per cent of its GHG emissions by 2015 — as well as in the Canadian province of Québec, in Mexico, and in the Republic of Korea (Kossoy and Guignon, 2012). Significantly, 2012 was also witness to the first GHG trades in China: four cement manufacturing companies in the southern industrial region of Guangdong province purchased several million dollars in carbon-pollution permits needed to expand operations (Lo, 2012). The Guangdong scheme is expected to cover more than 800 companies emitting more than 20,000 tonnes of CO_2 a year across nine industries, including the energy-intensive steel and power sectors. The Guangdong carbon market will regulate approximately 277 million tonnes of CO_2 emissions by 2015, which is almost equal to Ukraine's total annual CO_2 emissions (Lo, 2012). China plans to open six further regional emissions trading schemes this year, in the province of Hubei and in the municipalities of Beijing, Tianjin, Shanghai, Chongqing and Shenzhen. These initiatives are expected to be integrated by the end of the decade and linked to international markets (Lo, 2012).

In addition to regional and domestic cap-and-trade systems, the success of global climate governance also depends on the fate of different mechanisms for the transfer of wealth and technology between developed and developing countries. One such mechanism is Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative. According to paragraph 70 in the Cancun Agreement, REDD+ encourages developing countries to contribute to mitigation actions in the forest sector by reducing emissions from deforestation and forest degradation, by conserving forest carbon stocks, sustainably managing forests and enhancing forest carbon stocks. Moreover, countries that successfully implement these measures are financially compensated for their efforts. Thus, this global framework facilitates the social recognition of the economic value of the carbon stored in forests and creates economic incentives for the protection of forested lands and investment in low-carbon economic development paths for developing countries. The attachment of economic value to forest ecosystems allows preservation and sustainable management activities to compete with alternate land uses that result in forest destruction (Oakes et al., 2012). In the context of the initiative, for example, a 5 per cent reduction in Indonesia's deforestation rate could generate annual REDD+ payments of US$765 million; a 30 per cent reduction could generate more than US$4.5 billion per year (Barr et al., 2010).

However, analysts warn that unless corruption is effectively addressed - along with other catalysts of illicit deforestation -REDD+ is unlikely to produce the expected outcomes (Dermawan et al., 2011; TI, 2012a). Emphasizing that corruption challenges are not exclusive to Indonesia, Transparency International (TI) proclaimed that "REDD+ will inherit many of the corruption risks that have long beset the forestry sector, but it also brings with it new ones" (TI, 2012b). To date, abuses in the implementation of REDD+ have included the falsification or exaggeration of carbon credits from projects, favoritism in the allocation of projects and permits, and land-grabbing and price manipulation through fraud (García, 2011; Living on Earth, 2010; Reyes and Gilbertson, 2009; Standing, 2012). Journalists have, for example, exposed the abuses

GREENPEACE ESPERANZA / FOTER / CC BY-NC-ND by rogue businessmen - also known as "carbon cowboys" - who coerce and bribe local villagers into handing over the rights to the carbon in their forests (Cubby and Wilkinson, 2009; Lang, 2012; Lohmann, 2009; Martin, 2011). Abuses and corruption in the implementation of REDD+ reduce the effectiveness, efficiency, and equity expected of the approach, as well as creating barriers for the improved management and protection of forests, distorting the designed structure economic incentives, and leading to the unfair allocation of benefits derived from REDD+ payments. In addition to undermining social confidence in the usefulness of the approach, corruption can make REDD+ mechanism politically and economically unsustainable and subvert the effects of the initiative (UN-REDD, 2012a).

While still imperfect and vulnerable to the impact of corruption, the REDD+ initiative has significantly raised attention to the challenges and importance of forest management in the global political agenda. It has also helped to pave the way for other complementary initiatives, such as UN-REDD, which currently supports REDD+ readiness efforts in 46 countries, spanning Africa, Asia-Pacific, Latin America and the Caribbean. As of July 2012, UN-REDD had led to transfers of approximately US$117.6 million both for the domestic implementation of REDD+ strategies and for REDD+ readiness efforts, including the development of common approaches, analyses, methodologies, tools, data and best practices (UN-REDD, 2012b).

In face of the threats posed by corruption, a variety of international and national actors are currently working to reduce REDD+ corruption risks. For example, between 21 January and 15 February 2013, UN-REDD and the United Nations Development Programme (UNDP) held online discussions with anti-corruption experts, local government officials and climate change experts to develop a common understanding of the nature and severity of potential REDD+ corruption risks and promising approaches to reduce and manage these risks. These initiatives have been accompanied by the development of several informational websites and information systems, such as the Climate Funds Update and the Voluntary REDD+ Database, which have emerged to track climate finance, enabling identification of any misuse of funds in ongoing and projected initiatives.

What are the implications for policy?

In theory, the establishment of GHG emission caps and mandatory emissions trading markets can produce predictable environmental outcomes, as these mechanisms can help manipulate the economic incentives behind technological innovation and more environmentally-minded decisions. In practice, will emerging emission-valuation and trading schemes be able to effectively deal with the negative impact of corruption? Corruption can, for example, disrupt GHG market prices and facilitate fraudulent emissions reports, which reduces the overall effectiveness and reliability of these systems (Sweeney et al., 2011). Moreover, ongoing global discussions about how to meet environmental governance objectives are playing out against the backdrop of a protracted global financial crisis. In the context of spending cutbacks and the re-ordering of domestic priorities, international development aid expenditures are being scrutinised, and funding and support for the achievement of sustainable development targets is being conditioned on the demonstrable effectiveness of environmental governance initiatives. In view of the urgent need for mechanisms to develop and implement climate change mitigation and adaptation strategies, the fight against corruption must and undoubtedly will become a key issue in policy debates.

That said, positive steps are being taken by governments, inter-governmental organisations, non-governmental organisations and by businesses. In recent years, for example, most developed countries have ratified two significant international anti-corruption conventions: the United Nations Convention on Anti-Corruption (UNCAC) and the Organization for Economic Co-operation and Development´s Convention on Combating Bribery of Foreign Officials in International Business Transactions. While ratification of one or both of these conventions demonstrates the increasing interest in the fight against corruption, this interest extends to a new set of initiatives and regulatory systems aimed at fighting corruption at the domestic level. Across sectors of environmental governance, successful anti-corruption initiatives have resulted in the financial, practical and symbolic empowerment of enforcement agents, the reform of decision-making mechanisms for increased accountability and transparency, and new regulatory frameworks. Moreover, anti-corruption initiatives have not been restricted to the developing world. Although success stories are not abundant, such initiatives include the creation of anti-corruption agencies, such as Hong Kong's Independent Commission Against Corruption, Indonesia's Komisi Pemberantasan Korupsi (Corruption Eradication Commission), and the offices of the Ombudsman and Special Prosecutor in the Philippines. Anti-corruption initiatives have led to significant increases in the number of convictions on corruption charges, as well as the development of better anti-corruption methodologies — as highlighted in manuals such as the Consortium on Combating Wildlife Crime's (ICCW) Wildlife and Forest Crime Toolkit, the World Bank's Sourcebook for Deterring Corruption and Improving

Governance in the Urban Water Supply and Sanitation Sector, and Transparency International anti-corruption toolkits — which have significantly improved the performance of development projects in different sectors of natural resource governance. Globally, governments, experts and practitioners have explicitly recognised that tackling corruption is crucial to ensure the effectiveness of the systems devised to deal with environmental challenges.

In the case of climate governance, as the sector grows in size and complexity, the issue of corruption draws increasing attention. The issue is often employed to question the overall validity of emissions trading schemes. The most radical critics challenge the reliance of climate governance on market-driven solutions: "(widespread corruption) raises key questions about whether a market approach, in which relatively unregulated, complex and difficult to trace transactions are the bulk of activity, is really the best route to a solution to climate change" (Corporate Watch, 2010). They argue that the approach is an implicit validation of business-as-usual practices, to the detriment of alternative approaches to GHG emissions control (Gilbertson, 2010; Lohmann 2007 and 2009; Reyes and Gilbertson, 2009).

Cynicism about the potential of emissions trading is not entirely warranted. More constructive reviews emphasize the transformational power of GHG emissions trading and its potential for permanent improvement through reform and adjustments (Najam et al., 2006; Thorpe and Ogle, 2011; TI, 2012a; UNODC, 2012). Transparency International (TI), the global corruption watchdog, stresses that the mainstreaming of anti-corruption tools can help ensure the overall effectiveness of GHG emissions trading schemes (Sweeney et al., 2011; TI, 2012). These demands in favor of mainstreaming anti-corruption objectives into climate governance systems echo a second call made by the participants of the Rio+20 conference, which is the need to strengthen the science-policy interface and enhance evidence-based decision-making at all levels and contribute to strengthening ongoing efforts of capacity-building for data collection and analysis in developing countries (UN, 2012). Although reforms are unlikely to entirely suppress corruption in climate governance, reforms can nonetheless support the efforts of those dedicated to combating corruption's effects and improving the performance of environmental governance systems. Market regulators have started taking steps to eradicate weaknesses that criminal elements can exploit. European authorities, for example, have made significant changes aimed towards the improved transparency and integrity of trading operations. While it remains to be seen just how effective these new rules will be in securing the market, the overall position is likely to be much improved (Kossoy and Guignon, 2012).

The effects of climate change are already being felt all around the world; the poor, particularly in developing countries, are most vulnerable. Climate governance is one of the most complex, costly and urgent challenges in the global development arena. In this context, the lack of effective corruption monitoring and prevention is likely to significantly undermine climate change adaptation and mitigation initiatives, thwarting the Millennium Development Goals and sustainable development agendas. It is necessary for major environmental initiatives, including CDM, emissions trading, REDD+ and other future initiatives, to incorporate provisions to prevent corruption and close loopholes. Corruption in all its forms should be considered in protocols and conventions on climate governance at the international level. The recognition of the multi-faceted challenges posed by corruption is a necessary first step, but one that must be followed by concrete actions from governments, civil society and the private sector. Ultimately, the fight against corruption depends on concerted political action at the global level, as much as on new commitments in domestic arenas.

1 *To illustrate the shortcomings of any one definition of corruption, the definition proposed here restricts the issue of corruption to the abuses of power or office for illegitimate private gain or to instances of illegal activity. This approach focuses on the corrupt agents, and not on the structural factors — the incentives embedded in institutional systems — that may likewise facilitate and often cause corrupt behaviours.*

2 *Cap-and-trade systems mechanisms have already been implemented or are in the process of becoming operational in Belarus, Brazil, Chile, China, Colombia, Costa Rica, India, Indonesia, Japan, Jordan, Kazakhstan, Morocco, New Zealand, Canada (Alberta and British Columbia), South Africa, Switzerland, Thailand, Turkey, Ukraine, and Viet Nam.*

Acknowledgement

Writers: Martin Walter[a] and Michelle Luebke[h].

Production and Outreach Team: Arshia Chander[b], Erick Litswa[c], Kim Giese[b], Michelle Anthony[b], Lindsey Harriman[b] Reza Hussain[b], Theuri Mwangi[c] and Zinta Zommers[c]

Special thanks to Zinta Zommers[c], Dmitry Zhdankin[a], Justin Gosling[a], Kakuto Nagatani-Yoshida[d], Ron Witt[e], Ludgarde Coppens[c], Theuri Mwangi[c], Djaheezah Subratty[f], Tim Christophersen[g], Mark Radka[f], Marlyn Van Voore[f], Françoise D'Estais[f], Thomas Enters[d], and Pascal Peduzzi[e] for their valuable inputs and review.

([a] UNEP-RONA, Northwestern University and the Institut d'Etudes Politiques de Paris, [b] UNEP/DEWA/GRID-Sioux Falls, [c] UNEP/DEWA/Nairobi, [d] UNEP-ROAP, [e] UNEP/DEWA/GRID-Geneva, [f] UNEP-DTIE, [g] UNEP-DEPI, [h] New York University)

References

Aidt, T., 2003. Economic analysis of corruption: a survey. The Economic Journal 113(491): 632-652.

Barr, C., Dermawan, A., Purnomo, H., Komarudin, H., 2010. Occasional Africa 99 Financial governance and Indonesia's Reforestation Fund during the Soeharto and post-Soeharto periods, 1989-2009. Bogor Barat: Center for Forestry Research (CIFOR).

Campos, E. and Pradhan, S., 2007. The many faces of corruption: tracking vulnerabilities at the sector level. Washington, D.C.: World Bank Publications.

Corporate Watch, 2010. The Carbon Carousel: VAT Tax Fraud. Press Release. http://www.corporatewatch.org/?lid=3676 (accessed 03.15.13).

Cubby, B. and Wilkinson, M., 2009. 'Carbon cowboys' riding high in PNG. The Age. http://www.theage.com.au/national/carbon-cowboys-riding-high-in-png-20090903-f9yz.html (accessed 03.15.13).

Dermawan, A., Petkova, E., Sinaga, A., Muhajir, M., Indriatmoko, Y., 2011. Preventing the risk of corruption in REDD + in Indonesia. Bogor Barat: Center for International Forestry Research (CIFOR).

Dinda, S., 2004. Environmental Kuznets Curve Hypothesis: A Survey. Ecological Economics 49(4): 431-455.

Elges, L., 2011. Identifying corruption risks in public climate finance governance. In Handbook of global research and practice in corruption, eds. Adam. Graycar and Russell G Smith. Cheltenham; Northampton, MA: Edward Elgar, p. 138-156.

Foster, J., Horowitz, A., Mendez, F., 2012. An Axiomatic Approach to the Measurement of Corruption: Theory and Applications. The World Bank Economic Review 26(2): 217-235.

Fredriksson, P., Vollebergh, H., Dijkgraaf, E., 2004. Corruption and energy efficiency in OECD countries: theory and evidence. Journal of Environmental Economics and Management 47(2): 207-231.

García, B., 2011. Local Governance, Anti-Corruption and REDD + In Latin America and the Caribbean: Exploring Synergies to Strengthen Transparency and Accountability. Panama: UNDP.

Gilbertson, T., 2010. Fast Forest Cash. In NO REDD! A Reader, eds. Joanna Cabello and Tamra Gilbertson. Sonora: Carbon Trade Watch and Indigenous Environment Network, p. 120.

Heinrich, F. and Hodess, R., 2012. Measuring corruption. In Handbook of Global Research and Practice Corruption, eds. Adam Graycar and Russell G. Smit. Canberra: Edward Elgar Pb., p. 18-33.

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva.

Johnston, M., 1997. What can be done about entrenched corruption? Washington D.C.: World Bank.

Kaufmann, Daniel, Aart Kraay, and Massimo Mastruzzi. 2009. 146-188 Governance Matters VIII: Aggregate and Individual Governance Indicators, 1996-2008. Washington D.C.: The World Bank, Cambridge University Press.

Kishor, N. and Damania, R., 2007. Crime and justice in the Garden of Eden: improving governance and reducing corruption in the forestry sector. In The Many Faces of Corruption: Tracking Vulnerabilities at the Sector Level, eds. J Edgardo Campos and Sanjay Pradhan. Washington D.C.: World Bank.

Klitgaard, R., 1988. Controlling corruption. Berkeley: University of California Press.

Kossoy, A. and Guignon, P., 2012. 138 State and Trends of the Carbon Market 2012. Washington D.C.: World Bank Carbon Finance Unit.

Kotkin, S. and Sajó, A., 2002. 493 Political corruption in transition : a skeptic's handbook. Budapest; New York: Central European University Press.

Lang, C., 2012. Judge in Peru issues warrant for carbon cowboy David Nilsson's arrest. Redd+ Monitor.

Leitão, A., 2010. Corruption and the environmental Kuznets Curve: Empirical evidence for sulfur. Ecological Economics 69(11): 2191-2201.

Living on Earth, 2010. REDD Corruption. Transcribed Interview with Davyth Stewart by host Bruce Gellerman.

Lo, A., 2012. Carbon emissions trading in China. Nature Climate Change 2(11): 765-766.

Lohmann, L., 2007. Regulation vs . Corruption or Regulation as Corruption ? The Case of Carbon Offsets.

Lohmann, L., 2009. Regulation as Corruption in the Carbon Offset Markets Cowboys and Choirboys United. 18.

Lopez, R. and Mitra, S., 2000. Corruption, pollution, and the Kuznets environment curve. Journal of Environmental Economics and Management 40(2): 137-150.

Martin, C., 2011. The darker side of saving the rainforests. Transparency International Blog. http://blog.transparency.org/2011/11/11/the-darker-side-of-saving-the-rainforests/ (February 10, 2012).

McDervitt, A., 2012. 1-9 Aggregate Indices Topic Guide. Berlin: Transparency International.

Najam, A., Papa, M., Taiyab, N., 2006. Global Environmental Governance: a Reform Agenda. Winnipeg: International Institute for Sustainable Development.

Nakhooda, S., Watson, S., Caravani, A., Schalatek, L., Barnard, S., Trujillo, S., Scott, N., 2012. Things to Know About Climate Finance in 2012. Shaping Policy for Development. Overseas Development Institute (November). http://www.odi.org.uk/publications/6975-ten-things-know-about-climate-finance-2012 (February 12, 2012).

Oakes, N., Leggett, M. Cranford, M., Vickers, H., 2012. The Little Forest Finance Book. Oxford: Global Canopy Programme.

Olken, B. and Pande, R., 2012. Corruption in Developing Countries. Annual Review of Economics (4): 479-509.

Page, E., 2011. Cashing in on climate change: political theory and global emissions trading. Critical Review of International Social and Political Philosophy 14(2): 259-279.

Pellegrini, L. and Gerlagh, R., 2004. Corruption's Effect on Growth and its Transmission Channels. Kyklos 57(3): 429-456.

Rehman, F., Nasir, M., Kanwal, F., 2012. Nexus between corruption and regional Environmental Kuznets Curve: the case of South Asian countries. Environment, Development and Sustainability 14(5): 827-841.

Reyes, O. and Gilbertson, T., 2009. Carbon Trading: How it Works and Why it fails. Critical Currents (7): 7-9.

Sampford, C., Shacklock, A., Connors, C., 2006. Measuring Corruption. Abingdon: Ashgate Publishing Group.

Sequeira, S., 2011. Advances in Measuring Corruption in the Field. In New Advances in Experimental Research on Corruption, eds. Danila Serra and Leonard Wantchekon. bingley: Emerald Group Publishing Limited, p. 14-175.

Sik, E., 2002. The bad, the worse and the worst: guesstimating the level of corruption. In Political corruption in transition: a skeptic's handbook, eds. S Kotkin and A Sajó. New York: Central European University Press.

Smith, R., Muir, R., Walpole, M., Balmford, A., Leader-Williams, N., 2003. Governance and the loss of biodiversity. Nature 426(6962): 67-70.

Stålgren, P., 2006. Corruption in the water sector: Causes, consequences and potential reform. Stockholm: Stockholm International Water Institute (SIWI).

Standing, A., 2012. Corruption and REDD+. Berlin: U4, Anti-Corruption Resource Centre.

Sweeney, G., Dobson, R. Despota, K., Zinnbauer, D., Sweeney, G., 2011. Global corruption report: Climate Change. Washington, D.C.: Transparency International.

Thorpe, A. and Ogle, L., 2011. United Nations Development Programme Staying on track : Tackling corruption risks in climate change. New York.

TI, 2012a. Keeping REDD+ Clean. Berlin: Transparency international.

TI, 2012b. Corruption perceptions index. Berlin: Internet Center for Corruption Research. Transparency International.

UN, 2012. 43688 Outcome of the Conference 1-53 The Future We Want. United Nations.

UNEP, 2008. Kick the habit : a UN guide to climate neutrality. Nairobi, Kenya: United Nations Environment Programme.

UNFCCC, 2007. 273 Investments and Financial Flows to Address Climate Change. Bonn: Climate Change Secretariat (UNFCCC). United Nations Framework Convention on Climate Change.

UNODC, 2010. Methodologies, including evidence-based approaches, for assessing areas of special vulnerability to corruption in the public and private sectors. United Nations Office on Drugs and Crime.

UNODC, 2012. Corruption, Environment and the United Nations Convention. In Impact of Corruption on the Environment and the United Nations Convention against Corruption, Marrakesh: UNODC, p. 54.

UN-REDD, 2012a. 1-25 Guidance On Conducting REDD+ Corruption Risks Assessments (REDD+ CRA). Geneva.

UN-REDD, 2012b. About UN-REDD. http://www.un-redd.org/AboutUN-REDDProgramme/tabid/102613/Default.aspx (accessed 02.20.13).

Urra, F., 2007. Assessing Corruption An analytical review of Corruption measurement and its problems: Perception, Error and Utility. Edmund A. Walsh School of Foreign Service (May): 1-20.

Wara, M., 2007. Is the global carbon market working? Nature 445(7128): 595-6.

Welsh, H., 2004. Corruption, growth, and the environment: a cross-country analysis. Environment and Development Economics 9(05): 663-693.

Yilmaz, R. and Koyuncu, C., 2009. The impact of corruption on deforestation: a cross-country evidence. The Journal of Developing Ideas 42(2): 213-222.

Zugravu, N., Millock,K., Duchene, G., 2008. The Factors Behind CO_2 Emission Reduction in Transition Economies. Milan: Fondazione Eni Enrico Mattei.


KSM 31019K

APRIL 2013

Thematic Focus: Ecosystem management

Water hyacinth: Can its aggressive invasion be controlled?

The spread of invasive alien species is neither easy to manage nor easy to reverse, threatening not only biodiversity but also economic development and human wellbeing (UNEP, 2012). Native to the Amazon Basin in South America water hyacinth has emerged as a major weed in more than 50 countries in the tropical and subtropical regions of the world with profuse and permanent impacts (Patel, 2012, Téllez et al., 2008, Shanab et al., 2010, Villamagna and Murphy, 2010). Worryingly, climate change may allow the spread of water hyacinth to higher latitudes (Patel, 2012). Intensified monitoring, mitigation and management measures are needed to keep water hyacinth at unproblematic levels.

Why is this issue important?

The beautiful, large purple and violet flowers of the South American water hyacinth (Eichhornia crassipes) make it a very popular ornamental plant for ponds. However water hyacinth has also been labelled as the world's worst water weed and has garnered increasing international attention as an invasive species (Zhang et al., 2010). Efficient in utilizing aquatic nutrients and solar energy for profuse biomass production, water hyacinth can cause extensive environmental, social and economic problems. It is found in lakes, estuaries, wetlands, marshes, ponds, dambos, slow flowing rivers, streams, and waterways in the lower latitudes where growth is stimulated by the inflow of nutrient rich water from urban and agricultural runoff, deforestation, products of industrial waste and insufficient wastewater treatment (Villamagna and Murphy, 2010, Ndimele et al., 2011). According to recent climate change models, its distribution may expand into higher latitudes as temperatures rise, posing problems to formerly hyacinth free areas (Rahel and Olden, 2008).

MIKE_TN / FLICKR / CC BY-NC-ND 2.0

What are the findings?

Invasive alien species are a major global challenge requiring urgent action (Xu et al., 2012). They are considered one of the key pressures on world's biodiversity: altering ecosystem services and processes, reducing native species abundance and richness, and decreasing genetic diversity of ecosystems (Rands et al., 2010, Vila et al., 2011, Hejda et al. 2009). They cause substantial economic losses estimated by one study to total US$120 billion annually in the USA (Pimentel et al., 2005,

PHOTO LEFT: BOAT SURROUNDED BY WATER HYACINTH - GLOBAL ENVIRONMENTAL FACILITY (GEF) / FLICKR / CC BY-NC-SA 2.0

GLOBAL ENVIRONMENT FACILITY (GEF) / FLICKR / CC BY-NC-SA 2.0

Kettunen et al., 2009). In South Africa, estimated economic costs due to invasive alien species are currently above US$ 700 million (R6.5 billion) per annum or 0.3% of South Africa's GDP, and could rise to over 5% of GDP if invasive plants are allowed to reach their full potential (Wilgen and Lange, 2011).

Water hyacinth has been identified by the International Union for Conservation of Nature (IUCN) as one of the 100 most aggressive invasive species (Téllez et al., 2008) and recognized as one of the top 10 worst weeds in the world (Shanab et al., 2010, Gichuki et al., 2012, Patel, 2012). It is characterised by rapid growth rates, extensive dispersal capabilities, large and rapid reproductive output and broad environmental tolerance (Zhang et al., 2010). In Africa, for example, where water hyacinth is listed by law as a noxious weed in several countries, it is the most widespread and damaging aquatic plant species. The economic impacts of the weed in seven African countries have been estimated at between US$20-50 million every year. Across Africa costs may be as much as US$100 million annually (UNEP, 2006).

The success of this invasive alien species is largely due to its reproductive output. Water hyacinth can flower throughout the year and releases more than 3 000 seeds per year (Gopal,

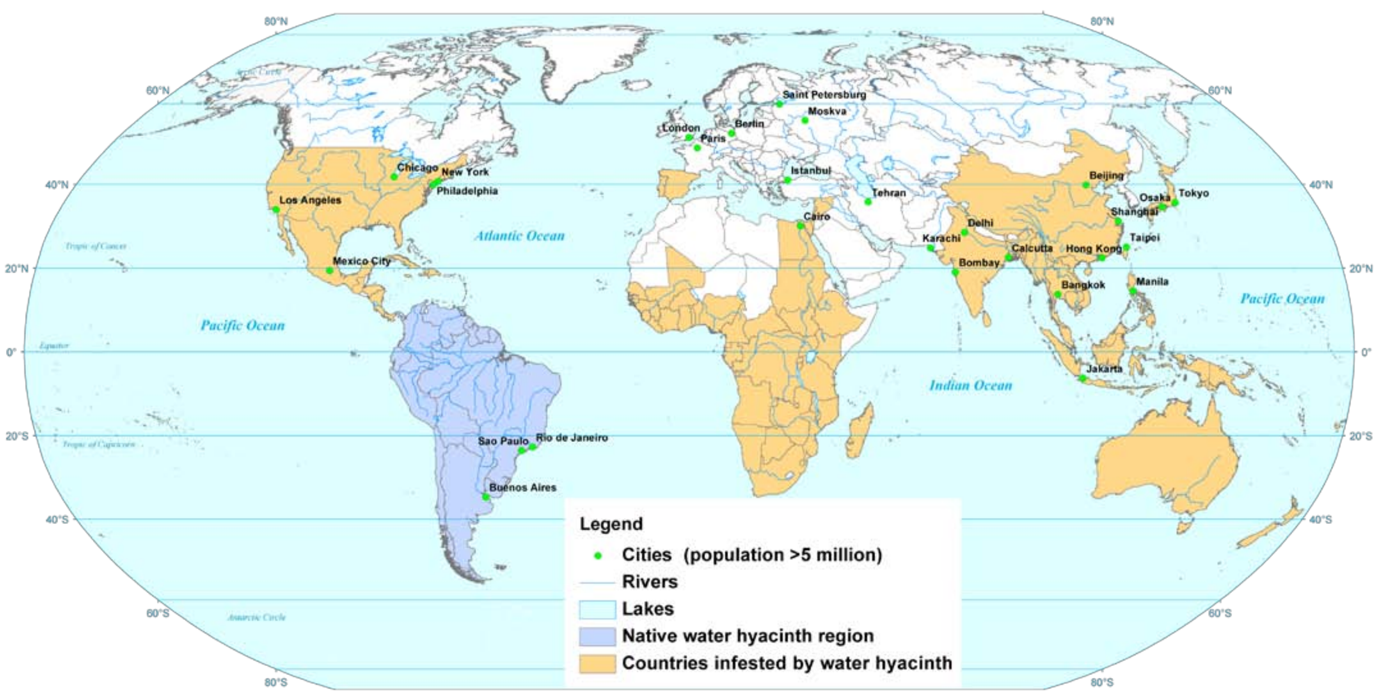


Figure 4.1. Global distribution of water hyacinth (Map redrawn by UNEP/DEWA from Téllez et al., 2008).

1987, EEA, 2012). The seeds are long-lived, up to 20 years (Gopal, 1987). While seeds may not be viable at all sites, water hyacinth commonly colonises new areas through vegetative reproduction and propagation of horizontally growing stolons. In the early stages of infestation, the weed takes foothold on the shoreline in the areas where native aquatic plants thrive (Gichuki et al., 2012). However, it is not restricted to shallow water, unlike many submersed and emergent macrophytes, because its roots are free-floating near the surface (Villamagna and Murphy, 2010).

Water hyacinth is found across the tropical and subtropical regions (Figure 4.1). Originally from the Amazon Basin, its entry into Africa, Asia, Australia, and North America was facilitated by human activities (Dagno et al., 2012).

Africa has particularly been affected by the introduction and spread of water hyacinth, facilitated in part due to a lack of naturally occurring enemies. In a review of water hyacinth infestation in eastern, southern and central Africa, Mujingni (2012) reports that the weed was first recorded in Zimbabwe in 1937. It colonized important water bodies, such as the Incomati River in Mozambique in 1946, the Zambezi River and some important rivers in Ethiopia in 1956. Rivers in Rwanda and Burundi were colonised in the late 1950s while the rivers Sigi and Pangani in Tanzania were infested in 1955 and 1959. The plant colonised Kafue river in Zambia in the 1960s, the Shire River in Malawi in 1968 and Lake Naivasha in Kenya in 1986 (Mironga et al., 2012). The plant was recorded from Lakes Kyoga in Uganda in 1988-89, Victoria in 1989–1990, Malawi/Nyasa in 1996 and Tanganyika in 1997. Lake Victoria in Africa is the second largest freshwater lake in the world and currently supports approximately 30 million people. Infestation of water hyacinth in the lake has been a serious nuisance, generating public outcry (World Agro Forestry Centre, 2006, Kateregga and Sterner, 2007, Gichuki et al., 2012). At its peak, it was estimated that the weed was growing at 3 hectares (12 acres) per day on the lake (Ayodo and Jagero, 2012). The plant also spread fast throughout Uganda's lakes and rivers in just 10 years.

Water hyacinth has also spread to West Africa. It was first reported in Cameroon between 1997 and 2000 and since then the country's wetlands have become "home" for the weed (Forpah, 2009). In Nigeria almost all river bodies have been dominated by water hyacinth (Borokini and Babalola, 2012). The water hyacinth problem is especially severe on the river Niger in Mali where human activities and livelihoods are closely linked to the water systems (Dagno et al., 2012). It occurs throughout the Nile Delta in Egypt and is believed to be spreading southwards, due to the construction of the Aswan Dam which has slowed down the river flow, enabling the weed to invade (Dagno et al., 2007). Infestation of water hyacinth in Ethiopia has also been manifested on a large scale in many water bodies of the Gambella area, Lake Ellen in the Rift Valley and Lake Tana (Fessehaie, 2012).

In Europe, water hyacinth is established locally in the Azores (Portugal) and in Corsica (France), and casual records are known from Belgium, the Czech Republic, Hungary, the Netherlands and Romania (EEA, 2012) In particular, it is a threat in Spain and Portugal (DellaGreca et al., 2009).

In Asia, water hyacinth is widespread on freshwater wetlands of the Mekong Delta, especially in standing water (MWBP/RSCP, 2006). It has been detected in the Sundarbans mangrove forest of Bangladesh (Biswas et al., 2007) and has caused heavy siltation in the wetlands of the Kaziranga National Park, India. Deepor Beel, a freshwater lake formed by the Brahmaputra River is heavily infested with this weed (Patel, 2012). The lake is considered one of the large and important riverine wetlands in the Brahmaputra valley of lower Assam, India. As in many other countries, water hyacinth has caused many economic, social and environmental problems in southern China (Choo et al., 2006).

In Mexico, more than 40 000 hectares of reservoirs, lakes, canals and drains are infested with water hyacinth (Jime0nez and Balandra, 2007). In California, USA, this weed has caused severe ecological impacts in the Sacramento- San Joaquin River Delta (Khanna et al., 2011).

Threats posed by water hyacinth

i. Destruction of biodiversity

Today, biological alien invasions are a major driver of biodiversity loss worldwide, (Pyšek and Richardson, 2010, Vila et al., 2011). Water hyacinth is challenging the ecological stability of freshwater water bodies (Khanna et al., 2011, Gichuki et al., 2012), out-competing all other species growing in the vicinity, posing a threat to aquatic biodiversity (Patel, 2012). Besides suppressing the growth of native plants and negatively affecting microbes, water hyacinth prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries (Gichuki et al., 2012, Villamagna and Murphy, 2010).

ii. Oxygen depletion and reduced water quality

Large water hyacinth mats prevent the transfer of oxygen from the air to the water surface, or decrease oxygen production by other plants and algae (Villamagna and Murphy, 2010). When the plant dies and sinks to the bottom the decomposing biomass depletes oxygen content in the water body (EEA, 2012). Dissolved oxygen levels can reach dangerously low concentrations for fish that are sensitive to such changes. Furthermore, low dissolved oxygen conditions catalyse the release of phosphorus from the sediment which in turn accelerates eutrophication and can lead to a subsequent increase in water hyacinth or algal blooms (Bicudo et al., 2007). Death and decay of water hyacinth vegetation in large masses deteriorates water quality and the quantity of potable water, and increases treatment costs for drinking water (Patel, 2012, Mironga et al., 2011, Ndimele et al., 2011).

iii. Breeding ground for pests and vectors

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems to decrease water currents increases breeding habitat for the malaria causing anopheles mosquito as evidenced in Lake Victoria (Minakawa et al., 2008). Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed (Chandra et al., 2006, Varshney et al., 2008). Snails serving as vector for the parasite of Schistosomiasis (Bilharzia) reside in the tangled weed mat (Borokini and Babalola, 2012). Water hyacinth has also been implicated in harbouring the causative agent for cholera. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population). Yearly water hyacinth coverage on the Kenyan section of the lake was positively associated with the number of cholera cases reported in the Province (Feikin et al., 2010). At the local level increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed which provides cover to the reptiles and poisonous snakes (Patel, 2012, Ndimele et al., 2011).

iv. Blockage of waterways hampering agriculture, fisheries, recreation and hydropower

Water hyacinth often clogs waterways due to its rapid reproduction and propagation rate. The dense mats disrupt socioeconomic and subsistence activities (ship and boat navigation, restricted access to water for recreation, fisheries, and tourism) if waterways are blocked or water pipes clogged (Ndimele et al., 2011, Patel, 2012). The floating mats may limit access to breeding, nursery and feeding grounds for some economically important fish species (Villamagna and Murphy, 2010). In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because water hyacinth mats blocked access to fishing grounds, delayed access to markets and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009). In the Wouri River Basin in Cameroon the livelihood of close to 900,000 inhabitants has been distorted; the entire Abo and Moundja Moussadi creeks have been rendered impassable by the weed leading to a complete halt in all the socioeconomic activities with consequent rural exodus (Mujingni, 2012). The weed has made navigation and fishing an almost impossible task in Nigeria (Ndimele et al., 2011).

While navigation in the Brahmaputra River in India has been affected by the weed, it has also blocked irrigation channels and obstructed the flow of water to crop fields (Patel, 2012). For example, in West Bengal, it causes an annual loss of paddy (Patel, 2012) by directly suppressing the crop, inhibiting rice germination and interfering with harvesting (EEA, 2012). The dense growth entangles with boat propellers, hampering fishing (Patel, 2012). Water hyacinth slows water flow by 40 to 95% in irrigation channels (Jones, 2009), which may cause severe flooding. The communities of Bwene and Bonjo in the Wouri River Basin in Cameroon regularly suffer from floods during the rainy season due to blockage of waterways around the villages by the weed (Mujingni, 2012).

It is estimated that the flow of water in the Nile could be reduced by up to one tenth due to increased losses from evapotranspiration by water hyacinth in Lake Victoria (Ndimele et al., 2011). Water loss by the same process and blocking of turbines on Kafue Gorge in Zambia translates into lost water for power generation and eventually into lost revenue of about US$15 million every year for the power company (ZEO, 2008). Many large hydropower schemes are also suffering the effects of water hyacinth (Shanab et al., 2010). For example, cleaning intake screens at the Owen Falls hydroelectric power plant at Jinja in Uganda were calculated to be US$1 million per annum (Mailu, 2001).

Control measures

Water hyacinth control is absolutely essential (Villamagna and Murphy, 2010). Control methods that are often used include mechanical, chemical and biological control. However, existing methods have often been insufficient to contain the aggressive propagation of the weed and viability of its seeds despite substantial monetary investments over the years (Gichuki et al., 2012), mainly due to lack of continued policy and management support by governments. The weed infestation on Lake Chivero which supplies water to Harare, Zimbabwe, was controlled and declined from 42% in 1976 to 22% in 2000. Re-invasion began to emerge in 2005 and included massive amounts of another invasive plant, spaghetti weed (Hydrocotyle ranunculoide (UNEP, 2008). The Oct 2012 image shows the extent of re-invasion (Figure 4.2).

i. Manual and mechanical control

Physical methods for control of water hyacinth involve drainage of the water body, manual removal of the weeds or pulling through nets (Patel, 2012). Employing machines like

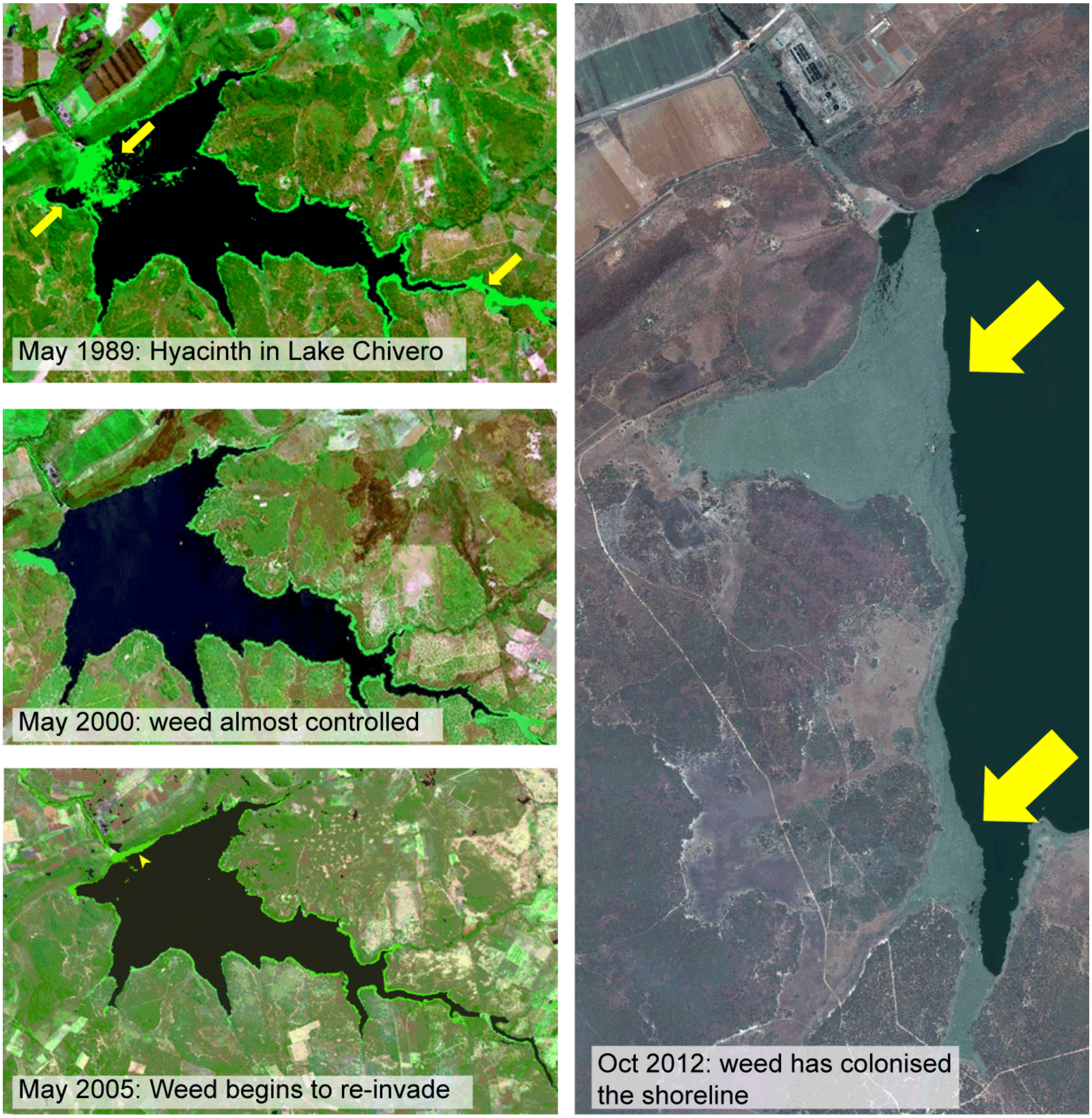


Figure 4.2: Satellite images showing progressive invasion, control and re-invasion of water hyacinth on Lake Chivero, Zimbabwe (Image source: Google Earth and Landsat).

weed harvesters, crusher boats, and destruction boats prove expensive, approximately US$600-1,200 per hectare (Malik, 2007, Villamagna and Murphy, 2010) as well as unpractical for areas larger than a hectare given the rapid rate of increase of the weed. There may also be additional fees for disposal of plant material. The costs of water hyacinth management in China were estimated to amount around EUR 1 billion annually (EEA, 2012). In Europe, management costs to remove 200,000 tonnes of the plant along 75 km in the Guadiana river basin on the Portuguese-Spanish border amounted to EUR 14,680,000 between 2005 and 2008 (EEA, 2012). Dagno et al. (2007) reported that mechanical management of the weed in Mali cost around US$ 80,000–100,000 per year. Maintaining a clear passage for ships to dock at Port Bell in Uganda is estimated to cost US$ 3-5 million per year (Mailu, 2001). Yet, while mechanical removal has been effective to a considerable extent, the infestations soon return because shredded bunches of the weed are carried by waves to other unaffected areas where they establish and start proliferating (Shanab et al., 2010).

