UNEP YEAR BOOK

NEW SCIENCE AND DEVELOPMENTS IN OUR CHANGING ENVIRONMENT

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Produced by
Division of Early Warning and Assessment (DEWA)
United Nations Environment Programme
P.O. Box 30552
Nairobi, 00100, Kenya

Tel: (+254) 20 7621234
Fax: (+254) 20 7623927
E-mail: uneppub@unep.org
Web: www.unep.org
UNEP Year Book web site: http://www.unep.org/geo/yearbook

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Preface

The UNEP Year Book 2009, focusing on the six areas of our new Medium-Term Strategy, comes against a back drop of food, fuel and financial upheavals that underline the choices facing humanity in the 21st century.

These centre around whether a brighter and more sustainable future can be found in the old economic models of the 20th century or in a fresh, Green Economy approach—one that rewards greater resource efficiency, vastly improved natural asset management and decent employment across the developed and developing world.

The answer can be found in the findings of the Year Book 2009.

Ecosystems, vast natural 'utilities' whose goods and services are worth trillions of dollars annually, are also changing—entire forest ecosystems have disappeared from 25 countries and have declined by 90 per cent in a further 29.

The biomass of large, commercially-targeted marine fish species have declined by 90 per cent since the 1960s. The amount of cropland available per person may, by mid century, be less than 0.1 hectares, requiring an increase in agricultural production unattainable via conventional methods.

Climate change is another poignant example. The failure to fully 'internalize' the costs of rising greenhouse gas emissions is triggering impacts unimaginable only a few years ago.

Reservoirs in the Mediterranean and the American Midwest could soon run dry: the Greenland ice sheet may already be losing over 100 cubic kilometres a year with ramifications for sea level rise.

The Arctic is also a vast store of methane. More than 250 plumes are now bubbling up northwest of Svalbard—the prospect of dangerous 'tipping' points in the Earth's climate are becoming ever more possible.

The Year Book also highlights more intelligent, creative approaches. Take biomimicry. The cooling system of the Eastgate Building in Harare, Zimbabwe was inspired by towers built by termites. It saves 90 per cent of the energy compared with a comparable building.

Rights-based catch shares for fishers—practiced in fishing grounds in countries like Canada and Chile to Mexico and the United States, there is evidence they can reduce and even reverse the risk of ecosystem collapse.

Hundreds of billions of dollars are being lined up to stimulate economies. It is an opportunity to overcome the current woes but also an opportunity to begin shaping markets—shaping them towards favouring not only the planet but also the livelihoods and well-being of six, soon rising to nine billion people. In short it is the chance to really kick-start the Green Economy.

Achim Steiner
United Nations Under-Secretary-General and Executive Director,
United Nations Environment Programme

Introduction

The UNEP Year Book 2009 presents work in progress on scientific understanding of global environmental change, as well as foresight about possible issues on the horizon. The aim is to raise awareness of the interlinkages among environmental issues that can accelerate the rates of change and threaten human wellbeing.

The chapters of this Year Book track the same trajectory as our awareness of environmental change. Transformations are inherent to this trajectory and are taking place on many fronts: from industrial agriculture to eco-agriculture; from a wasteful society towards a resource efficient one; and from a triad of competing interests among civil society, the private sector, and governments to a more cooperative model based on mutual benefits.

The first chapter, **ecosystem management**, presents ecosystems responding at accelerated rates to climatic, anthropogenic, and ecological changes and the critical thresholds that are advancing. It examines the call for an eco-agricultural approach to food production and the potential that sustainability principles offer to ensure that ecosystem management addresses poverty reduction.

The chapter on **harmful substances and hazardous waste** follows the discovery of synthesizing nitrogen to its application for chemical fertilizers that spurred unprecedented population growth and accelerated an era of large-scale industrial chemistry. Many of these chemicals are adversely affecting our environment and our health.

The **climate change** chapter draws attention to the latest research on increased concentrations of greenhouse gases in the atmosphere and new findings on the rates and distribution patterns of melting ice and rising sea levels. Potential consequences are considered for specific Earth systems such as ocean circulation, tropical monsoons, and familiar atmospheric oscillations. The concept of tipping elements and tipping points in Earth systems is introduced.

The **disasters and conflicts** chapter documents civil unrest, earthquakes, storms, and droughts that continue to stress human populations and the ecosystems they depend upon. In particular, vulnerable populations are at risk. Evidence is mounting, however, that disaster prevention and preparedness programmes are working. The chapter also contains a map of significant environmental events of 2008.

Alternative industrial approaches are explored in the chapter on **resource efficiency**. A significant transformation is underway through new patterns of production and consumption and improved resource-use efficiencies. Developing and up-scaling existing solutions from the private sector such as industrial symbiosis and dematerialization may help turn around the growing resource deficit.

The final chapter, **environmental governance**, gives a brief summary of key findings of the preceding chapters and discusses the cumulative effects expected from degradation of ecosystems, the release of substances harmful to those ecosystems and to human health, the consequences of our changing climate, the continued human and economic loss resulting from disasters and conflicts, and the overexploitation of resources. It calls for an intensified sense of urgency for responsible governance in the face of approaching critical thresholds and tipping points. A calendar of selected events in 2008 is also included in this chapter.

More in-depth, the chapter identifies some of the drivers that create challenges, such as increasing populations, their material aspirations, and a flawed economic model that does not assign appropriate values to many of the resources being exploited. These drivers have cumulative effects and require decisions to be made, often making the practice of environmental governance both challenging and complex. For example, pressures from population growth and material aspirations draw workers to settle near national parks where they may be forced to destroy the protected ecosystem to survive, or these pressures motivate people to build livelihoods in coastal urban areas where they are exposed to threats from increased intensity and frequency of storms.

This Year Book also explores some of the many solutions such as effective disaster preparedness programmes that can establish foundations for community cooperation that could resonate through future development projects. As well, resource efficient industrial symbiosis applications can feed sustainable economic growth, forestall pollution, and provide goods for the green economy. Re-tooled assessment processes and the establishment of innovative schemes with multiple social and environmental benefits are only samples of solutions that can be devised through institutional mechanisms and good governance.

Ecosystem Management

Earth's ecosystems are under threat. Twenty per cent of Earth's land cover has been significantly degraded by human activity and 60 per cent of the planet's assessed ecosystems are now damaged or threatened. The irrefutable pattern is one of natural resource overexploitation while simultaneously creating more waste than ecosystems can process.