MANUAL REMOVAL OF WATER HYACINTH, KISUMU, KENYA - GLOBAL ENVIRONMENTAL FACILITY (GEF) / FLICKR / CC BY-NC-SA 2.0

ii. Chemical control

A generally cheaper method has been used worldwide to reduce water hyacinth populations through the use of chemical herbicides (such as Paraquat, Diquat, Glyphosate, Amitrole, 2, 4-D acid) (Villamagna and Murphy, 2010). However, their use directly interferes with the biocontrol agents currently deployed against this weed. Long term use may degrade water quality and put aquatic life at risk (Malik, 2007) with significant socio-economic impacts if beneficial or designated uses of the water body such as drinking and preparing food are affected (Dagno et al., 2012). Considering that hundreds of thousands of hectares have been invaded by the weed, it is unlikely that it will be controlled by chemical means alone (Borokini and Babalola, 2012).

iii. Biological control

In recent years, focus has shifted to natural enemies of water hyacinth including plant pathogens (Dagno et al., 2012, Villamagna and Murphy, 2010). The aim of any biological control is not to eradicate the weed, but to reduce its abundance to a level where it is no longer problematic. While there exists several native enemies of water hyacinth, two South American weevil beetles (Neochetina eichhorniae and Neochetina bruchi) and two water hyacinth moth species (Niphograpta albiguttalis and Xubida infusella) have had effective long-term control of water hyacinth in many countries, notably at Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin (Williams et al., 2007, Venter et al., 2012, Gichuki et al., 2012, Dagno et al., 2012). Researchers have identified another tiny insect, Megamelus scutellaris, from South America which is highly host-specific to water hyacinth and does not pose a threat to native or economically important species (Coetzee et al., 2009).

The weevils reduce water hyacinth vigour by decreasing plant size, vegetative reproduction, and flower and seed production. They also facilitate the transfer and ingress of deleterious microorganisms associated with the weevils (both fungi and bacteria) into the plant tissues (Venter et al., 2012).

Control of water hyacinth using fungal pathogens has greatly stimulated interest in the management of the weed. Several fungal species among theme *Cercospora rodmanii, Alternaria alternata* and *A. eichhorniae* are recognized as potential mycoherbicide agents although no commercial mycoherbicide is available for water hyacinth (Dagno et al., 2012).

iv. Reduction by utilisation

Research into the utilisation and related technologies for the control of water hyacinth have been tested over the last few decades (Ndimele et al., 2011). It is being speculated that the biomass can be used in waste water treatment, heavy metal and dye remediation, as substrate for bioethanol and biogas production, electricity generation, industrial uses, medicines, animal feed, agriculture and sustainable development (Patel,

Box 4.1. An example of the benefits of biological control

Between 1991 and 1993, a biological control program of water hyacinth was undertaken in Southern Benin. It consisted of the release of three natural enemies, two weevil species (these are the two *Neochetina* spp.) and one moth that feed exclusively on water hyacinth. In 1999, a survey of 365 men and women from 192 households in 24 villages in the target area revealed that water hyacinth, although not eliminated, was perceived by the villagers as having been reduced from a serious pest to one of minor or moderate importance. At the peak of the infestation water hyacinth had reduced the yearly income of this population of about 200 000 by approximately US$84 million. Lost revenues for men were mostly in fishing, while women experienced lost revenues in trade, primarily food crops and fish. The reduction of water hyacinth cover through biological control was credited with an increase in income of US$30.5 million per year. The total cost of the control program is estimated at a present value of US$2.09 million. The benefits therefore appear to outweigh the costs by a ratio of 124:1 (De Groote et al. 2003).

Ganvié, Benin. Carsten ten Brink / Flickr / CC BY-NC-ND 2.0

2012). However, seldom does utilisation provide a sustained solution to the spread and impact of water hyacinth, and in fact could provide a perverse incentive to maintain the invasive plant to the detriment of the environment and production systems at high economic and social costs. There is not one example from anywhere in the world where utilisation alone has contributed to the management of any invasive plant (EEA, 2012).

Waste water treatment and clean-up of polluted environment

Water hyacinth has the potential to clean up various contaminated waters (Mahamadi and Nharingo, 2010, Rahman and Hasegawa, 2011, Smolyakov, 2012). It can be used to treat wastewater from dairies, tanneries, sugar factories, pulp and paper industries, palm oil mills, distilleries etc. (Jafari, 2010). The plant can absorb into its tissues large quantities of heavy metals from the water column and grows very well in water polluted with organic contaminants and high concentrations of plant nutrients (Chunkao et al., 2012, Ndimele, 2012). In the Ologe Lagoon, Nigeria, water hyacinth that was not deliberately introduced into the lagoon to absorb heavy metals did so, even when the concentration of the heavy metals in the water column was very small (Ndimele and Jimoh, 2011). In California, water hyacinth leaf tissue was found to have the same mercury concentration as the sediment beneath, suggesting that plant harvesting could help mediate mercury contamination (Greenfield et al., 2007). While water hyacinth's capacity to absorb nutrients makes it a potential biological alternative for treatment of agro-industrial wastewater, one of the major challenges is how to properly dispose the vast amount of the plant materials which may have to be considered as toxic waste (Zhang, 2012).

As alternative fuel and energy source

Water hyacinth fulfills all the criteria deemed necessary for bioenergy production – it is perennial, abundantly available, non-crop plant, biodegradable and has high cellulose content; however its strong disadvantage is that it has over 90% water content which complicates harvesting and processing. The biomass can be subjected to biogas production to generate energy for household uses in rural areas (Chuang et al., 2011). Experiments in China show that mixing biomass of water hyacinth with pig manure leads to a much higher biogas production than by using pig manure alone (Lu et al., 2010). It can also be used for producing ethanol, but technical and logistical challenges need to be overcome before the commercial scale ethanol production becomes a reality because of the high tissue water content (Ndimele et al., 2011).

Semi-industrial uses and household articles

As a readily available resource, water hyacinth has been used in several small cottage industries in the Philippines, Indonesia and India for paper, rope, basket, mats, shoes, sandals, bags, wallets, vases, etc (Ndimele et al., 2011, Patel, 2012). Yet these are rarely successful to reduce infestations and the market for these products is far too small to have any impact on water hyacinth populations. In addition, income generation may facilitate its spread to new, uninvaded, water bodies.

Animal feedstock and agricultural use

When sun-dried, water hyacinth has been found to be rich in protein, vitamins and minerals and serves as a high quality feedstock for some non-ruminant animals, poultry and fishery in Indonesia, China, the Philippines and Thailand (Lu et al., 2010, Saha and Ray, 2011). But it is not recommended for use if primarily used for removal of heavy metals and toxic substances from wastewater (Chunkao et al., 2012). Decomposed water hyacinth can also be used as green manure or as compost that improves poor quality soils (Ndimele et al., 2011). However, its high alkalinity (pH>9) and potentially toxic heavy metals contents would restrict its use to flowering-plants, with no allowable application to horticulture for edible vegetables (Chunkao et al., 2012, Zhang, 2012).

What are the implications for policy?

Water hyacinth infestation is a symptom of broader watershed management and pollution problems. It calls for a concise national and transboundary water hyacinth policy designating the plant as noxious weed to aquatic systems. In October 2010, world leaders adopted the Strategic Plan for Biodiversity (2011–2020) targeting the need for identification of invasive alien species and pathways, the need to control and eradicate priority species, and to manage pathways in order to prevent further invasions (CBD, 2010).

Given the complexity of control options and the potential for climate change to assist the spread of water hyacinth, it is critical to develop comprehensive management strategies and action plans. A multidisciplinary approach should be designed, which ensures that the highest political and administrative levels recognize the potential seriousness of the weed. Plans should also state clearly the role of each government department, stakeholders, municipal councils and local community involved in the fight against water hyacinth.

Awareness needs to be raised amongst local communities and all stakeholders on the inherent dangers of water hyacinth infestation to mobilize riparian communities towards control measures. One practical approach is to involve communities in manual and biological control activities, for example, in rearing weevils. There are excellent examples of community involvement in the rearing and distribution of the weevils to control the hyacinth around Lake Victoria.

Methods for water hyacinth control should include reduction of nutrient load in the water bodies through treatment of waters flowing from sewage works, urban wastes and factories. Changing land use practices in the riparian communities through watershed management will help reduce agricultural runoff as a mechanism for controlling the proliferation of water hyacinth. This is considered by many as one of the most sustainable long-term management actions.

In order for policy makers to make informed decisions, much more economic information is required on the costs and benefits of environmental programs. For example, it is frequently stated that there are insufficient resources to control hyacinth. However, if the costs of improved water treatment are compared with the costs of decreased fish catches and the costs of increased water-borne diseases, it is likely that resources needed for hyacinth control are modest in comparison to potential losses from its proliferation (see Box 4.1).

While researchers continue to investigate the perceived potential uses of water hyacinth, the current negative impacts of the weed far outweigh its benefits. The use of water hyacinth as raw material in cottage industry should not encourage propagation of the weed, but rather help control its growth.

Acknowledgement

Writer: Mwangi Theuri[a]

Production and Outreach Team: Arshia Chander[b], Erick Litswa[a], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Mwangi Theuri[a] and Zinta Zommers[a]

Special thanks to Zinta Zommers[a], Anna Stabrawa[a], Frank Turyatunga[a], Neeyati Patel[a], Max Zieren[c], Maxwell Gomera[d] and Arne Witt[e] for their valuable inputs and review.

([a] UNEP/DEWA/Nairobi, [b] UNEP/DEWA/GRID-Sioux Falls, [c] UNEP-ROAP, [d] UNEP-WCMC, [e] CAB International-Nairobi)

References

Ayodo, T. and Jagero, N., 2012. The economic, educational and social responsibilities of elders development groups in lake Victoria region. Academic Research International, 2 (3):610-620.

Bicudo, D., Fonseca, B., Bini, L., Crossetti, L., Bicudo, C. and Araujo-Jesus, T., 2007. Undesirable side-effects of water hyacinth control in a shallow tropical reservoir. Freshwater Biology, 52, 1120–1133.

Biswas, S., Choudhury, J., Nishat, A., Rahman, M., 2007. Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh? Forest Ecol Manag 245:1–9.

Borokoni, T. and Babalola, F., 2012. Management of invasive plant species in Nigeria through economic exploitation: lessons from other countries. Management of Biological Invasions 3 (1): 45–55 doi: http://dx.doi.org/10.3391/mbi.2012.3.1.05.

CBD, 2010. Strategic Plan for Biodiversity 2011–2020. Secretariat of the Convention on Biological Diversity, Montreal. http://www.cbd.int/decision/cop/?id=12268 (accessed 23 April 2013).

Chandra, G., Ghosh, A., Biswas, D. and Chatterjee, S., 2006. Host plant preference of Mansonia mosquitoes. J Aquatic Plant Manage 44:142–144.

Choo, T., Lee, C., Low, K. and Hishamuddin, O., 2006. Accumulation of chromium (VI) from aqueous solutions using water lilies (Nymphaea spontanea). Chemosphere 62:961–996.

Chuang, Y-S., Lay, C-H., Sen, B., Che,n C-C., Gopalakrishnan,. K., Wu, J-H., Lin, C-S. and Lin, C-Y., 2011. Biohydrogen and biomethane from water hyacinth (Eichhornia crassipes) fermentation: effects of substrate concentration and incubation temperature. Int J Hydr Energy 36:14195–14203.

Chunkao, K., Nimpee, C, and Duangmal, 2012. The King's initiatives using water hyacinth to remove heavy metals and plant nutrients from wastewater through Bueng Makkasan in Bangkok, Thailand. Ecological Engineering 39: 40–52.

Coetzee, J., Hill, M., Julien, M., Center, T. and Cordo, H., 2009. Eichhornia crassipes (Mart.) Solms–Laub. (Pontederiaceae). In: Biological Control of Tropical Weeds using Arthropods, (ed). R. Muniappan, G. V. P. Reddy, and A. Raman. Cambridge University Press, Cambridge. 183-210.

Dagno, K., Lahlali, R., Diourte, M., and Haissam, J., 2012. Fungi occurring on waterhyacinth (Eichhornia crassipes [Martius] Solms-Laubach) in Niger River in Mali and their evaluation as Mycoherbicides. J. Aquat. Plant Manage. 50: 25-32.

Dagno, K., Lahlali, R., Friel, D., Bajji, M. and Jijakli, H., 2007. Review: problems of the water hyacinth, Eichhornia crassipes in the tropical and subtropical areas of the world, in particular its eradication using biological control method by means of plant pathogens. Biotechnol. Agron. Soc. Environ. 11 (4): 299-311.

De Groote, H., Ajuonua, O, Attignona, S, Djessoub, R, and Neuenschwandera, P (2003). Economic impact of biological control of water hyacinth in Southern Benin. Ecological Economics, 45 (1): 105 – 117.

DellaGreca, M., Previtera, L. and Zarrelli, A., 2009. Structures of new phenylphenalene-related compounds from Eichhornia crassipes (water hyacinth). Tetrahedron 65:8206–8208.

EEA, 2012. The impacts of invasive alien species in Europe. EEA Technical report No 16/2012. Luxembourg: Publications Office of the European Union, 2012. http://www.eea.europa.eu/publications/impacts-of-invasive-alien-species (accessed 12 March 2013).

Feikin, D., Tabu, C. and Gichuki, J., 2010. Does water hyacinth on East African lakes promote cholera outbreaks? American Journal of Tropical Medicine and Hygiene 83: 370–373. doi:10.4269/ajtmh.2010.09-0645.

Fessehaie, R., 2012. Status of water hyacinth (Eichhornia crassipes) in Ethiopia: Challenges and response. In: Berihun Tefera, Workiye Worie and Melaku Wale(eds.). Proceedings of the Second National Workshop on Challenges and Opportunities of Water Resources Management in Tana Basin, Upper Blue Nile Basin, Ethiopia, 26 – 27 March 2012. Blue Nile Water Institute - Bahir Dar University (BNWI-BDU), Bahir Dar, Ethiopia, 159-166.

Forpah, N., 2009. Cameroon prepares a National Strategy for the control of water hyacinth (exotic species). Workshop proceedings on the elaboration of a national strategy for the control of water hyacinth in Cameroon, 15th – 18th September 2009, Douala, Cameroon. http://wtgpartners.org/ (accessed 12 March 2013).

Gichuki, J., Omondi, R., Boera, P., Tom Okorut, T., SaidMatano, A., Jembe, T. and Ofulla, A., 2012. Water Hyacinth Eichhornia crassipes (Mart.) Solms-Laubach Dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications forWater Quality and Biodiversity Conservation. The ScientificWorld Journal Volume 2012, Article ID 106429, 10 pages doi:10.1100/2012/106429.

Gopal, B., 1987. Aquatic Plant Studies 1. Water hyacinth. Elsevier, Amsterdam.

Greenfield, B.K., Siemering, G.S., Andrews, J.C., Rajan, M., Andrews, S.P., Spencer, D.F., 2007. Mechanical Shredding of Water Hyacinth (Eichhornia crassipes). Estuaries and Coasts. 30(4), 627 - 640.

Hejda, M., Pyšek, P. and Jarošík, V., 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology 97: 393–403.

Jafari, N., 2010. Ecological and socio-economic utilization of water hyacinth (Eichhornia crassipes Mart Solms). J Appl Sci Environ Manag 14:43–49.

Jimeonez, M. and Balandra, M., 2007. Integrated control of Eichhornia crassipes by using insects and plant pathogens in Mexico. Crop Prot 26:1234–1238.

Jones, R., 2009. The impact on biodiversity, and integrated control, of water hyacinth, Eichhornia crassipes (Martius) Solms-Laubach (Pontederiaceae) on the Lake Nsezi – Nseleni River System. Mc Thesis. Department of Zoology and Entomology-Rhodes University. South Africa. 115p.

Kateregga, E., and Sterner, T., 2007. Indicators for an invasive species: water hyacinths in Lake Victoria. Ecol Indic 7:362–370.

Kateregga, E. and Sterner, T., 2009. Lake Victoria fish stocks and the effects of water hyacinth. The Journal of Environment & Development, 18, 62–78.

Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U., ten Brink, P. and Shine, C., 2009. Technical support to EU strategy on invasive species (IAS): assessment of the impacts of IAS in Europe and the EU (final module report for the European Commission). Institute for European Environmental Policy, Brussels.

Khanna, S., Santos, M., Ustin, S., Haverkamp, P., 2011. An integrated approach to a biophysiologically based classification of floating aquatic macrophytes. Int J Remote Sens 32:067–1094.

Lu, J., Zhu, L., Hu, G. and Wu, J., 2010. Integrating animal manure-based bioenergy production with invasive species control: A case study at Tongren pig farm in China. Biomass Bioenerg 34: 821–827. doi: 10.1016/j.biombioe.2010.01.026.

Mahamadi, C. and Nharingo, T., 2010. Competitive adsorption of Pb2+, Cd2+ and Zn2+ ions onto Eichhornia crassipes in binary and ternary systems. Bioresour Technol 101:859–864.

Mailu, A., 2001. Preliminary assessment of the social, economic and environmental impacts of water hyacinth in the Lake Victoria basin and the status of control. In: Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes. ACIAR Proceedings No. 102.

Malik, A., 2007. Environmental challenge vis a vis opportunity: the case of water hyacinth. Environ Int 33:122–138.

Minakawa, N., Sonye, G., Dida, G., Futami, K. and Kaneko, S., 2008. Recent reduction in the water level of Lake Victoria has created more habitats for Anopheles funestus. Malaria J 7:119.

Mironga, J., Mathooko, J. and Onywere, S., 2011. The Effect of Water Hyacinth (Eichhornia Crassipes) Infestation on Phytoplankton Productivity in Lake Naivasha and the Status of Control. Journal of Environmental Science and Engineering 5(10) 1252-1261.

Mironga, J., Mathooko, J. and Onywere, S., 2012. Effect of Water Hyacinth Infestation on the Physicochemical Characteristics of Lake Naivasha. International Journal of Humanities and Social Science 2(7) 103-113.

Mujingni, C., 2012. Quantification of the impacts of Water Hyacinth on riparian communities in Cameroon and assessment of an appropriate method of control: The case of the River Wouri Basin: The Case of the Wouri River Basin. Msc disseratation. World Maritime University, Malmö, Sweden.

MWBP/RSCP, 2006. Invasive Alien Species in the Lower Mekong Basin: Current State of Play. Mekong Wetland Biodiversity Programme and Regional Species Conservation Programme, The World Conservation Union (IUCN), Asia, Sri Lanka; 22pp.

Ndimele, P., Kumolu-Johnson, C. and Anetekhai, M. 2011. The invasive aquatic macrophyte, water hyacinth {Eichhornia crassipes (Mart.) Solm-Laubach: Pontedericeae}: problems and prospects. Res J Environ Sci 5:509–520.

Ndimele, P. 2012. The Effects of Water hyacinth (Eichhornia crassipes [Mart.] Solms) Infestation on the Physico-Chemistry, Nutrient and Heavy Metal Content of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. Journal of Environmental Science and Technology, 5, 128-136. DOI: 10.3923/jest.2012.128.136.

Ndimele, P. and Jimoh, A., 2011. Water Hyacinth (Eichhornia crassipes [Mart.] Solms.) in Phytoremediation of heavy Metal Polluted Water of Ologe lagoon, Lagos, Nigeria. Research journal of Environmental Sciences, 5(5), 424-433. DOI: 10.3923/rjes.2011.424.433.

Patel, S. , 2012. Threats, management and envisaged utilizations of aquatic weed Eichhornia crassipes: an overview. Rev Environ Sci Biotechnol (2012) 11:249–259. DOI 10.1007/s11157-012-9289-4.

Pimentel, D., Zuniga, R. and Morrison, D., 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52(3), 273–288.

Pyšek, P., and Richardson, D., 2010. Invasive species, environmental change and management, and health. Annual Review of Environment and Resources 35: 25–55. doi: 10.1146/annurevenviron- 033009-095548.

Rahel, F. and Olden, J., 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology, 22, 521–533.

Rahman, M. and Hasegawa, H., 2011. Aquatic arsenic: phytoremediation using floating macrophytes. Chemosphere 83:633–646.

Rands, M., Adams, W., Bennun, L., Butchart, S., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J., Sutherland, W. and Vira, B., 2010. Biodiversity conservation: Challenges beyond 2010. Science 329: 1298–1303.

Saha, S., Ray, A.K., 2011. Evaluation of Nutritive Value of Water Hyacinth (Eichhornia crassipes) Leaf Meal in Compound Diets for Rohu, Labeo rohita (Hamilton, 1822) Fingerlings after Fermentation with Two Bacterial Strains Isolated from Fish Gut. Turkish Journal of Fisheries and Aquatic Sciences. 11, 199 - 207.

Shanab, S,, Shalaby, E., Lightfoot, D. and El-Shemy, H., 2010. Allelopathic effects of water hyacinth (Eichhornia crassipes). PLoS One 5(10):e13200. doi:10.1371/journal. pone.0013200.

Smolyakov, B., 2012. Uptake of Zn, Cu, Pb, and Cd by water hyacinth in the initial stage of water system remediation. Appl Geochem. 27(6), 1214 – 1219. doi:10.1016/j. apgeochem.2012.02.027.

Téllez, T., López, E., Granado, G., Pérez, E., López, R., and Guzmán, J., 2008. The water hyacinth, Eichhornia crassipes: an invasive plant in the Guadiana River Basin (Spain). Aquatic Invasions 3, 42-53.

UNEP, 2006. Africa Environment Outlook 2. Division of Early Warning and Assessment, United Nations Environment Programme, Nairobi.

UNEP, 2008. Africa Atlas of our changing environment Division of Early Warning and Assessment (DEWA). United Nations Environment Programme, Nairobi.

UNEP, 2012. Fifth Global Environment Outlook (GEO5): Environment for the future we want. United Nations Environment Programme, Nairobi.

Varshney, J., kumar, S., Mishra, J., 2008. Current status of aquatic weeds and their management in India. In: Proceedings of Taal2007: the 12th world lake conference, pp 1039–1045.

Venter, N., Hill, M., Hutchinson, S. and Ripley, B., 2012. Weevil borne microbes contribute as much to the reduction of photosynthesis in water hyacinth as does herbivory. Biological Control 64 (2013) 138–142.

Vila, M., Espinar, J., Hejda, M., Hulme, P., Jarošík, V., Maron, J., Pergl, J., Schaffner, U., Sun, Y. and Pyšek, P., 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters 14: 702–708.

Villamagna, A. and Murphy, B., 2010. Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. Freshwater Biology (2010) 55, 282–298 doi:10.1111/j.1365-2427.2009.02294.x

Wilgen, B, and Lange, W., 2011. The costs and benefits of biological control of invasive alien plants in South Africa. African Entomology 19(2): 504–514.

Williams, A., Hecky, R., Duthie, H., 2007. Water hyacinth decline across Lake Victoria-Was it caused by climatic perturbation or biological control? A reply. Aquatic Bot 87:94–96.

World Agroforestry Centre, 2006. Improved Land Management in Lake Victoria Basin: ICRAF Occasional paper No. 7. Nairobi; World Agro Forestry Centre.

Xu, H., Qiang, S., Genovesi, P., Ding, H., Wu, J., Meng, L., Han, Z., Miao, J., Hu, B., Guo, J., Sun, H., Huang, C., Lei, J., Le, Z., Zhang, X., He, S., Wu, Y., Zheng, Z., Chen, L., Jarošík, V. and Pyšek, P., 2012. An inventory of invasive alien species in China. NeoBiota 15: 1–26. doi: 10.3897/ neobiota.15.3575.

ZEO, 2008. Zambia Environment Outlook Report 3. Environmental Council of Zambia, 201pp.

Zhang H (2012). Can Water Hyacinth Clean Highly Polluted Waters? —A Short Paper for Discussion. Journal of Environmental Protection 3: 340-341 doi:10.4236/ jep.2012.34043.

Zhang, Y., Zhang, D., Barrett, S., 2010. Genetic uniformity characterises the invasive spread of water hyacinth (Eichhornia crassipes), a clonal aquatic plant. Molecular Ecology 19: 1774-1786.

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

MAY 2013

Thematic Focus: Climate change, Ecosystem management, Environmental governance

A new eye in the sky: Eco-drones

A drone is generally thought of as a military weapon or surveillance tool. Commonly referred to as an unmanned aerial vehicle (UAV), unmanned aerial system (UAS) or remotely piloted aircraft (RPA), a drone can also provide a low-cost and low-impact solution to environmental managers working in a variety of ecosystems. Drones used for these purposes are referred to as 'eco-drones' or 'conservation drones.' Their agility and quality imaging abilities make them advantageous as a mapping tool for environmental monitoring, but there are still several challenges and concerns to be surmounted.

Why is this issue important?

Although many types of satellite imagery are readily available – low resolution for free online (Landsat, MODIS) and high resolution for purchase (WorldView, Quickbird) – they sometimes cannot offer sufficiently high resolution, cover the specific area of study, or capture the time series necessary to fulfill the entire purpose of a project. For several types of situations, satellite imagery and remote sensing analysis are the only way to see what has occurred on the ground, but sometimes the information collected may not be adequate enough. If the image resolution is not high enough to see exact areas of devastation or change, coverage of an entire affected area is not available, or imagery is simply too expensive to acquire, then an analysis will be difficult to complete. The generally low-cost high resolution image capture capability of eco-drones creates the potential for them to fill the data gap between satellites and ground surveying in the aforementioned cases. In addition, eco-drones can do much more than image acquisition, occasionally making them advantageous over typical satellite or aircraft image acquisition.

In addition to image capture, eco-drones can function as a real-time monitoring mechanism for disaster events or illegal resource extraction, distribute broadcast messages and collect and transmit meteorological data (CielMap, 2012).

IMPREZE54 / WIKIPEDIA COMMONS / CC-BY-SA-3.0

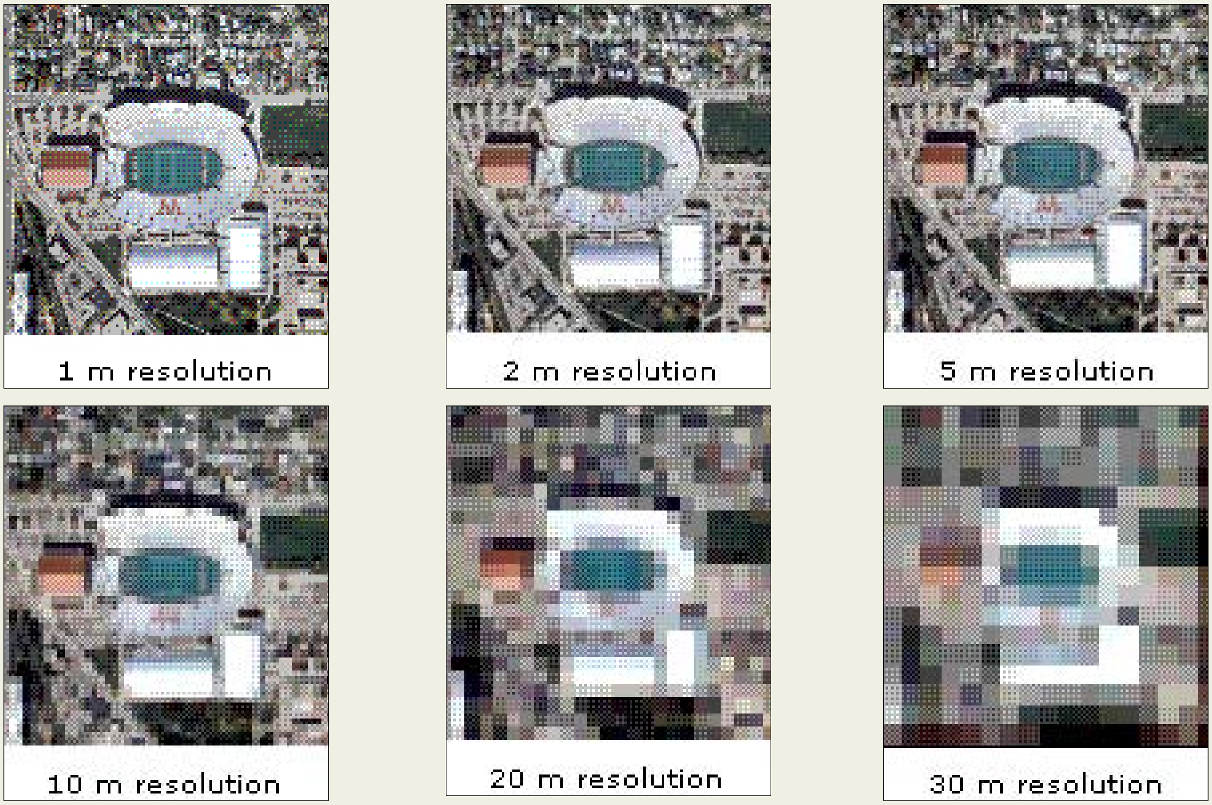
Drones can also fly in riskier and more treacherous areas than humans or manned aircraft can traverse, such as inaccessible shorelines or hurricanes (Nagai et al., 2008, Watts et al., 2012, NOAA, 2012). Due to the size and aerodynamics of drones, they are able to fly at lower altitudes, collecting more precise information than manned aircraft or satellites. This also means that they can fly below clouds making them advantageous in tropical areas where clouds can often impede satellite image collection. A typical UAS can capture images at about 6 cm spatial resolution when flying at an altitude slightly over 200 m (Rango and Laliberte, 2010). With changing ecosystems and disaster dynamics caused by climate change and urbanisation, as well as the elusive presence of environmental crime, on-demand aerial data collection and real-time environmental monitoring will become increasingly important.

What are the findings?

A drone can be defined as a system with 'an aircraft with the capacity to fly semi or fully autonomously thanks to an onboard computer and sensors' (CielMap, 2012). Interest in using drones for scientific investigations dates back to the 1970s in which developments during the Cold War created advantageous uses for drones in the research community (Watts et al.,

PHOTO LEFT: A HEXACOPTER PHOTOGRAPHING THE ATACAMA LARGE MILLIMETER/SUBMILLIMETER ARRAY (ALMA) IN CHILE - ESO / WIKIPEDIA / CC BY 3.0

Box 5.1. Variations in detail based upon image resolution.



Pictured above are several images of the same scene, but with varying spatial resolution. Notice the difference in the amount of detail that an image has as the resolution gets finer (from 30 m to 1 m). Landsat imagery, commonly used for land cover monitoring, has 30 m resolution. Other imagery such as MODIS, which is advantageous for climate monitoring, has resolution much lower (more coarse) than Landsat, ranging from 250 m to 1000 m. Drones can use cameras to capture images with resolution of 1 m or less (see Figure 5.2 in Benefits of high resolution images captured by an eco-drone below). Commercial high resolution imagery, such as WorldView, can also provide similar resolution, but imagery captured by drones can be a lower-cost option that is able to fly as the event occurs and below clouds.

2012). Since then, billions of dollars have been poured into research and development of military and experimental drones, alleviating the commercial market of much of these development costs and enabling the production of a low-cost product that soon will be more widely available and lucrative to the civil and commercial markets (CielMap, 2012).

Advantages	Challenges
Lightweight and easy to transport	Limited flight time depending on model
Low-cost high resolution images	Limited by camera weight
Low-cost operations	Air space limitations and restrictions
Can fly at variety of altitudes depending on data collection needs	Can be limited by wind speed and gusts
Can map areas no accessible by car, boat, etc. on an on-demand time schedule	Limited amount of appropriate software
Video recording capabilities	Time intensive to create ortho-mosaics with minimal geographic reference errors
Quick availability of raw data	Due to small image footprint, numerous images must be captured

Table 5.1. Advantages and challenges associated with drones (Sources: Hardin and Hardin, 2010, Niethammer et al., 2012, CielMap, 2012, Rango and Laliberte, 2010).

Projections for worldwide spending on unmanned aircraft, in all sectors, exceed US$89 billion over the next ten years (Teal Group, 2012). Technology has improved tremendously over time, but still has far to go.

There are a few challenges associated with using drones, such as smaller image footprint (image area), but with further technological exploration and field testing, solutions can be created. Table 5.1 describes the advantages of using a drone as well as the challenges users and operators currently face.

Components of the technology

There are three general classes of drones, the most cost effective being close range, and several different models of drones that vary in size, flight time, camera capability, takeoff and landing needs and altitude flight level (Table 5.2). Drones can vary in wingspan from about 0.5 m to more than 35 m. Altitude is often restricted by government regulations, but some small drones can fly as low as a few hundred metres and some as high as 6,000 m. Large scale drones built for extreme endurance can fly as high as 20 km.

Different models of drones are advantageous for different applications. For example, a fixed wing unmanned aircraft (Figure 5.1A) is best when an extended flight time is required over a long distance. If a small area is being mapped, a multicopter (Figure 5.1B), which can remain stationary, is best to use. Multicopters such as quad-rotors are also useful in areas of rugged terrain (Niethammer et al., 2012).

In addition to the drone itself, a complete unmanned aircraft system also refers to the ground control station and the sensors on board (Watts et al., 2012). The complexity of the ground station varies depending on the size of the drone (NOAA, n.d.). A small drone may only require a few laptops and an operator on the ground, while a larger drone involves more equipment that may be mounted in vehicles or trailers in the study area (Watts et al., 2012).

As the model of a drone varies, so does the type of camera or sensor used for image and information collection. Standard imaging equipment on board consists of a digital camera and a multispectral sensor. Depending on how much weight the drone can manage, additional types of sensors can also be carried onboard. Thermal infrared radiometres, hyperspectral radiometres, Light Detecting and Ranging (LIDAR) instruments and Synthetic Aperture Radars (SAR) can also be carried by drones (Rango and Laliberte, 2010). Images captured from a drone using these cameras and sensors can be stitched together and given a geographical reference much like images from a satellite or a manned plane can be (Hardin and Hardin, 2010).

Characteristic	Close Range	Short Range	Endurance
Range	~50 km	~200 km	>200 km
Flight time	30 min - 20 hrs	8 hrs - 10 hrs	> 24 hrs
Weight	<5 kg	<5,000 kg	<105 t
Speed	~60 km/h	<485 km/h	< 730 km/h
Altitude	<6 km	<16 km	<20 km
Cost (USD)	$500 - $70,000	< $8 mil	<$123 mil

Table 5.2. Characteristics of the three general classes of drones: close range, short range and endurance. (Sources: Lucintel, 2011, Koh and Wich, 2012, CielMap, 2012); t = metric tonnes)

As previously discussed, some types of drones are capable of carrying video cameras, meteorological sensors, communication transmitters, or a combination of the three (CielMap, 2012). Drones equipped with video cameras allow scientists to monitor

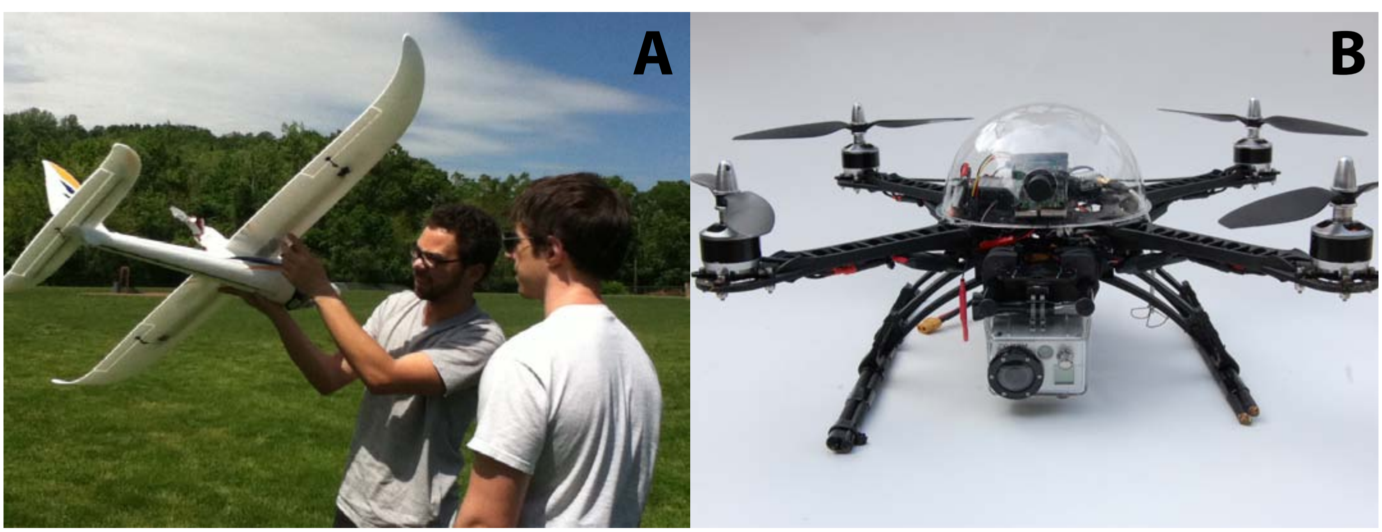
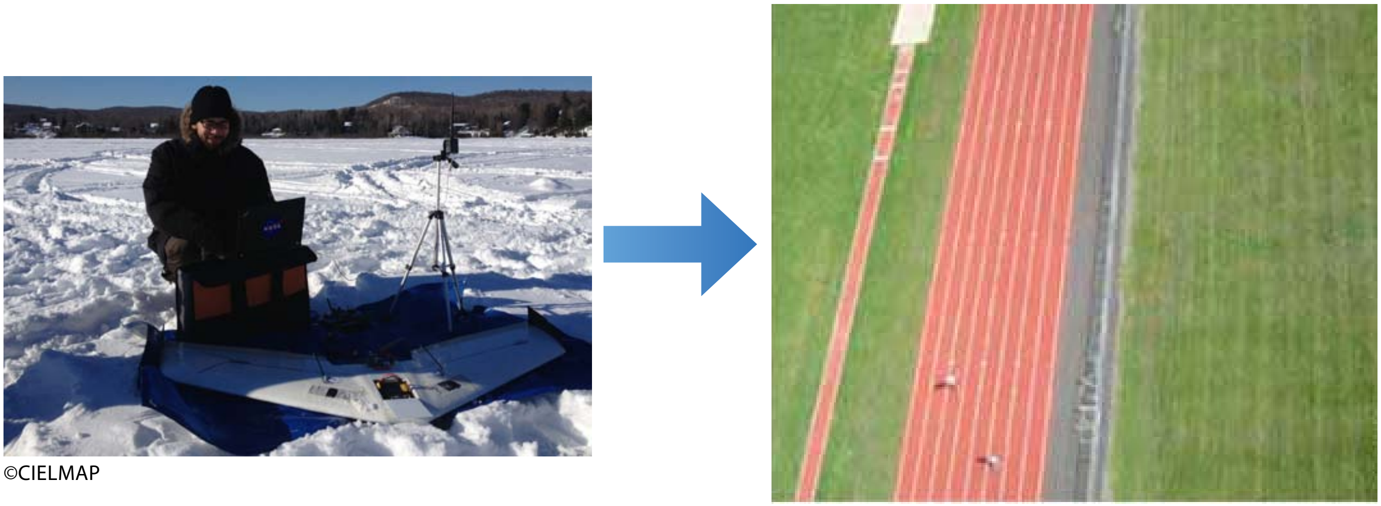


Figure 5.1. Types of unmanned aircrafts (drones). A. Fixed wing; B. Multicopter.



©CIELMAP

©CIELMAP

Figure 5.2. A prototype of a CielMap drone (left image) and a sample high resolution image (right image) taken with the 12 MP camera on board.

disaster situations or biological phenomena such as migration patterns in real time. Law enforcement officials monitoring remote sections of coastline or off-coast areas for illegal fishing can also benefit from a drone with video capability. Meteorological sensors can capture information such as wind, temperature, humidity and pressure (NOAA, 2012). There are many dynamic uses for drones.

Benefits of high resolution images captured by an eco-drone

Niethammer et al. (2012) used drones with a high resolution camera to map fissures on the Super-Sauze landslide in France that had never been mapped before with such detail. Each fissure is approximately 0.1 m in width, making them impossible to detect or measure using satellite data. Using drones enabled the researchers to detect changes in the fissures and draw conclusions they would have had difficulty reaching from the use of satellite imagery. Figure 5.2 shows a drone prototype and an image it took with a 12 megapixel (MP) camera. Future prototypes from CielMap will test 16 MP cameras as well as a three band (RGB) sensor.

Innovative Field Applications

Eco-drones have the potential to supplement data collection efforts and contribute to ecosystem inventory and accounting. Specific environmental and ecosystem applications suitable for the use of a drone can range from precision agriculture, to mapping coastline or soil erosion, to species and habitat monitoring. Drones can be launched into the eye of a hurricane to measure windspeed at altitudes and conditions in which a manned aircraft could not and they can fly over the Artic to observe sea ice conditions and track seal populations (NOAA, 2008). One of the most common civil applications is rangeland management (Rango and Laliberte, 2010). Other environmental applications are described in Table 5.3.

Use of drones for monitoring destructive activities such as poaching and illegal logging have been notably applied in Africa, Asia and South America. At the end of 2012, Google awarded a US$5 million grant to the World Wildlife Fund (WWF) to use drones, alongside other technologies, to monitor illicit trade in Africa by tracking poachers and the wildlife they are pursuing. Referring to the technology as 'remote aerial survey systems,' surveys will be taken of susceptible areas in Africa and Asia where illegal trade is a US$7 - $10 billion industry (WWF,

Change Mapping	Disaster Risk Management	Disaster Risk Mitigation	Illegal Activity	Monitoring
River erosion	Flooding risk	Map impacted areas	Poaching	Migration patterns
Deforestation	Landslide risk	Broadcast messages	Illegal fishing	Endangered species status
Urban Expansion	Volcano eruption risk	Monitor forest fire spread	Illegal trade	Agriculture

Table 5.3. Various environmental applications suitable for the use of a drone.

Box 5.2. Creating a baseline in South Dakota

Hazardous and difficult to reach areas such as fragile coastlines are well suited for drone mapping. The Lower Brule Sioux Tribe (LBST) in South Dakota, USA, has a need to monitor erosion along the western bank of the Missouri River that runs through their reservation. Erosion threatens their recreation and agricultural economy, cultural heritage and intake for their rural water treatment plant. However, the 11.6 km stretch of eroding riverbank cannot safely be accessed by roads or trails. The weak bank and shallow water cannot support motorcraft travel. Therefore, in August of 2011 and 2012, in partnership with the United States Geological Survey UAS Project Office (USGS-UASPO) and the South Dakota Water Science Centre (USGS-SDWSC), the LBST enlisted the aerial mapping technology of UAS Raven. By using a drone equipped with both a still camera and a video camera, baseline conditions could be developed to monitor future changes and bank loss. The image above shows a simple deployment of the drone, without the use of a runway, from a boat offshore of the Lower Brule RV Park. The LBST and USGS – UASPO have used, and will continue to use, the information collected to make educated land management decisions now and in the future (USGS, 2013).

2012). Brazil has purchased 14 drones for US$350 million for the Sao Paul Environmental Police to monitor deforestation in the Amazon, track poachers and seek out illegal mining operations (Cohen, 2011).

The growing occurrences of deforestation and forest degradation worldwide could be more precisely monitored and measured with the use of drones. Member countries of programmes such as the United Nations collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) could benefit from the monitoring capabilities of drones to measure and report deforestation, using the data to calculate forest carbon emissions more accurately. The option of a low-cost drone would be extremely beneficial to governments or organisations with small budgets seeking to fulfill REDD+ requirements.