A rich variety of plants and animals on the Hoang Lien Mountains give way to incredible montane landscapes and managed terrace fields in Sapa district, Lao Cai Province, northwest Vietnam. *Source: Graham Ford*

INTRODUCTION

Ecosystems are, by definition, resilient and adaptable to change—even to abrupt change. This makes the current worldwide collapse of ecosystem function all the more dramatic: Human activities over the last 50 years have accelerated rates of change, and introduced artificial connections and substances, to such an extent that natural systems are losing their ability to adjust. The stresses, including habitat destruction, species loss, pollution, and climate change, combine to make ecological breakdown more widespread, more severe, and more likely (Homer-Dixon 2007). Worse, as multiple stresses unfold simultaneously, major ecosystems are reaching critical thresholds beyond which they will no longer be able to recover from further disturbance.

Science cannot yet predict the precise thresholds for each ecosystem, but our ability to understand cumulative and non-linear change has improved dramatically, offering new insights into how far an ecosystem can be pushed before irreversible changes occur (Willis and others 2007). Crucially, these advances clarify the numerous links between long-term ecosystem health and human wellbeing. It has become clear that ecosystem management, environmental services, and socio-economic development must all be considered together.

In the face of climate change and mounting water vulnerabilities, 2008's unstable energy prices and food price crisis illustrate the global scope and cascading effects of pressures we exert on ecosystems. These events further underscore the vulnerabilities inherent in the global community's current doctrines of perpetual economic growth and demonstrate that conventional, highly compartmentalized ecosystem management methods are not working.

In 2008, voices from all corners of society called for dramatic change. Many endorsed significant long-term measures to incorporate the ecosystem approach for management of agriculture and conservation, with a new focus on integrated management systems, in which the needs of humans and the needs of nature are both taken into account, for the benefit of each.

Box 1: A red hot priority: The world's mammals in crisis

Of the 5487 recognized mammal species in the world, more than half are declining in numbers and more than 20 per cent are threatened with extinction, according to the Red List Index 2008. The Red List, an ongoing global inventory undertaken by the International Union for Conservation of Nature (IUCN), is widely recognized as the best assessment of distribution and conservation status of Earth's plant and animal species.

While the exact threat is hard to quantify, the situation is worst for marine mammal species, with 36 per cent at risk of extinction from pollution, changing climate, and encounters with fishing nets and cargo vessels. Since the last Red List Index assessment on mammal species in 1996, scientists have documented 700 species not covered previously, including 349 new species discovered mostly in Madagascar and the Amazon. Scientists expect that more species have yet to be discovered in regions such as the Congo Basin.

Threatened mammals tend to concentrate in rich ecosystems with high occurrence of endemic species—ecosystems under extreme pressure from human activities. The most vulnerable areas include South and Southeast Asia, the tropical Andes, the Cameroonian Highlands, the Albertine Rift in Africa, and the Western Ghats in India. Deforestation and agricultural expansion have left animals living on increasingly fragmented and smaller patches of land.

Meanwhile, protected areas may no longer offer a safe haven to species: The impact of tourism on local economies tends to attract settlement around conservation areas by people looking for employment. These communities then turn to timber harvesting, bush-meat hunting, and land clearing by fires—all activities that ultimately lead to higher rates of species loss in the protected sectors.

Source: Miller and others 2006, Schipper and others 2008, Wittemyer and others 2008, IUCN 2008

Severe habitat degradation, disease, and reduced water availability have brought the Grevy's zebra to near extinction with 750 adult animals remaining in Kenya and Ethiopia.
Source: Jason Jabbour/ UNEP

CHANGING ECOSYSTEMS

The 2005 Millennium Ecosystem Assessment reported a substantial and largely irreversible loss in the diversity of life on Earth, along with the deterioration of more than 60 per cent of all ecosystem services assessed (MA 2005) (**Box 1**). The sobering reality inspired a surge in scientific research and ideas. It prompted calls for a serious rethinking of our management approaches, seeking methods that better deal with the mounting risks and challenges to ecosystems. The stakes are high. If humans are to survive on this planet with a minimally acceptable, universal quality of life, we must manage and utilize our ecological assets in far more efficient and creative ways (Steiner 2008).

Irrefutable evidence of degradation

All ecosystems are undergoing change, but some transitions are more dramatic than others. Certainly one of the most visible and significant ecosystem changes is the widespread degradation and conversion of tropical and sub-tropical ecosystems (**Figure 1**). Increasing demands for food and other agricultural products has led to the intensification of agricultural production and the drastic expansion of land under cultivation (Yadvinder and others 2008). Today, farmland covers nearly a quarter of the planet's surface. Entire forest systems have effectively disappeared in at least 25 countries and have declined by 90 per cent in another 29 countries (Dietz and Henry 2008). This destruction continues at staggering rates. Such abrupt and comprehensive changes to ecosystems result in significant stress on ecological processes and biogeochemical cycles, with further adverse implications for both regional and global ecosystem services that derive directly from the health of basic ecological functions. This knock-on effect through conversion of tropical and sub-tropical ecosystems leads to critical losses in watershed protection, diminished soil integrity, increased erosion, disappearance of biodiversity, decrease in carbon sequestration capacity, and deterioration of regional and local air quality (Scherr and McNeely 2008, Hazell and Wood 2008).

Less visible but just as significant human-induced changes are underway in marine and coastal ecosystems. Coral reefs, intertidal zones, estuaries, coastal aquaculture operations, and seagrass beds have all experienced intense pollution, degradation, destruction, and overexploitation. The resulting decline of aquatic ecosystems has essentially forced the world's marine fisheries into a state of stagnation for nearly a decade (World Bank and FAO 2008). Since the onset of industrial fishing in the 1960s, the total biomass of large, commercially-targeted marine fish species has declined by a staggering 90 per cent (Halpern and others 2008, MA 2005).

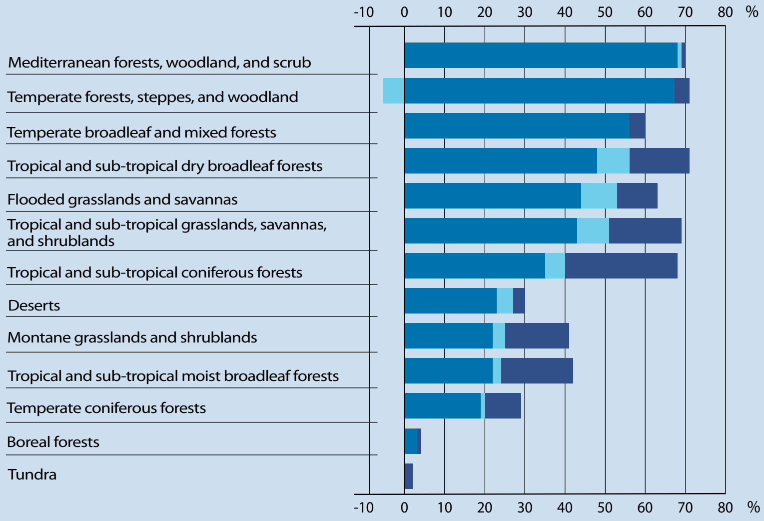
The need for action on fisheries is urgent. Over one billion people, many among the world's most vulnerable, depend on fish as their primary source of protein. According to a 2008 study commissioned by the World Bank and the UN Food and Agriculture Organization (FAO), the exploitation and near depletion of the ocean's most valuable fish stocks have caused an annual net loss in the value of global marine fisheries in the order of US$50 billion. The excessive build-up of redundant fishing fleet capacity, the deployment and mismanagement of increasingly powerful fishing technologies, and increasing pollution and habitat loss are to blame (World Bank and FAO 2008).

Rising food prices, the impending energy crisis, and increasing impacts of climate change all have the potential to put further pressure on marine ecosystems. The immediate and paramount need is to improve the resilience of those ecosystems, through a series of institutional and regulatory reforms. Recommendations for concerted national and international reforms are designed to increase investment in and to empower poor small-scale fishing communities. These would include the elimination of counterproductive subsidies and perverse incentives, as well as supporting initiatives to certify sustainable fisheries and new measures to eliminate illegal fishing (World Bank and FAO 2008).

Shifting ecosystems

Recent studies have revealed migration and some expansion of certain ecosystem types as they respond to changing climatic and biogeochemical conditions (Silva and others 2008). The conversion of Arctic tundra to shrubland has been observed as temperatures rise during recent years. The process involves warmer winter temperatures when a few shrubs can stabilize a snow layer, the snow layer insulates the soil, and the local soil

Figure 1: Per cent of available area converted by 2050



Percentage of potential area of ecosystems estimated to have been converted by 1950, converted between 1950 and 1990, and will have been converted between 1990 and 2050 under Millennium Ecosystem Assessment scenarios. The vast majority of conversions are for agricultural purposes.

Source: Millennium Ecosystem Assessment

Loss by 1950

Loss between 1950 and 1990

Projected loss by 2050

microbes that remain active for longer periods under the warmer conditions produce the nutrients the shrubs need to thrive. This process fosters the colonization of tundra by more shrubs (Strum and others 2005). The resulting ecosystem shift has forced caribou populations out of traditional grazing areas in search of the lichens and grasses normally found on tundra (Tape and others 2006). In 2008 new evidence showed that while warmer Arctic temperatures encourage earlier availability of caribou grazing resources, caribou reproductive cycles are not advancing with resource availability. This has significant repercussions on caribou reproductive success (Post and others 2008).

In the northern Ural Mountains of Russia, the warming summer climate and the doubling of winter precipitation have altered the composition, structure, and growth forms of Siberian larch (Devi and others 2008). As mature forests, these 10-20 metre conifers typically grow in a mix of single- and multi-stemmed tree clusters. But a recent study found that 90 per cent of trees emerging after 1950 were single-stemmed, a characteristic of less mature forests. The researchers concluded that this tree generation largely reflects the expansion in both space and time of a new forest. This forest-tundra ecosystem may already have advanced as far as 20 to 60 metres up the mountains in the past century (Devi and others 2008).

Scientists had long thought that the boundaries between savannas and gallery forests, two distinct and separate ecosystems, were effectively fixed due to sharp contrasts in soil properties such as water content, nutrients, aeration, and acidity (Furley 1992, Beerling and Osborne 2006). In 2008, new evidence from central Brazil revealed a surprising migration of gallery forests into surrounding savanna regions. It appears that climatic changes can initiate such ecosystem migration and that subsequent feedback mechanisms including nutrient accumulation and fire suppression may push the expansion process further still (**Figure 2**) (Silva and others 2008).

Non-linear changes and emerging ecosystems

The occurence frequency and accelerated rates at which environmental conditions are transforming vegetated landscapes—and the unexpected manner in which existing natural systems are responding—raise important questions about our understanding of ecosystem thresholds. What we are learning about accelerated, abrupt, unexpected, and potentially irreversible ecosystem changes leads to serious uncertainties about the future of those ecosystems, the consequences of our interventions, and the implications for human wellbeing.

Such evidence has prompted a renewed investment in monitoring and early warning systems, and highlights the value of alternative management options. Already these investigations have expanded our ability to explain and predict some of the drivers and positive feedback mechanisms that influence non-linear ecosystem change (Dakos and others 2008, Scheffer and others 2006, Lenton and others 2008, Tallis and others 2008).

Observations of non-linear changes and expectation of their increasing occurrence have encouraged concepts of emerging ecosystems. These are assemblages of species within a given ecosystem that are documented in previously unrecognized combinations and abundances under new ecological conditions (Milton 2003, Seastedt and others 2008, Silva and others 2008). The emerging ecosystems concept borrows from the idea that as ecosystems pass through

Figure 2: Vegetative regions and ecological transitions in Brazil

Map of Brazil showing major vegetative regions and areas of ecological transition. Complex factors associated with changing climate and subsequent soil, moisture, and nutrient conditions have given to an increase in these ecological transition regions and the expansion of certain vegetative biomes including gallery forests into savannas.

Vegetation class

- Other vegetation
- Amazon / Atlantic forest
- Ecological transitions
- Woodland savanna (Cerrado)
- Shrubland (Caatinga)
- Water

Source: Màrton Bàlint and Jason Jabbour/ UNEP; adapted from Heckenberger and others 2008, Silva and others 2008 various states of vulnerability and resilience, they evolve—adapting to disturbances differently, and restructuring themselves as a function of both the state of the system and the spatial scale at which the disturbance occurs. Accelerated rates of change from human-induced forces have pushed some ecosystems towards extinction. But these forces have also propelled some ecosystems past their historical range of variability into states that are relatively stable despite being new (Sax and Gains 2008). As emerging ecosystems and their enabling conditions evolve, management approaches must be able to analyse the costs incurred and benefits offered. Study of the current state of ecosystem functioning is essential, but management of dynamic systems must also focus on likely trajectories or predictions of future changes to anticipate opportunities for disaster prevention. Emerging ecosystems require novel management approaches, including a more deliberate collaboration between scientists and managers in developing methods and measures for achieving short- and long-term objectives (Seastedt and others 2008).

In the United States of America's Yellowstone National Park, new insights on the cascading ecological changes occurring in a warmer park have prompted managers and scientists to rethink traditional assumptions and strategies. An invasive thistle species, long established in North America, was initially thought to be thriving in the park because of changing climate. Researchers recently discovered the thistle's success is part of a larger feedback loop in which a simultaneous expansion of pocket gophers has helped the plant spread. The gophers create ideal growing conditions for their thistle food source by churning surface soil as they tunnel. More thistles feed more gophers and, at the same time, grizzly bear populations have stabilized due to an ample supply of both (Robbins 2008). Consequently, park efforts to control the thistle have been significantly reduced.