Early warning applications

Quick, easy deployment and ability to enter hazardous areas make drones a beneficial tool for collecting real-time data about atmospheric conditions, mapping disaster impacts as they occur and their aftermath. This information can be incorporated into current and future early warning systems. Drones can provide information to emergency planners by monitoring evacuation, identifying where environmental conditions are worsening (i.e. flood spreading) and contribute to rescue efforts serving as an emergency response mechanism.

TURRIALBA VOLCANO, COSTA RICA - ZETABASE / FOTER.COM / CC BY-NC

Rapid urbanisation and road construction in China have led to increased frequency and intensity of landslides along highways and roadways (Huang et al., 2011). With more social and economic growth anticipated in China, more roads will be built. Therefore, it is necessary for China to work towards mitigating disasters induced by road construction. Drones can be used to monitor highways vulnerable to landslides, using high resolution cameras to detect cracks that may indicate the onset of a landslide and sensors to detect changes in stress. Once detected, data collected from the drone can be used by authorities to initiate early warning allowing people currently in the area to escape and those travelling to the area to avoid the disaster event before it occurs.

The National Aeronautics and Space Administration (NASA) recently flew a drone into the sulfur dioxide plume and over the vent of the Turrialba Volcano in San Jose, Costa Rica (pictured top) to collect data about its volcanic emissions (NASA, 2013). Determining temperature, ash height and gas concentrations (such as sulfur dioxide) over the vent can help scientists predict the direction of the volcanic plume. Manned aircraft would not be able to collect this type of data because the engines would ingest the ash emitted from the volcano, ruining the engines and proving the effort obsolete.

Information collected from these missions helps to reduce the impact of potential environmental hazards such as volcanic smog (sulfur dioxide), which can be harmful to people living near the volcano and can eventually be used for early warning.

The use of drones for early warning of forest fires has been tested by several federal agencies in the USA. By collecting data about forest fires, the public can be alerted of impending danger and firefighters can better plan for how to attack the fires. While helicopters and manned planes could collect similar information, pilot projects conducted by the United States Forest Service (USFS) have proven that UAS technology has a place in wildland fire-fighting especially when considering flight costs, contract requirements, regulations and operations (Hinkley and Zajkowski, 2011). The United States Department of Agriculture (USDA) and NASA have used a drone named Ikhana (pictured above) to gather information that helps fight raging forest fires in California, USA (NASA, 2010). Ikhana has a wingspan of about 20 m, is 11 m in length and can carry more than 180 kg of sensors internally and over 900 kg in pods under its wings. It is designed for long endurance flights at higher altitudes, typically flying at an altitude of 12 km, allowing it to gather a significant amount of data over a long period of time and at an altitude high enough to stay out of the heat of the fires (NASA, 2007). Ikhana is also being used to test new capabilities and advance its technological capabilites to improve the design and function of drones.

NASA'S IKHANA DRONE - NASA

What are the implications for policy?

As UAVs become more prevalent in the public and private sectors for research and non-military surveillance, many policy considerations will need to be made. According to a 2012 United States Government Accountability Office (GAO) report, the number of countries with a UAV system for military, commercial, or civil use grew from 41 countries in 2004 to 76 countries by 2011 (GAO, 2012). Tremendous cooperation between nations in regards to airspace jurisdiction will be necessary in the future as eco-drones, and other research drones, become more commonplace. Policy creation and enforcement for demarcation of eco-drones is necessary for communicating to people on the ground that the drones are safe, only for research and to be clearly visible to other air traffic. Future regulations will need to address weight and size of the drones. Data sharing standards will need to be created if data is collected in airspace not native to the research team. Regulations specific to drones used for environmental modeling or research will need to be developed, implemented and enforced with heavy regard to public safety and privacy (Rango and Laliberte, 2010).

Currently, within American airspace, some universities and research establishments in the public and private sector are able to fly drones for purposes that appeal to public interests, such as disaster relief, search and rescue and border patrol (FAA, 2013). To fly a drone, the public sector must obtain a Certificate of Waiver or Authorisation (COA) and the private sector must obtain an experimental airworthiness certificate in addition to following many regulations (FAA, 2013). For both sectors, drones may not be flown over densely populated areas to ensure public safety. For the USA, a better understanding of the systems, operations and technology will be gained over the next few years as the Federal Aviation Administration (FAA) works towards fully integrating UASs into the National Airspace System (NAS) by 2015 (FAA, 2012).

On a global scale, UAV manufacturing and export as well as licensing will need to be regulated to ensure that purpose remains ethical and legitimate and does not violate public safety and privacy (GAO, 2012). European regulations generally coincide with those of the USA, but requirements among most other countries vary considerably (Watts et al., 2012).

Acknowledgement

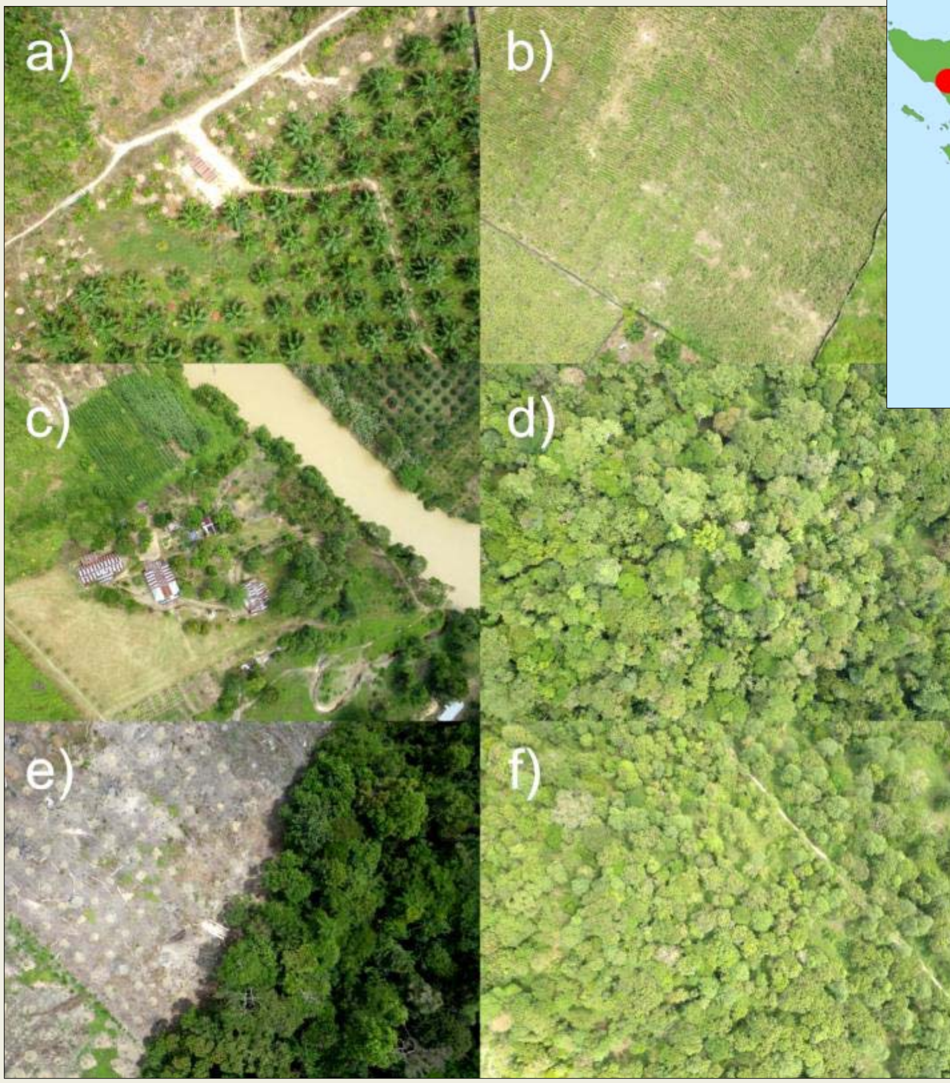
Writers: Lindsey Harriman[a] and Joseph Muhlhausen[b].

Production and Outreach Team: Arshia Chander[b], Erick Litswa[a], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Mwangi Theuri[a] and Zinta Zommers[a]

Special thanks to Ashbindu Singh[a,c], Arshia Chander[a], Zinta Zommers[c], Andrea Salinas[d] and Shelley Robertson[e] for their valuable inputs and review and to the USGS-UASPO for their photo contribution.

([a] UNEP/DEWA/GRID-Sioux Falls; [b] CielMap; [c] UNEP/DEWA-Nairobi; [d] UNEP/DEWA-LAC; [e] University of Toronto, Munk School of Global Affairs)

Box 5.3. Conservation mapping in Sumatra



To the left are images captured by a drone used in this study:

a) Young palm plantation

b) Maize field

c) Elephant Patrol Unit camp

d) Forest

e) Recently logged forest

f) Forest trail

In Aras Napal, Sumatra, Indonesia, Koh and Wich (2012) used a low-cost drone (less than US$2,000) to achieve real-time mapping of rainforest loss and biodiversity. This area is an important habitat for Sumatran orangutans, elephants and tigers. The drone used both a still camera capable of taking images with less than 10 cm resolution and high definition video. The drone flew at an altitude of 180 m at a speed of 10 m/s. The camera was programmed to take an image every 10 seconds. The high resolution images enabled the researchers to easily differentiate land use types, detect individual orangutans and elephants and identify specific plant species. The video footage contributed additional information about events occurring at the time, including capturing footage of fire that local patrols could use to track its spread (Koh and Wich, 2012).

References

CielMap, 2012. Low-Cost Unmanned Aircraft Systems for Development Projects: A quiet revolution. Presentation, Sciences Po Paris.

Cohen, M.J., 2011. Brazilian Eyes in the Sky Focus on the Disappearing Rainforest. Scientific American. http://www.scientificamerican.com/article.cfm?id=brazilian-eyes-in-the-sky-focus-on-2011-10 (accessed 25.04.2013).

FAA, 2012. FAA Makes Progress with UAS Integration. Federal Aviation Administration. http://www.faa.gov/news/updates/?newsId=68004 (accessed 18.04.2013).

FAA, 2013. Fact Sheet – Unmanned Aircraft Systems (UAS). Federal Aviation Administration. http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14153 (accessed 18.04.2013).

GAO, 2012. Agencies Could Improve Information Sharing and End-Use Monitoring on Unmanned Aerial Vehicle Exports. United States Government Accountability Office. Available online: http://www.gao.gov/assets/600/593131.pdf.

Hardin, P.J. and Hardin, T.J., 2010. Small-scale remotely piloted vehicles in environmental research. Geography Compass. 4(9), 1297-1311.

Hinkley, E.A. and Zajkowski, T., 2011. USDA forest service – NASA: unmanned aerial systems demonstrations – pushing the leading edge in fire mapping. Geocarto International. 26(2), 103 – 11.

Huang, Y., Yi, S., Li, Z., Shao, S., Qin, X., 2011. Design of highway landslide warning and emergency response systems based on UAV. Proc. SPIE 8203, Remote Sensing of the Environment: The 17th China Conference on Remote Sensing, 820317. http://dx.doi.org/10.1117/12.910424.

Koh, L.P. and Wich, S.A., 2012. Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. Tropical Conservation Science. 5(2), 121-132. Available online: www.tropicalconservationscience.org.

Lucintel, 2011. Growth Opportunity in Global UAV Market. Lucintel Brief. Available online: http://www.lucintel.com/LucintelBrief/UAVMarketOpportunity.pdf.

MAIC, 2004. Remote Sensing Resolution. Mine Action Information Center Spatial Information Clearinghouse. http://maic.jmu.edu/sic/rs/resolution.htm (accessed 21.04.2013).

Nagai, M., Chen, T., Ahmed, A., Shibasaki, R., 2008. UAV Borne Mapping by Multi Sensor Integration. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing. pp. 1215-1222.

NASA, 2007. Ikhana Unmanned Science and Research Aircraft System. National Aeronautics and Space Administration. http://www.nasa.gov/centers/dryden/news/FactSheets/FS-097-DFRC.html (accessed 19.04.2013).

NASA, 2010. NASA's Ikhana Aircraft Helps Fight 1,000+ California Fires. National Aeronautics and Space Administration. http://www.nasa.gov/offices/ipp/centers/dfrc/news_events/SS-Ikhana.html (accessed 18.04.2013).

NASA, 2013. NASA flies Dragon Eye unmanned aircraft into volcanic plume. National Aeronautics and Space Administration. http://climate.nasa.gov/news/891 (accessed 19.04.2013).

Niethammer, U., James, M.R., Rothmund, S., Travelletti, J., Joswig, M., 2012. UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results. Engineering Geology. 128, 2-11.

NOAA, n.d. NOAA Unmanned Aircraft Systems Program. National Oceanic and Atmospheric Administration. http://uas.noaa.gov/(accessed 18.04.2013).

NOAA, 2008. NOAA Invests $3 Million for Unmanned Aircraft System Testing Pilotless Craft Gather Data for Hurricane Forecasts, Climate, West Coast Flood Warnings. National Oceanic and Atmospheric Administration. http://www.esrl.noaa.gov/news/2008/uas.html (accessed 18.04.2013).

NOAA, 2012. NOAA Scientists Part of NASA-Led Mission to Study the Damaging Storms with Unmanned Aircraft, New Instruments. National Oceanic and Atmospheric Administration. http://uas.noaa.gov/news/target-hurricanes.html(accessed 19.04.2013).

Rango, A. and Laliberte, A., 2010. Impact of flight regulations on effective use of unmanned aircraft systems for natural resources applications. Journal of Applied Remote Sensing. 4(1).

Teal Group, 2012. Teal Group Predicts Worldwide UAV Market Will Total $89 Billion in its 2012 UAV Market Profile and Forecast. Teal Group Corporation. http://tealgroup.co/index.php/ (accessed 19.04.2013).

USGS, 2013. UAS Raven flight operations to monitor bank erosion on the Lower Brule Reservation in South Dakota. United States Geological Society. http://rmgsc.cr.usgs.gov/UAS/missouriRiverErosion.shtml (accessed 18.04.2013).

Watts, A.C., Ambrosia, V.G., Hinkley, E.A., 2012. Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use. Remote Sensing. 4(6), 1671 – 1692.

WWF, 2012. Google Helps WWF Stop Wildlife Crime. World Wildlife Fund. http://worldwildlife.org/stories/google-helps-wwf-stop-wildlife-crime?utm_source=twitter.com (accessed 18.04.2013).

JUNE 2013

Thematic Focus: Climate change, Ecosystem management, Environmental governance

Balancing economic development and protecting the cradle of mankind - Lake Turkana basin

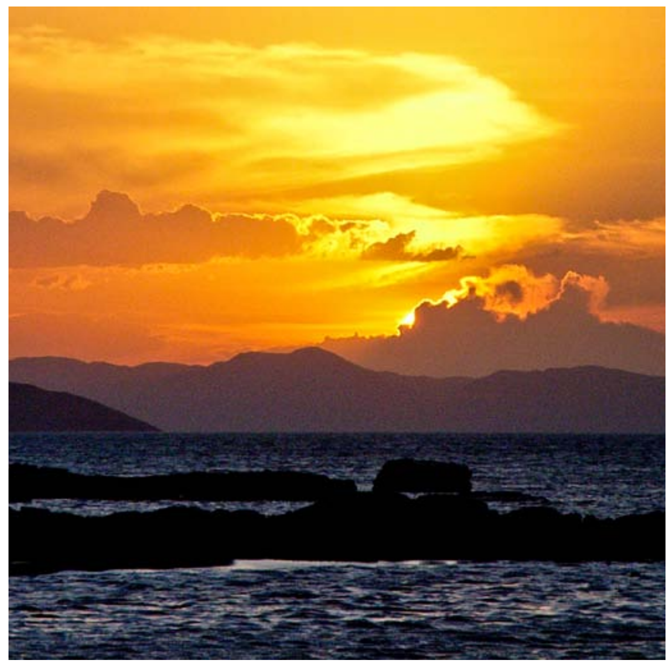
Cooperation on the Omo-Turkana transboundary water issues needed

A number of transboundary water agreements exist in Africa. However, many of these agreements are limited to larger basins such as the Nile, Niger, Senegal or Volta. There are very few international river basin agreements or cooperative arrangements in the small transboundary basins where development activities such as dam building and/or irrigation development are currently taking place. Such changes affect water redistribution and could pose, on one hand, a potential threat for conflict, on the other hand, could provide opportunities for cooperation.

Why is this issue important?

The United Nations (UN) General Assembly has declared 2013 as the United Nations International Year of Water Cooperation. The objective of this International Year is to raise awareness, both on the potential for increased cooperation, and on the challenges facing water management in light of the increase in demand for water access, allocation and services. The Year will highlight the history of successful water cooperation initiatives, as well as identify key issues on water education, water diplomacy, transboundary water management, financing cooperation, national/international legal frameworks, and the linkages with the Millennium Development Goals (MDG).

The Intergovernmental Panel on Climate Change (IPCC) Technical Paper on Climate Change and Water stressed the fact that increased demand and reduced availability of fresh water under global climate change will significantly affect global food security in the 21st century (Bates et al., 2008).



GAKIGE / FOTER / CC BY-NC-ND

Furthermore, Wolf et al. (1999) emphasised that the challenges to integrated watershed management are compounded when water resources cross international boundaries. Both regional and cross-sectorial cooperation are important for addressing the water-food-energy nexus in transboundary basins.

Transboundary basins and water cooperation in Africa

Compared to the other continents in the world, Africa has the highest percentage of land area (62%) within transboundary basins. It is interesting to note that with the obvious exception of island states, all sub-Saharan African countries share at least one international river basin. In fact, the region has more transboundary river basins than countries. Depending on the source, there are about 61 to 80 transboundary river and

PHOTO LEFT: LAKE TURKANA - WASHING FISH - WORLDFISH / FOTER.COM / CC BY-NC-ND

Figure 6.1: Major transboundary basins in Africa. Source: UNEP, 2010.

lake basins in Africa. Figure 6.1 shows major transboundary river basins (small international basins are not shown). This accounts for around one fourth of the total transboundary basins and about one-third of the world's major international river basins (basins larger than 100,000 km^2).

A number of transboundary water agreements exist in Africa. For example, according to Lautze et al. (2005), there were up to 15 agreements in the Nile River basin between 1925 and 2003, 6 in the Senegal River basin between 1963 and 1988, 10 in the Niger River basin and 3 in the Volta River Basin over the last several of decades. Although several other agreements or cooperation arrangements exist which serve different objectives and purposes, such agreements and cooperative use of water has been limited to the large international river basins. Presence of very few international river basin agreements or cooperative arrangements in the smaller international transboundary basins poses a potential threat to water conflict as smaller international basins are currently experiencing basin developmental activities such as dam building and irrigation development.

Hydropower projects in Africa

Hydropower contributed up to 16.5% of the global electricity production, or up to 3/4 of the total global estimated renewable energy share, by the end of 2012 (REN21, 2013).

Based on multiple sources, the Renewable 2013 Global status report summarised that globally, hydropower generated an estimated 3,700 TWh of electricity during 2012, including approximately 864 TWh in China, followed by Brazil (441 TWh), Canada (376 TWh), the United States (277 TWh), the Russian Federation (155 TWh), Norway (143 TWh), and India (>116 TWh).

It is estimated that globally, approximately two-thirds of the economically feasible potential locations for dam construction remain to be developed. Untapped hydro resources are still abundant in Latin America, Africa, India and China. Africa has plentiful water resources for hydroelectricity and can boost energy security and economic development by increasing hydropower development with appropriate social and environmental safeguards. Currently electricity production in Africa is the lowest in the world. Although Africa has the second largest population after Asia, it has the lowest energy consumption per capita of any continent. Many African nations have per capita electricity consumption of less than 80 kWh/yr compared to 26,280 kWh/yr in Norway, 17,655 kWh/yr in Canada and 13,800 kWh/yr in the United States (Bartle, 2002). Technically, feasible hydropower, estimated at nearly 15,000 TWh/yr, still exists in the world today. However, it is mostly in countries where increased power supplies from clean and renewable sources are most urgently needed to progress social and economic development (Kaygusuz, 2004). The technically feasible hydropower potential of Africa is around 1,750 TWh which is about 12% of the global capacity. However, only about 4% of this technically feasible potential had been exploited by 2002 (Bartle, 2002).

Thus, Africa is referred to as an "under-dammed" continent (The Economist, 2010). Only 3% of its renewable water is used, against 52% in Asia and 21% in Latin America. Figure 6.2 shows the growth of dams between years 1900 – 2000 globally. As shown by the red dashed line in Figure 6.2, the number of dams in Africa (around 1,200) by the end of 20th century is equal to the number of dams that were built in

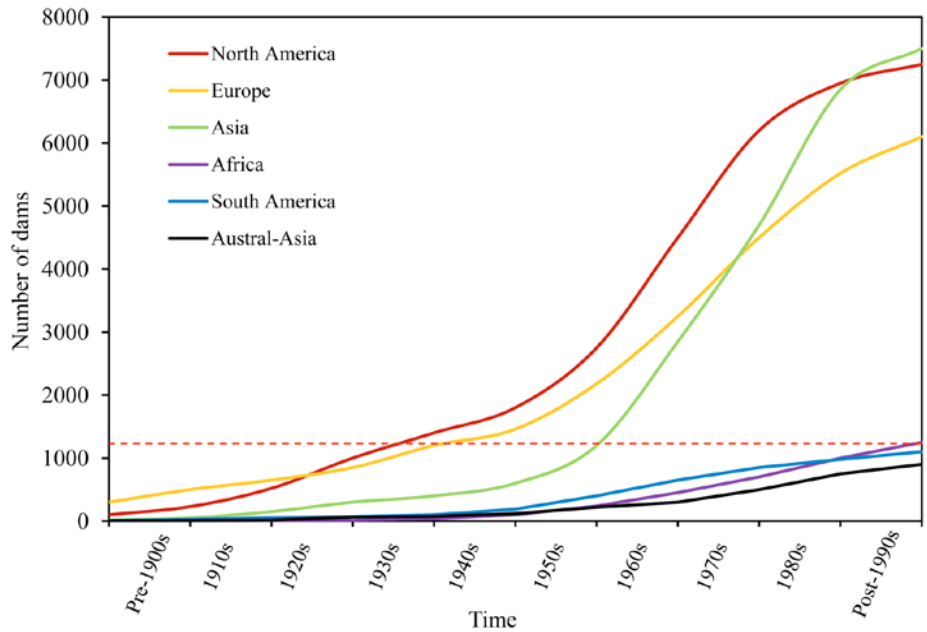


Figure 6.2: Global distribution of dams between years 1900 – 2000. Source: modified from WCD, 2000.

Note: Information excludes the time-trend of dams in China. The red dashed line compares the number of dams in Africa by the end of 20th century with other continents.

BOATS ON THE SHORE OF LAKE TURKANA -NAGA MANOHAR VELPURI/ UNEP GRID-SIOUX FALLS 2011

North America or Europe by mid-1940s or in Asia by the end of 1950s. A green revolution in Africa would not be possible without increasing water storage and availability.

Although several new dam projects are currently underway in African nations, many of them are happening in the international river basins which do not have transboundary agreements in place. Here we are highlighting the example of Gibe dams in Ethiopia and their potential impact on Lake Turkana water levels. Also, the need for a transboundary water cooperation and management arrangement or mechanism in the Lake Turkana basin is stressed.

Lake Turkana basin – the cradle of mankind

Lake Turkana is the largest saline lake among the most northerly of the Rift Valley lakes; its watershed extends into Ethiopia, Kenya, South Sudan and Uganda (Figure 6.3). The lake is 250 km long, 15–30 km wide, has an area of nearly 7,000 km^2 and is the fourth largest lake in Africa by volume. It has a maximum depth of 125 m and an average depth of 35 m. It is believed that this is where human life is expected to have begun, therefore the Lake Turkana area is considered the cradle of mankind (Amin, 1983).

More than 80 per cent of inflows to the lake come from the Omo River in Ethiopia (Cerling 1986; Ricketts and Johnson, 1996). The Omo River is perennial and flows nearly 1,000 km from north to south before ending in Lake Turkana. Most of the remaining inflows come from two southern tributaries, the Turkwel and Kerio Rivers. Lake Turkana is considered an endorheic or closed lake because there is no surface outlet and insignificant seepage. The outflow is almost wholly dominated by evaporation. The annual loss through evaporation is estimated to be around 2.4 m (Velpuri and Senay, 2012). Rainfall over the lake can be as low as 200 mm/year (UNEP, 2013).

Lake Turkana's water levels usually show seasonal fluctuations of 3–4 m. Generally, the annual amplitude of lake-level fluctuation is 1–1.5 m, but it also undergoes considerable long-term variations that exceed those of any other lakes of natural origin (Butzer, 1971).

Paleolimnological studies indicate that during the Holocene period, the lake level was about 60–80 m higher than the present-day level and that it was connected to the Nile River (Yuretich, 1979). The current lake has no outlet and the mean lake level is 360 m above sea level. In 1988, Kallqvist et al.

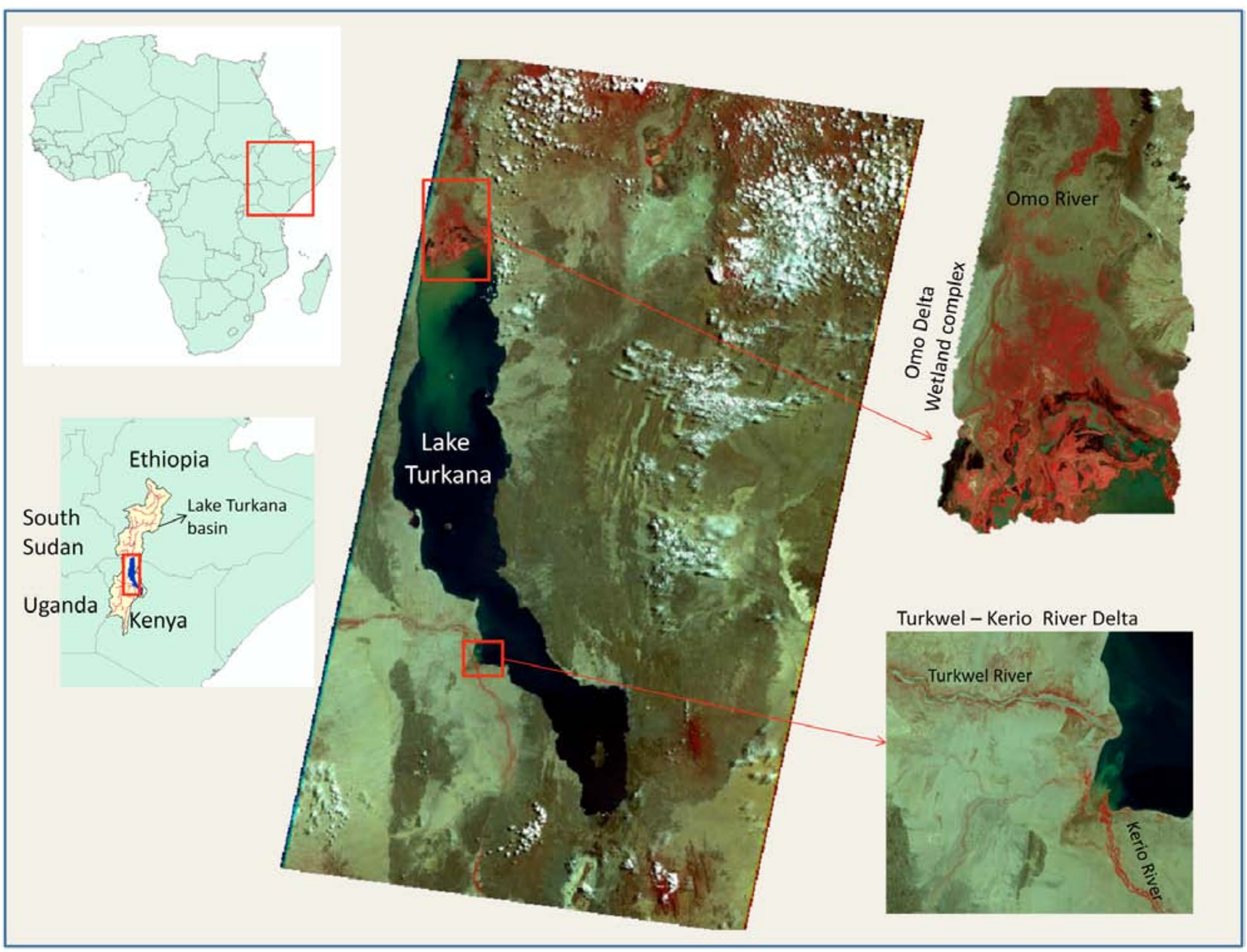


Figure 6.3: Location of Lake Turkana - the cradle of mankind - located in East Africa; insets show Lake Turkana and Omo, Turkwel and Kerio River Deltas.

OMO RIVER - NAGA MANOHAR VELPURI/ UNEP GRID-SIOUX FALLS 2011

(1998) synthesised Lake Turkana's water levels for the previous 100 years and concluded that around 1895, the lake was about 20 m higher than in 1988. The lake declined gradually during the first half of the 20th century, reaching its lowest level in the 1950s, after which there was a rapid increase in the 1960s through the 1970s, with the peak level attained during late 1970s and early 1980s (Figure 6.4).

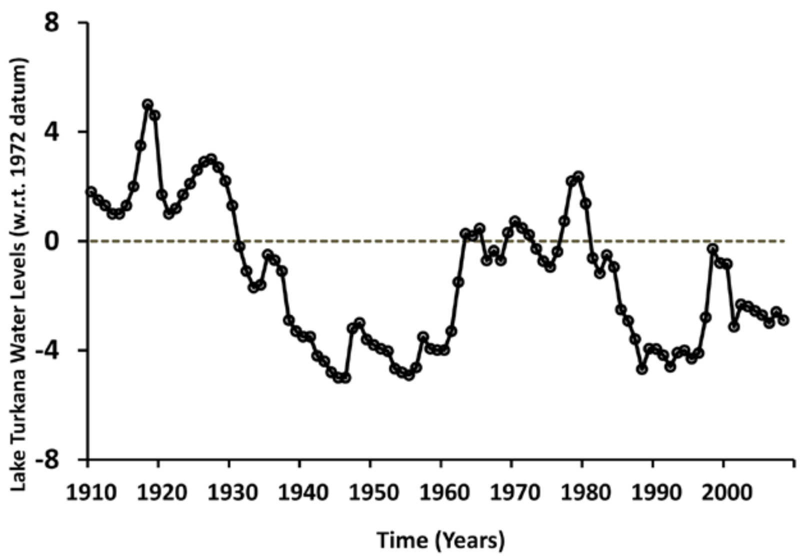


Figure 6.4: Lake Turkana water levels in the 20th century. Source: Data from Kenya Marine and Fisheries Research Institute (KMFRI).

The Gibe hydroelectric power projects in Omo River basin, Ethiopia

With abundant rainfall and suitable physical features, Ethiopia has several potential sites for hydropower development. The Ethiopian government has started building a series of dams on the Omo River, primarily to meet the demands of the power industry in the East African region. These dams on the main Omo River and its tributaries will also regulate the flow of water into Lake Turkana. Gibe I and Gibe II are already commissioned and operational. Gibe III is now under construction and Gibe IV and Gibe V are proposed dams.

The Gilgel Gibe I dam (Gibe I), the hydroelectric project with 184 MW capacity, was built in 2004 on the Gilgel Gibe River, a small tributary of the main Gibe River, which flows into the main Omo River (Figure 6.5). Commissioned in 2010, the Gibe II hydroelectric plant channels the water already impounded by the existing Gibe I hydroelectric plant through a 26-km long tunnel directly into the Gibe-Omo River. The resulting 500 m head is used to generate 420 MW of electric power. As this project does not impound any water itself, it is assumed to have no substantial impact on Lake Turkana water levels.

The Gibe III dam is located on the Omo River around 150 km downstream of the Gibe II outlet. Near the dam, the area is characterised by a large plateau with a long and relatively narrow canyon through which the river flows (The Gilgel Gibe Affair, 2008, Velpuri et. al., 2012, UNEP, 2013). Upon completion, a 150-km dammed reservoir will be created, flooding the canyon from the dam upstream on the Gibe River, retaining about 14.7 billion m^3 of water at maximum capacity, which is equivalent to the total annual flows in Omo River. When construction of the Gibe III dam is completed, it will be the tallest dam in Africa. It is estimated that the dam will be completed by the end of 2014 and possibly be operational

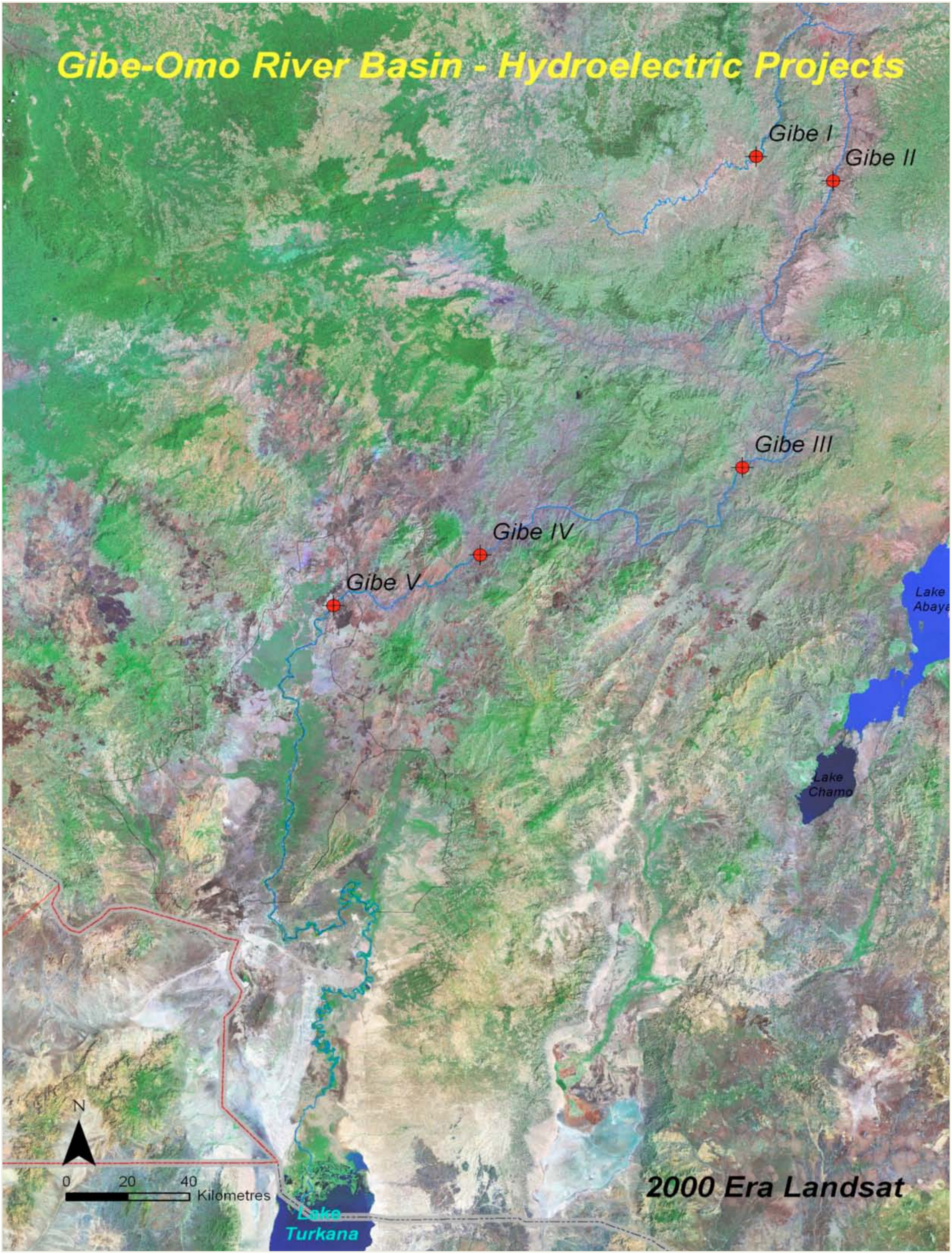


Figure 6.5: Map of Turkana basin north of Lake Turkana and the cascade of the Gibe reservoirs.

by mid-2014. The mean annual inflow or discharge into the reservoir is estimated to be 438 m^3/s (13,800 million m^3/year) with seasonal inflows varying from less than 60 m^3/s in March to over 1,500 m^3/s in August. In terms of power generated, the capacity of Gibe III is around 8% of the capacity of the Three Gorges hydroelectric project in China (22,500 MW), the largest in the world. Despite its smaller size/capacity with respect to the annual Omo River flows, there is a need to evaluate the likely environmental, ecological, hydrological and social impacts of the Gibe III dam on downstream water resources within the Turkana basin to avoid and/or to mitigate any adverse impacts. Once evaluated, suitable management strategies can be developed.

What are the findings?

Gibe III impact assessment on Lake Turkana water levels

Recently, UNEP published a report which is based on a study that used satellite-based data and a robust modeling approach to shed light on some aspects of the hydrologic impact of Gibe III hydroelectric dam on Lake Turkana water levels (UNEP, 2013).

The focus of the UNEP study was to understand the impact of the Gibe III on Lake Turkana water levels using multi-source satellite data and hydrologic and statistic modeling approaches. In this study, the impact assessment was performed beyond the first impoundment period. The report also identified potential impacts of the dam under different future scenarios of rainfall using three different approaches: historical, knowledge based and nonparametric resampling. This study incorporated the operational strategies for the Gibe III dam published by the Ethiopian Electric Power Corporation. This study analysed average inflows into Lake Turkana using data from 1998–2009. The average rate of inflows into the lake was found to be around 650 m^3/s (wet season flow rate of more than 1,500 m^3/s and dry season flow rate of 150 m^3/s). During 1992–2010, Lake Turkana's water level fluctuated between 360 m and 365 m above sea level. The potential impact of the Gibe III dam was assessed for a period of 12 years from the commencement of the dam using three different approaches; consistent results were obtained from all three. The key findings from this study are:

The Gibe III reservoir would reach the Minimum Operational Level (MOL) of 201 m in 8–10 months. During this initial impoundment period, it was found that the rate of inflow into Lake Turkana would be 42% of the average flow. This is because the area of Lake Turkana basin upstream of Gibe III dam (catchment of Gibe III) contributes up to 58% of the Lake Turkana inflows. The total estimated impounded volume of the Gibe III reservoir will be equal to 6% of the Lake Turkana volume.

GIBE III DAM SITE - NAGA MANOHAR VELPURI/ UNEP GRID-SIOUX FALLS 2011

- However, after the initial impoundment period, because of the Gibe III dam, the peak flows into the lake are reduced and dry season flow was increased with a dam moderated average flow rate of 640 m^3/s, which was only 10 m^3/s less than average lake inflows without Gibe III.
- During the first impoundment period (8-10 months) Lake Turkana would lose an average of 1 m due to reduction in the lake inflows. After the first impoundment period, Lake Turkana would lose up to 1.8 m over the 12-year analysis period.
- Based on the analysis of evapotranspiration data from 2001–2009, Gibe I and Gibe III would lose up to 1.34 m/yr and 1.46 m/yr of water, respectively, due to evaporation. On the other hand, evaporation losses from Lake Turkana would account for up to 2.4 m/yr.
- Due to the regulation of lake inflows, the dam would have a greater impact when the basin receives above-normal rainfall and a smaller impact when the basin receives below-normal rainfall.
- Changes in the shoreline or surface area are associated with the lake-level variations. This study identified 'hot spots' of shoreline change, such as the Omo River Delta, Ferguson's Gulf and the Turkwel–Kerio River Deltas, which will show possible shrinking and expansion due to construction of the Gibe III dam.
- This study indicated that under a below-normal rainfall scenario, the lake level would decline which could cause the lake shoreline to recede up to 2 km along 'hot spot' areas. A

normal rainfall scenario would result in minimal shoreline changes and an above-normal rainfall scenario would expand the lake up to 3 km along the 'hot spot' areas.

- Based on the model simulation, the impact of the Gibe III dam on Lake Turkana water levels was found to be within the natural variability of the lake observed since 1992.

This report (UNEP, 2013) also provides background information on hydroelectric projects in Africa, Gibe hydroelectric projects in Ethiopia, climatic and physical factors in the Turkana basin that influence the lake levels and a detailed description of the methodology used to model the potential impact of Gibe III on Lake Turkana water levels.

The use of satellite-based data to estimate runoff and evapotranspiration in this study made the modeling approach consistent and robust, especially for a basin where long-term historical runoff and climate data are scarce. The results obtained under different scenarios would be of great use to planners and others assessing the hydrological and environmental impacts of the dam under future climatic uncertainty.

However, this case study only considers the hydrologic impact of Gibe III dam on Lake Turkana water levels and does not include the potential irrigation scenarios from the Omo River. This kind of in depth scientific analysis has not been done before. It provides a starting point for commencement of further ground based studies on the lake and its environments. The impact of Gibe dams would vary if additional developments, such as large scale irrigation, occurred, resulting in permanent removal of water from the Omo River.

What are the implications for policy?

Fader et al. (2013) reports that up to 1.3 billion people may be at risk of food insecurity by 2050 in present low-income economies (mainly in Africa), if their economic development does not allow them to afford productivity increases, cropland expansion and/or imports from other countries. Fader et al. (2013) further claim that it would only be possible to secure food security by cropland expansion, or by productivity improvements in Africa. However, the key question to answer is 'How will African countries expand croplands or increase productivity unless they have enough water storage capacity?' A way forward is to increase water availability through large and/or small dams. However, a comprehensive assessment, which includes hydrological, ecological and economic factors, must be taken up for each project. In addition to such assessment studies, transboundary water agreements must be considered by the respective governments.

In the Turkana basin, several research studies (Avery, 2010, 2012; Velpuri and Senay, 2012; UNEP, 2013) have indicated that the impact of some of these dams (Gibe I or Gibe III) on Lake Turkana water levels would be minimal or within the natural variability of the lake if water is only used for hydropower generation. However, these studies have also highlighted that the impact of the Gibe dams would vary if additional developments (such as irrigation), which would result in permanent removal of water from Omo River are undertaken. Further studies, which would include the assessment of eco-hydrological impacts of the dam, potential irrigation projects and accompanying socioeconomic changes in the basin, should be carried out in collaboration with the Lake Turkana basin countries and stakeholders. The need for a comprehensive environmental assessment of the impacts of the Gibe Dam has been already recognised by UNEP, the riparian Governments and supported by the Ethiopian and Kenyan Governments.

Considering the future interests of Lake Turkana, the people within the Ethiopian and Kenyan areas of the Lake Turkana basin and for the protection of the cradle of mankind – the Lake Turkana region – a transboundary water agreement to govern the use of Omo River flows is needed. An agreement of this kind should provide a provision to regulate the permanent use of Omo River flows in a way that the hydrologic and ecological impact of the dams or developmental projects are minimal while also ensuring protection of the basin and benefitting the Lake Turkana basin communities in both Ethiopia and Kenya.

Acknowledgement

Synthesised by: Ashbindu Singh[a,b] (This bulletin is primarily based on the research work done by Naga Manohar Velpuri and Gabriel Senay).

Production and Outreach Team: Arshia Chander[a], Erick Litswa[b], Kim Giese[a], Lindsey Harriman[a], Michelle Anthony[a], Reza Hussain[a], Mwangi Theuri[b] and Zinta Zommers[b]

Special thanks to Naga Manohar Velpuri and Gabriel Senay for their valuable inputs and, most importantly, for their extensive efforts to conduct this research.

Reviewed by: Djaheezah Subratty[c], Robert Wabunoha[d], Kaisa Uusimaa[b], Neeyati Patel[b], Patrick M'mayi[b], Peter Bjornsen[e], Ron Witt[f] and Andrea Salinas[g]

([a] UNEP/DEWA/GRID-Sioux Falls; [b] UNEP/DEWA-Nairobi; [c] UNEP/DTIE; [d] UNEP/DELC; [e] UNEP-DHI Centre; [f] UNEP/DEWA/GRID-Geneva, [g] UNEP-ROLAC)

References

Amin, M., 1983. Cradle of mankind. Chatto and Windus Ltd., London.

Avery, S., 2010. Hydrological impacts of Ethiopia's Omo basin on Kenya's Lake Turkana water levels and Fisheries. The Africa Development Bank: Tunis, Nairobi.

Avery S., 2012. Lake Turkana and The Lower Omo: Hydrologic impacts of major dam and irrigation developments: Volume 1 – Report. African Studies Centre, University of Oxford.

Bates, B., Kundzewicz, Z. , Wu, S., Palutikof, J. , 2008. Climate Change and Water, Technical Paper of the IPCC, IPCC Secretariat, Geneva.

Bartle, A., 2002. Hydropower potential and development activities. Energy Policy 30(14) , 1231-1239.

Butzer, K. , 1971. Recent history of an Ethiopian delta - The Omo River and the level of Lake Rudolf, Department of Geography, Research Paper No. 136. The University of Chicago Press Chicago.

Cerling, T., 1986. A mass-balance approach to basin sedimentation: Constraints on the recent history of the Turkana basin. Palaeogeography, Palaeoclimatology, Palaeoecology 54(1-4), 63 – 86.

Fader, M., Gerten, D., Krause, M., Lucht, W., Cramer, W. , 2013. Spatial decoupling of agricultural production and consumption: quantifying dependences of countries on food imports due to domestic land and water constraints. Environmental Research Letters 8(1), 014046.

Kallqvist, T., Lien, L., Liti, D., 1998. Lake Turkana Limnological Study 1985 – 1988. Norwegian Institute of Water Resources, Report no. 0-85313.

Kaygusuz, K., 2004. Hydropower and the world's energy future. Energy Sources 26(3), 215-224.

Lautze, J., Giordano, M. and Borghese, M., 2005. Driving forces behind African transboundary water law: internal, external and implications. International workshop on African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, 26-28 January 2005, South Africa.

REN21, 2013. Renewable 2013 Global Status report, Renewable Energy Policy Network for the 21st Century. Renewable Energy Policy Network for the 21st Century. www.ren21.net/REN21Activities/GlobalStatusReport.aspx (accessed 19.06.13).

Ricketts, R., Johnson, T., 1996. Climate change in the Turkana basin as deduced from a 4000 year long δO18 record. Earth and Planetary Science Letters 142 (1-2), 7-17.

The Gilgel Gibe Affair, 2008. An independent study about the Gilgel Gibe hydroelectric projects in Ethiopia – How states and corporations make business using the international public money, Publication of European Union.

The Economist, 2010. Tap that water: controversy surrounds the argument for dam-building in Africa. The Economist, reprinted from print edition. http:// www.economist.com/node/16068950/ (accessed 19.06.13).

Velpuri, N., Senay, G., 2012. Assessing the potential hydrological impact of the Gibe III Dam on Lake Turkana water level using multi-source satellite data. Hydrology and Earth System Sciences 16, 3561-3578, doi:10.5194/hess-16-3561-2012.

Velpuri, N., Senay, G., and Asante K., 2012. A multi-source satellite data approach for modelling Lake Turkana water level: calibration and validation using satellite altimetry data, Hydrology and Earth System Sciences, 16:1-18.

UNEP, 2010. Africa Water Atlas. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme, Nairobi.

UNEP, 2013. Ethiopia's Gibe III Dam: its Potential Impact on Lake Turkana Water Levels (A case study using hydrologic modelling and multi-source satellite data). Division of Early Warning and Assessment (DEWA), United Nations Environment Programme, February 2013.

WCD, 2000. Dams and Development – A new framework for decision making, the report of the World Commission on Dams. Earthscan Publication Ltd., London and Sterling, VA.

Wolf, A., Natharius, J., Danielson, J., Ward, B., Pender, J., 1999. International River Basins of the World, International Journal of Water Resources Development 15(4), 387-427.

Yuretich, R., 1979. Modern sediments and sedimentary processes in Lake Rudolf (Lake Turkana) eastern Rift Valley, Kenya. Sedimentology 26(3), 313-331.

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

JULY 2013

Thematic Focus: Climate change, Ecosystem management, Environmental governance

From Hotspots to Hopespots: Connecting local changes to global audiences

As changes to ecosystems and the environment continue to occur in response to growing population pressure and natural processes, ways to measure and observe these changes on a regular basis will become increasingly important. Satellite imagery offers an important way to provide evidence of such changes and connect local changes to wider audiences.

NASA GODDARD PHOTO AND VIDEO / FOTER / CC BY

Why is this issue important?

A significant area of Earth's surface that is susceptible to slow-onset or rapid environmental change is referred to here as a 'hotspot' and is explained through the use of two or more satellite images showing change over time (a 'change pair'). A positive outlook for the future is captured through the concept of a 'hopespot' which encompasses areas where actions have led to, or are leading to, positive changes. These images, when accompanied by a short storyline and ground photos, are an important method for communicating environmental changes and their impacts to the international community and can ultimately function as a unique decision-support tool.

Visually obvious and compelling stories of positive and negative environmental changes and the transition of hotspot to hopespot can be told through satellite imagery. Scientific articles can be complex, offering numbers or graphics that can sometimes be challenging for non-scientists and decision-makers to visualise and comprehend. Satellite imagery can put those numbers into perspective by offering a way to monitor our shrinking resource base and visually document the extent of the many ways that humans and natural processes have had an impact on our planet (UNEP, n.d.a). In addition, changes may not be noticeable on an everyday time scale, but when examined over an extended period of time and the present can be compared with the past, changes, and their impacts, become increasingly evident. A more temporal and accurate method of observing and documenting the changes the environment has undergone, and continues to face, is needed. Satellite data is one type of mechanism that can be used to accomplish this feat (Hansen and Loveland, 2012).

The United Nations Environment Programme (UNEP) has identified more than 200 environmental change hotspots in its Atlas of Our Changing Environment series, and other publications, and continues to do so through constant monitoring and research. The hotspots illustrate changes over thousands or millions of hectares of land or coastline spanning more than 100 countries and all seven continents

PHOTO LEFT: BLUE EARTH - SAAD FARUQUE / FOTER.COM / CC BY

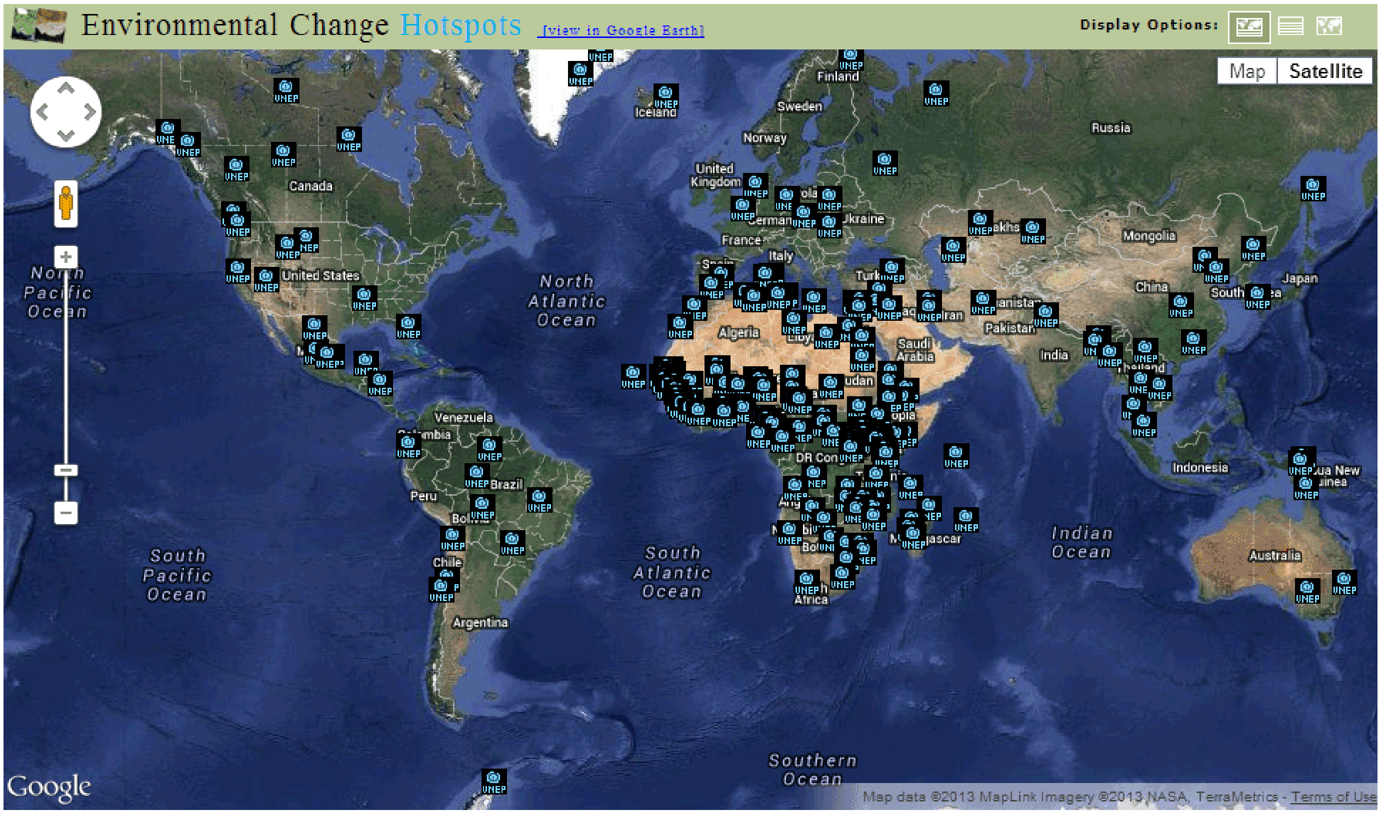


Figure 7.1: UNEP environmental change hotspots hosted at https://na.unep.net

(Figure 7.1). Satellite images and supporting storylines are hosted at https://na.unep.net, www.uneplive.org and as a GoogleEarth layer where the images are free for download. Animations of some of the hotspot change sequences are also available through the website, offering another dynamic way of viewing and understanding environmental change. The hotspots and Atlas series have helped to create environmental awareness around the world.

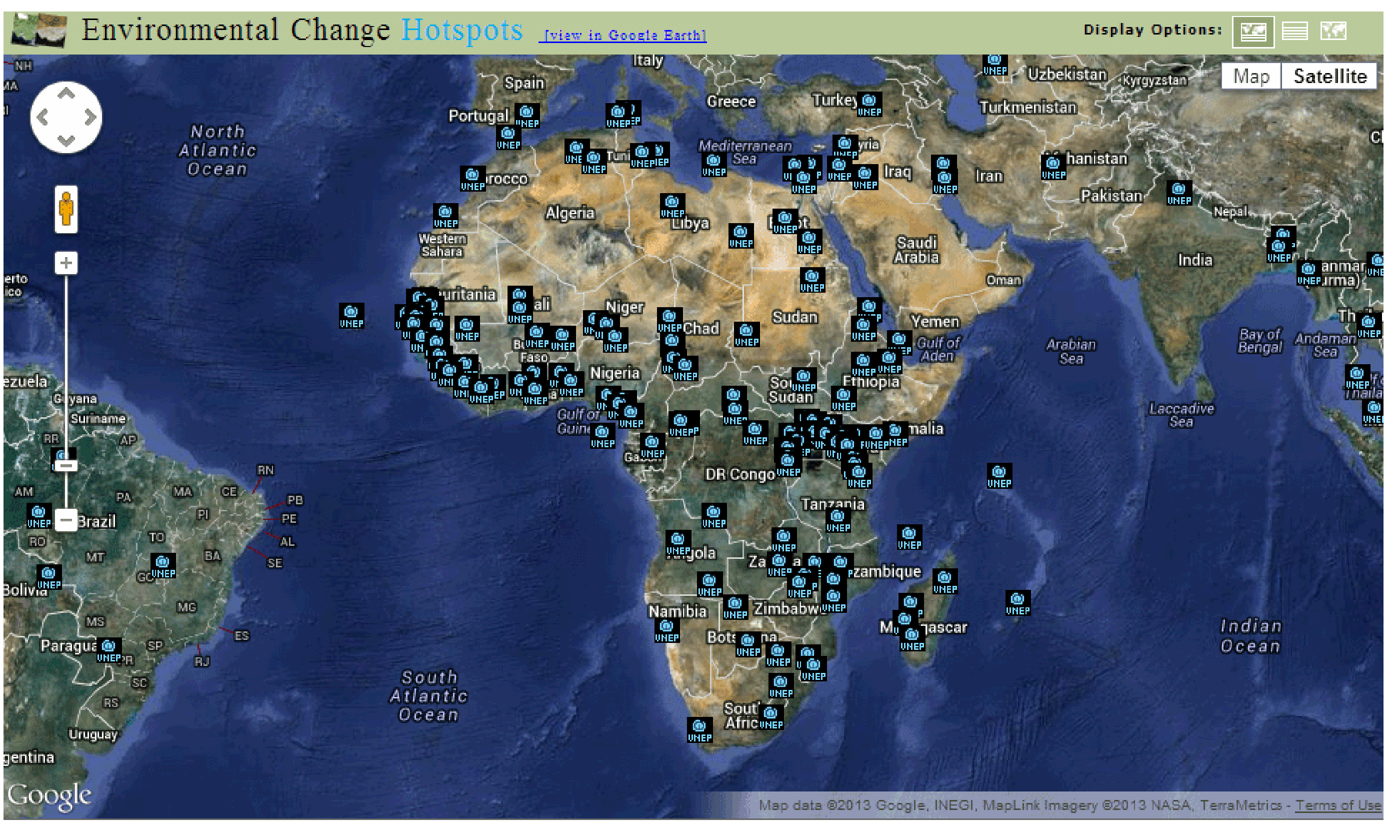
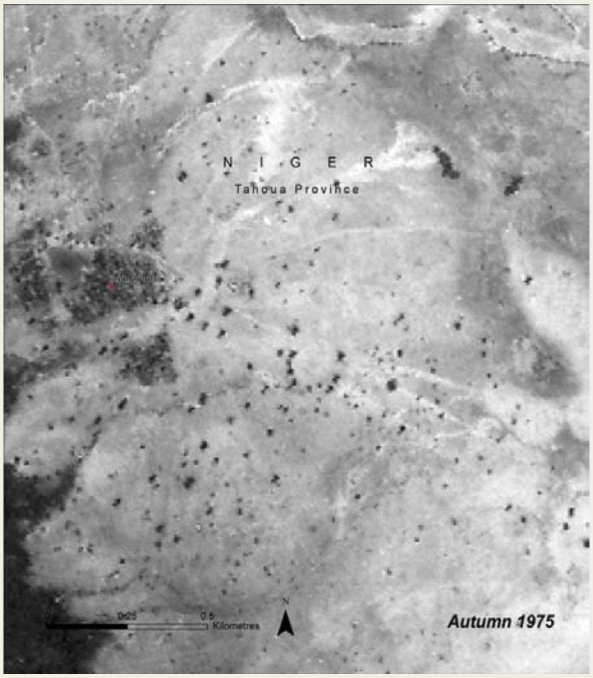
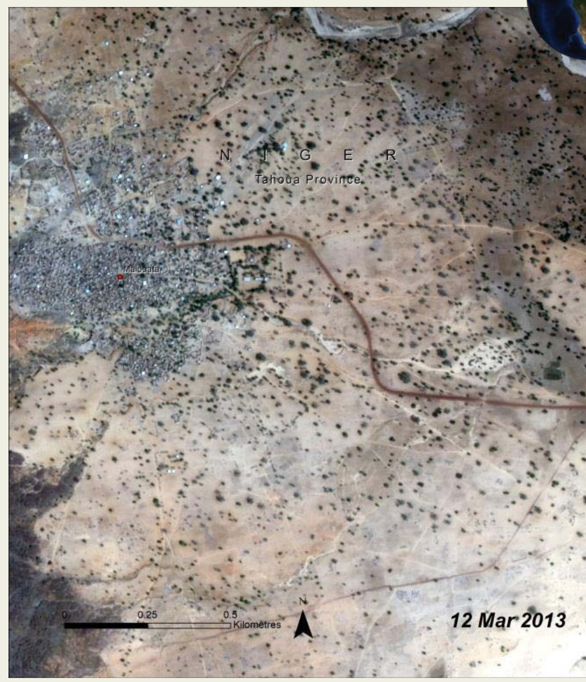


Figure 7.2: UNEP environmental change hotspots of Africa hosted at https://na.unep.net

Box 7.1. Tahoua Province, Niger, Africa

Major Theme: *Ecosystems* ***Themes:*** *Deserts and Drylands; Agriculture & Aquaculture*





The Tahoua Province is found in a southern area of Niger that is semi-arid and conducive to rain-fed agriculture and pastoralism, but in recent decades, Niger's climate and its demographic problems have forced agriculture onto land that did not receive much rain and historically had been used for livestock. The aerial image from 1975 shows how this change of practice resulted in acute environmental devastation. However, land revitalisation projects over the past few decades, such as tree planting and farmer initiatives to protect the trees, have led to a significant increase in the number of trees across three of Niger's southern provinces. The influx of trees, evident in the 2013 Quickbird image, has helped to reduce drought vulnerability and reliance on rain-fed crops.

Source: Adapted from UNEP, n.d.b; 1975 image: UNEP, n.d.b; 2013 image: DigitalGlobe; visualisation by UNEP/GRID-Sioux Falls

Many methodologies can be employed to identify potential hotspots, including:

- Laboriously examining wall-to-wall satellite imagery from the many image-capturing satellites in orbit
- Performing specific scientific sampling analysis to detect changes, which can be precise, but also time-consuming
- Using knowledge-based analysis

Due to limited resources, the latter approach is used by UNEP to identify environmental change hotspots. The knowledge-based process identifies hotspots through:

- Consultations with visiting scientists and subject matter experts (SMEs)
- Reviews of scientific literature
- Keeping up with current events
- Using institutional knowledge

Many of the UNEP hotspots are focused on Africa due to the amount of research UNEP has conducted on the continent and the many Atlases and other publications stemming from the research (Figure 7.2).

What are the findings?

The UNEP environmental change hotspots feature a time series of two or more satellites images to demonstrate positive or negative large-scale local environmental changes. Four major themes are used to classify the hotspots: Ecosystems, Resource Extraction, Climate Change and Atmosphere and Disasters and Conflicts. From there, the hotspots are classified into additional minor themes such as Population and Urban Growth, Water and Agriculture and Aquaculture. A breakdown of how many countries and continents are represented by each major theme, and the number of corresponding hotspots, is presented in Table 7.1. The changes that these satellite images depict include ecosystem restoration (see Box 7.1), impacts of mining and other resource extraction activities (see Box 7.2), forest loss and/or gain (see Box 7.3), changes in glacier

Theme	# of Hotspots	# of Countries	# of Continents
Climage Change and Atmosphere	10	14	5
Disasters and Conflicts	10	13	3
Ecosystems	156	92	6
Resource Extraction	29	25	6

Table 7.1: UNEP environmental change hotspots by theme

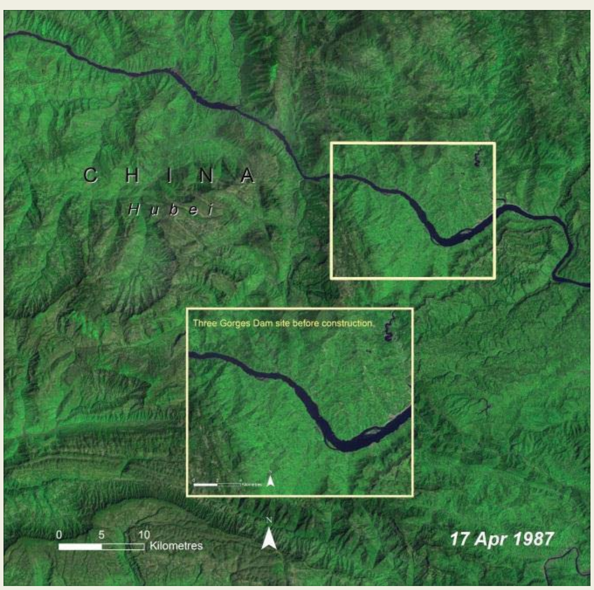
mass balance, altered coastlines and shrinking freshwater ecosystems (see Box 7.4) among others. Selected hotspots also feature a significant environmental event that a location has experienced, such as a volcanic eruption. However, it is important to note that not all types of environmental changes are evident in images. Changes occurring in deep ocean ecosystems or seasonal changes would not be very well represented by satellite image change pairs as the changes might not be very apparent, or the viewer could be convinced that significant changes are occurring, even if they are not.

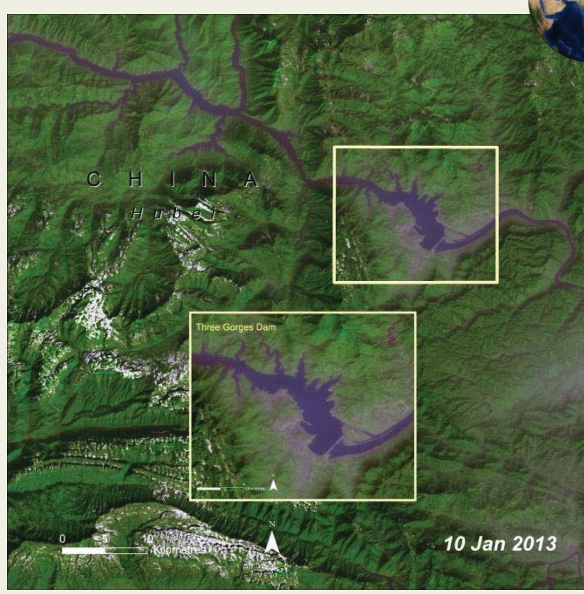
There are many types of Earth-observing, image-capturing satellites in orbit, operated by a number of countries and organisations, including sixteen operated by the United States National Aeronautics and Space Administration's (NASA) in support of its Earth science missions (Figure 7.3). These satellites have varying capabilities regarding the type of images they can take, as well as image resolution (level of detail visible in the image). Some types of satellites can capture chlorophyll concentrations, sea surface temperature and aerosol content in addition to simply capturing an image. At times, aerial imagery, acquired by cameras on airplanes, can also be used for change pairs or image time series showing environmental change if suitable satellite imagery was not available for the area of interest.

However, the Landsat series of satellites is most often used to create UNEP hotspot images and perform additional scientific analysis. First launched in 1972, the Landsat programme offers more than 40 years of vast spatial coverage – the longest continuous data record of Earth's surface available (NASA, 2012). The Landsat imagery is free to download from the

Box 7.2. Three Gorges Dam, China, Asia

Major Theme: *Resource Extraction* ***Themes:*** *Water; Energy and Mineral Extraction*





The Three Gorges Dam on the Chang Jiang (Yangtze) River in China was constructed to supply approximately one-ninth of China's electricity. It is a relatively environmentally clean option compared to coal burning or nuclear power plants. However, the Dam project has had negative environmental and social impacts including the submergence of land along the river above the Dam. The 1987 image shows the nature of the river and surrounding landscape before work on the dam began. In the January 2013 image the Dam is clearly visible, as is the reservoir of impounded river water that has been created behind it.

Source: Adapted from UNEP, n.d.b; Images: Landsat, visualisation by UNEP/GRID-Sioux Falls

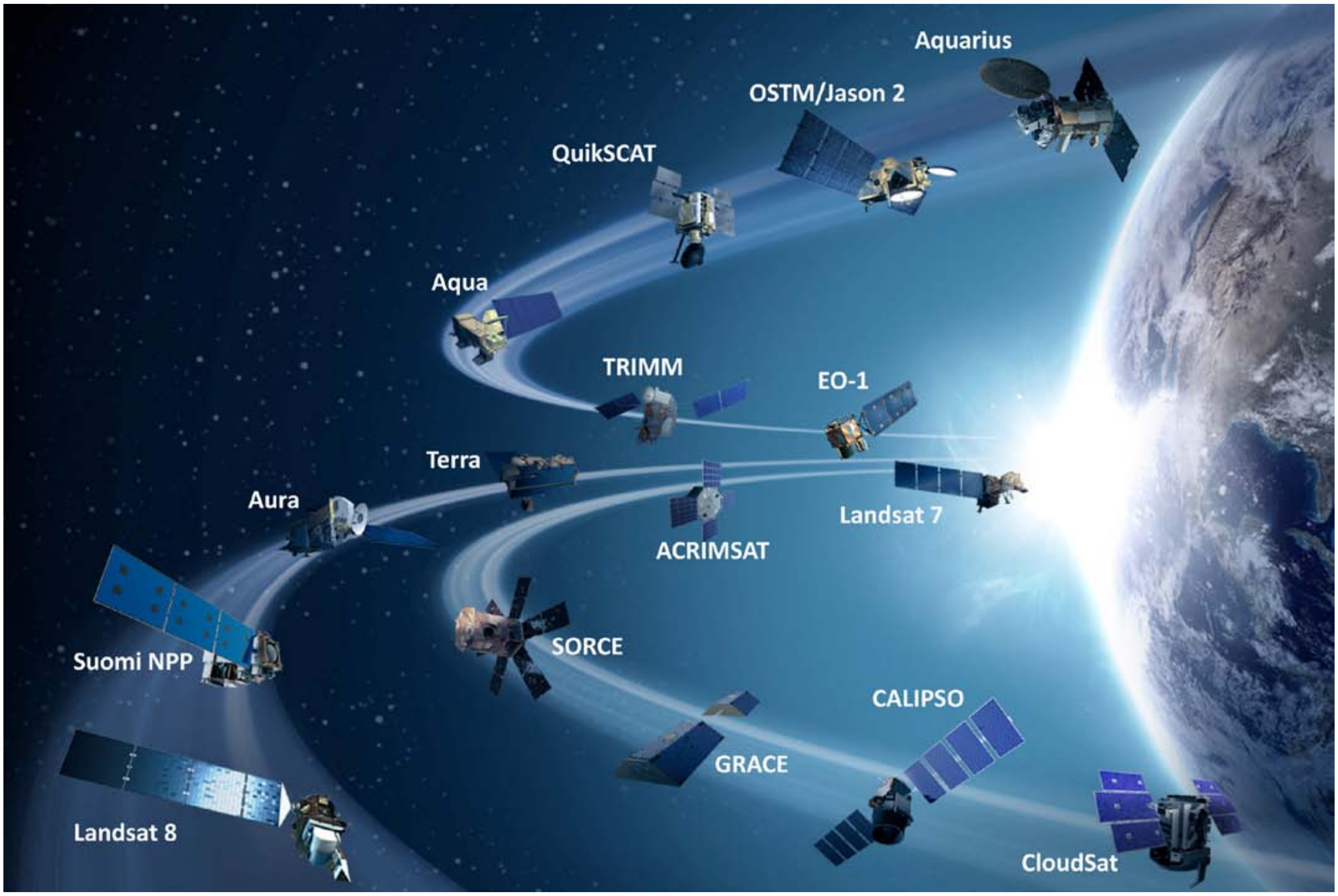


Figure 7.3: NASA's sixteen Earth-observing satellites currently in orbit. Source: NASA, 2013

United States Geological Survey Earth Resources Observation and Science (USGS/EROS) center archives (http://earthexplorer.usgs.gov/). The extensive history of Landsat enables all users to witness change of the planet's surface over many decades, thus creating a better understanding of the magnitude of environmental change that an area has experienced and how much the change has influenced the surrounding ecosystems and human populations.

Images captured by the Landsat satellites, including those from imagers on the recently launched Landsat 8, have different bands that can be combined to create an image that allows users to detect different environmental change elements such as fire scars, drought and variations in land use, making it an advantageous observation tool. Landsat imagery is especially suitable for detecting ecosystem fragmentation and degradation and offers a resolution (level of detail) that is ideal for developing comprehensive land cover classification datasets, another way to detect land use change (Giri et al., 2013). Recent uses of Landsat imagery are presented in Figure 7.4.

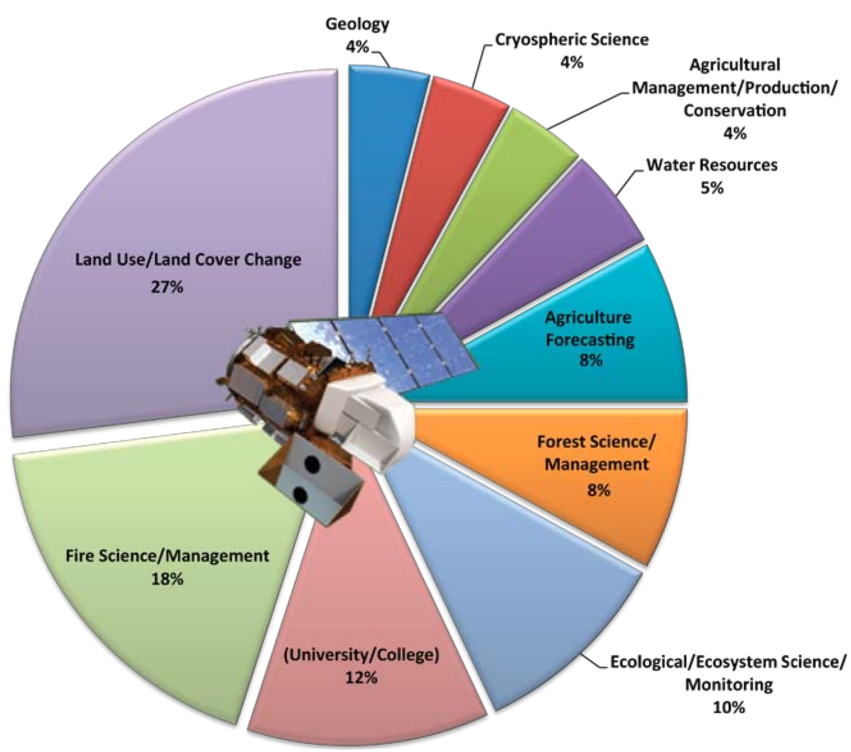


Figure 7.4: Primary uses of Landsat as recorded by the USGS from October 1, 2012 to April 30, 2013; Source: Adapted from USGS, 2013; visualisation by UNEP/DEWA/GRID-Sioux Falls.

Box 7.3. Mato Grosso, Brazil, South America
Major Theme: *Ecosystems* ***Themes:*** *Forests; Population and Urban Growth*

Mato Grosso, a Brazilian Amazonian province, lost 13.6 million ha of forest between 1988 and 2012, accounting for about 33 per cent of the total amount of forest loss in the entire 'Legal Amazon' over the same time period. Deforestation was prompted by the construction of major highways through the region and the ensuing development of supporting infrastructure; white areas in the 2012 image indicate where forest has been replaced with agriculture and development. The rate of loss peaked in 2004, and although rates have slightly subsided, deforestation is still ongoing and the destruction may have already inhibited secondary forest growth.

Source: Adapted from UNEP, n.d.b; Images: Landsat, visualisation by UNEP/GRID-Sioux Falls

Due to factors such as lack of temporal availability or presence of cloud cover, it sometimes can be difficult to obtain enough imagery to create a change pair or time series over certain areas of the world using imagery from one type of satellite. Therefore, imagery from other satellites must be used as well.

The environmental change hotspots identified by UNEP have enabled scientists, decision-makers and the general public to visualise changes such as:

- Widespread deforestation throughout South America
- Reduction in glacial coverage in mountainous zones and polar regions, but also glacial advance, as evidenced by the Hubbard Glacier in Alaska, USA
- Impact of diversion of water sources for irrigation in North and East Africa and West Asia
- Significant changes in land appearance, and ensuing impacts, due to introduction of resource extraction activities in places such as North America and Australia
- Efforts of reforestation in the Mabira Forest Reserve in Uganda and in the semi-arid regions of Niger and the general absence of major frontiers of deforestation in Africa

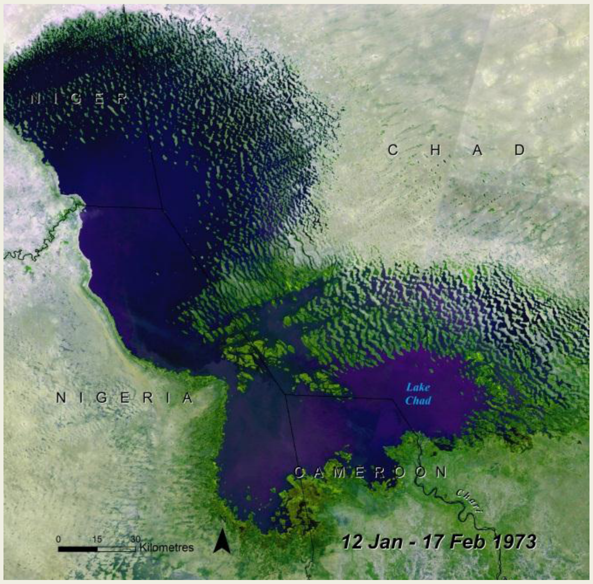
Continual monitoring is essential to fully evaluate and gauge the impact of environmental changes, both positive and negative, that the planet faces. To do this, imagery of existing hotspots will continue to be, and should be, updated on a regular and scheduled basis, accompanied by new observations and measurements for existing hotspots and the initiative expanded to identify new hotspots and hopespots.

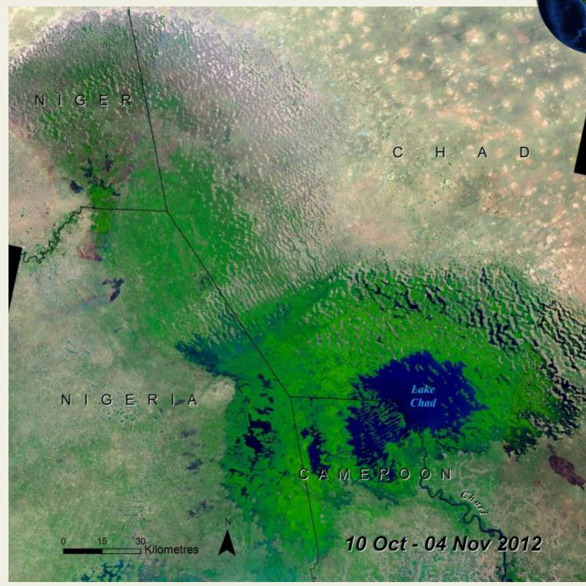
What are the implications for policy?

The identification of hotspots and hopespots, and the images used to illustrate them, can provide insight to the potential long-term consequences that human activities can have on the environment. This insight can help decision-makers to identify and form policies, regulations and corrective measures for future sustainable development. As a decision-support tool, the images, and the measurable changes derived from them, can enable more informed decision-making during the policy formulation process. This is possible through the creation of more accurate datasets, increased exposure of changes and as a way to visualise transboundary changes. In addition, the ease of availability of satellite imagery and

Box 7.4. Lake Chad, Nigeria, Niger, Chad and Cameroon, Africa

Major Theme: *Climate Change and Atmosphere* ***Themes:*** *Wetlands; Water; Atmosphere and Climate*





Climate variability and increased water consumption by the area's inhabitants have changed the water balance within the Lake Chad drainage basin, and continue to do so. Since the early 1960s, rainfall over the basin decreased significantly while irrigation increased dramatically over the same period resulting in a 95% reduction in the lake's area. As these satellite images from 1973 and 2012 show, the surface area of the lake has declined dramatically.

Source: Adapted from UNEP, n.d.b; Images: Landsat, visualisation by UNEP/GRID-Sioux Falls

its current temporal nature increase its importance in the creation of recent and accurate datasets.

Imagery can also serve as a compliance-monitoring tool, providing both developed and developing nations with economically efficient reporting tools to more effectively meet their obligations to international environment agreements and achieve conservation targets. As a result, governments and regulatory agencies can be encouraged to increase conservation or protective measures already in place or justify putting the environment higher on a government's agenda, perhaps creating initiative for identification of hopespots. Ultimately, the information obtained from the images can be used justify funding for restorative and/or corrective actions. Examples of ecosystems that benefitted from issues highlighted by satellite imagery and resulting restorative action include the Mau Forest Complex in Kenya, the Mesopotamia Marshlands in Iraq and the Islamic Republic of Iran and Lake Faguibine in Mali.

The global coverage of satellite imagery allows for transboundary issues to come to light, demonstrating changes occurring across certain borders and how the changes are affecting the associated countries. As shown in Box 7.4, for instance, as the water level of Lake Chad receded, Nigeria, Niger, Chad and Cameroon, in addition to the countries located in the Lake Chad basin, each lost a significant amount of an ecosystem essential for fishing and agricultural practices, albeit in varying proportions. The images used to illustrate the hotspot help to highlight the changes in each country and could serve as a tool for future management decisions. In the same way, satellite imagery can help to identify change in a surrounding or neighboring area that might have an impact on an area not in the immediate vicinity - e.g. the Merowe Dam, Sudan hotspot showing how dam construction can affect ecosystems tens or even hundreds of kilometres downstream.

The economic benefit of using imagery as a decision-support tool stems from the fact that some imagery, such as Landsat, is free for users to acquire, and the modeling processes that use the data have been known to add more value to the data. For example, the USGS, in cooperation with the United States Department of Agriculture (USDA) National Agricultural Statistics Service and the Iowa Department of Resources, used satellite imagery to model the relationship between land use, agriculture and dynamic nitrate aquifer contamination. The results of the modeling exercise revealed that by using information such as satellite imagery, the effeciency of agricultural production can be increased and nitrate-leaching estimates can be improved (Raunikar et al., 2013). The study estimated that the value of the information derived from imagery could be as much as US $858 million ±US $197 million per year, corresponding with a current value of US $38.1 billion, ±US $197 billion, for benefits extending into the foreseeable future.

Despite the numerous benefits of using imagery to detect and visualise environmental changes, a few challenges exist. Gathering adequate resources to first develop an accurate and compelling storyline can be difficult if recent and relevant information is not widely available. Moreover, due to the large file size of most raw satellite images, a robust Internet connection is necessary for download. Specific software is then needed to process and analyse the imagery, which can be costly. Some open-source programs can process imagery, but may require additional skills to operate or again, a robust Internet connection to download. Further, as mentioned previously, if one particular satellite cannot offer the spatial and temporal imagery needed, other types of imagery must be acquired. It can be a daunting task to gather images that are cloud-free, cover the entire area of interest and are time-appropriate for the change that is being described. Overall, the process of identifying, describing and illustrating a hotspot or hopespot can be laborious and lengthy, but ultimately the hard work should pay off with the benefit of creating awareness, encouraging restorative action and demonstrating progress.

As the planet continues to change to accomodate the growing global population, and as a result of natural processes, observing and mapping changes in an economically efficient, understandable and communicable way will be essential for improved environmental management. Hotspot and hopespot locations, illustrated with several satellite images, can serve as a method of mapping and tracking changes and restorative progress, as well as a basis for further actions to strive for a more sustainable future. Further, the accessibility of information will play a substantial role in global change studies as local level changes are brought to global audiences. UNEP plans to continue to aid in the accessibility of information as part of its mandate to continually review the state of the global environment with the identification of new hotspots and hopespots and the updates of existing ones with new information and imagery.

Acknowledgement

Writer: Lindsey Harriman[a]

Production and Outreach Team: Arshia Chander[a], Erick Litswa[b], Kim Giese[a], Lindsey Harriman[a], Michelle Anthony[a], Reza Hussain[a], Mwangi Theuri[b] and Zinta Zommers[b]

Special thanks to Ashbindu Singh[a,b], Ron Witt[c], Zinta Zommers[b], Theuri Mwangi[b], Arshia Chander[a], Frank Turyatunga[b], Jacqueline Alder[d], Andrea Salinas[e] and Shelley Robertson[f] for their valuable comments and review.

([a] UNEP/DEWA/GRID-Sioux Falls; [b]UNEP/DEWA-Nairobi; [c]UNEP/DEWA/GRID-Geneva; [d]UNEP-Marine and Coastal Ecosystem Branch; [e]UNEP/DEWA-LAC; [f]Munk School of Global Affairs, University of Toronto)

References

Giri, C. ,Pengra,B., Long,J., Loveland,T.R.,2013. Next generation of global land cover characterization, mapping and monitoring. International Journal of Applied Earth Observation and Geoinformation 25, 30 - 37.

Hansen, M.C., Loveland, T.R., 2012. A review of large area monitoring of land cover change using Landsat data. Remote Sensing of Environment 122(Landsat Legacy Special Issue), 66 – 74.

NASA, 2012. Landsat Overview. National Aeronautical and Space Administration. http://www.nasa.gov/mission_pages/landsat/overview/index.html (accessed 18.06.2013).