Should an emerging ecosystem persist, it could offer new valuable ecosystem products and services. The extent that these new systems can contribute to future diversity, renewal, and resilience will require careful research. A key goal for the future of ecosystem management is to maximize beneficial changes and reduce less advantageous elements, while tracking the processes and persistence of both benefits and costs (Hobbs and others 2008).

A shrimp farmer in Apalachicola, Florida, USA, describes the drastic decline of fisheries in the Gulf of Mexico and the increasing challenges that fishers face. *Source: Tara Thompson*

ECOSYSTEMS AND HUMAN WELLBEING

Healthy ecosystems, and the goods and services they provide, are the foundations of survival for all societies. Given current consumption levels in the industrialized world and the rapidly accelerating material aspirations in developing countries, those foundations are threatened. The problems associated with environmental degradation and agricultural growth alone will incur substantial costs to future generations in the form of threats to human and ecosystem health (Hazell and Wood 2008, Levin and others 2008, RRI 2008). Externalities of climate change and economic globalization are accelerating the approach of critical thresholds for already threatened ecosystem health at local and global scales. The potential for catastrophic mistakes grows.

The prospects for biofuels

It is difficult to think of an environmental issue that attracted more controversy in 2008 than biofuels. Sweeping rhetoric has both championed biofuels as a renewable, low-carbon energy solution and condemned their production as a threat to human and environmental wellbeing. For many, the juxtaposition of 'food versus fuel' captures the central tension of the biofuel industry.

Dramatic increases in grain prices throughout much of 2008 brought food security and vulnerability issues to the fore. Experts disagreed over the extent to which biofuel production contributed to these price increases, with perhaps the highest estimate of 75 per cent responsibility attributed to a combination of diversion of grains into biofuels, farmers setting aside land for energy crops, and financial speculation (Chakrabortty 2008). Others saw a less clear relationship between biofuels and food prices, contending that biofuels may actually be able to reduce local food shortages and raise the incomes of the world's most impoverished—if proper policies are implemented (Müller and others 2008). Looking beyond a direct trade-off between food and energy, another perspective sees land use management as the lens for assessing the linked implications of biofuels, biodiversity, ecosystem integrity, and food.

Approaches such as smallholder production for local consumption stand in contrast to the dominant model of large-scale agribusiness biofuel production. As well, such approaches represent an important ongoing experiment within the broader effort to promote rural energy self-sufficiency, livelihood opportunities, and environmental integrity in the developing world.

Using an eco-agriculture approach, smallholders producing biodiesel or vegetable oil for local use can achieve conservation benefits including crop diversity and restoration of degraded land (Milder and others 2008). This strategy has the potential to enhance local energy security, increase household incomes, and generate new economic opportunities that rely on a small but steady energy supply (Ejigu 2008). Such small-scale biofuel projects are now underway in several countries.

Large, monoculture plantations invite environmental damages related to intensive chemical use, biodiversity loss, soil degradation, wildlife displacement, and water consumption (**Table 1**). They can also have significant social repercussions in terms of livelihoods and human rights. In places where the land tenure situation is insecure or contested, an increase in biofuel production can cause poorer groups to lose crucial access to land (Cotula and others 2008). Still, many developing countries see an opportunity for economic development in the growing international biofuel trade.

Table 1: Biofuels and water projections for 2030

	Biofuel production (billion litres)	Crop	Irrigated water needed (km^3) for biofuels	Percentage of irrigation water used on biofuels
US/Canada	51.3	Maize	36.8	20
Brazil	34.5	Sugarcane	2.5	8
EU	23.0	Rapeseed	0.5	1
China	17.7	Maize	35.1	7
India	9.1	Sugarcane	29.1	5
South Africa	1.8	Sugarcane	5.1	30
Indonesia	0.8	Sugarcane	3.9	7

Sources: Molden 2008, Serageldin and Masood 2008

Research attempts to analyse the full costs and benefits of various biofuel production processes, including the implications of large scale land-use change, predict the loss of stored carbon, and raise the possibility of biofuels as a net contributor to climate change (Fargione and others 2008). A new study using a worldwide agricultural model to estimate emissions from land-use change reveals that corn-based ethanol would increase greenhouse gas emissions by nearly 100 per cent over 30 years and would continue emitting for 167 years (Searchinger and others 2008). As initial enthusiasm over biofuels is tempered by concerns about the social and environmental trade-offs in places where energy crops would be grown, several governments with fuel-blending mandates have recently revisited their targets or considered adding conditions related to sustainable sourcing.

The development of a global standard outlining sustainability principles and decision making criteria will be an important step towards appropriate policy decisions when applied in combination with enhanced bioenergy mapping tools and an understanding of local preconditions and needs. Small-scale biofuel projects designed to promote rural energy self-sufficiency in the developing world pose a creative challenge to the dominant scenario of biofuels for international transport needs (UN-Energy 2007). Whether these efforts will translate into an effective strategy for meeting rural energy needs while enhancing livelihoods and ecosystem integrity will remain an important question in the months and years to come.

Cycle of poverty and environmental degradation

Environmental degradation has created uncertainty and risk across the globe. Yet the greatest burden continues to fall on the most impoverished regions, and on marginalized and indigenous communities (Levin and others 2008). If current trends persist, the disruptive effects of climate and ecosystem change will continue to impair the wellbeing of at least 2 billion of the world's human population and to diminish their prospects for a better future (See Climate Change, Chapter Three) (WRI 2008). And yet, attempts to mitigate the current global economic downturn have cost considerably more than the amounts allocated for official development assistance (See Environmental Governance, Chapter Six) (Ban 2008).

Poverty and the environment are inextricably linked. It is well accepted that ecosystem degradation and natural resource depletion are exacerbated by socio-demographic factors, particularly when combined with poverty (WRI 2008, UN 2008). The co-incidence of rapid population growth and environmental degradation has emphasized the importance of understanding the complex linkages among societies, ecosystems, and governance. While the overall changes that humans have made to ecosystems have contributed to substantial overall benefits in human wellbeing and economic development, these gains are not equitably distributed: They have come at the serious and growing cost of displaced degradation, increased risks of non-linear changes, and exacerbation of poverty among the most vulnerable populations (Holden and others 2006, WRI 2008, Hazell and Wood 2008).

For most people in developing countries, especially those living in rural areas, functioning natural environments form an essential part of their livelihood strategies. A balanced relationship between people and functioning ecosystems is crucial when addressing sustainable ecosystem management and poverty reduction (IAASTD 2008, WWF 2008, UNEP 2007). Nature-based income routinely accounts for more than half of the total income stream for the world's rural poor (WRI 2008). Reliable estimates suggest that 90 per cent of the rural poor depend on forests for at least a portion of their income (WRI 2005). In rural Africa, small-scale agriculture, the backbone of developing country economies, is the principal source of income for over 90 per cent of people (UN 2008). As a function of these critical dependencies, impoverished regions and rural indigenous communities have consistently suffered disproportionately from degradation and changing climatic and ecosystem conditions.