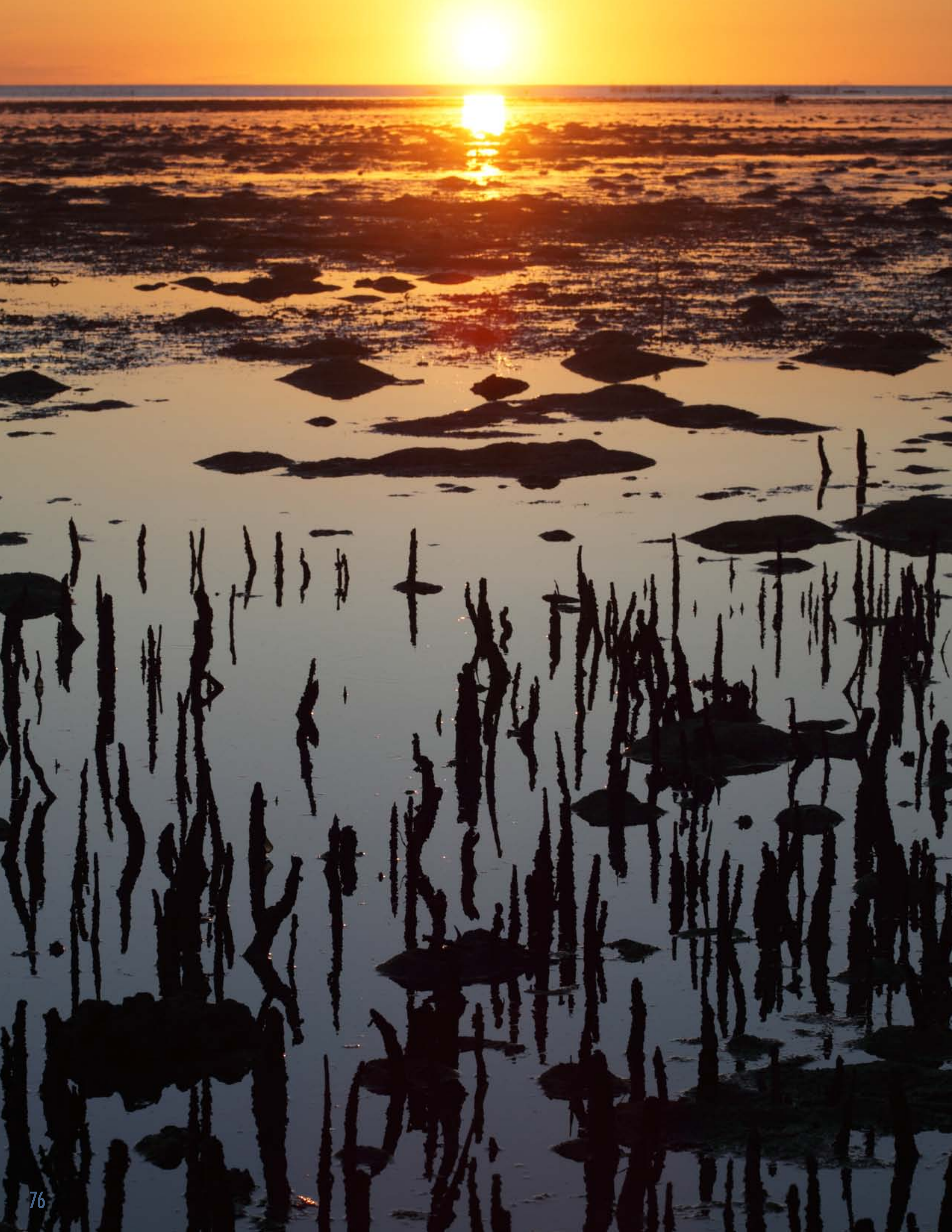
Raunikar, R.P., Forney, W.M., Benjamin, S.P., 2013. What is the economic value of satellite imagery?, Hendley, J.W. (Ed.). United States Geologic Survey, USDA National Agricultural Statistics Service, and Iowa Department of Natural Resources.

NASA, 2013. NASA's Earth Science Satellite Fleet. National Aeronautics and Space Administration Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=81559&src=eoa-iotd (accessed 10.07.13).

UNEP, n.d.a Atlas of Our Changing Environment. United Nations Environment Programme. https://na.unep.net/atlas/index.php (accessed 18.06.13).

UNEP, n.d.b. Environmental Change Hotspots. United Nations Environment Programme. https://na.unep.net/atlas/google.php (accessed 18.06.13).

USGS, 2013. Landsat Project Statistics. United States Geological Survey. http://landsat.usgs.gov/Landsat_Project_Statistics.php (accessed 27.06.13).



UNEP
UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

AUGUST 2013

Thematic Focus: Ecosystem management, Disasters and conflicts, Climate change

Mangrove forest cover fading fast

The uniquely adapted mangrove forests on the marine-terrestrial interface preserve coastline integrity by buffering wave energy from marine processes. The ecosystem services they provide and their support for coastal livelihoods worldwide are worth at least US $1.6 billion a year. Despite their global importance, mangroves are being lost rapidly and action is urgently needed to protect them.

Why is this issue important?

Mangroves are an important bulkhead against climate change: they afford protection for coastal areas from tidal waves and cyclones and are among the most carbon-rich forests in the tropics (Cornforth et al., 2013). In the face of rising sea levels and changing climates, coastal buffering against negative impacts of wave action will become critical and will play an important role in climate change adaptation.

Distributed in the tropical and sub-tropical regions of the world (Figure 8.1), mangroves provide shoreline protection and an array of ecosystem services. They support nutrient and organic-matter processing, sediment control for other inshore habitats (e.g. seagrass beds and coral reefs), and a source of wood for coastal communities. As a habitat for commercially valuable marine species (Walters et al., 2008), it is estimated that almost 80% of global fish catches are directly or indirectly dependent on mangroves (Ellison et al., 2008; Sullivan, 2005). Thus, the food security for many indigenous coastal communities is closely linked to the health of mangrove ecosystems (Horwitz et al., 2012). As much as 7% of the carbon dioxide reductions required to keep atmospheric concentrations below 450 ppm could be achieved simply by protecting and restoring mangroves, salt marshes and seagrass communities (Nellemann et al., 2009). Mangroves sequester up to 25.5 million tonnes of carbon per year and contribute more than 10% of essential organic carbon to the world's oceans (Dittmar et al., 2006).

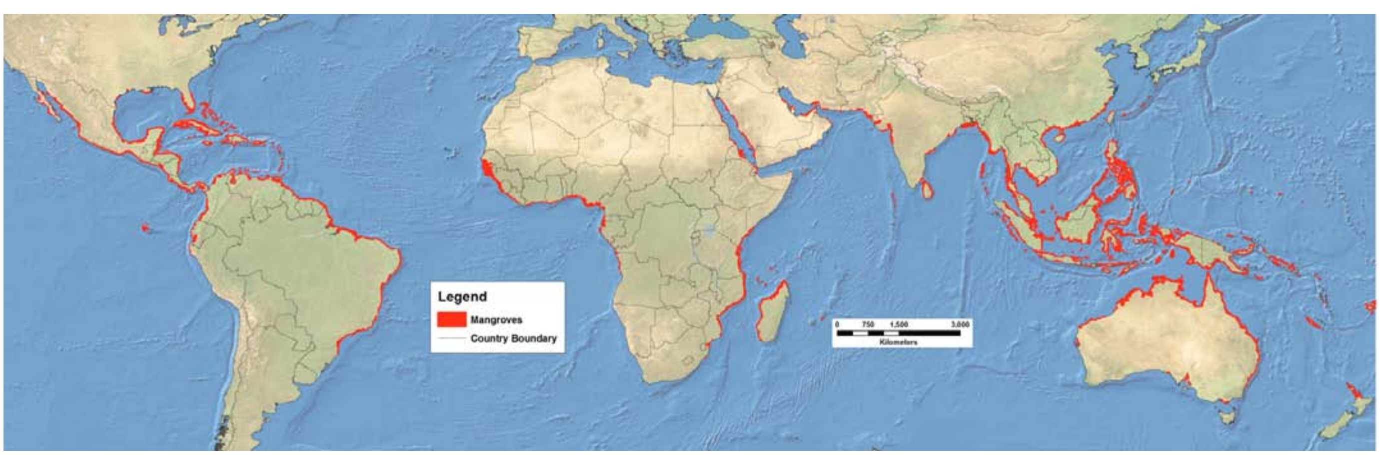


Figure 8.1: Global mangrove forests distribution – 2000 (Giri et al., 2011). Map redrawn by UNEP/DEWA.

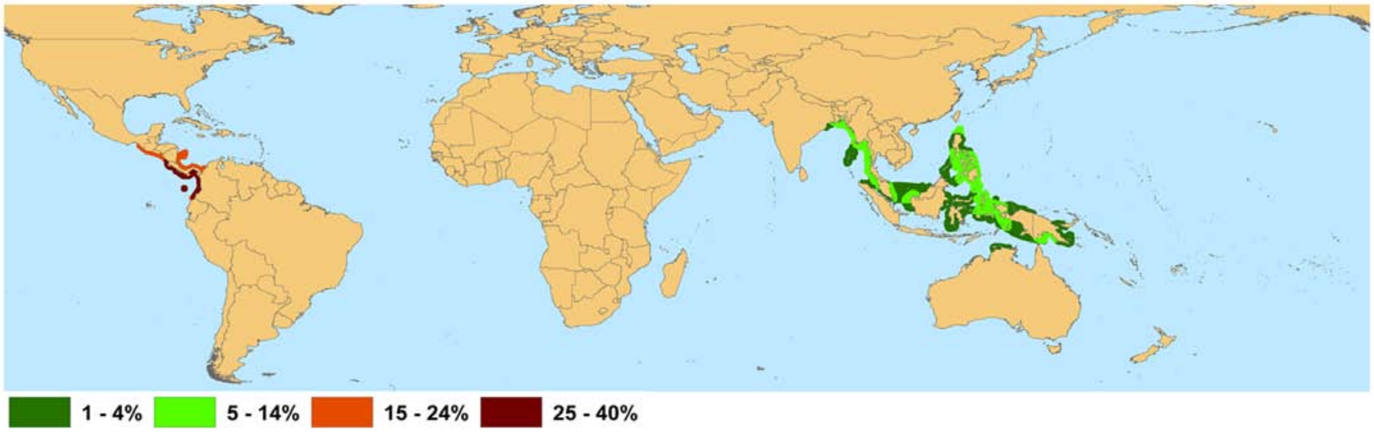


Figure 8.2: Proportion of Threatened (Critically Endangered, Endangered, and Vulnerable) Mangrove Species. (Polidoro et al., 2010).

What are the findings?

Mangrove ecosystems, which make up less than 0.4% of the world's forests (Spalding et al., 2010), are being lost at the rate of about 1% per year (FAO, 2007); in some areas, the rate may be as high as 2 to 8% per year (Miththapala, 2008). From 20% to 35% of the world's mangrove area has been lost since 1980 (FAO, 2007). The rates of loss are highest in developing countries where mangroves are cleared for coastal development, aquaculture, timber and fuel production (Polidoro et al., 2010). In as few as 100 years, the world's mangrove forests may become so degraded and reduced in area that they would be considered to have "functionally disappeared" (Duke et al., 2007). Figure 8.2 shows the areas where mangroves are already threatened in the world.

Importance of mangroves

(i) Storm surge protection:

Relatively small ocean waves are reduced in height from 12% to 66% over a distance of 100 metres of mangroves and 50% to 99% over 500 metres (McIvor et al., 2012). A number of factors determine the extent of wave energy reduction, including water depth, wave period, wave height, mangrove species, stand density, and trunk and root diameter (Mazda et al., 1997) (Figure 8.3). In southern Thailand, where 50% of mangrove forests have been lost since 1961, Thampanya et al. (2006) found that coastlines eroded by 0.01 to 0.32 square kilometre a year from 1967 to 1998. Sediment accumulation was observed only in coastlines with mangrove forests.

In the Red River Delta in Vietnam, it has been estimated that an earthen sea dyke with a rock face on the open ocean side would require repairs in about five years, whereas the same dyke would last about 50 years if the rock face were replaced by a 100-metre-wide protective mangrove belt (Macintosh and Ashton, 2004). In another project in Vietnam, the cost of planting and protecting mangroves was about US $1.1

million, and the project saved US $7.3 million a year in dyke maintenance. Moreover, during Typhoon Wukong in 2000, the project areas remained unharmed while neighboring provinces suffered major losses in lives, property and livelihoods. The Vietnam Red Cross estimated that some 7,750 families have benefited from mangrove rehabilitation (Reid and Swiderska, 2008).

(ii) Provisioning value:

In some cases, the provisioning benefits of mangroves may be worth even more than their coastal protection value. The 1,800 hectares of Ream National Park in Cambodia was valued at US $300,000 for storm protection and erosion services alone. The additional provisioning services of the park, such as breeding grounds for fish, firewood, medicinal plants and construction materials, were valued at US $600,000 (Emerton et al., 2002). Moreover, the park's ecosystem service benefits far exceed the value of clear cutting the area for timber and shrimp ponds (Horwitz et al., 2012).

Threats to mangroves

(i) Conversion of mangrove forests:

Increasing population in coastal areas has spurred the widespread clearing of mangroves (Polidoro et al., 2010). Over-exploitation for fuelwood and timber production has

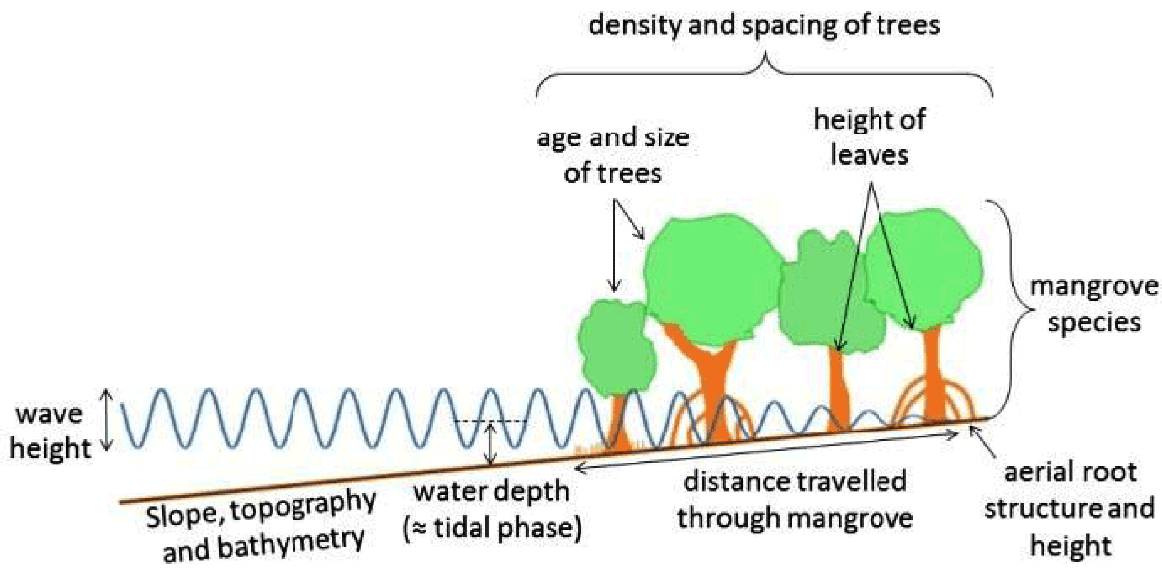


Figure 8.3: Factors affecting wave energy in mangroves (McIvor et al., 2012).

degraded about 26% of mangrove forests around the world (Valiela et al., 2001). Shrimp aquaculture has contributed to about 38% of global mangrove loss and other types of aquaculture account for approximately another 14% (Ellison, 2008; Figure 8.4). In India, more than 40% of the mangrove area on the western coast has been converted to agriculture and urban development (Upadhyay et al., 2002). While direct anthropogenic impacts are the biggest threat to mangrove ecosystems, changing climates probably will pose even greater risks in the future (Gilman et al., 2008).

(ii) Global temperature rise:

While mangroves often show resistance and resilience in the face of disturbances, the additional stresses brought by climate change may cause sudden and irreversible losses at many sites (Huxham et al., 2010). Warmer temperatures will increase evaporation rates and salinity in the sediments on the landward fringe of a mangrove forest. This may cause a die-back of mangroves or a reduction in diversity (Huxham et al., 2010).

(iii) Rising sea levels:

The global sea level has already risen 12 to 22 centimetres over the course of the 20th century due to global warming and sea-level rise could be the greatest threat facing the future of mangroves (Gilman et al., 2008). If local conditions restrain mangroves from adapting to rising sea levels through inland migration, they will become increasingly submerged.

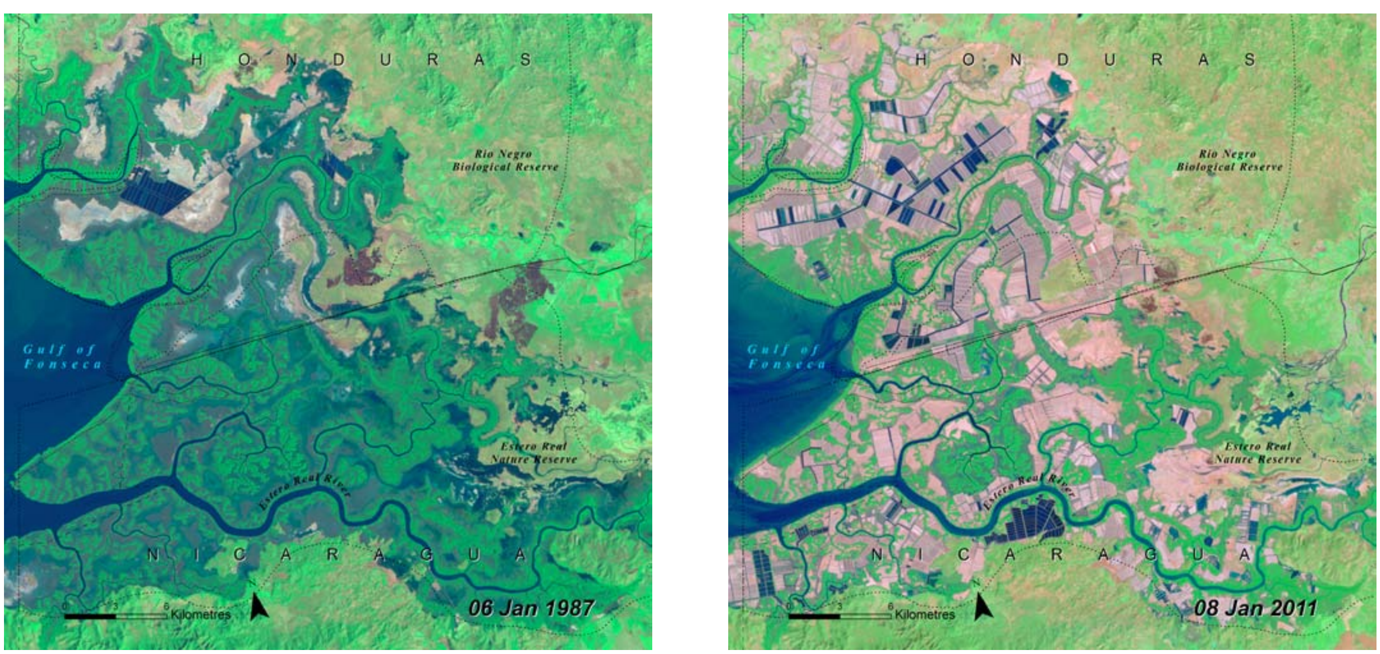


Figure 8.4: Satellite images showing an increase of shrimp farms in the Gulf of Fonseca, Honduras. The shrimp ponds appear as blue and pink rectangles near the water line scattered across the mangrove delta in the 2011 image, a period of 24 years since 1987.

CFOR/Flickr/CC BY NC-ND 2.0

Box 8.1: Successful Management: The Matang Mangrove Forest Reserve

The Matang Mangrove Forest Reserve in the State of Perak, Malaysia, is arguably the best example of a sustainably managed mangrove ecosystem and demonstrates that an effective balance can exist between the harvest of natural resources and conservation (Lavieren et al., 2012). The existing management plan regulates forestry, fishing, and aquaculture activities and only non-destructive practices are permitted. Harvesting of mangrove timber for poles, firewood, and charcoal production, occurs on a 30 year rotation cycle (Chong, 2006). Selective felling is carried during year 15 and year 20 and then a final clear-felling occurs during year 30. When necessary, re-vegetation programmes are implemented two years after the final felling. The annual value of charcoal between 2000 and 2009 was estimated to be RM 27.2 million (equivalent to approx. US$ 8.9 million) while the annual value of poles was estimated at RM 2.6 million (equivalent to approx. US$ 847 thousand). Fisheries in the Matang Mangroves are also an important contributor to the Malaysian economy. Fish cage and cockle aquaculture are allowed, and cockle farming is estimated to have an annual market value of RM 32.45 million (equivalent to approx. US$ 10.7 million). Most of the natural resources obtained from the forest are exported to markets in the states of Selangor, Penang, and Kedah. This case provides evidence that mangrove forests can be conserved and enjoyed while still providing reliable long-term but reasonably high economic return for local and larger communities. It shows that when well-managed, mangroves can ensure sustainable yields of products (numbers are from the Malaysian Timber Council, 2009).

Even in circumstances in which inland migration could occur, there may still be negative impacts on people, since it is the seaward fringes, and not the inland margins, that provide the most valuable environmental services for fisheries and coastal protection (López-Medellín et al., 2011).

(iv) Storms and natural disasters:

High levels of damage may be inflicted on mangroves during storms. A massive loss of mangroves following a hurricane in Honduras led to peat collapse, which reduced recovery rates (Cahoon et al., 2003). Furthermore, mangrove ecosystems can be converted to other types of ecosystems as a consequence of storm impact. For example, mangrove forests in Everglades National Park in Florida have been converted to intertidal mud flats following the impacts of hurricanes Andrew in 1992 and Wilma in 2005 (Smith et al., 2009).

Progress in the conservation and restoration of mangroves

Since the 2004 Indian Ocean tsunami, there has been a general increase in the awareness of the importance of mangrove ecosystems; efforts to conserve, protect and restore them can be seen in Bangladesh, India, Indonesia, Myanmar, Seychelles, Sri Lanka, Pakistan, Thailand and Vietnam (Macintosh et al., 2012). The Ministries of Environment and Natural Resources of Guatemala, Honduras and Nicaragua, in collaboration with the UN Environment Programme, have embarked on sustainable mangrove management, raising awareness of the critical role mangroves play in areas that are constantly threatened by the risk of hurricanes and sea level rise (UNEP, 2012).

What are the implications for policy?

As the negative impacts of climate change, including rising sea levels, become more evident, the economic value of coastal wetlands for protection will also increase as the need for their buffering services becomes more critical (Costanza et al., 2008). While market pressures push for mangroves to be cleared for aquaculture and urbanization, coastal land managers must consider not only the value of the services that mangroves provide, but also their potential value in the future (see Box 8.1).

Mangrove conservation and management

Curbing deforestation may be more effective than reforestation. In the last decade, a study in Thailand found that the cost of restoring mangroves was US $946 per hectare, while the cost for protecting existing mangroves was only US $189 per hectare (Ramsar Secretariat, 2001).

Framework policy and legislation established at national levels, and integrated into a broader spatial framework of coastal zone management, should cross all sectors and involve all stakeholders to prevent piecemeal loss and degradation (Lavieren et al., 2012). For example, countries such as Tanzania and Malaysia have placed all mangroves in forest reserves under state ownership. In some locations in Australia and the United States, local policies of "no net loss" have placed specific limitations on future mangrove clearance. These strategies will be effective in the long term if backed by strong political will, enforcement measures and penalties for noncompliance.

An array of market-oriented strategies have been proposed to curtail the conversion of mangrove areas to other land uses. The fact that mangrove forests are increasingly recognized as a valuable source of revenue should in theory make it easier to entice those who benefit from mangroves to make payments for the ecosystem services that they generate (Lavieren et al., 2012). Furthermore, because mangrove forests store significant amounts of carbon and are threatened by the economic allure of conversion, they could be ideal targets for carbon financing. Such initiatives and investment funds provide exciting new opportunities to better protect natural capital, benefit communities, and utilize cost-effective green technologies to address the challenges of climate change.

Acknowledgement

Writer: Braedon Cashion[a]

Production and Outreach Team: Arshia Chander[b], Ashbindu Singh[b,c], Erick Litswa[c], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Tejaswi Giri[b], Theuri Mwangi[c] and Zinta Zommers[c].

Special thanks to Charles Davies[a], Silvia Giada[a], Andrea Salinas[a], Lucia Scodanibbio[a], Zinta Zommers[c] and Pascal Peduzzi[d] for their valuable inputs and Shelley Robertson[e] for copy editing.

([a] UNEP/DEWA-LAC- Panama; [b] UNEP/DEWA/GRID-Sioux Falls; [c] UNEP/DEWA-Nairobi; [d] UNEP/DEWA/GRID-Geneva; [e] Munk School of Global Affairs, University of Toronto)

References

Cahoon, D., Hensel, P., Rybczyk, J., McKee, K., Proffitt, E., Perez, C., 2003. Mass tree mortality leads to mangrove peat collapse at Bay Islands, Honduras after Hurricane Mitch. J. Ecol. 91, 1093–1105.

Chong, V., 2006. Sustainable utilization and management of mangrove ecosystems of Malaysia. Aquatic Ecosystem Health and Management 9, 249-260.

Cornforth, A., Fatoyinbo, E., Freemantle, P., Pettorelli, N., 2013. Advanced Land Observing Satellite Phased Array Type L-Band SAR (ALOS PALSAR) to Inform the Conservation of Mangroves: Sundarbans as a Case Study. Remote Sens. 5, 224-237.

Costanza, R., Pérez-Maqueo, O., Martinez, M., Sutton, P., Anderson, S., Mulder, K., 2008. The value of coastal wetlands for hurricane protection. Ambio. 37(4), 241–248.

Dittmar, T., Hertkorn, N., Kattner, G., Lara, R., 2006. Mangroves, a major source of dissolved organic carbon to the oceans. Global Biogeochem Cycles 20(1), DOI: 10.1029/2005GB002570.

Duke, N., Meynecke, J., Dittmann, S., Ellison, A., Anger. K, U. Berger, Cannicci, S., Diele, K., Ewel, K., Field, C., Koedam, N., Lee, S., Marchand, C., Nordhaus, I., Dahdouh-Guebas, F., 2007. A world without mangroves. Science 317(5834), 41-42.

Ellison, A., 2008. Managing mangroves with benthic biodiversity in mind: moving beyond roving banditry. Journal of Sea Research 59(1-2), 2–15.

Emerton, L., Seilava, R. and Pearith, H., 2002. Bokor, Kirirom, Kep and Ream National Parks, Cambodia: Case studies of economic and development linkages, field study report, in Review of Protected Areas and their Role in the Socio-Economic Development of the Four Countries of the Lower Mekong Region, International Centre for Environmental Management, Brisbane and IUCN Regional Environmental Economics Programme, Karachi. http://cmsdata.iucn.org/downloads/casestudy03ream.pdf (accessed 15.08.13).

FAO, 2007. The World's Mangroves 1980-2005, FAO Forestry Paper 153. Rome: Forest Resources Division, FAO. The Food and Agriculture Organisation of the United Nations. 77 p.

Gilman, E., Ellison, J., Duke, N. and Field, C., 2008. Threats to mangroves from climate change and adaptation options: a review. Aquat. Bot. 89(2), 237–250.

Giri, C., Ochieng, E., Tieszen, L., Zhu, Z., Singh, A., Loveland, T., Masek, J., Duke, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecol. Biogeogr. 20(1), 154–159.

Horwitz, P., Finlayson, M. and Weinstein, P., 2012. Healthy wetlands, healthy peo¬ple: a review of wetlands and human health interactions. Ramsar Technical Report No. 6. Secretariat of the Ramsar Convention on Wetlands, Gland, Switzerland, & the World Health Organization, Geneva, Switzerland.

Huxham, M., Kumara, M., Jayatissa, L., Krauss, K., Kairo, J., Langat, J., Mencuccini, M., Skov, M. and Kirui, B., 2010. Intra- and interspecific facilitation in mangroves may increase resilience to climate change threats. Philosophical Transactions of the Royal Society B: Biological Sciences 365(1549), 2127-2135.

Lavieren, H., Spalding, M., Alongi, D., Kainuma, M., Clüsener-Godt, M., Zafar, A., 2012. Policy Brief: Securing the future of mangroves. United Nations University. Institute for Water, Environment and Health, Canada. http://unesdoc.unesco.org/images/0021/002192/219248e.pdf (accessed 13.08.13).

López-Medellín, X., Ezcurra, E., González-Abraham, C., Hak, J., Santiago L., Sickman, J., 2011. Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico. Journal of Vegetation Science 22, 143–151.

Macintosh, D. and Ashton, E., 2004. Principles for a code of conduct for the management and sustainable use of mangrove ecosystems. The World Bank, Washington D.C..

Macintosh, D., Mahindapala, R., Markopoulos, M. (eds), 2012. Sharing Lessons on Mangrove Restoration. Bangkok, Thailand: Mangroves for the Future and Gland, Switzerland: IUCN.

Malaysian Timber Council, 2009. Timber Malaysia. Retrieved from: http://www.mtc.com.my/info/images/stories/pdf/tm-vol-15-3.pdf (accessed 13.08.13).

Mazda, Y., Magi, M., Kogo, M., Hong, P.N., 1997. Mangrove on coastal protection from waves in the Tong King Delta, Vietnam. Mangroves and Salt Marshes 1(2), 127-135.

McIvor, A., Möller, I., Spencer, T., and Spalding, M., 2012. Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report 1: The Nature Conservancy and Wetlands International. http://www.wetlands.org/LinkClick.aspx?fileticket=fh56xgzHilg%3D&tabid=56 (accessed 13.08.13).

Miththapala, S., 2008. Mangroves. Coastal Ecosystems Series Volume 2. Colombo Sri Lanka: Ecosystems and Livelihoods Group Asia IUCN 28.

Nellemann, C., Corcoran, E., Duarte, C.M., Valdés, L., DeYoung, C., Fonseca, L., Grimsditch, G. (eds), 2009. Blue carbon: a rapid response assessment. United Nations Environment Programme, GRID-Arendal.

UNEP, 2012. Proyecto Manglares. United Nations Environment Programme. http://www.pnuma.org/manglares/ (accessed 16.08.13).

Polidoro, B., Carpenter, K., Collins, L., Duke, N., Ellison, A., et al., 2010. The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. PLoS ONE 5(4), doi:10.1371/journal.pone.0010095.

Ramsar Secretariat, 2001. Wetland Values and Functions: Climate Change Mitigation. Gland, Switzerland. http://www.ramsar.org/cda/ramsar/display/main/main.jsp?zn=ramsar&cp=1-26-253%5E22199_4000_0__ (accessed 13.08.2013).

Reid, H. and Swiderska, K., 2008. Biodiversity, climate change and poverty: exploring the links. International Institute for Environment and Development. http://pubs.iied.org/pdfs/17034IIED.pdf (accessed 13.08.13).

Smith, T., Anderson, G., Balentine, K., Tiling, G., Ward, G. and Whelan, K., 2009. Cumulative Impacts Of Hurricanes On Florida Mangrove Ecosystems: Sediment Deposition, Storm Surges And Vegetation. Wetlands, 29(1), 24-34.

Spalding, M., Kainuma, M. and Collins, L., 2010. World atlas of mangroves. Earthscan, London.

Sullivan, C., 2005. The importance of mangroves. http://ufdc.ufl.edu/UF00093446/00028/1x (accessed 13.08.13).

Thampanya, U., Vermaat, J., Sinsakul, S. and Panapitukkul, N., 2006. Coastal erosion and mangrove progradation of Southern Thailand. Estuar. Coast Shelf Sci. 68 (1-2), 75–85.

Upadhyay, V., Ranjan, R., Singh, J., 2002. Human-mangrove conflicts: The way out. Curr Sci India 83, 1328–1336.

Valiela, I., Bowen, J. and York, J., 2001. Mangrove forests: one of the world's threatened major tropical environments. BioScience 51(10), 807–815.

Walters, B., Rönnbäck, P., Kovacs, J., Crona, B., Hussain, S. et al., 2008. Ethnobiology, socio-economics and management of mangrove forests: a review. Aquatic Bot 89(2), 220–236. where mangroves are already threatened in the world.

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

SEPTEMBER 2013

Thematic Focus: Climate change, Ecosystem management, Environmental governance

Where will the water go? Impacts of accelerated glacier melt in the Tropical Andes

QUILCAYHUANCA VALLEY - TWIGA269 FEMEN / FOTER / CC BY NC

More than 99% of the world's tropical glaciers are located in the Andes Mountains in South America, of which 71% are located in Peru, concentrated on the Cordillera Blanca, and 20% in Bolivia (Kaser, 1999; Rabatel et al., 2013; Bury et al., 2011; IRD et al., 2007). Recent studies have found the glaciers to be melting at an accelerated rate. Though glaciers are melting around the world, in the Tropical Andes the nexus of melting glaciers, dwindling water resources, climate change and a dense population meet (Bradley et al., 2006), creating an urgent need for awareness and management. This bulletin will focus on the impacts of this reported accelerated loss of tropical glaciers to water supplies in Peru as well as broader impacts to the hydrologic cycle, future water supplies and ecosystem status.

Why is this issue important?

Glaciers dot the western part of South America and can be divided into three general regions: 1) the Tropical Andes, beginning at the start of the Andes mountain range in western Venezuela and stretching south to 23°S latitude (Vuille and Bradley, 2000); 2) the central Andes in eastern Chile and 3) the Patagonia Ice Fields (North and South) in southernmost Chile and Argentina below 46°S (Glasser et al., 2011) (Figure 9.1). Glaciers in each region have been reported to be retreating at varying rates and threatened by future climate change (Rabatel et al., 2013; Willis et al., 2012; Nicholson et al., 2009).

More than 80% of freshwater available for downstream populations and ecosystems in the semi-arid tropics and subtropics originates in mountains (Messerli, 2001). Glaciers partly contribute to the water that travels down the western

Figure 9.1: Glaciers of South America. Source: Glacier location data from WGMS, 2012; Rabatel et al., 2013; Digital Elevation Model (DEM) from: USGS-EROS, 1996; visualisation by UNEP/DEWA/GRID-Sioux Falls.

slope of the Andes, supplying coastal regions with water, mostly during the dry season (Chevallier et al., 2011). Where a distinct rainy season occurs only once a year and lasts only a few months, such as in parts of Peru and Bolivia, melting snow and glaciers are a crucial water supply for the dry season (Peduzzi et al., 2010; Kaser, 2001; Rabatel et al., 2013). The dry season generally lasts from May to September (IRD et al., 2007), but may vary slightly according to region and year.

A recent overview of the findings of many studies conducted in recent decades (Rabatel et al., 2013) reports that glacier loss in the Tropical Andes has accelerated over the past three decades and now is occurring at an unprecedented rate. This loss has already had some ecological and social effects and could lead to the disappearance of some glaciers, especially those in lower elevations (Bradley et al., 2006; Urrutia and Vuille, 2009).

What are the findings?

Current trends

Each country in the Tropical Andes has experienced significant decreases in glacier area and mass balance (See Box 9.1). Locations of features mentioned are shown in Figure 9.2.

- Venezuela has the smallest area of glacier coverage of any country in the Tropical Andes. In 1952, glaciers covered an area of 3 km^2, spanning four peaks, but by 2003 only one peak, Humboldt, had glacier cover remaining (about 1 km^2) (Azancot, 2010).
- Between the 1950s and the mid-2000s, 51% of glacier coverage in Colombia was lost, with the greatest loss occurring between the late 1990s and mid-2000s. In just the five years from 2002 to 2007, the total amount of glacier area shrunk from 60 km^2 to less than 45 km^2, with some regional differences in pace and magnitude of retreat (Poveda and Pineda, 2009). Approximately 30% of glacier surface area on Nevado del Huila was lost in just two years due to volcanic eruptions in 2007 and 2008 (Rabatel et al., 2013). Four of Colombia's six remaining glaciers are on volcanos, which can increase the pace of glacier loss (Rabatel et al., 2013; Poveda and Pineda, 2009). Poveda and Pineda (2009) project that all Colombian glaciers will disappear within the 2010-2020 decade.
- Some glaciers in Ecuador are also located on volcanoes. The Antisana glaciers (12 and 15) experienced a period of rapid retreat between 1995 and 1999, followed by a short period of advance from 1999 to 2001 (Vuille et al., 2008) and another year of advance, in which a few metres were gained, in 2008 (Rabatel et al., 2013), but

Figure 9.2: Locations of physical features prominent in the discussion of glaciers in the Tropical Andes. Source: Glacier location data from WGMS, 2012; Rabatel et al., 2013; DEM from: USGS-EROS, 1996; visualisation by UNEP/DEWA/GRID-Sioux Falls.

since then, Antisana glaciers have begun to retreat again (Vuille et al., 2008).

- Most of the world's tropical glaciers are concentrated along the Cordillera Blanca in Peru (Bury et al., 2011). The Cordillera Blanca alone lost about 200 km^2 in glacier surface area from 1980 to 2006, going from 742.8 km^2 to a little more than 500 km^2 (Ordoñez et al., 2010). The glacier on Nevado Coropuna, south of the Cordillera Blanca, has decreased at least 60% in surface area since 1955. If it continues to decline at the current rate, it may disappear before 2045, although continued studies on ice thickness and volume are needed (Peduzzi et al., 2010). Across all glaciers on the Andes in Peru, the rate of glacier mass balance loss between 1964 and 1975 was 0.2 m water equivalent per year (w.e./yr) and between 1976 and 2010, the rate accelerated to a loss of 0.76 m w.e./yr (Rabatel et al., 2013).

- There was a 48% decline in surface area of 376 glaciers investigated in the Cordillera Real in Bolivia from 1975 to 2006 (Soruco et al., 2009); the glacier Chacaltaya completely disappeared in 2009 (WGMS, 2011).

Causes of melting

Glaciers located in different regions have varying rates of melt and accumulation due to geographic factors such as latitude and elevation and atmospheric factors such as albedo and climate. Detailed discussion of melting dynamics is outside the scope of this bulletin, but can be found in Mark and Seltzer (2003), Rabatel et al. (2013), and Chevallier et al. (2011) among others. A basic discussion is presented below and definitions of glacier terminology are explained in Box 9.1.

Box 9.1. Glacier terminology

Accumulation *occurs when snowfall exceeds melting*
Ablation *occurs when snow or ice is lost through evaporation and/or melting*
Mass Balance *is the net profit or net loss of snow and ice*
Equilibrium Line *exists where mass accumulation equals mass loss; it separates the accumulation zone from the ablation zone*
Source: USGS, 2007.

Melt water is produced only during above-freezing temperatures over the lowest glacier point (tongue) and storage increases only when there is precipitation over the accumulation zone (Kaser et al., 2010). Changes in glaciers due to melting can be described in four ways (Rabatel et al., 2013; Mark and McKenzie, 2007; Peduzzi et al., 2010; Huh et al., 2012; IRD et al., 2007):

- Length, measured by changes in the location of the glacier tongue (where it terminates)
- Mass balance, expressed through loss or gain in water equivalent (such as mm of w.e./yr)
- Volume, expressed through cubic measurements, such as km^3, and measured using remote sensing techniques or snow stakes
- Surface area, typically measured using remote sensing techniques or aerial photographs

Rabatel et al. (2013) report a trend among glacial melt for selected glaciers between Colombia and Bolivia with extended mass balance time series in the Tropical Andes. They observed that over the past 35 years, glaciers with a maximum elevation of 5,400 m above sea level (a.s.l.) or more have been losing mass balance at a rate of 0.6 m w.e./yr, while those at elevations below 5,400 m have been losing volume at a rate of 1.2 m w.e./yr. This trend may occur because lower elevations are exposed to ablation more than glaciers at higher elevations, which are able to maintain a permanent accumulation zone (Rabatel et al., 2013). Smaller glaciers at low elevations, without a permanent accumulation zone, have also been retreating at a pronounced rate and could soon disappear completely (Rabatel et al., 2013; Vuille et al., 2008).

Impacts of continued melting

Mountain glaciers serve as a crucial buffer as they help to provide water (as melt water) when rainfall is minimal or nonexistent (Vuille et al., 2008), such as during the dry season or during drought conditions. This implies that some melting is necessary to fuel the existing hydrologic processes and fulfil consumption needs. However, an accelerated rate of melting will bring a short-term surge in supply that could create an unsustainable dependency (Vuille, 2013), degrade seasonal capacity (Bury et al. 2011), increase risk of hazards such as landslides, massive flood events referred to as glacial lake outburst floods (GLOFs) (see Box 9.2) and avalanches (Chevallier et al., 2011; Chisolm et al., 2012) and alter ecosystems (Rabatel et al., 2013). Reduction in glacier size can and will affect availability of water downstream (Vuille et al., 2008). For example, glacier retreat in the area surrounding the Shallap, Tararhua and Uruashraju glaciers along the Cordillera Blanca could lead to a 30% decrease in average dry season discharge (Baraer et al., 2012).

Glaciers supply water to the countries of the Tropical Andes in varying quantities, creating an uneven distribution of potential impact and result in an even larger disparity in the distribution of water resources in the region (Chevallier et al., 2011). Currently, the Antisana glaciers (12 and 15) supply approximately 5% of potable water to the capital city of Quito, Ecuador (Moreno, 2010). About 24% of flow source for the Humboldt and Crespo rivers comes from the Antisana 15 glaciers (UNEP, 2011). In Bolivia, glaciers of the southern Cordillera Real supply approximately 15% of potable water for the urban areas of La Paz and El Alto and can increase to approximately 30% during the dry season from May to August (Soruco, 2012). The World Bank (2008) reports that the volume of glaciers that Peru has already experienced is equivalent to about 10 years of water supply for Lima, Peru's capital of more than 9 million people (UN, 2012), an estimated 7 billion m^3 of water. In addition to water supplies for big cities such as Lima and La Paz, glacier melt water also contributes to the water supply for rural settlements (Poveda and Pineda, 2009).

CHACALTAYA - CHRISTIAN MEHLFÜHRER / WIKICOMMONS_/ CC-BY-3.0

For example, melt water from the Coropuna glacier in Peru directly supplies approximately 8,000 people with water and indirectly supports 30,000 people (Peduzzi et al., 2010). Stern (2006) estimates that a 1°C temperature increase could cause smaller glaciers to disappear, affecting the water supply of almost 50 million across the Andes.

Loss of glacier cover and eventual reduction in runoff volume has a significant impact on unique ecosystems such as high-altitude paramos, and cloud forests (Bury et al., 2013; Poveda and Pineda, 2009). For many small towns and villages along the Andes, including the Colombian capital of Bogotá, paramos provide a source of potable water (Poveda and Pineda, 2009). Wetlands that cannot continue to be sustained risk increasing fragmentation of biodiversity, already observed in the Quilcayhuanca Valley in Peru (Bury et al., 2013). Additionally, survival of regional and endemic species could be at risk if glacier loss altered the hydrologic system. Based on a study of glacier-fed catchments in the Ecuadorian Andes, Jacobsen et al. (2012) estimate that 11% of regional and endemic species could be lost if glaciers were to disappear and there would also be noticeable loss in species richness downstream.