The proportion of rural people in poverty rises markedly in locations that are marginal for agricultural productivity, remote from services, and prone to natural disasters. Under these conditions, people are often compelled to over-exploit adjacent resources to survive (Hazell and Wood 2008). The UN Food and Agriculture Organization estimates that 7.8 million hectares of forest are lost each year to subsistence hillside farming and shifting cultivation as a result of declining yields on traditional agricultural land (FAO 2008, FAO 2008b). Pressures exerted through low-productivity agricultural practices, overgrazing, slash and burn activities, soil-mining, deforestation, and expansion into forested areas threaten not only the ecological balances of an increasingly fragile natural resource base, but also livelihoods and wellbeing of the communities that depend on these ecosystems. The result is a negative feedback loop, in which poverty contributes to ecosystem degradation and ecosystem degradation contributes to the perpetuation and intensification of poverty (Wade and others 2008).

Mainstreaming ecosystem management into poverty reduction

Ecosystem approaches to alleviating poverty have received substantial attention in recent years. Integrating environmental issues and ecosystem management with poverty reduction strategies has become central to sustainable development programmes (UNDP 2007, WRI 2008, Svadlenak-Gomez and others 2007). Given the huge disparity between average incomes and those of the rural poor, as well as the important relationships these populations have with the land and natural ecosystems, development strategies stand little chance of success if they do not take into account the circumstances, knowledge, capabilities, and environmental needs of the rural poor.

With a deliberate shift to a strong governance regime, ecosystem management could become a powerful model for nature-based enterprise that delivers continuing economic and social benefits to the poor as it improves the natural resource base, and that sustains those ecosystems as they provide essential services at regional and global scales (WRI 2008). So far, the poorest and most vulnerable segments of society lack the necessary means and empowerment to utilize nature-based enterprise to improve their wellbeing. Even where resources are abundant, revenues are often appropriated by elites, leaving rural communities and their local ecosystems worse off (Gardiner 2008, FAO 2007).

Development in poor rural communities requires innovative strategies and processes that promote local interests while building local capacity. Meeting such challenges was inherent in the Millennium Development Goals. But momentum towards those goals is faltering.

The need for action is urgent. We face a global economic crisis and a food security crisis, both of uncertain magnitude and duration. In the meantime, climate change has become more apparent—usually in the background but more frequently as a phenomenon that cannot be ignored. These developments will directly affect our efforts to reduce poverty: The economic slowdown will diminish the incomes of the poor; the food crisis will increase the number of hungry people in the world and push millions more into poverty; and climate change will have a disproportionate impact on the poor. The need to address these concerns, pressing as they are, must not be allowed to detract from our long-term efforts to achieve the Millennium Development Goals (UNDESA 2008).

Women agricultural workers harvesting tea leaves at a tea plantation in West Java, Indonesia. *Source: M. Edwards/ Still Pictures*

NEW MANAGEMENT PARADIGMS

Ecosystem management practices continue to evolve as new science emerges, leading to re-consideration of fundamental principles, values, and the specific nature of management interventions. The underlying problem is ultimately quite simple: Management approaches that do not respond to, and adapt faster than, changing ecosystems will invariably fail—as will the societies that are content with such mismanagement.

While the challenge is daunting, new advances offer hope. The closer we come to achieving an accurate, holistic picture of the distribution of the ecosystem costs, benefits, and trade-offs of our actions, the better positioned we will be to formulate responses.

Degradation, conservation, and productivity

Over the next four decades the amount of available cropland per person is projected to drop to less than 0.1 hectares, due to biological limits, requiring an increase in agricultural production that is unattainable through conventional means (Montgomery 2008). A sense of urgency has been growing, in response to the universal decline of soil quality that results from various systems of intensive agriculture.The problem of soil degradation, which has affected all but 16 per cent of the world's croplands, presents serious implications for agricultural productivity and broader ecosystem services, including biodiversity (Hazell and Wood 2008).

An emerging body of scientific research focuses on spatially integrated management approaches to agriculture. This would involve a move away from the conventional model of land-use segregation, in which some areas are dedicated wholesale to food production, while others are set aside for conservation or other uses (Scherr and McNeely, Holden and others 2008). For decades, biodiversity conservation and agricultural productivity were thought to be incompatible and mutually exclusive pursuits. But practitioners of eco-agriculture challenge these notions. Their approach transforms large-scale, high-input monoculture plantations at the farm level to a more diverse, low-input, and integrated system at the landscape level.

Given the necessary management, policy, and governance structures, these new eco-agricultural land-use mosaics could support biodiversity while meeting increasing demands for wider ecosystem services and achieving critical goals of agricultural sustainability (Scherr and McNeely 2008). By treating food production as just one of many possible ecosystem services, eco-agriculture in a sense encourages landholders to cultivate clean air, sweet water, rich soil, and biological diversity, as well as food (**Box 2**).

Forms of eco-agriculture have been practiced in the past and at impressive scales: Terra Preta soils of central Amazonia exhibit approximately three times more soil organic matter, nitrogen, and phosphorus and 70 times more charcoal compared to adjacent soils. The Terra Preta soils were generated by pre-Columbian native populations by adding large amounts of charred residues, organic wastes, excrement, and bones. Large-scale generation and utilization of Terra Preta soils would decrease the pressure on primary forests that are currently extensively cleared for agricultural use. This would maintain biodiversity while mitigating both land degradation and climate change and, if done properly, can alleviate waste and sanitation problems in some communities (Glaser 2007).

Scaling up financial incentives

The Fourth Global Environment Outlook Report called attention to the critical role the environment can play in enabling development and human wellbeing. It also rendered a compelling argument that Earth's ecosystems and the goods and services they provide offer tremendous economic opportunities valued at trillions of dollars (UNEP 2007). This conclusion reinforces the growing movement to incorporate inventories of our natural capital and nature-based assets into our efforts to develop and execute ecosystem management.

In recent years, interest in and scientific research on the assessment of ecosystem services, particularly biophysical valuation, has grown markedly (Cowling 2008). Valuation of ecosystem services has created a basis for innovative financial interventions and economic incentives as powerful instruments that can help regulate the use of ecosystem goods and services and even redistribute benefit flows.

Box 2: Semi-natural and cultural landscapes: Reservoirs of biodiversity and ecosystem services

Conservation of biodiversity and landscapes is often framed as a 'human versus nature' tradeoff: Pristine, untouched nature is considered optimal, while human influence in the ecosystem is considered unwanted intrusion. Conservation programs that limit human impact on natural ecosystems are important, but conservation of semi-natural landscapes is also necessary for both biodiversity and ecosystem services.

Historically, there are many semi-natural landscapes developed in association with societies' traditional land use over long periods of time. These semi-natural ecosystems, or cultural landscapes, are associated with traditional livelihood activities. The most common cultural landscape types, managed meadows and forests, are kept in a stable but artificial state through activities such as animal grazing, fodder collection, forest floor litter clearance, and harvesting of forest resources. These activities alter important environmental features of the landscape, including moisture levels, light penetration, temperature regimes, and nutrient cycles. Many such sites are high in biodiversity and, more importantly, contain a higher percentage of rare and endangered species than either monoculture plantations or natural ecosystems on the margins of cultivated areas.

Coon Creek Watershed in southwest Wisconsin was once one of the most heavily eroded regions of the United States. Advances in soil and farmland restoration have revitalized both form and function of this impressive landscape. *Source: Jim Richardson*

Cultural landscapes were traditionally managed for the provision of a particular ecosystem service. The grasslands of Europe, for example, have been managed for grazing and fodder production for domesticated livestock. Indigenous peoples of the Americas used controlled burns in forests to create wooded meadows for deer to graze. In North America, sugar bush woodlots are maintained to produce maple syrup. In Central Asia, the natural fruit and nut forests have been managed to enhance the production of these important foodstuffs.

Most ecosystems in Europe are managed or semi-managed. However, these semi-natural ecosystems have declined in both quality and quantity in the past century. In Finland, for example, traditionally managed forest and meadows are the most threatened habitats, with the majority of these landscapes now critically endangered. At the same time, nearly one-third of all endangered species in Finland are found primarily in these threatened and endangered grazed forests and meadows.

In letting these landscapes go, we lose not only important habitat for species, but also landscapes that have high cultural value. These landscapes have irreplaceable aesthetic and historical value by providing cultural ecosystem services. Semi-natural and cultural landscape have inspired great painters, musicians, and poets and help to form peoples' cultural identities. The aesthetic value of cultural landscapes is evident in the importance they have in tourism and in attracting new residents from urban areas.

What does this mean for future management of ecosystems, when human impact is felt in every ecosystem on Earth? Although humans have been responsible for massive environmental changes and large-scale extinctions, our valuable cultural landscapes show that people can manage ecosystems sustainably. Although we need wild places, too, it may be time to revisit the past to learn how to manage for the future.

Sources: Wittemyer and others 2008, Lindborg and others 2008, Furura and others 2008, MOE 2007, Raunio and others 2008, Kareiva 2007, Merchant 2005, Schama 1995

Among the possibilities, a rapidly evolving instrument called 'payment for ecosystem services' (PES) offers great potential. The objective is to ensure that individuals, groups, and communities are compensated for their efforts in protecting critical ecosystem functions. This approach offers the necessary institutional platforms for poor and marginalized populations to engage in good ecosystem management while they claim economic and other benefits that emerge (WRI 2008). New initiatives to scale up PES arrangements offer promise for achieving both ecological and social progress without detracting from the primary objective of balancing conservation and development (Tallis 2008, Svadlenak-Gomez 2008). Through use of rigorous monitoring and appropriate valuation for both ecology and human wellbeing, PES could provide an important remedy for the tendency to shift burdens of ecosytem damages onto the vulnerable, poor, and future generations (Schultz 2008, WRI 2008, Hazell and Wood 2008).

Compensated reduction of deforestation

The consensus among scientists and experts is that conserving tropical forests represents one of the central ecosystem management priorities of our time. Yet forest destruction continues at the staggering rate of 13 million hectares a year, an area equivalent to half the UK. Attributed mainly to land conversion and agricultural expansion, tropical forest loss accounts for an estimated 17 per cent of all greenhouse gas emissions, making it a major cause of global warming (Ceccon and Miramontes 2008, IPCC 2007). Until recently, tropical forests' critical role in influencing and potentially moderating our changing climate was only conjecture: It is now observed reality.

This recognition has given rise to the concept of 'compensated reduction'. Reducing emissions from deforestation and forest degradation (REDD) promotes avoided deforestation as eligible activities for participating in the international mandatory carbon market. Carbon offset payments would provide compensation to encourage developing countries to reduce and stabilize national deforestation below a previously determined historical level (See Environmental Governance, Chapter Six).

Enthusiastic proponents speculate that REDD offers a crucial set of new incentives for reducing greenhouse gas emissions that could simultaneously accomplish several ancillary benefits: biodiversity conservation, watershed protection, capacity building in tropical forest nations, and poverty alleviation for rural communities. In principle, compensated reductions should enhance the welfare of the poor through the provision of stable and long-term revenue-sharing arrangements and non-financial benefit flows to rural communities. In practice, however, these systems could pose new risks to already vulnerable populations including restricted access to land, conflict over resources, centralization of power, and distortion effects in local economic systems (Preskett and others 2008). Although existing mechanism proposals for REDD emphasize the delivery of pro-poor and social ancillary benefits, most appear to leave achievement of these ends to chance.

From food crisis to agricultural renaissance

In spring 2008 precipitous increases in staple food prices, which threatened the lives of tens of millions, provoked demonstrations and food riots in 37 countries (Gidley 2008). These events may signal the arrival of an era in which longstanding relative inequalities have reached a breaking point for the global poor.

It has become clear that ecosystem management and food security are intimately linked. The surplus living resources and ecological margin of error in many regions are gone. As societies struggle over diminishing tracts of fertile and irrigable land—and over traditional fishing grounds—the accelerating threats of changing climate, ecosystem collapse, and population stress have converged in a way that calls the very future of food availability into question (**Box 3**). The debates are vigorous and highly contentious, but the issue of food security created global political panic in 2008 and will no doubt continue to occupy much of the international agenda for years to come.

There is a growing consensus within the international community that our current global agricultural system needs to be reorganized and rationalized; some are calling for a new agricultural revolution (Montgomery 2008, Wade and others 2008). While the issues at play are complex, involving diverse geopolitical and agro-ecological circumstances, the underlying distinctions are not hard to identify: Agricultural intensification through increased emphasis on chemical and technological inputs—or a move toward an integrated eco-agriculture approach at nested scales (Hazell and Wood 2008).