The hydropower industry will also feel the residual effects of melting glaciers such as reduced streamflow, which could result in decreased efficiency and energy output. Since hydropower accounts for approximately 71% of electricity generation in Colombia, 49% in Ecuador, 32% in Bolivia and 56% of energy in Peru (World Bank, 2010), maintaining the integrity of the industry is important for the people of the Tropical Andes. While glacier melt water does not supply all the water needed for hydropower, it does have some impact. Vergara et al. (2007) derived an estimate for the impact of the reduction of glacial melt water on the power generation capacity of the Cañon del Pato hydropower plant on the Rio Santa in Peru. They conclude that a 50% reduction in glacier runoff would result in a decrease in annual power output of approximately 10% (from 1540 GWh (gigawatt hours) to 1250 GWh). Further, if glacier melt water disappeared completely, annual power output would be reduced to 970 GWh. Additional regional impact studies are needed to determine the localised impact and potential for future impact of reduced flow to rivers that are used for hydropower.

Additional research is needed to quantify the impact future glacier loss will have on the environment and human populations more precisely so that appropriate and effective adaptation and water management strategies can be developed. A challenge in the data analysis process is that some glaciers have been closely monitored for only a few decades, using data with varying degrees of resolution and accuracy, and many missing years of data in between.

A Pacific climate shift from 1976 most likely contributed to the accelerated retreat of Chacaltaya (Francou et al., 2003). Figure 9.3 shows the decline of Chacaltaya from the Little Ice Age

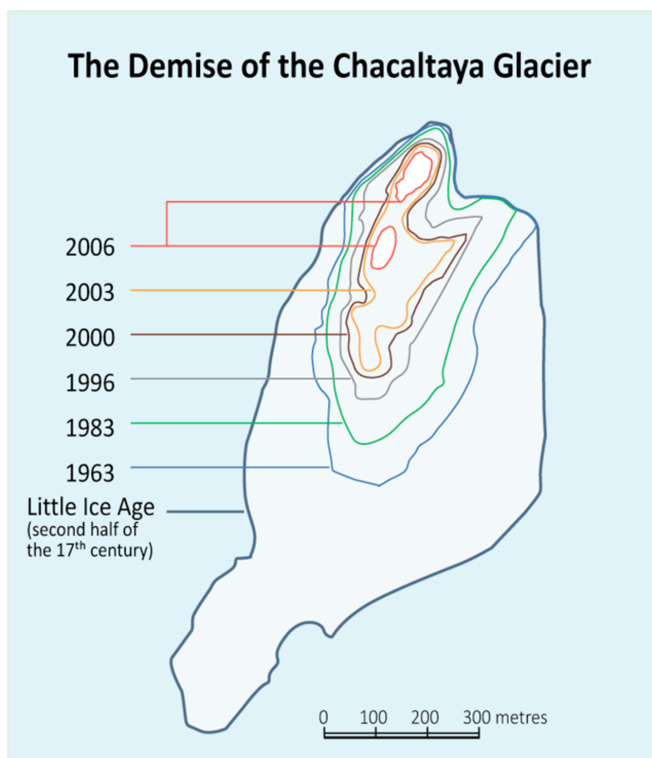


Figure 9.3: Changes in size of the Chacaltaya Glacier. Source: adapted from UNEP/GRID-Arendal, 2010; IRD, et al., 2007).

ARTESONRAJU_GLACIER_- EDUBUCHER / WIKICOMMONS / CC-BY-SA-3.0

to 2006. In 2005, it was estimated that only 5% of its surface area and 0.6% of its volume remained, as compared with records from 1740 (IRD et al., 2007). Chacaltaya completely disappeared in 2009 (WGMS, 2011), a few years before scientists predicted that it would (Francou et al., 2003; Mark and Seltzer, 2003).

Impacts of glacier loss on the watersheds of the Cordillera Blanca, Peru

Hazard potential in the Paron watershed

The Paron watershed, which contains the Artesonraju glacier, has experienced a loss of more than 30% of its glacier surface area since 1930. Glacier coverage in the watershed increased slightly between 1990 and 1997. However, coverage has decreased ever since (Baraer et al., 2012).

The Artesonraju glacier has been losing mass balance at an average of 0.6 m w.e./yr over the past 40 years (Rabatel et al., 2013). Retreat of Artesonraju and the neighboring Artesoncocha glaciers has resulted in the formation of a new highland lake (denoted with a yellow arrow in Figure 9.4) that is characterised by overhanging ice and loose rocks, making the area vulnerable to landslides. In addition, the new lake sits above two previously formed lakes, including Lake Parón, the largest lake in the Cordillera Blanca. This positioning poses a threat for a catastrophic GLOF event should an avalanche or landside, triggered by additional melting into the new lake, occur (Chisolm et al., 2012).

Threat to water supply in the Querococha watershed

Using satellite image analysis, Huh et al. (2012) found that the surface area of Yanamarey decreased 85% between 1962 and 2008. Mark et al. (2010) predict that it will completely disappear by 2020. In addition to retreating, it has also thinned, causing it to lose more than 88% of its volume (Huh et al.,

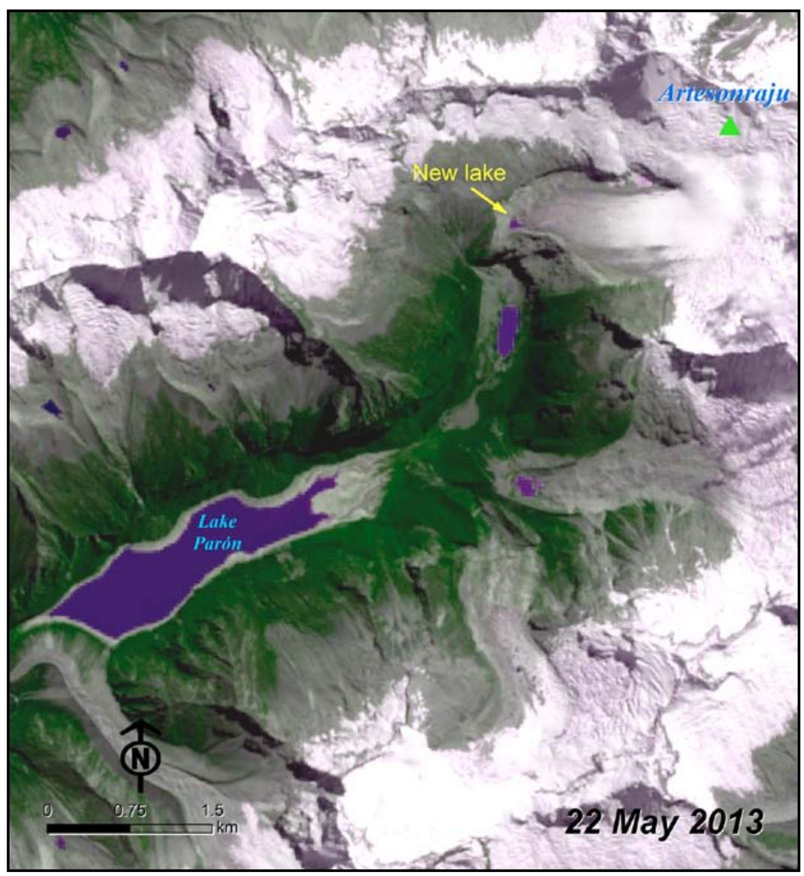


Figure 9.4:Artesonraju glacier; Source: Landsat, visualisation by UNEP/DEWA/GRID-Sioux Falls.

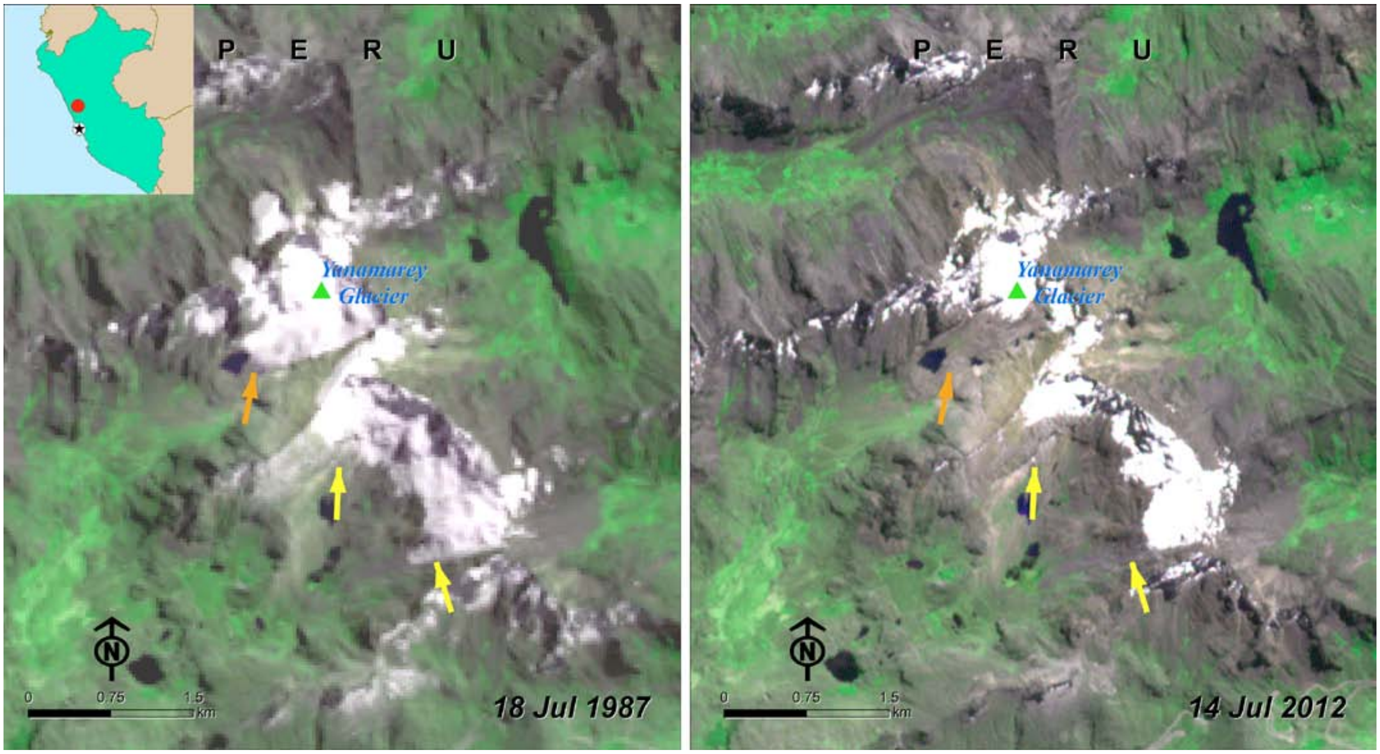


Figure 9.5: Satellite images showing changes in the Yanamarey glacier. Source: 1987 image: Landsat, 2012 image: ASTER, visualisation by UNEP/DEWA/GRID-Sioux Falls.

2012) and decreasing its seasonal storage capacity (Bury et al., 2011). Yanamarey lies within the Querococha sub-watershed of the Rio Santa watershed, which has lost more than half of its glacier-covered area since 1948 (Baraer et al., 2012). The orange arrow in Figure 9.5 indicates where Yanamarey has retreated and yellow arrows point to noticeable changes in snow and ice cover from 1987 to 2012 in smaller surrounding glaciers. Melt water from Yanamarey contributes 100% of the streamflow to its watershed during the dry season (June to September) in its immediate watershed and proportionately less downstream – ~24% to more than 50% depending on year and season (Bury et al., 2011) – so continued loss and eventual disappearance will have a significant impact on the hydrologic scheme of the area as well as the associated ecosystems and human populations.

What are the implications for policy?

The disappearance of small glaciers is pronounced and happening on a shorter time scale (Rabatel et al., 2013), making it an important issue for water managers, decision- and policy-makers now. It also presents a pressing supply issue. Decreased water supplies caused by the disappearance of smaller glaciers that contribute melt water will also likely result in increased competition for use and governance among hydropower companies, municipalities and agricultural stakeholders, as well as competition for governance and water rights (Vuille et al., 2013; Bury et al., 2013).

Climate change modelling and policy-making

The Andean region has already experienced numerous climate changes in the past few decades (Vuille et al., 2008). Over the past decade temperatures have increased ~0.1°C and precipitation has increased slightly in the inner tropics while decreasing in the outer tropics. However, the trend in precipitation is not significant on most regional and national levels, so it cannot explain the retreat in glacial cover (Rabatel et al., 2013; Poveda and Pineda, 2009). Increased temperatures will alter the rain/snow dynamic, causing the rain/snow line to increase in elevation and result in increased rain and decreased snowfall in higher elevations, inhibiting snow accumulation and contributing to rain-induced melting (Poveda and Pineda, 2009). Modeling studies (Bradley et al., 2006; Urrutia and Vuille, 2009) have found that future climate change could bring increased temperatures at higher elevations, primarily affecting the high mountains of Ecuador, Peru, Bolivia and northern Chile (i.e. those with elevations higher than 4,000 m a.s.l.). Additionally, higher temperatures would affect evaporation rates of existing water stores, further putting pressure on water resources (UNEP, 2011) and calling for policy and management measures. Climate change modeling could help project future retreat of glaciers which could

PARAMO IN THE COLOMBIAN ANDE - RITACUBA / FOTER / CC BY NC SA

influence policy-making for water management and creation of adaptation strategies. However, much still needs to be studied and understood regarding climate interactions and lower latitude glaciers, since research processes still need to be refined and glacier records are not extensive (Sicart et al., 2011).

Monitoring through policy: Adaptation, research and water rights

Since melting is predominantly a result of climatic shifts outside the direct control of Andean countries, adaptation is necessary for a sustainable water supply and healthy environment. Policies specific to adaptation to environmental changes can encompass technical, behavioural, managerial and political components (UNEP, 2011). Technical adaptation pertains to physical actions that address the change. In the case of accelerated glacier melt, creation of highland reservoirs to stabilise the cycle of seasonal runoff to increase the efficiency of capturing and storing water (Bradley et al., 2006) would be a technical adaptation. Engaging the community to change its current use of resources and promote ecosystem resilience is one way to address behavioural adaptation. Managerial adaptation can stem from behavioural adaption through the implementation and regulation of land-use practices, encouraged by behavioural changes. An example of using both types of these strategies is the Proyecto Regional Andino de Adaptación, based in Peru. The project is working toward increasing the resilience of the ecosystems and the local economy in an effort to protect itself from impacts of melting glaciers. It also has a cost-benefit component for developing adaptation strategies (Ordoñez et al., 2010). Further, the Proyecto Glaciares project, a joint venture between Peru and Switzerland that focuses on the regions of Ancash and Cusco, has already begun to take action to mitigate the effects of glacier decline by increasing adaption capacity and establishing disaster risk-management protocols (CARE Peru, 2012). The project aims to generate specific products including early warning systems to address glacial hazards, increasing capacity building through strengthening human resources in the fields of glaciology, climate change and risk management and increasing public investment in monitoring glaciers.

Some projects utilise several aspects of adaptation. To help increase ecosystem and economy resilience across several countries of the Tropical Andes, the governments of Bolivia, Ecuador and Peru, in collaboration with the World Bank, are participating in the Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes Project (World Bank, 2013). One objective of the project is to create a methodological guide for high-mountain ecosystems adaptation; none had previously existed. This objective was achieved through the AndesPlus sub-project and all four stakeholder countries have agreed. Other results of the overarching project include using ensembles of high resolution data for climate change monitoring and development of corresponding short-term predictions for Ecuador and Bolivia, creation of impact maps on key crops in Peru, completion of studies pertaining to economic impacts and installation and operation of eight new meteorological stations that disseminate information to Bolivia, Colombia, Ecuador and Peru. Through the initiate plans and materials developed, the project hopes to use the successful outcomes as a basis for other projects in the future.

Management of water rights

Political adaptation strategies concern elements such as zoning regulations and could be applied to water rights. Adequate policies need to be put into place to protect water rights, as there is likely to be an increasing reliance on mechanisms to capture and save water during the wet season to be used during the dry season. Research can model

Box 9.2. Hazards of melting glaciers

Huaraz, Peru. twiga269 FEMEN / Foter.com / CC BY-NC

The Palcaraju and Pucaranra glaciers sit above Lake Palcacocha, approximately 15 miles northeast of Huaraz, Peru. A devastating event occurred in 1941, when a chunk of the Palcaraju glacier fell into the lake, causing a wave that flooded a third of the city and killed more than 5,000 people. Risk subsided for decades, but floods are now again a threat. In February 2013, the Huaraz Risk Management Office had to alert citizens to a possible lake outflow event, as Lake Palcacocha had filled beyond its record capacity and threatened to release 17 million m^3 of water, endangering the more than 100,000 residents of Huaraz (Pérez, 2013).

and estimate the impact that decreased runoff will have on coastal and glacier populations alike, but further studies are needed to examine how much water is being used by these communities so that future management activities can be appropriately designed. For cities in which hydropower efficiency or output may be reduced by reduced streamflow, policy- and decision-makers could use the situation as an opportunity to encourage other kinds of renewable energy, aside from hydropower (Bradley et al., 2006), that could lessen the stress on water as an energy source.

Water management initiatives taken in Peru are a good example of how regional needs can be addressed. In 2008, a water management framework was created and in the following year, a new water resources law was put into effect: the National System for Water Resources Management (Condom et al., 2012) aiming to develop water management strategies at a watershed level. Since not all watersheds will be affected equally regarding water issues, a local-level approach, such as this one, is needed to accommodate all vulnerable areas and resources.

Many data gaps regarding precipitation records and hydrologic models remain, as well as the means to communicate the findings to a general audience, so continued research is needed (Vuille, 2013) to develop the best adaptation strategies and policies possible. Mandates for monitoring and research could be included in legislation, such as in Peru (Ordoñez et al, 2010), to encourage the continuation of such studies. Specific research areas could address comprehensive mass and energy balance studies (Poveda and Pineda, 2009), distinct properties of clouds and precipitation in the wet and dry seasons and their relationship to mass balance (Sicart et al., 2011), as well as the human-environment interaction and vulnerability (Bury et al., 2011) and quantification of glacier melt water contributions to firmly determine the magnitude of impact of decreased melt water at regional, national and ecosystem levels. Continued climate change research and monitoring is also needed, especially using higher resolution data at a regional level. If the opportunity for long-term adaptation planning is seized now, a more sustainable future can be created.

Acknowledgement

Writer: Lindsey Harriman[a]

Production and Outreach Team: Arshia Chander[a], Ashbindu Singh[a,b], Erick Litswa[b], Kim Giese[a], Lindsey Harriman[a], Michelle Anthony[a], Reza Hussain[a], Tejaswi Giri[a], Theuri Mwangi[b] and Zinta Zommers[b].

Special thanks to Ashbindu Singh[a,b], Tejaswi Giri[a], Andreas Salinas[c], Charles Davies[c], Isabel Martinez[d], Bernard Francou[e], Cedomir Marangunic[f], Ron Witt[g], Andrea Sabelli[d], Pascal Peduzzi[g], Silva Giada[d], Alvaro Soruco[h], Arshia Chander[a] and Shelley Robertson[i] for their valuable comments, input and review.

([a] UNEP/DEWA/GRID-Sioux Falls; [b]UNEP/DEWA-Nairobi; [c]UNEP/DEWA-ROLAC, [d]UNEP/ROLAC, [e]Institut de Recherche pour le Développement (IRD), Bolivia, [f]GEOESTUDIOS, Chile, [g]UNEP/DEWA/GRID-Geneva, [h]Instituto de Geologia y del Medio Ambiente, Universidad Mayor de San Andres, Bolivia, [i]Munk School of Global Affairs, University of Toronto)

References

Azancot, M., 2010. Venezuela, Laboratorio Nacional de Hidráulica. Presented at the PNUMA Curso Iberoamericano de Glaciares, June 6 – 10, 2011, Quito Ecuador http://www.pnuma.org/agua-miaac/GLACIOLOGIA2011/CODIA%20II%20IBEROAM%20GLACIOLOGIA/MATERIAL%20ADICIONAL/PONENCIAS/PARTICIPANTES/Venezuela.pdf

Baraer, M., Mark, B., McKenzie, J., Condom, T., Bury, J., Huh, K., Portocarrero, C., Gomez, J., Rathay, S., 2012. Glacier recession and water resources in Peru's Cordillera Blanca. Journal of Glaciology 58(207), 134-150.

Bradley, R., Vuille, M., Diaz, H., Vergara, W., 2006. Threats to Water Supplies in the Tropical Andes. Science. 312, 1755 – 1756.

Bury, J., Mark, B., McKenzie, J., French, A., Baraer, M., Huh, K., Luyo, M., Lopez, R., 2011. Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru. Climatic Change. 105, 179-206.

Bury, J., Mark, B., Carey, M., Young, K., McKenzie, J., Baraer, M., French, A., Polk, M., 2013. New Geographies of Water and Climate Change in Peru: Coupled Natural and Social Transformations in the Santa River Watershed. Annals of the Association of American Geographers 103(2), 363 – 374.

CARE Peru, 2012. Bulletin October – November 2012 No. 2. CARE Peru. http://proyectoglaciares.wix.com/boletinproyectoglaciares02#!__page-0-copy1/proyecto/vstc5=objetivos (accessed 24.06.13).

Chevallier, P., Pouyaud, B., Suarez, W., Condom, T., 2011. Climate change threats to environment in the tropical Andes: glaciers and water resources. Supplement to Regional Environmental Change 11(1), 179 – 187.

Chisolm, R., McKinney, D., Gomez, J., Voss, K., 2012. Emerging Glacial Lakes in the Cordillera Blanca, Peru: A Case Study at Arteson Glacier. American Geophysical Union 2012 Conference e-poster. http://fallmeeting.agu.org/2012/eposters/eposter/gc11a-0958/

Condom, T., Escobar, M., Purkey, D., Pouget, J., Suarez, W., Roamos, C., Apaestegui, J., Tacsi, A., Gomez, J., 2012. Simulating the implications of glaciers' retreat for water management: a case study in the Rio Santa basin, Peru. Water International 37(4), 442 – 459.

Francou, B., Vuille, M., Wagnon, P., Mendoza, J., Sicart, J., 2003. Tropical climate change recorded by a glacier in the central Andes during the last decades of the twentieth century: Chacaltaya, Bolivia, 16oS. Journal of Geophysical Research: Atmospheres 108(D5, 16), doi: 10.1029/2002JD002959.

Glasser, N., Harrison, S., Jansson, K., Anderson, K., Cowley, A., 2011. Global sea-level contribution from the Patagonian Icefields since the Little Ice Age maximum. Nature Geoscience Letters. DOI: 10.1038/NGEO1122.

Huh, K., Mark, B., Hopkinson, C., 2012. Changes of topographic context of the Yanamarey glaciers in the Tropical Peruvian Andes. Remote Sensing and Hydrology 2010 Symposium, September 2010, Jackson Hole, Wyoming, IAHS Publ. 352, 2012.

IRD, GSAC, UNEP/ROLAC, 2007. The End of Snowy Heights? Glaciers and Climate Change in the Andean Community. Great Secretariat of the Andean Community (GSAC), the French Institute of Research for Development (IRD), United Nations Environment Programme Regional Office for Latin America and the Caribbean (UNEP/ROLAC), and the Spanish International Cooperation Agency. Lima, Peru.

Jacobsen, D., Milner, A., Brown, L., Dangles, O., 2012. Biodiversity under threat in glacier-fed river systems. Nature Climate Change Letters 2, doi: 10.1038/NCLIMATE1435.

Kaser, G., 1999. A review of the modern fluctuations of tropical glaciers. Global and Planetary Change 22(1-4), 93 – 103.

Kaser, G., 2001. Glacier-climate interaction at low latitudes. Journal of Glaciology 47(157), 195 – 204.

Kaser, G., Brobhauser, M., Marzeion, B., 2010. Contribution potential of glaciers to water availability in different climate regimes. PNAS Open Access Online, doi: 10.1073/pnas.1008162107.

Mark, B., Seltzer, G., 2003. Tropical glacier meltwater contribution to stream discharge: a case study in the Cordillera Blanca, Peru. Journal of Glaciology 49(165), 271-281.

Mark, B., McKenzie, J., 2007. Tracing Increasing Tropical Andean Glacier Melt with Stable Isotopes in Water. Environmental Science and Technology 41(20), 6955 – 6960.

Messerli, B., 2001. The International Year of the Mountains, the Mountain Research Initiative and PAGES, editorial. PAGES News 9(2).

Moreno, O., 2010. Strategies and actions to adapt Quito's climate change: Water supply and sanitation sector (From the Water Supply Company of Quito). Presented at Resilient Cities 2010: 1st World Congress on Cities and Adaptation to Climate Change, May 28 – 10, 2010, Bonn, Germany, http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/docs/C5-Bonn2010-Othon-Zevallos.pdf

Nicholson, L., Marin, J., Lopez, D., Rabatel, A., Bown, F., Rivera, A., 2009. Glacier inventory of the upper Huasco valley, Norte Chico, Chile: glacier characteristics, glacier change and comparison with central Chile. Annals of Glaciology 50(53), 111 – 118.

Ordoñez, J., Sandro, A., Zubieta, R., et al., 2010. Los Recursos Hidricos y los Glaciares en el Peru. Presentation for Glaciology Course, Oct 25 – 29 2010, Santiago, Chile. http://www.pnuma.org/agua-miaac/CursoGlaciologiaPresent.php.

Peduzzi, P., Herold, C., Silverio, W., 2010. Assessing high altitude glacier thickness, volume and area changes using field, GIS and remote sensing techniques: the case of Nevado Coropuna (Peru). The Cryosphere 4, 313 – 323.

Pérez, I., 2013. Glaciers: Meltwater catastrophes are forming high in the Andes. E&E Publishing, LLC: Climate Wire. http://www.eenews.net/stories/1059977803 (accessed 16.03.13).

Poveda, G., Pineda, K., 2009. Reassessment of Colombia's tropical glaciers retreat rates: are they bound to disappear during the 2010-2020 decade? Advances in Geosciences 22, 107 – 116.

Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., et al., 2013. Current state of glaciers in the tropical Andes: a multi-century perspective on glacier evolution and climate change. The Cryosphere 7, 81-102.

Sicart, J., Hock, R., Ribstein, P., Litt, M., Ramierz, 2011. Analysis of seasonal variations in mass balance and meltwater discharge of the tropical Zongo Glacier by application of a distributed energy balance model. Journal of Geophysical Research 116(D13105).

Soruco, A., Vincent, C., Francou, B., Gonzalez, J., 2009. Glacier decline between 1963 and 2006 in the Cordillera Real, Bolivia. Geophysical Research Letters 36(L03502), doi: 10.1029/2008GL036238.

Soruco, A., 2012. Medio siglo de fluctuaciones glaciares en la Cordillera Real, y su efectos hidrológicos en la ciudad de La Paz. IRD, La Paz, pp. 227.

Stern, N., 2006. The Economic of Climate Change: The Stern Review. London, Cambridge, University Press.

UN, 2012. World Urbanization Prospects: The 2011 Revision. United Nations Department of Economic and Social Affairs/Population Division, New York.

UNEP/GRID-Arendal, 2010. Chacaltaya glacier. Vital Climate Change Graphics for Latin America and the Caribbean. UNEP/GRID-Arendal. http://www.grida.no/graphicslib/detail/chacaltaya-glacier_128f (accessed 25.06.13).

UNEP, 2011. Environment Climate Change Outlook (ECCO) Metropolitan District of Quito Summary. United Nations Environment Programme, Panama.

Urrutia, R. and Vuille, M., 2009. Climate change projections for the tropical Andes using a regional climate model: Temperature and precipitation simulations for the end of the 21st century. Journal of Geophysical Research 114(D02108), doi: 10.1029/2008JD011021.

USGS-EROS, 1996. 30 arc-second DEM of South America. United States Geological Survey Earth Resources Observation and Science Center. http://databasin.org/datasets/d8b7e23f724d46c99db1421623fd1b4f (accessed 06.25.13).

USGS, 2007. Glossary of Selected Glacier and Related Terminology. United States Geological Survey. http://vulcan.wr.usgs.gov/Glossary/Glaciers/glacier_terminology.html (accessed 25.06.13).

Vergara, W., Deeb, A., Valencia, A., Bradley, R., Francou, B., Zarzar, A., Grünwaldt, A., Haeussling, 2007. Economic Impacts of Rapid Glacier Retreat in the Andes. EOS, Transactions American Geophysical Union 88(25), 261 – 264.

Vuille, M., 2013. Climate Change and Water Resources in the Tropical Andes. Inter-American Development Bank Environmental Safeguards Unit Technical Note, No. IDB-TN-515.

Vuille, M. and Bradley, R.S., 2000. Mean annual temperature trends and their vertical structure in the tropical Andes. Geophysical Research Letters 27(23), 3885 - 3888.

Vuille, M., Francou, B., Wagnon, P., Irmgard, J., Kaser, G., Mark, B., Bradley, R., 2008. Climate change and tropical Andean glaciers: Past, present and future. Earth Science Reviews. 89, 79-96.

WGMS, 2012 (original, 1999). World Glacier Monitoring Service. World Glacier Inventory. Boulder, Colorado USA: National Snow and Ice Data Center. http://dx.doi.org/10.7265/N5/NSIDC-WGI-2012-02 (accessed 01.06.13).

WGMS, 2012 (original, 1999). World Glacier Monitoring Service. World Glacier Inventory. Boulder, Colorado USA: National Snow and Ice Data Center. http://dx.doi.org/10.7265/N5/NSIDC-WGI-2012-02.

Willis, M., Melkonian, A., Pritchard, M., Rivera, A., 2012. Ice loss from the Southern Patagonian Ice Field, South America, between 2000 and 2012. Geophysical Research Letters 29(L17501), doi:10.1029/2012GL053136.

World Bank, 2008. Retracting glaciers impacts economic outlook in the tropical Andes. The World Bank. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/LACEXT/0,,print:Y~isCURL:Y~contentMDK:21739254~pagePK:146736~piPK:146830~theSitePK:258554,00.html (accessed 26.06.13).

World Bank, 2010. World DataBank. http://databank.worldbank.org (accessed 13.09.13).

World Bank, 2013. Adaptation to the Impact of Rapid Glacier Retreat in the Tropical Andes. The World Bank. http://www.worldbank.org/projects/P098248/adaptation-impact-rapid-glacier-retreat-tropical-andes?lang=en&tab=overview(accessed 16.09.13).

UNEP

UNEP Global Environmental Alert Service (GEAS)

Taking the pulse of the planet: connecting science with policy

Website: www.unep.org/geas E-mail: geas@unep.org

OCTOBER 2013

Thematic Focus: Ecosystem management, Environmental governance, Harmful substances and hazardous waste

Municipal solid waste: Is it garbage or gold?

STARS FOUNDATION / FOTER / CC BY NC-ND

Waste management has become an issue of growing global concern as urban populations continue to increase and consumption patterns change. The health and environmental implications associated with garbage disposal are mounting in urgency, particularly in developing countries. However, the growth of the solid-waste market, increasing resource scarcity and the availability of new technologies are offering opportunities for turning waste into a resource.

Why is this issue important?

Urbanization has increased in speed and scale in recent decades, with more than half the world's population now living in urban centres (Tacoli, 2012; UNPD, 2012a) (see Figure 10.1). By 2050, urban dwellers probably will account for 86 per cent of the population in developed countries and for 64 per cent of the population in developing countries (UNPD, 2012a). Rapid urban population growth has resulted in a number of land-use and infrastructural challenges, including municipal solid-waste management. National and municipal governments often have insufficient capacity or funding to meet the growing demand for solid-waste management services (Tacoli, 2012). Solid-waste management is the single

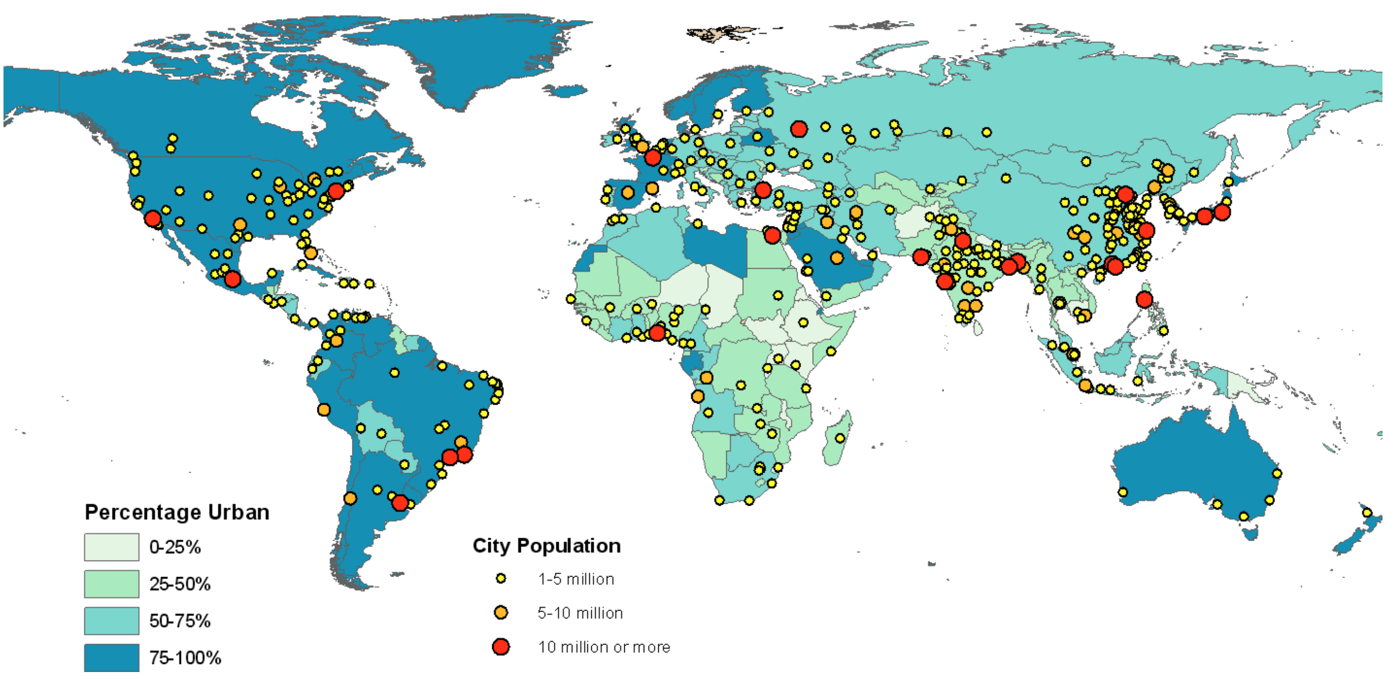


Figure 10.1: Percentage of urban population and agglomerations by size class, 2011 (UNPD, 2012b).

Electronic waste

Poor children from slums spend a lot of time in garbage-picking

largest budget item for many cities (World Bank, 2012; UN-HABITAT, 2010).

The waste sector traditionally refers to municipal solid waste and excludes wastewater, which tends to be categorised under the water or industry sectors. The scope of this bulletin is therefore limited to municipal solid waste (MSW). Municipal solid waste is generally composed of electrical and electronic equipment (such as discarded computers, printers, mobile phones, TVs and refrigerators), construction and demolition waste, health-care waste, and waste from households, offices, shops, schools and industries, and agricultural residues. These include food waste, garden (yard) and park waste, paper and cardboard, wood, textiles, nappies (disposable diapers), rubber and leather, plastics, metal, glass (and pottery and china) and refuse such as ash, dirt, dust, soil and electronic waste (Guerrero et al., 2013; IPCC, 2007). The content of MSW differs between developing and developed countries, and even between regions or cities in countries. For example, MSW in developing countries has a much larger proportion of organic waste than in developed countries (World Bank, 2012).

Electronic waste constitutes a major source of new and complex hazardous garbage to the environment and human health and presents a growing challenge to both developed and developing countries (UNEP and UNU, 2009). There are concerns over medical consequences from landfill sites and older incinerators, including cancer, mortality, birth defects and low birth weight (WHO, 2007). Ozone-depleting substances released from discarded electronic appliances and building materials (e.g. foams), as well as industrial waste practices, contribute to ozone-layer depletion (UNEP, 2011).

In developing countries, open dumpsites are the most common method of disposing of waste (World Bank 2012). Dumping of mixed waste occurs alongside open burning, grazing of stray animals and pollution of surface and groundwater by hazardous substances such as leachate and gas (UNEP, 2011). Dumpsites have been linked to many harmful health effects, including skin and eye infections, respiratory problems, vector-borne diseases such as diarrhoea, dysentery, typhoid, hepatitis, cholera, malaria and yellow fever, high blood lead levels and exposure to heavy-metal poisoning (UNEP, 2011). However, in developing countries, data on waste generation and composition are largely unreliable and insufficient, seldom capturing system losses or informal activities (Jha et al., 2011; UN-HABITAT, 2010). Without proper data it might be difficult to design sound strategies or to make wise budget decisions on waste management (Wilson et al., 2012).

This bulletin provides examples from Europe, where considerable progress has been made toward solutions for waste management. Landfill sites continue to represent one of the most serious environmental threats in several European countries (Raco et al., 2013). Cities such as Naples

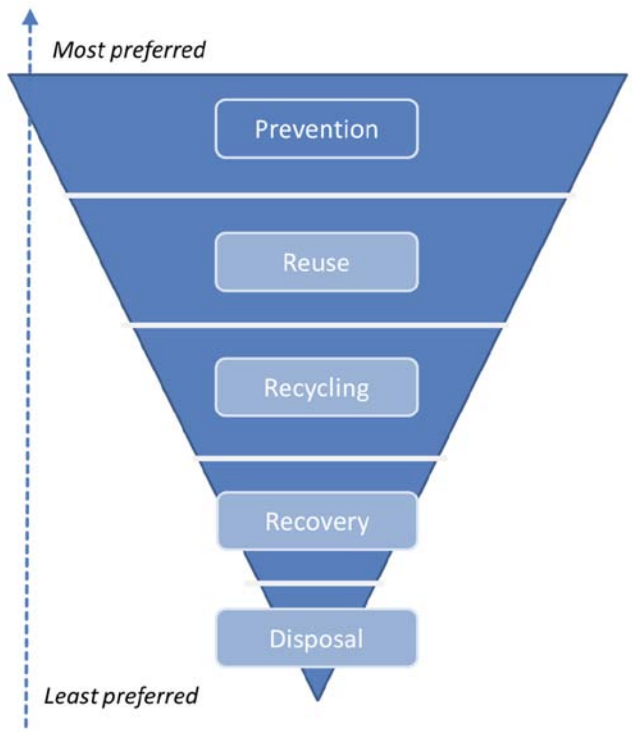


Figure 10.2: Waste management hierarchy (UNEP, 2011).

in Italy have experienced extended waste-management crises (Mazzanti et al., 2012). However, new communication tools and technology options such as waste-to-energy (or energy from waste) offer possible strategies forward.

What are the findings?

The waste hierarchy is now used globally as a communication tool to remind those who generate waste and those who manage it that preventing waste through efficient use of resources and raw materials is the best option. Re-using discarded goods without reprocessing or remanufacture is assumed to provide greater savings in resource consumption and is given priority over recycling (Figure 10.2) (Wolsink, 2010).

Increased scarcity of natural resources and the consequent rise in commodity prices have influenced the demand for recycled products. The resource value of waste has become an important driver in many developing countries today and provides a livelihood for the urban poor (UN-HABITAT, 2010). Recycling materials such as paper, glass and plastics, as well as composting and digestion of bio-waste, becomes the obvious next preferable option. Aerobic (with oxygen) composting of MSW avoids the formation of methane associated with anaerobic conditions. The method is generally less complex and less costly (World Bank, 2012).

The world market for municipal waste, from collection to recycling, is worth an estimated US $410 billion a year (Chalmin and Gaillochet, 2009). However, only a quarter of the 4 billion tonnes of municipal waste produced each year is recycled or recovered (Chalmin and Gaillochet, 2009).

Figure 10.3 shows the recycling rates of MSW in the European Union in 2010 compared with 2001. A line further from the centre in the radar chart signifies better waste management. As the figure indicates, recycling performance has improved in most European countries. In a report assessing recycling's economic implications, recycling had a turnover of EUR 32 billion in 2004, and increased by almost 100 per cent to a minimum of EUR 60 billion in 2008 in the European Union countries (EEA, 2011). From 2000 to 2008, employment growth in the recycling sector increased 7 per cent each year, with an overall increase of 45 per cent. Recycling generated more jobs at higher income levels than other forms of waste management in European countries (EEA, 2011). The general increase in recycling of municipal waste reduced the percentage of municipal waste landfilled (EEA, 2013).

The U.S. recycling industry is estimated to have earned US $236 billion in revenue in 2007, employing more than a million people and accounting for about 2 per cent of the country's GDP (EPN, 2009). Another estimate suggests that

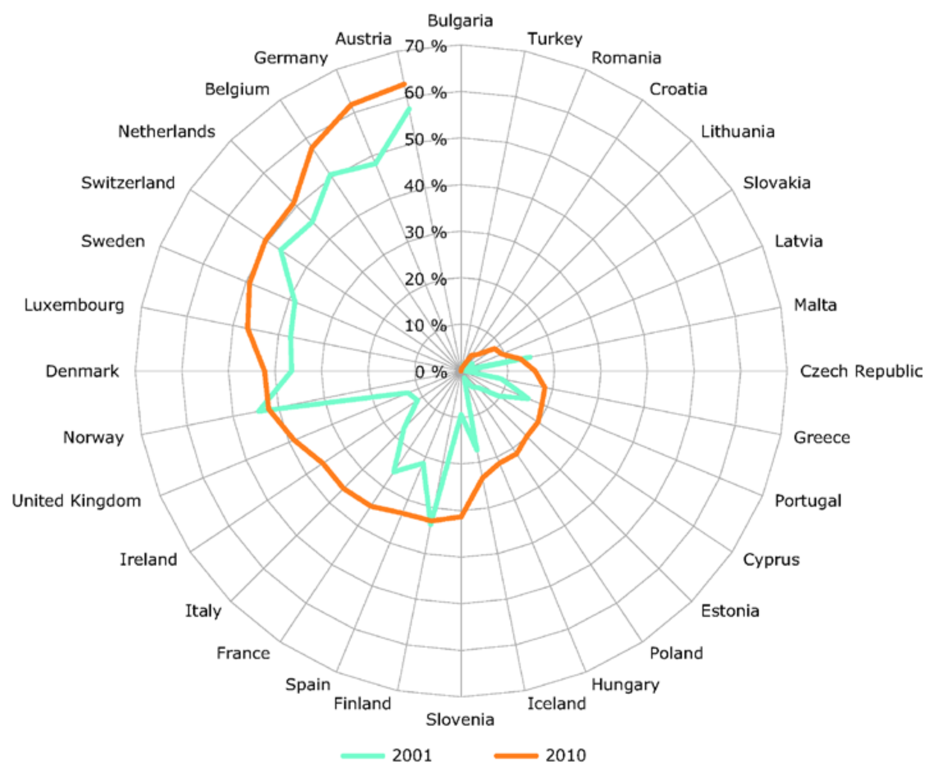


Figure 10.3: Municipal waste recycling rates in 32 European countries, 2001 and 2010 (EEA, 2013).

PART OF THE DANDORA DUMPSITE, KENYA - STARS FOUNDATION / FOTER / CC BY-NC-ND

about 1 per cent of the urban population in developing countries is engaged in waste collection for their livelihood (Medina, 2008).

New energy recovery technologies

Where waste cannot be reused or recycled due to technical, economic and environmental considerations, recovering value from waste is being promoted. Incineration alone, without energy recovery, is not a preferred option because of costs and pollution. Open-burning of waste is particularly discouraged because of the severe air pollution associated with low- temperature combustion (World Bank, 2012). As a result, there has been renewed interest in investing in waste-management technologies for extracting energy from organic waste (Papageorgiou et al., 2009; Marshall and Farahbakhsh, 2013) and efficient gas capture from landfills (UNEP, 2011). Energy from waste techniques (sometimes referred to as waste to energy, WtE) has replaced mass-burning of organic waste without energy recovery in many of the countries of the Organisation for Economic Cooperation and Development (UNEP, 2011). The process generates energy, usually in the form of electricity or heat, from controlled thermal treatment of a waste.

Anaerobic digestion is considered to be one of the most viable options for recycling the organic fraction of solid waste with substantial amounts of methane (biogas) (Khalid et al., 2011). The technique involves microorganisms in an enclosed vessel that break down biodegradable material in the absence of oxygen. Biogas produced can be used to generate electricity and heat, and can be used as a substitute for natural gas and transportation fuel. The digested slurry can be further processed into compost and liquid fertilizer (Khalid et al., 2011). Unlike fossil fuel, biogas does not contribute much to the greenhouse effect, ozone depletion or acid rain. This is one of the main reasons that anaerobic digestion might play a crucial role in meeting energy challenges of the future generation (Ward et al., 2008; Khalid et al., 2011). The technique has been recognised as suitable for processing organic wet waste in developing countries (UNEP, 2011).

Incineration of waste (with energy recovery) is the most common thermal treatment of waste and can reduce the volume of disposed waste by up to 90 per cent (World Bank, 2012). The gases from the thermal step are used to boil water to create steam. This is then fed into a steam turbine to generate electricity and/or used for heating (DEFRA, 2013). Incineration is expensive in terms of capital and operating costs, and requires high standards of operation and maintenance. In many developing countries, MSW generally has a low energy value because of its high moisture content and the prior removal of paper and plastic by waste pickers. Incineration of such waste will require additional fuel (usually oil) in order to keep the wastes burning (UN-HABITAT, 2010).

The advanced thermal treatment of waste includes such technologies as pyrolysis and gasification. Pyrolysis leads to the chemical decomposition of organic material at elevated temperatures of 430°C in the absence of oxygen (DEFRA, 2013). The main product — syngas — can be used as a fuel to generate electricity or steam or as a basic chemical feedstock in the petrochemical and refining industries (FOE, 2009). Gasification uses very high temperatures that convert organic materials at controlled amounts of oxygen into carbon monoxide, hydrogen, carbon dioxide and methane (Arena, 2011). Hydrogen is high in energy and an engine that burns pure hydrogen produces almost no pollution. However, the technologies are technically difficult, relatively unproven at commercial scale, and some of the generated energy is used to power the process and hence reduces the overall benefits (DEFRA, 2013; Arena, 2011; FOE, 2009).

A number of thermal-based energy recovery processes have been reported, mainly in Europe, the United States, Japan, China and South Korea (ISWA, 2013). WtE in Europe already supplies a considerable amount of renewable energy (some 38 billion kilowatt-hours in 2006). By 2020, the amount might grow to as much as 98 billion kilowatt-hours, enough to supply 22.9 million inhabitants with electricity and 12.1 million inhabitants with heat (CEWEP, 2009). By 2009, USA had 88 WtE plants that combust about 26.3 million tonnes of MSW and serve a population of 30 million (Psomopoulos et al., 2009). Interestingly, the communities that use WtE in the U.S. have a 17.8 per cent higher recycling rate than the U.S. EPA average, showing that energy from waste coexists with high recycling (Psomopoulos et al., 2009).

What are the implications for policy?

Managing waste is a complex task that requires changes in consumption and waste production patterns, appropriate technology, organizational capacity, and co-operation among a wide range of stakeholders (Zarate et al., 2008). Data on waste management should be collected, although complete and reliable data are extremely difficult to obtain (Wilson et al., 2012). Municipal and national governments can help fill data gaps by developing waste data strategies, as produced by the Scottish Environment Protection Agency, and by ensuring statutory reporting requirements are met. Research institutions and universities have a role to play — finding cleaner, greener ways to process waste and discovering viable ways to extract energy from waste.

There is also an on-going need to develop municipal and national waste-management plans. A democratic, public process of formulating MSW goals is essential to determine the actual needs of citizens, and so to be able to prioritize limited municipal resources in a just manner (Marshall and Farahbakhsh, 2013). Waste management solutions in one region might not be appropriate elsewhere. For example, some WtE techniques might be more appropriate in developed or middle-income countries, while in developing countries, composting organic waste and biogas capture may be more useful to deal with waste high in organic matter. Large-scale investment in a specific technology, such as WtE, might also lead to technological "lock-in," narrowing options in the future. The waste hierarchy can be used to identify the most resource-efficient, long-term approach to waste management. Guidelines also exist for how to generate national waste management strategies (UNEP and UNITAR, 2013).

Ultimately, waste management presents an opportunity, not only to avoid the detrimental impacts associated with waste, but also to recover resources, realise environmental, economic and social benefits and to take a step on the road to a sustainable future. Decision makers, responsible for planning and policy making, need to be well informed in order to develop integrated waste-management strategies adapted to the needs of citizens (Guerrero et al., 2013). When informed decisions about waste management are made and applied to the circumstances that prevail, waste can even provide economic value.

MSW management has not always been a high priority for local and national policy makers and planners, especially in developing countries. Other issues with more social and political urgency might take precedence and leave little budget for waste issues (Memon, 2010). Thus, in many cities around the world, effective, functioning policy measures have been elusive and the resources invested in the sector inadequate (Konteh, 2009). National governments can make a critical contribution by making waste management a national priority. They can also ensure the availability of skills, knowledge, and capacity to implement waste management programs effectively, especially at the local level, helping turn garbage to "gold."

Acknowledgement

Writer: A. Rozenberg[a]

Production and Outreach Team: Arshia Chander[b], Ashbindu Singh[b,c], Erick Litsa[c], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Tejaswi Giri[b], Theuri Mwangi[c] and Zinta Zommers[c]

Special thanks to Ron Witt[a], Max Gomera[d], Surya Chandak[e], Djaheezah Subratty[e], Llorenc Mila I Canals[e], David Piper[e], Lindsey Harriman[b], Frank Turyatunga[c], Theuri Mwangi[c], Zinta Zommers[c], Charles Davies[f], Jordi Pon[f], Andrew Morton[g], David Jensen[g] for their valuable comments, input and review, and Shelley Robertson[h] for copy editing.

([a] UNEP/DEWA/GRID-Geneva, [b] UNEP/DEWA/GRID-Sioux Falls, [c] UNEP/DEWA-Nairobi, [d] WCMC, [e] DTIE, [f] UNEP/ROLAC, [g] DEPI, [h] Munk School of Global Affairs, University of Toronto)

References

Arena, U., 2011. Process and technological aspects of municipal solid waste gasification. A review. Waste Management 32(4), 625–639.

CEWEP, 2009. Position paper on sustainable energy from waste. Confederation of European Waste-to- Energy Plants (CEWEP), Brussels. http://www.cewep.eu/m_431 (accessed 24.10.13).

Chalmin, P. and Gaillochet, C., 2009. From waste to resource, An abstract of world waste survey. Cyclope, Veolia Environmental Services, Edition Economica, France.

DEFRA, 2013. Energy from Waste: A guide to the debate. Department for Environment, Food and Rural Affairs, UK. http://www.defra.gov.uk/publications/2013/02/27/pb13892-energy-from-waste/ (accessed 23.10.13).

EEA, 2011. Earnings, jobs and innovation: the role of recycling in a green economy. European Environment Agency, Copenhagen. http://www.eea.europa.eu/publications/earnings-jobs-and-innovation-the (accessed 10.10.13).

EEA, 2013. Managing municipal solid waste – a review of achievements in 32 European countries. European Environment Agency, Copenhagen. http://www.eea.europa.eu/publications/managing-municipal-solid-waste (accessed 10.10.13).

EPN, 2009. Opportunities for Economic Growth and Carbon Emissions Reduction in the U.S. Pulp and Paper Industry. Environment Paper Network. http://www.environmentalpaper.org/ (Accessed 27.09.13).

FOE, 2009. Briefing - Pyrolysis, gasification and plasma. Friends of the Earth. http://www.foe.co.uk/resource/briefings/gasification_pyrolysis.pdf (accessed 23.10.13).

Guerrero, L., Maas, G., Hogland, W., 2013. Solid waste management challenges for cities in developing countries. Waste Management 33(1), 220–232.

IPCC, 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Chapter 10 — Waste management. J. Bogner, Coordinating Lead Author. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds). Cambridge University Press.

ISWA, 2013. White Paper: Alternative waste conversion technologies. International Solid Waste Association. http://www.iswa.org/ (accessed 10.10.13).

Jha, A., Singh, G., Gupta P., 2011. Sustainable municipal solid waste management in low income group of cities: a review. Tropical Ecology 52, 123-131.

Khalid, A., Arshad, M., Anjum, M., Mahmood, T., Dawson, L., 2011. The anaerobic digestion of solid organic waste. Waste Management 31(8), 1737–1744.

Konteh, F., 2009. Urban sanitation and health in the developing world: reminiscing the nineteenth century industrial nations. Health & Place 15, 69–78.

Marshall, R. and Farahbakhsh, K., 2013. Systems approaches to integrated solid waste management in developing countries. Waste Management 33(4), 988-1003.

Mazzanti, M., Montini, A., Nicolli, F., 2012. Waste dynamics in economic and policy transitions: decoupling, convergence and spatial effects. Journal of Environmental Planning and Management 55, 563-581.

Medina, M., 2008. The informal recycling sector in developing countries - Organizing waste pickers to enhance their impact. Note No.44. October 2008, GRIDlines. https://www.ppiaf.org/ (accessed 22.10.2013).

Memon, M., 2010. Integrated solid waste management based on the 3R approach. Journal of Material Cycles and Waste Management 12, 30–40.

Papageorgiou, A., Barton, J., Karagiannidis, A., 2009. Assessment of the greenhouse effect impact of technologies used for energy recovery from municipal waste: A case for England. Journal of Environmental Management 90, 2999–3012.

Psomopoulos, C., Bourka, A., Themelis, N., 2009. Waste-to-energy: a review of the status and benefits in USA. Waste Management 29, 1718–1724.

Raco, B., Dotsika, E., Battaglini, R., Bulleri, E., Doveri, M., Papakostantinou, K., 2013. A quick and reliable method to detect and quantify contamination from MSW landfills: a case study. Water Air and Soil Pollution 224(1380), doi: 10.1007/s11270-012-1380-5

Tacoli, C., 2012. Urbanization, Gender and Urban Poverty: Paid Work and Unpaid Carework in the City. International Institute for Environment and Development: United Nations Population Fund, London, UK.

UNEP, 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication, United Nations Environment Programme (UNEP).

UNEP and UNITAR, 2013. Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities. United Nations Environment Programme (UNEP) and United Nations Institute for Training and Research (UNITAR), http://www.unep.org/ietc/Portals/136/Publications/Waste%20Management/UNEP%20NWMS%20English.pdf (accessed 28.10.13).

UNEP and UNU, 2009. Recycling- from e-waste to resources. Sustainable innovation and technology transfer industrial sector studies. United Nations Environment Programme & United Nations University.

UN-HABITAT, 2010. Collection of Municipal Solid Waste in Developing Countries. United Nations Human Settlements Programme (UN-HABITAT), Nairobi.

UNPD, 2012a. World Urbanization Prospects, the 2011 Revision. Department of Economic and Social Affairs, Population Division, United Nations, New York. http://esa.un.org/unup/pdf/WUP2011_Highlights.pdf (accessed 09.10.13).

UNPD, 2012b. World Urbanization Prospects, the 2011 Revision. Department of Economic and Social Affairs, Population Division, United Nations, New York. http://esa.un.org/unup/Maps/maps_urban_2011.htm (accessed 09.10.13).

Ward, A., Hobbs, P., Holliman, P., Jones, D., 2008. Optimization of the anaerobic digestion of agricultural resources. Bioresour. Technol. 99, 7928–7940.

WHO, 2007. Population health and waste management — Scientific data and policy options. Report of WHO workshop, Rome, Italy, 29-30 March 2007. Available at: http://www.euro.who.int/__data/assets/pdf_file/0012/91101/E91021.pdf (accessed 23.10.13).

Wilson, D., Rodic, L., Scheinberg, A., Velis, C. and Alabaster, G., 2012. Comparative analysis of solid waste management in 20 cities. Waste Management & Research 30, 237-254.

Wolsink, M., 2010. Contested environmental policy infrastructure: socio-political acceptance of renewable energy, water, and waste facilities. Environmental Impact Assessment Review 30, 302010.

World Bank, 2012. What a Waste: A Global Review of Solid Waste Management. Urban Development Series Knowledge Papers. http://documents.worldbank.org/curated/en/2012/03/16537275/waste-global-review-solid-waste-management (accessed 09.10.13).

Zarate, M., Slotnick, J., Ramos, M., 2008. Capacity building in rural Guatemala by implementing a solid waste management program. Waste Management 28(12), 2542-2551.

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

NOVEMBER 2013

Thematic Focus: Environmental governance, Disasters and conflicts

Cyclone Phailin in India: Early warning and timely actions saved lives

Effective disaster planning, preparation and dissemination of early warning information led to a minimal death toll in the wake of the strongest cyclone to hit India in 14 years. In mid-October, Cyclone Phailin swept over the Bay of Bengal and across the eastern coast of India, causing hundreds of millions of dollars in damage and affecting the livelihoods of 13 million people. The evacuation of more than a million people in the states of Odisha and Andhra Pradesh in response to effective early warnings resulted in a much lower death toll than a catastrophic cyclone of similar strength that struck in 1999, leaving 10,000 people dead. Continued early warning efforts could have similar positive results in the future, and when accompanied by good communication and adequate preparation, impacts of disasters could be mitigated or even prevented. This bulletin will focus on the lessons learned from Cyclone Phailin and how they can be applied to other disasters such as the recent Typhoon Haiyan.

Why is this issue important?

On the evening of October 12, 2013 a very severe tropical cyclone, Phailin, brought torrential downpours, damaging winds of more than 220 kilometres per hour (km/h) and storm surges of up to 3.5 metres (m) to the eastern Indian states of Odisha and Andhra Pradesh (GoO, 2013). A satellite image of Cyclone Phailin is pictured in Figure 11.1. The impacts of Phailin and ensuing floods affected more than 13.2 million people, left five districts of Odisha under water, and caused hundreds of millions of dollars (GoO, 2013) in damage to homes, schools, crops and the fishing industry (Froberg, 2013). However, early warning alerts, disseminated four days before Phailin struck land, allowed for the evacuation of approximately 400,000 people on or by 11 October (Senapati, 2013). Ultimately, a total of nearly 1.2 million people were evacuated (GoO, 2013), resulting in the largest evacuation


STORM SURGE DURING PHAILIN REACHED 3.5 METRES IN SOME AREAS - EU HUMANITARIAN AID AND CIVIL PROTECTION / FLICKR / CC BY ND 2.0

operation in India in 23 years (IFRC, 2013). Early warning also allowed for the relocation of more than 30,000 animals. A total of 21 lives were lost as a result of the cyclone and an additional 23 lives due to severe flash flooding in the aftermath of the cyclone (GoO, 2013). A comparable cyclone, Cyclone 05B, hit the same area in 1999 with winds of up to 260 km/h (IFRC, 1999), but had a much more devastating outcome: more than 10,000 lives were lost (World Bank, 2013). Government cooperation, preparedness at the community level, early warning communication and lessons learned from Cyclone 05B contributed to the successful evacuation operation, effective preparation activities and impact mitigation. This event exhibits the importance, benefits and effectiveness of the use of early warning for a massive disaster.

What are the findings?

From 1970 to 2010, the Asia-Pacific population living in cyclone-prone areas increased from 71.8 million to 120.7 million, expanding the magnitude of vulnerability to disasters (ESCAP and UNISDR, 2012). However, significant improvements in disaster management, preparedness, forecasting capabilities and early warning, such as the improvements exhibited by India during Cyclone Phailin in October 2013, have helped

PHOTO LEFT: BEGINNING THE CLEAN-UP EFFORTS - EU HUMANITARIAN AID AND CIVIL PROTECTION / FOTER.COM / CC BY-ND

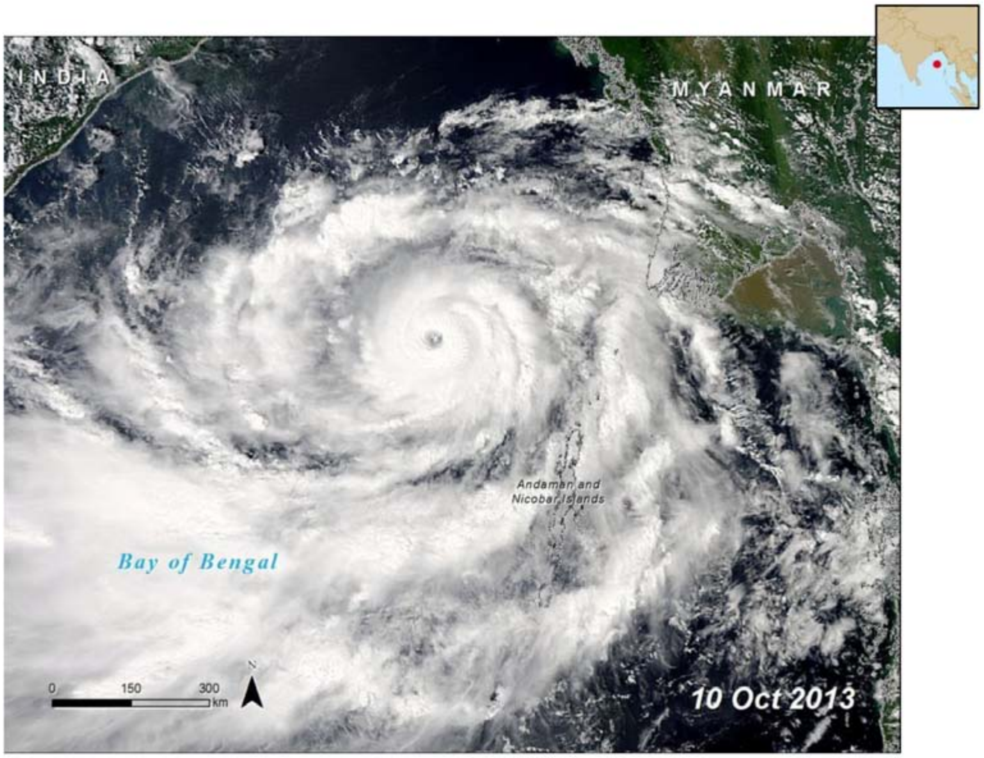


Figure 11.1: NASA MODIS Aqua image of Tropical Cyclone Phailin circling over the Bay of Bengal, moving west towards India, on October 10, 2013. (Credit: NASA MODIS Rapid Response Team in Gutro, 2013; visualisation by UNEP/DEWA/GRID-Sioux Falls).

to mitigate some disaster-related impacts. Preparedness and early warning communications and activities had been much improved since the comparable Cyclone 05B 14 years earlier (Singh, 2013). In response to Cyclone 05B in 1999, Odisha established the first state agency in India to address disaster management specifically (Odisha State Disaster Management Authority – OSDMA) (World Bank, 2013). This initiative has led to the construction of 200 new cyclone shelters, operating in places such as schools and community centres to ensure regular maintenance (Singh, 2013). Cyclone shelters have proven to be useful as 75 shelters operated by the Indian Red Cross provided safety to more than 100,000 people during Phailin (Mukherji and Agarwal, 2013) with some shelters holding up to 500 people (Froberg, 2013).

CYCLONE SHELTER IN GANJAM DISTRICT - EU HUMANITARIAN AID AND CIVIL PROTECTION / FLICKR / CC BY ND 2.0

Regarding forecasts, the India Meteorological Department (IMD) was able to predict wind velocity more accurately, contributing to better forecasts and more effective early warning communications (TOI, 2013). Warnings from the IMD were disseminated as early as four days before Phailin made landfall, as compared with two days of warning provided for Cyclone 05B in 1999 (Senapati, 2013). In addition to early warning alerts that prompted evacuations, precautions to protect cattle were taken and reservoirs were lowered to mitigate anticipated flooding (GoO, 2013). Also, preparedness meetings were held among various Disaster Response Teams in Odisha and volunteer teams, such as the International Federation of Red Cross (IFRC), were also on hand to assist with evacuation and relief (IFRC, 2013).

Several means of communication were exercised in the days prior to the landfall of Phailin to disperse early warning information. Different means and methods of communication are essential to reaching a large population. Examples of the means of communication included:

- Constant news coverage before and throughout the event, including broadcasts of Doppler radar information providing coordinates of location, intensity and timing of impending cyclones (Jain, 2013);
- Use of email, fax, telephone and print media to communicate warnings and alerts (GoO, 2013). including mobile sending phone text message alerts to more than 10,000 people in Andhra Pradesh the day before the cyclone made landfall (Price, 2013);
- Warnings and alerts delivered by the IMD through channels such as online news networks (Kumar, 2013);
- Loudspeakers used in various districts to warn residents of impending danger and to warn fishing boats that were out at sea (Senapati, 2013); and
- Distribution of satellite phones to representatives in the 14 most vulnerable districts to ensure that

Box 11.1. Typhoon Haiyan (Yolanda), the Philippines

Less than four weeks after Cyclone Phailin made landfall in India, Typhoon Haiyan (locally known as Yolanda), one of the largest super typhoons ever to make landfall on earth, brought heavy rains, raging storm surges and damaging winds to the Philippines and Viet Nam. Haiyan made landfall in the Philippines six times, beginning on 8 November (NDRRMC, 2013), causing storm surges of up to 7 m on the island of Leyte, one of the hardest islands hit, and wind gusts up to 312 km/h (OG, 2013). The Philippines is extremely vulnerable to typhoons, both geographically and economically (ESCAP and UNIDSR, 2012); Haiyan is the 24th storm to hit this year (NASA, 2013). Geographically, the Philippines is situated in the western Pacific Ocean, with not much to break the force of storms that sweep over the water (Vergano, 2013). The lack of natural protection makes its agricultural lands, which cover about 40.6 per cent of the land area (World Bank, 2011), and its 96.7 million residents very vulnerable (World Bank, 2012). Damage estimates thus far to agriculture land from the impact of Haiyan top US$200 million and the storm has affected the livelihoods of approximately 9 million people, and resulted in a death toll close to 4,000 (NDRRMC, 2013), a number expected to increase once all provinces are accounted for. Hundreds of thousands of people were evacuated from the Philippines and Viet Nam in response to early warnings, including 1,000 from the tiny island of Tulang Diyot in the Philippines which saved its entire population as all 500 homes on the island were destroyed (UNISDR, 2013), but not all were so lucky. Some refused to leave their homes, could relocate only within their cities, or could not take refuge in a structure that could withstand the storm (Mersereau, 2013; BBC, 2013). Given the intensity of the typhoon, some shelters in the Philippines were unable to survive the heavy rains and intense winds, endangering those who took shelter here (AP, 2013; Ehrenfreund, 2013). The case of Haiyan highlights the many challenges encountered when a storm approaches and when relief efforts begin, including excessive resources needed to accommodate evacuation, increased vulnerability to extreme wave and wind action, including the vulnerability of typhoon shelters themselves, travel over difficult terrain during both evacuation and relief efforts and the necessity of community cooperation with local and national officials (Mersereau, 2013; Ehrenfreund, 2013).

VIEW OF TYPHOON HAIYAN FROM THE INTERNATIONAL SPACE STATION - KAREN NYBERG/NASA

A CHILD AMONG DESTRUCTION IN LEYTE PROVINCE, PHILLIPINES - EU HUMANTIARIAN AID AND CIVIL PROTECTION/FLICKR.COM/CC-BY-ND 2.0

warning communications continued during the storm (GoO, 2013).

Benefits of early warning in coastal districts

Many coastal villages bore the brunt of Cyclone Phailin's impact. Early warning enabled coastal villages to be evacuated, especially those in Puri and Ganjam districts in Odisha. As many as 102,000 residents of Puri district and 180,000 residents of Ganjam district were evacuated (GoO, 2013). Ganjam and Puri districts were two of the few districts that received special warnings from the OSDMA on 10 October, two days before the cyclone's landfall, to evacuate those living in mud houses and low lying areas before the morning of 12 October. According to the IMD, Puri district experienced the worst winds of the cyclone with windspeeds up to 223 km/h and received 221.6 millimetres (mm) of rain between 9 October and 14 October and its western neighbour, Khurda district, received the most rain with 273.3 mm over the same time period (GoO, 2013).

EARLY WARNING PROMPTED FISHERMEN TO COME IN FROM SEA BEFORE THE CYCLONE MADE LANDFALL, BUT MANY BOATS WERE TOO HEAVY TO CARRY TO SAFETY, RESULTING IN PILES OF BOATS ALONG SHORELINES - EU HUMANITARIAN AID AND CIVIL PROTECTION / FLICKR / CC BY ND 2.0

Evidence of the rainfall is exhibited by the influx of Chilika Lake, Asia's largest brackish water lake (Barik, 2013) (Figure 11.2), which is bordered by Khurdha, Puri and Ganjam districts and the Bay of Bengal. Approximately 40,000 villagers who live among the islands scattered in and around Chilika were able to evacuate prior to the cyclone's landfall, a challenging feat considering the logistics required to get from an island to the mainland (Barik, 2013). But the environment was not as fortunate. The cyclone breached the natural coastal barrier of Chilika, destroying kilometres of its delicate mangrove forests, which are favoured by some migratory species (Mohanty, 2013) and several endangered plants and animals (Chauhan, 2013). A significant proportion of casuarina forests, which served as a protective barrier for residents of the area, were buried by sand (Mohanty, 2013). Damage to Forest Department infrastructure is approximated at US$27,000 (Mohanty, 2013). Yellow arrows in Figure 11.2 indicate significant areas of change between the extent of the lake in October 2012 and the extent a few days after Phailin dissipated. Now that the barrier between Chilika and the Bay of Bengal has been breached, protection from future events is compromised (Mohanty, 2013), demonstrating the importance of continued early warning efforts, establishment of new damage-control mechanisms, restoration of forest ecosystems, and incorporation of ecosystem-based adaptation measures.

What are the implications for policy?

Globally, the number of lives lost to hydro-meteorological disasters, such as cyclones, has decreased 10 times, yet the recorded economic losses have increased 50 times (Golnaraghi et al., 2009). Golnaraghi et al. (2009) explain that the decrease in loss of life can be attributed to the formulation of policies pertaining to disaster risk reduction (DRR) and linking national and local levels to development of early warning systems (EWS), preparedness and planning. In addition, as countries continue to develop and urban growth increases, the quantity of assets exposed to disasters will increase as well (ESCAP and UNISDR, 2012). To reduce future economic loss and impacts on livelihoods, overarching DRR management plans, in conjunction with EWS, could be developed to establish medium- and long-term plans that address appropriate land use zoning, development of infrastructure and agricultural planning (WMO, n.d.). Examples of disaster risk management activities identified by the OSDMA in its Disaster Risk Reduction Programme include urban vulnerability assessment and mapping, amending building codes accordingly and increasing access to local level financial mechanisms and mitigation funds (OSDMA, 2012). Financing mechanisms such as cash transfer programmes for immediate offsets of costs, weather-related insurance and planning could also accompany these plans to help mitigate economic impact.

The World Meteorological Organization (WMO) regards political recognition of the benefits of developing and implementing EWS at the local and national level as one of ten principles of EWS good practice (WMO, 2011). The role of cooperation and effective communication between local and national officials was evident during Cyclone Phailin. It was reported that coordination between the local and national levels was "remarkably good," which helped lead to successful preparedness efforts (Jain, 2013). For governments looking to

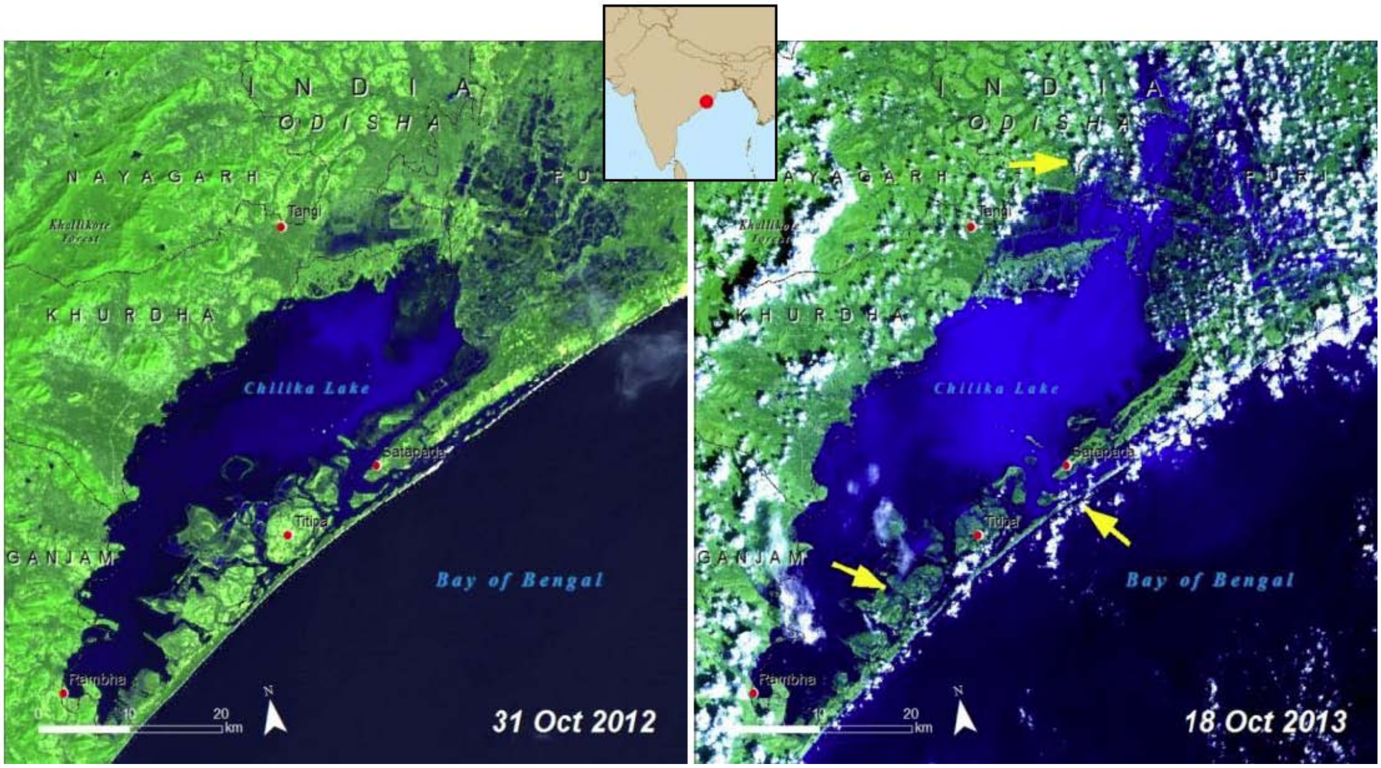


Figure 11.2: False-colour Landsat satellite images of Chilika Lake in 2012, when the coastline was intact, and six days after Phailin in 2013, when the coastline had been breached. Images: USGS/NASA; visualisation by UNEP/DEWA/GRID-Sioux Falls.

emulate the collaborative approach the Indian government took, policies could be put in place to encourage participation at local and national levels for early warning communication, recovery and relief efforts. Moreover, the involvement of the community and the private sector are also essential to the establishment and implementation of prevention policy (UNISDR, 2007).

The Odisha government, with support from the World Bank National Cyclone Risk Mitigation project, has spent US$255 million on increased disaster preparations including building shelters, evacuation planning, conducting drills and strengthening embankments (World Bank, 2013). Since its inception in 2011, the project has helped to increase disaster preparedness and early warning communication down to the local level (World Bank, 2013). A reported 148 additional evacuation shelters are to be built under this project and 28 were operational during Phailin (Singh, 2013). It is the World Bank's first project in India concerning preventative disaster risk management (World Bank, 2013).

However, to address the increasing economic losses that occur as a result of a disaster, in addition to development of risk management plans discussed previously, support of adequate disaster relief should accompany early warning efforts to aid in a full and speedy recovery. In the days following Phailin's landfall, several measures were taken to jumpstart the recovery effort. The Indian Army, Navy, Air-Force, National Disaster Response Forces (NDRF) were called to action for emergency and relief efforts, helicopters distributed food rations and the Red Cross emphasized the distribution of safe drinking water as a top priority for those involved in relief efforts (IFRC, 2013). Successful and unsuccessful results of recovery efforts can be assessed by policy and decision makers when developing and improving future early warning systems and risk management plans and evaluated for effectiveness to ensure improvement to the system over time (WMO, 2011). Early warning and response activities for Phailin exhibited major improvements over those performed during Cyclone 05B in 1999 due to the evaluation and inclusion of lessons learned.

Loss of lives in the case of Cyclone Phailin was minimised by effective early warning communication supported by joint efforts from the community, volunteer organisations, local and national levels of government and by donors, but also by the level of preparedness the community and local and national government exhibited. The destruction and impacts of Typhoon Haiyan demonstrate the need for the further strengthening of early warning systems in conjunction with increased preparation efforts and government and community cooperation. For both India and the Philippines, the focus is now directed to relief and recovery efforts and identifying lessons learned to reduce the impacts of future disasters that are imminent in the Asia-Pacific.

Acknowledgement

Writer: Lindsey Harriman[a]

Production and Outreach Team: Arshia Chander[b], Ashbindu Singh[b,c], Erick Litswa[c], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Tejaswi Giri[b], Theuri Mwangi[c] and Zinta Zommers[c]

Special thanks to Tejaswi Giri[a], Ashbindu Singh[b,c], Theuri Mwangi[b], Zinta Zommers[b], Arshia Chander[a], Anna Stabrawa[b], Ron Witt[c], Pascal Peduzzi[c] and Shelley Robertson[d] for input and review.

([a] UNEP/DEWA/GRID-Sioux Falls, [b] UNEP/DEWA-Nairobi, [c] UNEP/DEWA/GRID-Geneva, [d] Munk School of Global Affairs, University of Toronto).

References

AP, 2013. Philippines prepared for Typhoon Haiyan, but evacuation sites couldn't withstand storm surges. Associated Press (AP) In: The Washington Post. 11 November 2013. http://www.washingtonpost.com/world/asia_pacific/philippines-prepared-for-typhoon-haiyan-but-evacuation-sites-couldnt-withstand-storm-surges/2013/11/11/8515f684-4ac9-11e3-bf60-c1ca136ae14a_story.html (accessed 12.11.13).

Barik, 2013. Residents of Chilika islands prepare for the worst. The Hindu. 12 October 2013. http://www.thehindu.com/news/national/other-states/residents-of-chilika-islands-prepare-for-the-worst/article5228792.ece (accessed 04.11.13).

BBC, 2013. Severe Tropical Storm Haiyan makes landfall in Vietnam. British Broadcasting Corporation (BBC). 11 November 2013. http://www.bbc.co.uk/news/world-asia-24890114 (accessed 12.11.13).

Chauhan, C., 2013. Odisha: Phailin-hit Chilika may take years to recover. Hindustan Times. 16 October 2013. http://www.hindustantimes.com/india-news/phailineyeofthestorm/odisha-phailin-hit-chilika-may-take-years-to-recover/article1-1136094.aspx (accessed 29.10.13).

Ehrenfreund, M., 2013. Evacuees in shelters were not safe as Haiyan ravaged Tacloban, the Philippines. The Washington Post. 11 November 2013.

http://www.washingtonpost.com/world/evacuees-in-shelters-were-not-safe-as-haiyan-ravaged-tacloban-the-philippines/2013/11/11/30fb51f2-4aec-11e3-ac54-aa84301ced81_story.html (accessed 12.11.13).

ESCAP and UNISDR, 2012. Reducing Vulnerability and Exposure to Disasters: The Asia-Pacific Disaster Report 2012. United Nations Economic and Social Committee for Asia and the Pacific (ESCAP) and United Nations Office for Disaster Risk Reduction (UNISDR), Bangkok.

Froberg, M., 2013. Preparedness saved thousands of lives during Cyclone Phailin; now the recovery begins. International Federation of Red Cross and Red Crescent Societies. 17 October 2013. http://www.ifrc.org/en/news-and-media/news-stories/asia-pacific/india/recovering-from-cyclone-phailin-survivors-face-massive-hardships--63582/ (accessed 24.10.13).

Golnaraghi M., Douris, J., Migraine, J., 2009. Saving Lives Through Early Warning Systems and Emergency Preparedness. Risk Wise, Tudor Rose, 137–141.

GoO, 2013. Memorandum on the Very Severe Cyclone Phailin and the Subsequent Flood 12-15 October 2013. The Revenue and Disaster Management Department Government of Odisha. http://www.osdma.org/userfiles/file/MEMORANDUMPhailin.pdf (accessed 29.10.13).

Gutro, R., 2013. Deadly Cyclone Phailin Makes Landfall in Eastern India. National Aeronautics and Space Administration. 18 October 2013 http://www.nasa.gov/content/goddard/phailin-northern-indian-ocean/ (accessed 24.10.13).

IFRC, 1999. Cyclone: Orissa, India Information Bulletin No. 1. International Federation of Red Cross (IFRC) and Red Crescent Societies. http://www.ifrc.org/docs/appeals/rpts99/in005.pdf (accessed 30.10.13).

IFRC, 2013. Disaster relief emergency fund (DREF) India: Cyclone Phailin DREF operation No. MDRIN013 14 October 2013. International Federation of Red Cross (IFRC) and Red Crescent Societies. http://www.ifrc.org/docs/Appeals/13/MDRIN0013dref.pdf (accessed 24.10.13).

Jain, B., 2013. Cyclone Phailin: Superior preparedness could reduce casualties. The Times of India. 13 October 2013. http://timesofindia.indiatimes.com/india/Cyclone-Phailin-Superior-preparedness-could-reduce-casualties/articleshow/24059498.cms (accessed 24.10.13).

Kumar, A.V., 2013. Cyclone Phailin hits Odisha at 200 kmph, over 7 lakh evacuated. Z News. 13 October 2013 http://zeenews.india.com/news/nation/live-cyclone-phailin-80-kms-from-gopalpur-three-dead-ahead-of-landfall_882698.html (accessed 30.10.13).

Mersereau, D., 2013. Why so many people died from Haiyan and past southeast Asia typhoons. Washington Post 11 November 2013. http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2013/11/11/inside-the-staggering-death-toll-from-haiyan-and-other-southeast-asia-typhoons/ (accessed 11.11.13).

Mohanty, S., 2013. Phailin wipes out Chilika's natural coastal barrier. New Indian Express. 17 October 2013. http://newindianexpress.com/states/odisha/Phailin-wipes-out-Chilikas-natural-coastal-barrier/2013/10/17/article1840156.ece?playVideo=true (accessed 29.10.13).

Mukherji, B. and Agarwal, V., 2013. Early Warnings, Evacuations Saved Lives in Cyclone. The Wall Street Journal. 13 October 2013. http://online.wsj.com/news/articles/SB10001424052702304561004579132673017312350 (accessed 24.10.13).

NASA, 2013. Super Typhoon Haiyan Surges Across the Philippines. Earth Observatory. National Aeronautics and Space Administration (NASA). http://earthobservatory.nasa.gov/NaturalHazards/view.php (accessed 11.11.13).

NDRRMC, 2013. SitRep No. 21 Effects of Typhoon "YOLANDA" (HAIYAN). Republic of the Philippines National Disaster Risk Reduction and Management Council (NDRRMC). http://ndrrmc.gov.ph/attachments/article/1125/doc02478220131115205825.pdf (accessed 15.11.13).

OG, 2013. Status of relief and rehabilitation efforts in Yolanda-affected areas as of November 15, 2013. Official Gazette, Philippines.

http://www.gov.ph/2013/11/15/status-of-relief-and-rehabilitation-efforts-in-yolanda-affected-areas-as-of-november-15-2013-600-a-m/ (accessed 15.11.13).

OSDMA, 2012. A Brief Note on GOI UNDP Disaster Risk Reduction (DRR) Programme. Odisha State Disaster Management Authority (OSDMA). http://www.osdma.org/Download/Brief_Note_10212.pdf (accessed 04.11.13).

Price, G., 2013. India Survives Cyclone Phailin. Chatham House. 15 October 2013. http://www.chathamhouse.org/media/comment/view/194862 (accessed 30.10.13).

Senapati, A., 2013. Mass evacuation on in coastal districts. Down to Earth. 11 October 2013. http://www.downtoearth.org.in/content/mass-evacuation-coastal-districts (accessed 24.10.13).

Singh, J., 2013. How Phailin was different from super cyclone 1999. Down to Earth. 15 October 2013. http://www.downtoearth.org.in/content/how-phailin-was-different-super-cyclone-1999(accessed 24.10.13).

TOI, 2013. Cheating Phailin: The calibrated approach to disaster management in Odisha and Andhra must continue to run effectively. The Times of India. 14 October 2013. http://timesofindia.indiatimes.com/home/opinion/edit-page/Cheating-Phailin-The-calibrated-approach-to-disaster-management-in-Odisha-and-Andhra-must-continue-to-run-effectively/articleshow/24105446.cms (accessed 24.10.13).