There is no denying the achievements of past agricultural intensification in the mid to late 20th century. The economic and social advances that characterize India, China, and much of Latin America today are, to a significant degree, due to that agricultural intensification. The problem is that while the global agricultural system that emerged is undeniably more productive, in a mid 20th century sense, its practice has accelerated soil erosion, soil salination, nitrification of water bodies, and overuse of synthetic pesticides with subsequent loss of natural pest control and other ecosystem services affecting agricultural sustainability. As well, our agricultural systems' distribution flaws make whole populations vulnerable to supply shocks as we witnessed in 2008 (Surowiecki 2008). Despite higher crop yields in many countries, we still face vast, persistent, and widening gaps in the ability of societies to feed themselves, much less to protect future resources and ecosystem services (Hazell and Wood 2008). For most developing countries, entrenched and deepening poverty stems from the fact that millions of small-scale farmers, many of whom are women, are simply unable to grow enough food to sustain their families, their communities, or their countries (AGRA 2008, Ngongi 2008) (**Box 4**). The efficiencies derived from the economy of scale in intensified agricultural systems do not apply at the scale of these families and communities (Dossani 2008).

As the human population continues to grow and the pool of land available for agricultural production shrinks, the costs and efforts required to avert a worst-case global food crisis will inevitably increase for developing countries. A new land grab may already be underway in Africa, with rich governments and corporations competing for some of the last remaining cheap land in the world, hoping to secure their own long-term food or biofuel supplies. In 2008, a number of countries, including Sudan, Ethiopia, and Madagascar, were entangled in wholesale land deals, the details of which have been largely concealed, causing many to speculate on whether these transactions have built-in safeguards for local populations (Borger 2008). Another new trend involves industrial food

Box 3: Avoiding marine ecosystem collapse through rights-based catch shares

Global fisheries have exerted enormous demands on the ecosystem goods and services of the world's oceans for decades, and this is becoming increasingly difficult to sustain. A recent study, which synthesized 17 global data sets of various human-induced drivers of ecological change, used nested scale spatial modeling to map the global extent of impacts on marine ecosystems from human activities.The findings were grim, revealing that humans have adversely influenced all marine ecosystems examined, with 41 per cent affected by more than one human-induced driver.

As commercial fisheries across the globe descend towards widespread collapse, due to systematic over-exploitation and cumulative mismanagement, calls for an ecosystem approach to fisheries management are being raised. Incremental progress has been made in the improvement of stock assessments and spatial indicators of ecosystem status, which in turn have led to more scientifically credible catch limits for some species. However, many of the inherent problems of overfishing have been institutionalized through poor fisheries governance and a systemic absence of resource stewardship. This lack of stewardship has marginalized many artisanal fishers who may be forced to turn to other marine-based economic activities.

The movement to use an ecosystem approach has been paralleled by efforts to stimulate reward-based management strategies and regulatory incentives for promoting stewardship. A new study from the University of California, Santa Barbara (UCSB) is advocating an innovative and controversial solution called 'rights-based catch shares'. This approach offers incentives for promoting ecologically responsible behavior by guaranteeing individual fishers a fixed portion of the total allowable catch. By granting fishers a share in—and responsibility for—the natural resource, regulatory and management objectives including sustainability are likely to be more closely aligned with the economic incentives of the resource users. Similar to corporate stock shares, catch shares can be bought and sold and are subject to the market signals of supply and demand, thereby creating a stewardship incentive. As fisheries are better managed and fish populations increase, so do the value of the catch shares.

Artisanal fishers on the Zambezi River cast a net for today's catch. *Source: David Gough/ IRIN*

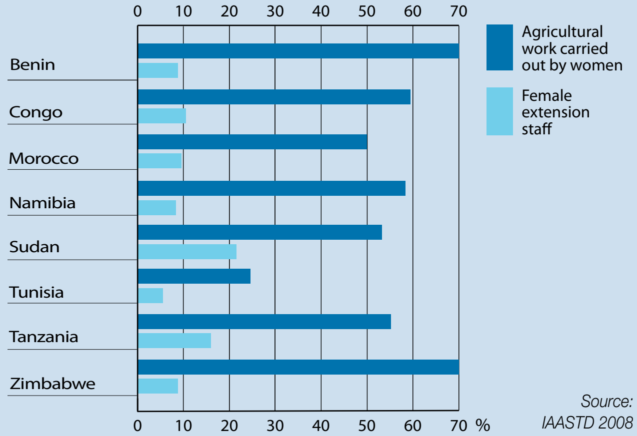
The UCSB study, which analyzed data from 11 135 fisheries worldwide, found a striking correlation between fisheries that implemented catch-share reforms and a reduction, or even reversal, of the trend towards collapse. The study posits that well-designed catch share programmes assigning secure resource rights to fishers reduces the probability of collapse by 9.0 to 13.7 per cent. In addition to addressing overfishing and ecosystem performance, various catch-based programs in New Zealand, Canada, Mexico, Chile, and the USA have shown an increased ability for individuals and fishing communities to improve their livelihoods.

Source: Costello and others 2008, Festa and others 2008, Halpern and others 2008, Mutsert and others 2008

Box 4: The role of women in agriculture in developing countries

A woman with her child prepares for planting at the Mshikamano women's group-farm in Bagamoyo, Tanzania where approximately 30 women share a small plot to raise fruits and vegetables. The socially constructed gender relations of agriculture are important dynamics in existing global farming systems, and a formidable challenge to ongoing agricultural restructuring. In most developing countries the percentage of rural women involved in agricultural production and post-harvest activities is disproportionately higher than men, with the proportion of agricultural management services skewed in the opposite direction. With the proliferation of export-oriented irrigated farming at low pay, the demand for female labour is increasing further. These developments have brought some benefits, but the situation for rural women worldwide must be improved. If they are shut out from higher paying agricultural roles, they will continue to face deterioration of health, working conditions, access to education, and rights to land and natural resources.

Source: Tara Thompson



Source: IAASTD 2008

production in one country, cultivated by another. Sudan is exporting wheat for Saudi Arabia; sorghum for camels in the United Arab Emirates; and wheat, beans, potatoes, onions, tomatoes, oranges, and bananas for Jordan. Sudan supplies the land while its neighbors supply the money, the management, the science, and the equipment (Gettleman 2008).

A number of institutions and research bodies are pressing for a complete rethink of the role of agriculture in achieving equitable development and sustainability. Increasingly, they are advocating for approaches to agriculture that recognize the importance of multiple ecosystem services. An extensive intergovernmental assessment of agriculture knowledge, science, and technology, released in 2008, advocates for a radical move away from technologically-based production enhancements to a focus on the needs of small farmers in diverse ecosystems, particularly in areas of high vulnerability to ecosystem change. Recognizing that the poor have benefited the least from increased productivity, the study argues for improving rural livelihoods, empowering marginalized stakeholders, enhancing ecosystem services, integrating diverse knowledge, and providing more equitable market access for the poor (IAASTD 2008).