UNISDR, 2007. Developing Early Warning Systems: A Checklist. United Nations Office for Disaster Risk Reduction. Third International Conference on Early Warning: From concept to action, March 27 – 29, 2006, Bonn.

UNISDR, 2013. Evacuation saves whole island from Typhoon Haiyan. News Archive. United Nations Office of Disaster Risk Reduction. 15 November 2013. http://www.unisdr.org/archive/35524 (accessed 18.11.13).

Vergano, D., 2013. 5 Reasons the Philippines is So Disaster Prone. National Geographic. 12 November 2013. http://news.nationalgeographic.com/news/2013/11/131111-philippines-dangers-haiyan-yolanda-death-toll-rises/ (accessed 13.11.13).

WMO, n.d. WMO Disaster Risk Reduction Programme. World Meteorological Organization (WMO). http://www.wmo.int/pages/prog/drr/ (accessed 04.11.13).

WMO, 2011. Multi-Hazard Early Warning Systems (MHEWS). Disaster Risk Reduction (DRR) Programme. World Meteorological Organization (WMO). http://www.wmo.int/pages/prog/drr/projects/Thematic/MHEWS/MHEWS_en.html#goodpractices (accessed 04.11.13).

World Bank, 2011. Data: Agricultural land (% of land area). http://data.worldbank.org/indicator/AG.LND.AGRI.ZS (accessed 13.11.13).

World Bank, 2012. Data: Philippines. The World Bank. http://data.worldbank.org/country/philippines (accessed 13.11.13).

World Bank, 2013. Cyclone Devastation Averted: India Weathers Phailin. The World Bank News. 17 October 2013. http://www.worldbank.org/en/news/feature/2013/10/17/india-cyclone-phailin-destruction-preparation (accessed 24.10.13).

UNEP Global Environmental Alert Service (GEAS)
Taking the pulse of the planet: connecting science with policy
Website: www.unep.org/geas E-mail: geas@unep.org

DECEMBER 2013

Thematic Focus: Ecosystem management, Environmental governance, Climate change

Saving the Great Migrations: Declining wildebeest in East Africa?

The iconic wildebeest migrations of East Africa are an important ecological phenomenon and massive tourist attraction. However, many wildebeest populations are in drastic decline across the region (Estes and East, 2009). Their dispersal areas and migratory corridors are being lost due to high human population densities, increasing urbanisation, expanding agriculture and fences. Their loss would contribute to biodiversity decline, and jeopardise tourism and other ecosystem services. Urgent efforts need to be made to protect wildebeest migratory corridors and dispersal areas to ensure these great migrations for the future.


JULIAN MASON / FOTER / CC BY

Why is this issue important?

Large scale animal migrations were once common around the world, but many have now collapsed, and others face serious decline (Bolger et al., 2008; Harris et al., 2009). For example, on the Great Plains of North America, the American bison once numbered as many as 30 million animals; today only few remnants remain due to over- hunting (Bolger et al., 2008). In Central Asia, the Saiga antelope has declined from over 1 million animals in 1980 to less than 200,000 in 2000 (Milner-Gulland et al., 2001). In Kenya, the migration of vast herds of zebra and Thomson's gazelle between the Lake Nakuru-Elementaita region and the Lake Baringo disappeared in the early part of the 20th century due to over-hunting, habitat loss and other human disturbances (Ogutu et al., 2012).

The East African savannas are well known for the large-scale seasonal migrations of grazing herbivores. Perhaps one of the most well-known is the annual migration of 1.3 million wildebeest, 0.6 million zebras and Thomson's gazelle in the Serengeti-Mara ecosystem (Sinclair, 1995). The significance of this migration is huge: it is the largest and most species diverse large mammal migration in the world. It is of iconic importance for tourism and has huge ecological significance, resulting in the Serengeti National Park in Tanzania being listed as a World Heritage Site (UNESCO, 2013).

The East African savannas are highly variable ecosystems, so migration enables animals to track spatially and temporally varying resources across the landscape. This gives migratory populations an advantage over resident populations, and allows these populations to rise to very high abundances (Hopcraft et al., 2013). Migrants may also move to access breeding grounds, to reduce the risks of predation and disease, and to enhance their genetic health (Bolger et al., 2008).

Wildebeest migrations are important both ecologically and economically. They play a vital role in ecosystem function and provide a number of important ecosystem services. They also have a direct effect on predator populations and other wildlife species, and on grass food resources (Sinclair et al., 2008). Economically, wildebeest migrations are important because they draw in tourism and thus contribute significantly to national economies. Tourism generated an estimated US$1.2 billion revenue in Kenya in 2012 and US$1.3 billion in Tanzania in 2011 (KNBS, 2013; RoT, 2011). In Tanzania, the northern safari circuit alone, the main attraction of which is the Serengeti-Mara wildebeest migration, generated an estimated US$550 million in 2008 (Mitchell et al., 2009). Any

PHOTO LEFT: WILDEBEAST - SERENGETI - TANZANI - MARC VERAART / FOTER.COM / CC BY-ND loss of wildlife migrations, or their habitats, could undermine some of East Africa's key tourism products with significant impacts on national economies.

What are the findings?

Declining wildebeest in East Africa

Wildebeest depend on migratory corridors and dispersal areas as they migrate out of protected areas to their seasonal habitats, often located in pastoral lands. Migratory corridors and dispersal areas usually cross human-dominated landscapes where land use practices are becoming increasingly incompatible with wildlife. As these areas are degraded or lost, severe declines in the wildebeest populations can result.

In East Africa, the white-bearded wildebeest, found across Kenya and Tanzania as shown on Figure 12.1, is facing large declines due to incompatible land uses in their migratory corridors and dispersal areas (Estes and East, 2009). This has occurred as their migratory corridors and dispersal areas have become blocked or lost, limiting their migratory movements. The result has been the near collapse of many wildebeest populations. The exception to this general pattern is the Serengeti-Mara population, which increased six fold between 1963 and 1977 following the eradication of rinderpest, before stabilizing at its current population of approximately 1.3

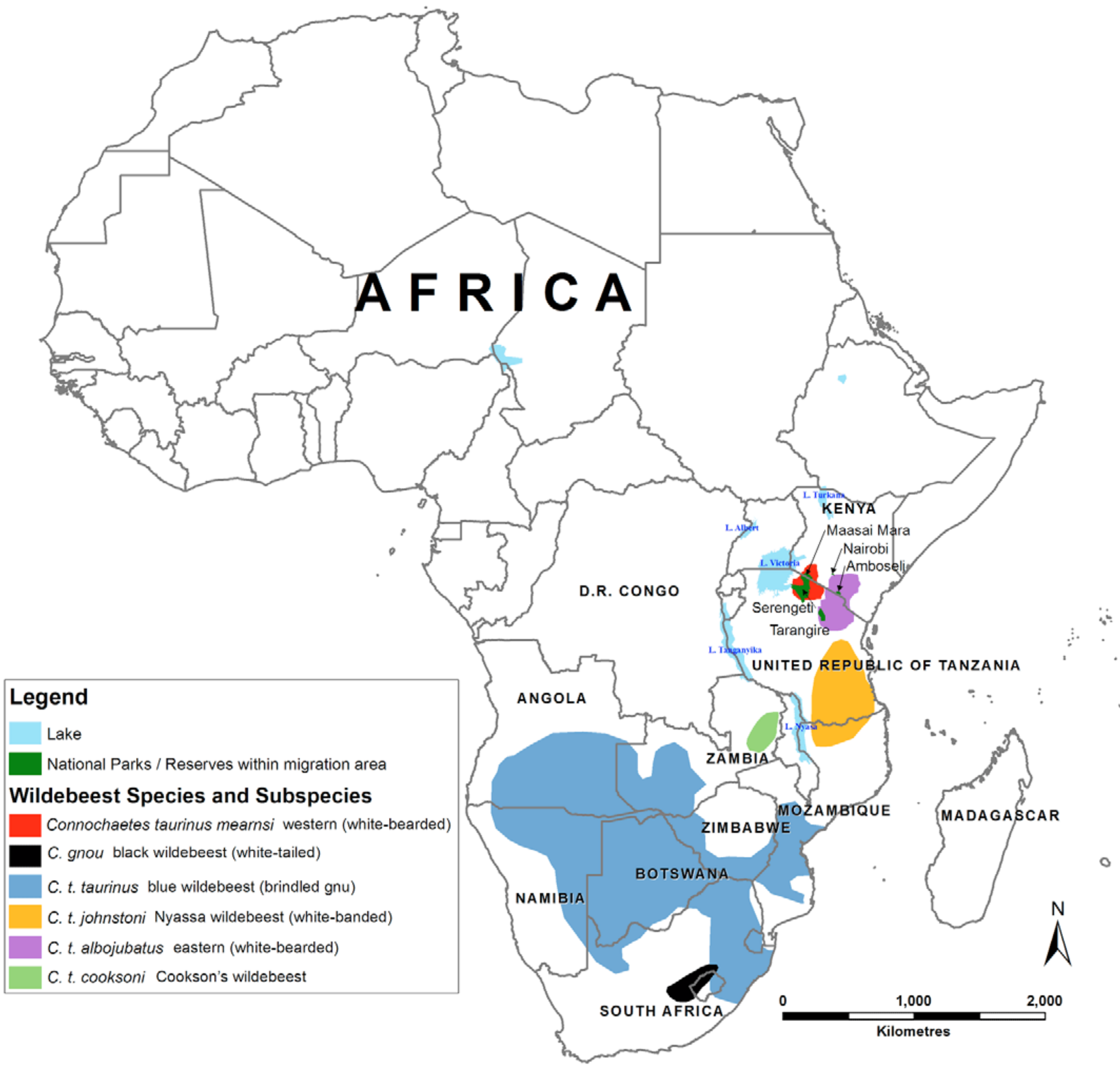


Figure 12.1: Map showing the distribution of wildebeest subspecies in Africa including some important National Parks and Reserves in Kenya and Tanzania. Source: (Estes, 2006), visualisation by UNEP/DEWA.

million (Hopcraft et al., 2013). In southern Africa, the blue wildebeest is stable or increasing; although their numbers are still far lower than their 1960s levels (Estes and East, 2009).

In Kenya, all four wildebeest populations are declining dramatically as indicated by the latest trends (Figure 12.2). In particular, in the Mara ecosystem, found within Narok County, the wildebeest population that migrates annually between the Maasai Mara National Reserve and the Loita Plains declined by more than two-thirds, from approximately 113,000 in 1977 to 35,000 by 2009 due to the expansion of agriculture (Ogutu et al., 2011) and continues to decline to date. In the Athi-Kaputiei ecosystem, the wildebeest migration between the Nairobi National Park and the adjoining Athi-Kaputiei Plains declined by more than 90%, from over 30,000 in 1978

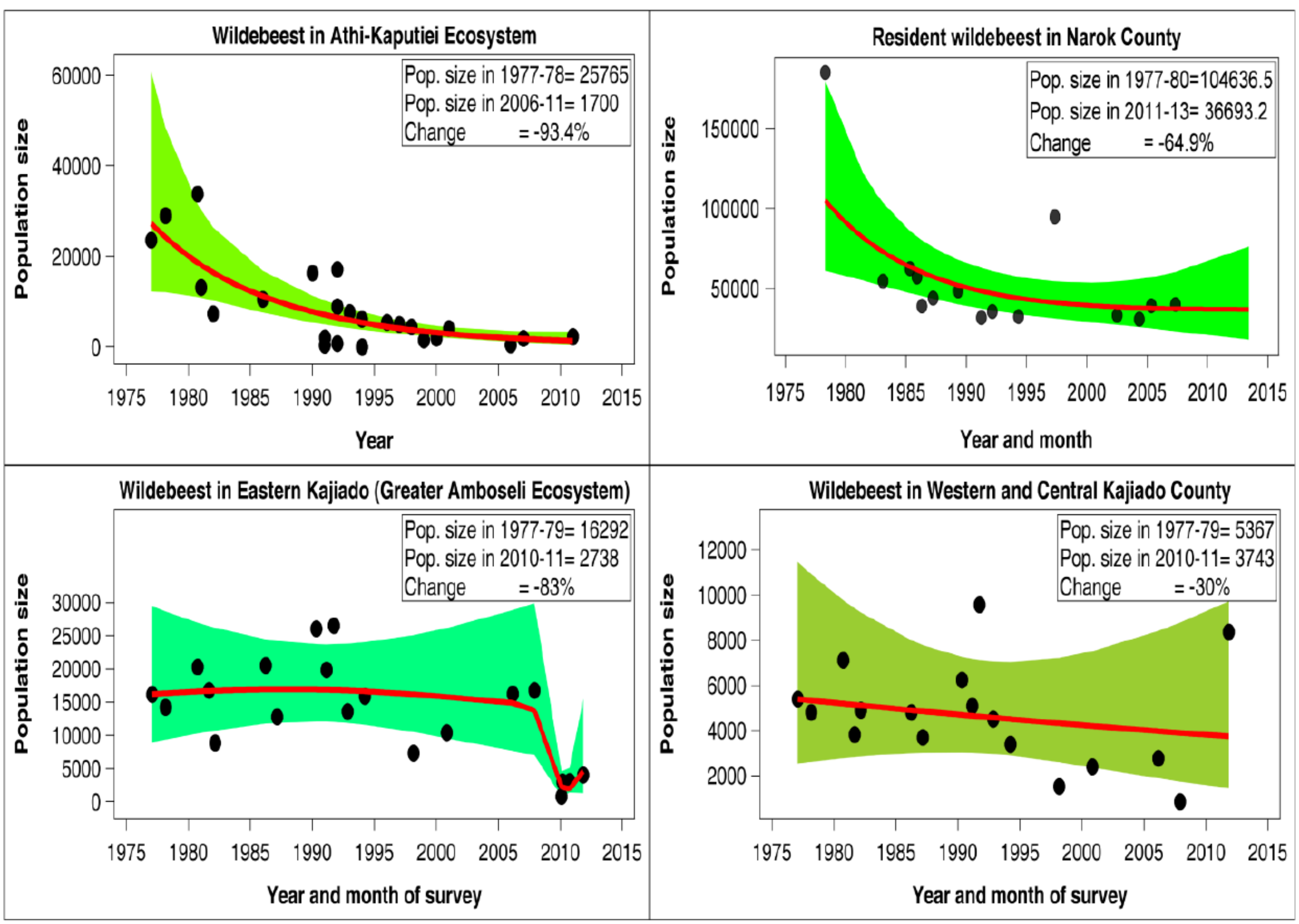


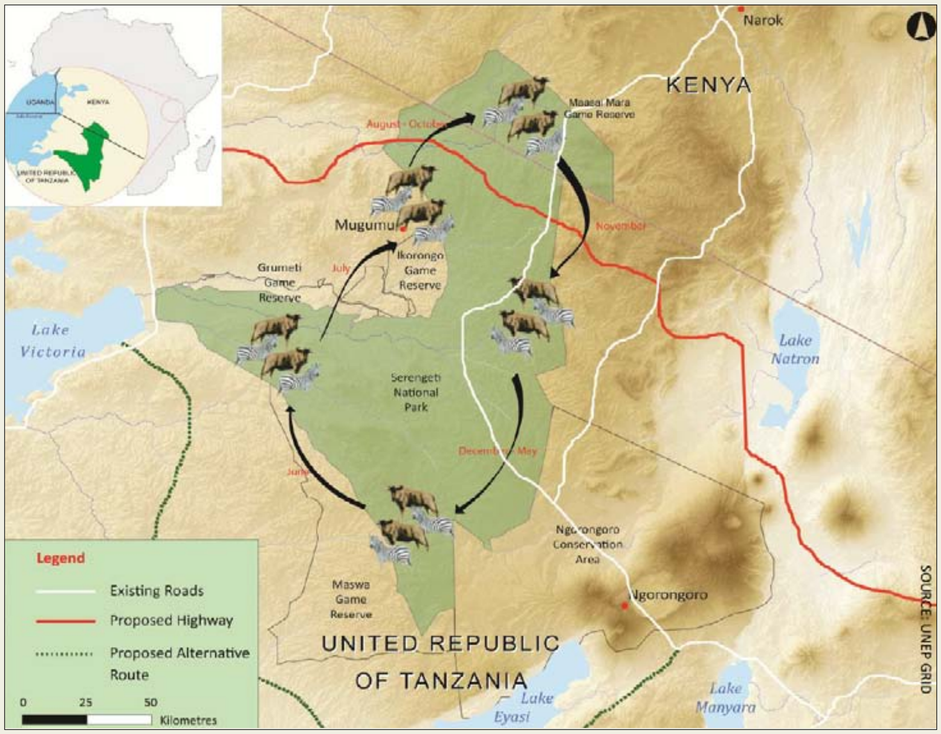
Figure 12.2: Trends in wildebeest populations in four regions of Kenya. Black dots are population estimate from aerial surveys, the red lines are the fitted trend curves, and the shaded bands are the 95% confidence bands. (Figure courtesy of Joseph O. Ogutu, data drawn from Ogutu et al., 2013; Ogutu et al., submitted).

to under 2,000 by 2011 as a result of increasing urbanisation, fencing, settlements, mining and other developments (Ogutu et al., 2013).

In Tanzania, in the Tarangire-Simanjiro ecosystem, the wildebeest migration from Tarangire National Park to the Simanjiro Plains declined by 88%, from 43,000 in 1988 to 5,000 in 2001 due to expanding cultivation and settlements blocking their migratory corridors (Bolger et al., 2008; Msoffe et al., 2011).

In each of these cases, wildebeest are prevented from accessing their wet season ranges due to the blockage of migratory corridors or the loss of habitat in their dispersal areas. Wildebeest are especially vulnerable to human impacts in their wet season ranges. Many protected areas in East

Box 12.1. Road and other threats to Serengeti-Mara wildebeest migration



The government of Tanzania plans to build a road across 50 km of the northern part of the Serengeti National Park to link the coast to Lake Victoria and other inland countries. The environmental impact assessment predicted that by 2015, 800 vehicles per day would cross the road and by 2035, this would rise to 3000, an average of one every 30 seconds (RoT, 2010).

There are concerns over the road's impact on the migrating animals which cross the path of the road on their way to Kenya and back (Dobson et al., 2010). Holdo et al., (2011) estimate that the road could lead to a 35% loss in migrating wildebeest due to the effect of habitat fragmentation. Moreover, these effects could be magnified by incoming fences, development and vehicle collisions (Dobson et al., 2010). There are also concerns of the wider implications of the road, not just its impact on wildebeest numbers because the migration plays an important role in a number of ecosystem processes which could have knock-on effects on other flora and fauna (Holdo et al., 2011).

From a development point of view, the importance of the road for socio-economic development in the area is emphasized, as is the need to consider local people and their livelihoods as key components of the ecosystem (Fyumagwa et al., 2013; Homewood et al., 2010). The lack of a developed road system can exacerbate poverty amongst local communities, leading to illegal or ecologically destructive activities, such a poaching, due to the lack of alternative livelihood options (Fyumagwa et al., 2013). The road should be viewed from a broader perspective of the threats facing the Serengeti-Mara ecosystem and its migration, along with agricultural intensification, destruction of the Mau Forest catchment area of the Mara River, and climate change (Fyumagwa et al., 2013; Hopcraft et al., 2013).

Alternative solutions to the road have been suggested, including a southern route that bypasses the Serengeti altogether (Dobson et al., 2010; FZS, 2010), or an elevated highway allowing animals to cross underneath (Main, 2013). However, despite initial news that the road project would be cancelled (Hance, 2011a), the Tanzanian government confirmed in mid-2011 that the road construction would go ahead, but as an unpaved road (Hance, 2011b), although construction is yet to start.

Africa primarily conserve the dry season habitat for migratory wildlife, with the wet season ranges occurring almost entirely outside of protected areas on adjacent communal or private lands (Fynn and Bonyongo, 2011). Protected areas also tend to be small and were not designed to conserve all of a migratory species' habitat requirements (Fynn and Bonyongo, 2011). As a result, wildebeest must journey outside of protected areas to reach their wet season ranges. Here they face a number of pressures due to human population growth, land use change and increasing development.

In the past, protected areas were able to sustain large migratory wildebeest populations because human population densities were low enough to allow them to migrate outside of protected areas to their wet season ranges. However, this is becoming increasingly difficult as human populations surrounding protected areas rise, and land use changes and habitat loss intensify. Today, nearly all the world's remaining large wildlife populations exist in unfragmented migratory systems (Fynn and Bonyongo, 2011). For example, the Serengeti-Mara ecosystem migration has been sustained because it has survived in a relatively intact ecosystem contained within a network of protected areas that encompass all the grazing habitats required to support a large migratory population. However, this migration too now faces a number of threats (see Box 12.1).

Threats to wildebeest migrations

The l**oss or fragmentation** of habitats is one of the main threats to wildlife migrations globally (Bolger et al., 2008; Harris et al., 2009). In East Africa, wildebeest migrations are in decline due to a number of land use activities causing habitat loss and fragmentation in their wet season dispersal areas. These land use activities, which include cultivation, land subdivision, settlements, fencing and other infrastructure, disrupt migratory movements and cause wildebeest populations to decline.

Fences obstruct migratory routes and have deleterious impacts on wildlife populations (Bolger et al., 2008; Harris et al., 2009). Fences are used to stop resource competition and disease transmission between wildlife and livestock, to prevent poaching and to protect crops and homes. Fencing is one of the main causes of the crash in the wildebeest population in the Athi-Kaputiei ecosystem in Kenya, blocking and threatening migratory routes (Ogutu et al., 2013). More than 20% of the ecosystem is now fenced, and a number of

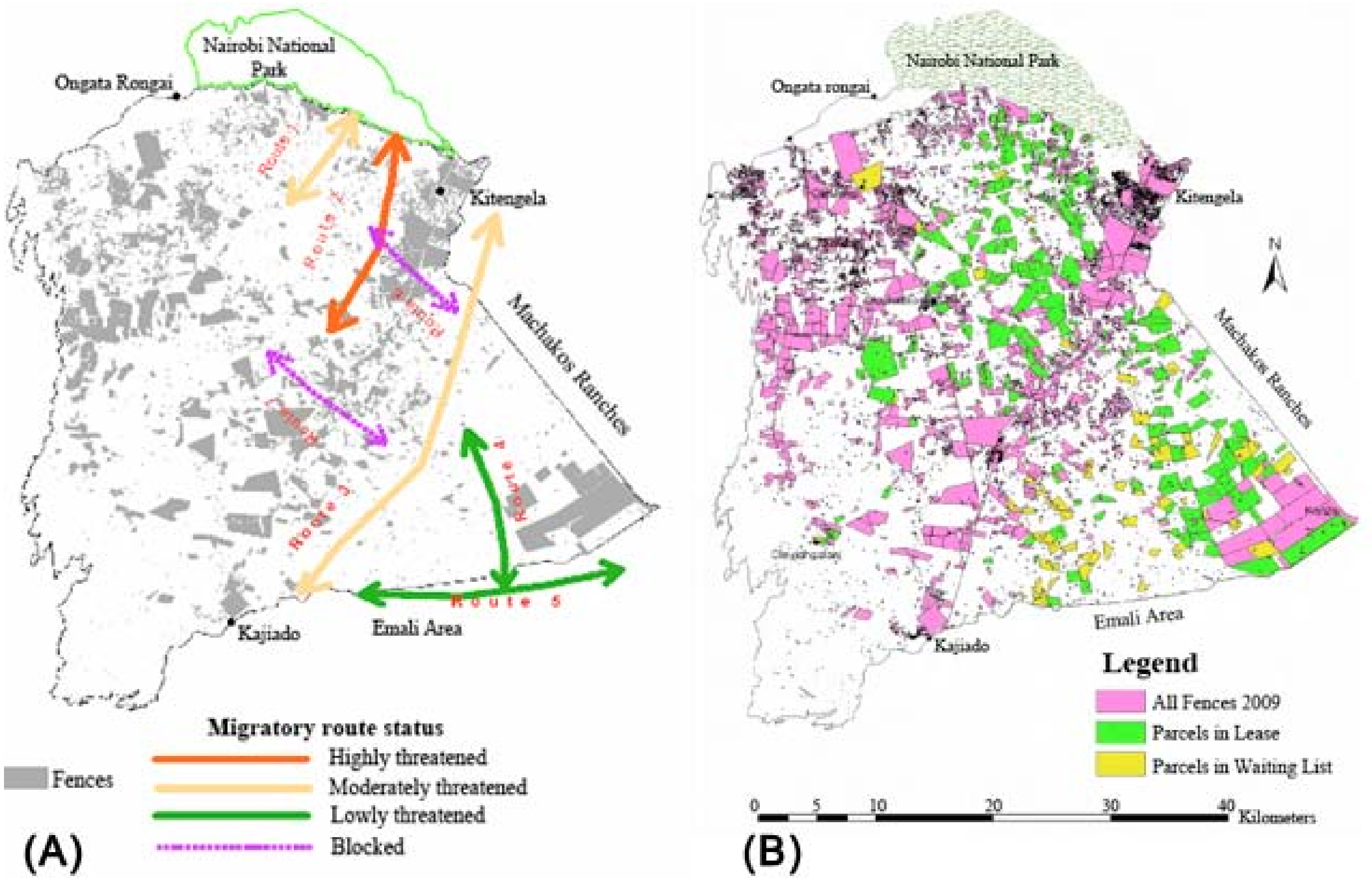


Figure 12.3: (A) Map showing the position of fences blocking wildlife migratory routes to and from the Nairobi National Park of the Athi-Kaputiei ecosystem in Kenya, and (B) initially fenced land parcels now signed up to the wildlife lease program prohibiting fencing (from MEMR, 2012).

migratory corridors linking the Nairobi National Park and the Athi-Kaputiei Plains have been blocked by fences (MEMR, 2012) (Figure 12.3). Now, only few wildebeest enter Nairobi National Park during the dry season (Ogutu et al., 2013). Similarly, fencing, cultivation and other developments now threaten the wildebeest migrations in the Amboseli ecosystem and the Mara-Loita Plains (MEMR, 2012).

Roads obstruct migratory routes, cause wildlife mortality due to vehicle collisions, and decrease landscape connectivity (Lesbarrères and Fahrig, 2012). Due to increased access, roads can also open up new areas for development, leading to land uses incompatible with wildlife. These are many of the concerns in the development of a new road through the Serengeti National Park (see Box 12.1). In Kenya, a similar threat faces the wildebeest migration in the Athi-Kaputiei ecosystem due to the upgrading of the Athi River-Namanga Road and the proposed Greater Southern Bypass Road along the southern boundary of Nairobi National Park (FoNNAP, 2011).

Poaching is a threat to many migratory populations, particularly as human populations around protected areas increase (Bolger et al., 2008; Harris et al., 2009). In the Serengeti National Park it is estimated that local consumption of bushmeat is responsible for approximately 70,000-129,000 wildebeest deaths per year (Rentsch and Packer, 2012). A high intensity of poaching is also linked to a decline in wildlife numbers in the Mara area of Kenya (Ogutu et al., 2009). Any further increase in the amount of poaching in the Serengeti-Mara ecosystem could lead to declines in the wildebeest population (Hopcraft et al., 2013).

Climate change is a new and growing threat to wildlife migrations in the East African savannas. The increased frequency and severity of droughts and floods that is expected to occur (IPCC, 2012) will modify vegetation growth and hence food availability for the migrating animals. In the Amboseli ecosystem, a severe drought caused the wildebeest population to crash by more than 85% in 2009 (MEMR, 2012). By 2010, the population numbered only 3,000 animals, down from over 15,000 animals before the drought, the lowest observed for more than 30 years (MEMR, 2012; Ogutu et al., submitted; Figure 12.2).

The ability of migrants to respond to changing climatic conditions is likely to be impaired by such man-made threats as habitat loss and fragmentation. As migratory corridors and dispersal areas are lost due to land use change, this will curtail migratory movements and compromise the ability of migrants to cope with the widening climatic variability expected as a consequence of global warming (Owen-Smith and Ogutu, 2012). In the Athi-Kaputiei ecosystem, Ogutu et al. (2013) show how compounding of the effects of human development with those of widened annual rainfall variation threatens wildlife populations.

What is being done?

Since most migrants wander outside of protected areas, it is crucial to include communities and landowners in conservation efforts through participation in wildlife management and benefit-sharing. In the East African rangelands, economic benefit to local communities from wildlife has been meagre (Homewood et al., 2009) with little incentive to help protect migrants or their dispersal areas and migratory corridors.

Efforts are now being made to secure wildlife dispersal areas and migratory corridors through the use of community conservancies, payments for ecosystem services and other economic incentives. For example, in the Mara, eight wildlife conservancies have been formed, which offer land lease payments of US$25-40 per hectare (ha) per year to landowners (Bedelian, 2012). These schemes, financed by ecotourism operators, aim to keep land open for wildlife and provide landowners with a regular income stream. They now cover over 90,000 ha, securing vital migratory corridors and dispersal areas for wildebeest from both the Serengeti and the Loita Plains (MEMR, 2012).

In the Athi-Kaputiei ecosystem, the wildlife conservation lease programme, supported by a number of donors, offers participating landowners US$10 per hectare per year to keep their land open for wildlife and livestock in the wildebeest dispersal area. This programme is being targeted to secure wildlife migratory corridors and critically reduce fencing in this ecosystem and by 2012 covered 24,200 ha (Figure 12.3) (MEMR, 2012; Ogutu et al., 2013). In another approach, environmental easements are being applied to protect privately owned land adjacent to Nairobi National Park, including placing it under park management (Watson et al., 2010; USAID, 2013). Also in this ecosystem, the community and other stakeholders have recently developed the first community driven land use master plan to sustainably manage wildlife dispersal areas alongside livestock grazing, settlements and other land uses in the ecosystem (Nkedianye et al., 2009). In the Tarangire-Simanjiro ecosystem in Tanzania, payments for ecosystem services, financed by tour operators, are being used to protect the dispersal area of migratory wildebeest and other wildlife in the Simanjiro plains (Nelson et al., 2010).

What are the implications for policy?

Conserving migratory routes requires implementing conservation plans beyond protected area boundaries. Dispersal areas and migratory corridors can be kept open for wildlife, by encouraging wildlife-friendly land uses, and the cooperation and participation of community and private landowners. Governments need to provide the correct enabling policy and legislative environment to support the types of initiatives already emerging to protect migratory habitat. Due to the trans-boundary nature of wildebeest migration in East Africa, the respective countries and governments need to work together to mitigate threats to the migrations.

Good scientific information on where, when and why wildlife migrations occur is needed to inform conservation and management decisions. This includes mapping the movements and ranges of wildebeest, the ecological drivers of migration, population levels, and a good understanding of the threats to migrants and their habitats. The Kenya and Tanzania governments are already mapping wildlife corridors and migratory routes with the aim of securing critical wildlife areas (Jones et al., 2009; MEMR, 2012; TAWIRI and WCS, 2013). In other initiatives, researchers are collaring wildebeest to track their movements to understand how landscape fragmentation and climate change are affecting wildebeest, and reporting their movements online (CSU, 2013).

Conserving migrations requires a proactive approach, anticipating and responding to threats before the abundance of migrating animals is critically reduced, and thus the phenomenon of migration long gone (Harris et al., 2009; Wilcove and Wikelski, 2008). In this regard, conservation organisations such as the Convention of Migratory Species, which works to conserve migrations of species threatened with extinction, could be expanded to conserve threatened or endangered migrations, and not just those which contain rare or endangered species (Harris et al., 2009).

Efforts to secure dispersal areas and migratory corridors will require an integrated approach to land use planning both inside and outside of protected areas. By taking into account wildlife and their migratory routes, people, livestock, landscapes and natural resources, a more comprehensive conservation effort can be made. Thus, there is a need to work collaboratively with landowners and users to identify threats along migratory routes so these critical areas can be effectively protected. Extensive consultation with communities and landowners, as well as governments, conservation organisations and other stakeholders, must be a prerequisite to any action. The rapid and dramatic wildebeest population declines in East Africa calls for urgent, comprehensive and decisive remedial steps to protect the remaining populations and rehabilitate their habitats. This will enhance their resilience to the intensifying droughts and contribute to the sustainability of local livelihoods.

Acknowledgement

Writer: Claire Bedelian[a]

Production and Outreach Team: Arshia Chander[b], Erick Litswa[c], Kim Giese[b], Lindsey Harriman[b], Michelle Anthony[b], Reza Hussain[b], Tejaswi Giri[b], Theuri Mwangi[c] and Zinta Zommers[c]

Special thanks to Lindsey Harriman[b], Peter Gilruth[c], Frank Turyatunga[c], Anna Stabrawa[c], Theuri Mwangic, Zinta Zommers[c], Joseph Ogutu[d], Zeke Davidson[e], Michael Hoffmann[f] for their valuable comments, input and review, and Shelley Robertson[g] for copy editing

([a] University College, London, [b] UNEP/DEWA/GRID-Sioux Falls, [c] UNEP/DEWA-Nairobi, [d] University of Hohenheim, [e] Conservation Biologist, Kenya, [f] UNEP-WCMC, [g] Munk School of Global Affairs, University of Toronto)

References

Bedelian, C., 2012. Conservation and ecotourism on privatized land in the Mara, Kenya: The case of conservancy land leases. Land Deal Politics Initiative Working Paper 9.

Bolger, D., Newmark, W., Morrison, T., Doak, D., 2008. The need for integrative approaches to understand and conserve migratory ungulates. Ecology Letters 11(1), 63-77.

CSU, 2013. Gnu Landscapes. NREL Colorado State University. http://www.nrel.colostate.edu/projects/gnu (accessed 26.11.13).

Dobson, A., Borner, M., Sinclair, A., Hudson, P.J., Wolanski, E., 2010. Road will ruin Serengeti. Nature 467(7313), 272–273.

Estes, R.D., 2006. Wildebeests of the Serengeti. Natural History Magazine. September. 28 – 35.

Estes, R., East, R., 2009. Status of the wildebeest (Connochaetes taurinus) in the wild 1969-2005. Wildlife Conservation Society Working Paper No. 37.

Fynn, R., Bonyongo, M., 2011. Functional conservation areas and the future of Africa's wildlife. African Journal of Ecology 49(2), 175-188.

Fyumagwa, R., Gereta, E., Hassan, S., Kideghesho, J., Røskaft, E., 2013. Road as a Threat to the Serengeti Ecosystem. Conservation Biology 27(5), 1122-1125.

FoNNAP, 2011. How the proposed greater southern bypass will affect Nairobi Park. Friends of Nairobi National Park. http://fonnap.wordpress.com/2011/08/23/how-the-proposed-greater-southern-bypass-will-affect-nairobi-park/ (accessed 26.11.13).

FZS, 2010. The Serengeti North Road Project. Frankfurt Zoological Society. http://www.zgf.de/download/1135/SerengetiRoad_Presentation2.pdf (accessed 26.11.13).

Hance, J., 2011a. Serengeti road cancelled. Mongabay. 23 June 2011. http://news.mongabay.com/2011/0623-hance_serengeti_road.html (accessed 26.11.13).

Hance, J., 2011b. Unpaved road through Serengeti to progress. Mongabay. 2 July 2011. http://news.mongabay.com/2011/0702-hance_serengeti_road.html (accessed 26.11.13).

Harris, G., Thirgood, S., Hopcraft, J., Cromsigt, J., Berger, J., 2009. Global decline in aggregated migrations of large terrestrial mammals. Endangered Species Research 7(1), 55-76.

Holdo, R., Fryxell, J., Sinclair, A., Dobson, A., Holt, R., 2011. Predicted impact of barriers to migration on the Serengeti wildebeest population. PloS one 6(1), e16370.

Homewood, K., Brockington, D., Sullivan, S., 2010. Alternative view of Serengeti road. Nature 467(7317), 788–789.

Homewood K., Kristjanson, P., Chevenix Trench, P., 2009. Staying Maasai? Livelihoods, conservation and development in East African Rangelands. Springer, New York.

Hopcraft, J., Sinclair, A., Holdo, R., Mwangomo, E., Mduma, S., Thirgood, S., Borner, M., Fryxell, J., Olff, H., 2013. Why are wildebeest the most abundant herbivore in the Serengeti ecosystem? Serengeti IV: Sustaining Biodiversity in a Coupled Human–Natural System, University of Chicago Press, Chicago.

IPCC, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

Jones, T., Caro, T., Davenport, T., 2009. Wildlife Corridors in Tanzania. Unpublished report. Tanzania Wildlife Research Institute (TAWIRI), Arusha.

KNBS, 2013. Economic survey 2013 highlights. Ministry of Devolution and Planning. Kenya National Bureau of Statistics. http://www.knbs.or.ke/Economic%20Surveys/Cabinet_Secretary_Presentation_on_Economic_Survey_May_2013.pdf (accessed 26.11.13).

Lesbarrères, D. and Fahrig, L., 2012. Measures to reduce population fragmentation by roads: what has worked and how do we know? Trends in ecology & evolution 27(7), 374-380.

Main, D., 2013. 'Serengeti Highway Compromise Proposed by Famed Scientist.' Live Science, 15th May 2013. http://www.livescience.com/32046-leakey-elevated-serengeti-highway.html (accessed 26.11.13).

MEMR, 2012. Mapping Wildlife Dispersal Areas and Migratory Routes/Corridor (Part I): Southern Kenya Rangelands (Draft Version March 2012). Ministry of Environment and Mineral Resources (MEMR). Nairobi, Kenya.

Milner-Gulland, E., Kholodova, M.V., Bekenov, A., Bukreeva, O., Grachev, I., Amgalan, L., Lushchekina, A., 2001. Dramatic declines in saiga antelope populations. Oryx 35(4), 340–345.

Mitchell, J., Keane, J., Laidlaw, J., 2009. Making success work for the poor: Package tourism in Northern Tanzania. ODI/SNV.

Msoffe, F., Kifugo, S., Said, M., Neselle, M., Van Gardingen, P., Reid, R., Ogutu, J., Herrero, M., de Leeuw, J., 2011. Drivers and impacts of land-use change in the Maasai Steppe of northern Tanzania: an ecological, social and political analysis. Journal of Land Use Science 6(4), 261-281.

Nelson, F., Foley, C., Foley, L., Leposo, A., Williams, A., 2010. Payments for Ecosystem Services as a Framework for Community-Based Conservation in Northern Tanzania. Conservation Biology 24(1), 78-85.

Nkedianye, D., Radeny, M., Kristjanson, P., Herrero, M., 2009. Assessing returns to land and changing livelihood strategies in Kitengela, in: Homewood, K., Kristjanson, P., Chevenix Trench, P. (Eds), Staying Maasai? Livelihoods, conservation and development in East African Rangelands. Springer, New York, pp. 115-149.

Ogutu, J., Owen-Smith, N., Piepho, H-P., Kuloba, B., Edebe, J., 2012. Dynamics of ungulates in relation to climatic and land use changes in an insularized African savanna ecosystem. Biodiversity Conservation 21; 1033-1053.

Ogutu, J., Owen-Smith, N., Piepho, H., Said, M., 2011. Continuing wildlife population declines and range contraction in the Mara region of Kenya during 1977–2009. Journal of Zoology, 285(2), 99-109.

Ogutu, J., Owen-Smith, N., Piepho, H., Said, M., Kifugo, S., Reid, R., Gichohi, H., Kahumbu, P., Andanje, S., 2013. Changing Wildlife Populations in Nairobi National Park and Adjoining Athi-Kaputiei Plains: Collapse of the Migratory Wildebeest. Open Conservation Biology Journal, 7, 11-26.

Ogutu, J., Piepho, H., Dublin, H., Bhola, N., Reid, R., 2009. Dynamics of Mara-Serengeti ungulates in relation to land use changes. Journal of Zoology 278, 1-14.

Ogutu, J., Piepho, H., Said, M., Kifugo, S., submitted for publication. Herbivore dynamics and range contraction in Kajiado: Climate change and land use changes, population pressures, governance, policy and human-wildlife conflicts. Submitted and under consideration for publication in Open Conservation Biology Journal.

Owen-Smith, N., Ogutu, J., 2012. Changing Rainfall and Obstructed Movements: Impact on African Ungulates. Wildlife Conservation in a Changing Climate, 153.

Rentsch, D., Packer, C., 2012. Bushmeat Consumption and Local Demand for Wildlife: Wildebeest Offtake Estimates for Western Serengeti (mimeo).

RoT, 2010. Environmental and Social Impact Assessment for upgrading of Natta-Mugumu-Loliondo Road, Draft Report, October 2010. Submitted to The National Environmental Management Council, Dar es Salaam, Tanzania. http://www.savetheserengeti.org/issues/highway/tanzanian-governments-evironmental-impact-assessment/ (accessed 26/11/13).

RoT, 2011. The economic survey 2011. President's Office, Planning Commission, Dar es Salaam. Republic of Tanzania. http://www.mof.go.tz/mofdocs/Micro/Economic%20Survey%202011.pdf (accessed 26.11.13).

Sinclair, A., 1995. Serengeti past and present, in: Sinclair, A.R.E, Arcese, P. (Eds.), Serengeti II, dynamics, management and conservation of an ecosystem. University of Chicago Press, Chicago.

Sinclair, A.R.E., Hopcraft, J.G., Olff, H., Mduma, S.A.R., Galvin, K.A., Sharam, G.J., 2008. Historical and future changes to the Serengeti ecosystem, in: Sinclair, A.R.E., Packer, C., Mduma, S.A.R., Fryxell, J.M. (Eds.), Serengeti III: Human impacts on ecosystem dynamics. University of Chicago Press, Chicago.

TAWIRI and WCS, 2013. Tanzania Wildlife Corridors. Tanzania Wildlife Research Institute and Wildlife Conservation Society. http://www.tzwildlifecorridors.org (accessed 26.11.13).

UNESCO, 2013. Serengeti National Park. World Heritage List. United Nations Educational, Scientific and Cultural Organization (UNESCO). http://whc.unesco.org/en/list/156 (accessed 26.11.13).

USAID, 2013. Kitengela Wildlife Conservation Project. United States Agency for International Development (USAID) Kenya. http://www.usaid.gov/sites/default/files/documents/1860/Kenya%20Wildlife%20Conservation%20FACT%20SHEET_May2013.pdf (accessed 26.11.13).

Watson, R., Fitzgerald, K., Gitahi, N., 2010. Expanding options for habitat conservation outside protected areas in Kenya: The use of environmental easements. African Wildlife Foundation. Technical Papers No. 2.

Wilcove, D., Wikelski, M., 2008. Going, going, gone: is animal migration disappearing. PLoS biology 6(7), e188.

www.unep.org

United Nations Environment Programme
P.O. Box 30552 - 00100 Nairobi, Kenya
Tel.: +254 20 762 1234
Fax: +254 20 762 3927
e-mail: uneppub@unep.org
www.unep.org

UNEP