In November 2008, the UN's Food and Agricultural Organization called for an immediate plan of action on a new 'World Agricultural Order' to ensure that production meets rising demand in the face of climate change, while safeguarding the goals of sustainable ecosystem management (FAO 2008). It proposed a new governance system for world food security and agricultural trade that offers farmers, in developed and developing countries alike, the means of earning a decent living (Diouf 2008).

In this new World Agricultural Order, can we learn from those experiences with high-input, high-yield agriculture to define a rational eco-agricultural system? While increased chemical and technological inputs may keep the agricultural production system going over the short term, it becomes progressively more difficult to sustain (See Harmful Substances and Hazardous Waste, Chapter Two) (Montgomery 2008, Pretty 2008). Sooner or later, the existing realities will compel those responsible for the new agricultural paradigm to reach a balance between production and ecosystem integrity. If we can establish the balance sooner, we will avoid the inevitable shocks and panics that result from business-as-usual practices (Montgomery 2008).

CONCLUSION

As the first decade of the 21st century draws to an end, virtually all ecosystems on the planet have been significantly modified in both structure and function (Seastedt and others 2008). To a greater or lesser extent, they have all been adversely affected by human activity. The most widespread human impacts include extensive deforestation, land conversion and fragmentation, desertification, the disruption of freshwater systems, the pollution and over-exploitation of marine ecosystems, excessive nutrient loading, severe changes in species distribution, and loss of biodiversity. Given humankind's cumulative influence on Earth's ecological systems and the consequent disruption of vital processes—especially carbon, water, nitrogen, and phosphorus cycling—it is too optimistic to describe future prospects for the planet's ecosystems as precarious and uncertain.

Rather than continue with business-as-usual practices that allow cascades of environmental and social damage to result from ecosystem mismanagement, we should be designing ecosystem management systems that minimize wasted resources, maximize community self-sufficiencies, and optimize access to emerging opportunities among the most vulnerable populations to build their resilience. Approaching ecosystem management from an industrial perspective has increased productivity, but at a high cost to the quality of soils, water, atmosphere, and ecological health. Based on insights revealed by 2005's Millennium Ecosystem Assessment, new approaches under consideration suggest that productivity can be decoupled from environmental degradation. Imminent critical thresholds require that this decoupling proceed at once.

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Harmful Substances and Hazardous Waste

The chemicals we use to produce energy, to control pests, to enhance productivity, to catalyze industrial processes, and to meet human health needs—as well as the chemicals we just discard—continue to weaken ecosystems and to imperil human health.

Nickel tailings at Subury, Ontario, Canada. *Source: Edward Burtynsky*

INTRODUCTION

In just one century, we have poisoned much of our environment. One hundred years ago, Fritz Haber succeeded in synthesizing ammonia from hydrogen and atmospheric nitrogen. Used in weapons, ammonia enabled the proliferation of munitions and explosives in the twentieth century; used in chemical fertilizers it helped the human population multiply from 1.9 billion in 1900 to nearly 6.87 billion in 2008 (Smil 2001).

Perhaps more significantly still, Haber's process accelerated an era of large-scale industrial chemistry. Humans have been using basic chemistry for thousands of years, but the intensification of both the industrial and chemical revolutions over the last century have introduced myriad new chemicals into our environment and boosted the concentrations of others to levels never before experienced. The concentration of chemicals and the complexity of the compounds have initiated a cascade of environmental repercussions (Erisman and others 2008).

Fifty years after Haber's breakthrough, Rachel Carson began her research into the environmental effects of complex compounds used as pesticides. She helped launch modern environmental science, and the environmental movement, in her influential 1962 book, *Silent Spring*. Ideas and terms which were exotic then, such as biomagnification, bioaccumulation, persistent organic pollutants, carcinogens, and heavy metal poisoning, have since become unfortunately commonplace.

We have come a long way in tracking the ecological and human health implications of these side-effects of our industrial and economic advances. But significant uncertainties remain. In recent decades, we have addressed some problems of harmful substances and hazardous waste through international agreements, national legislation, and industrial efficiencies.

However, human enterprise is producing toxic and hazardous substances at increasing rates, and vast quantities of these dangerous compounds are reaching the atmosphere, water bodies, and soils that support life, with devastating and potentially accelerating impact. Earth's ecosystems are suffering the consequences, as are too many of the world's most vulnerable populations, who most often are at the receiving end of chemical contamination—children, the poor, and the marginalized.

Box 1: What's in a toy?

Manufacturers add phthalates to plastic products to make them soft and flexible. Until 1998, phthalates were commonly used to make bath toys, teething rings, and other toys for infants.

In 1998, a study conducted by the Danish National Environmental Research Institute showed that phthalates used in the manufacture of these soft toys tended to leak out of the material. The European Commission's Scientific Committee for Toxicity, Ecotoxicity and the Environment published a statement on this leakage indicating that animal testing has shown that phthalates can have negative health effects. It is recognized through cell cultures and animal tests that at varying concentrations phthalates can cause testicular and ovarian toxicity, developmental toxicity, and liver damage including the development of tumours.

Based on animal tests, phthalates are considered endocrine disruptors—chemicals that can interfere with the production, release, transport, metabolism, binding, action, or elimination of natural hormones that are responsible for normal metabolism and are essential for normal growth and development.

The unrelated safety recalls of children's toys in 2007, prompted when lead paint was found on toys manufactured in China, led to broad new toxicity regulations for a wide range of children's products. In 2008, the Consumer Product Safety Improvement Act was passed in the United States to restrict excessive amounts of certain substances in children's products, including potential endocrine disrupters such as phthalates. At the same time, the OECD's Endocrine Disrupter Testing and Assessment Task Force, set up in 1996 to develop test methods for identifying endocrine disrupters, refined analytical approaches to determining the compounds' toxicological effects. Endocrine disrupters were also addressed under the 6th EU Research Framework Programmes for 2002-2006 and will again be addressed under the 7th Framework Programme of the European Community for Research, Technological Development and Demonstration Activities covering 2007-2013.

Sources: ICIS 2008, WHO/DEPA 2004, Schettler 2005, Canadian Cancer Society 2008, Wolff 2006, EC 2008.

Until 1998 many baby toys contained phthalates to make them softer for chewing. *Source: Viktoryia Bankova*

DANGEROUS SUBSTANCES IN FOOD AND DRINK

The globalization of trade in food has been enabled by technological developments in food production, processing, handling, and distribution. Globalization of the food supply has in turn increased the potential for contamination and disruptions in the food supply chain. Multi-layered supply links with poor traceability and transparency are particularly vulnerable. Threats to the food supply from harmful substance contamination are nothing new, but in 2008 a series of scandals placed food safety and quality assurance as high priorities on the global agenda (**Box 1**).

Harmful compounds found in food

In March 2008, dangerous dioxin levels were found in mozzarella cheese from the Italian region of Calabria, including the provinces of Caserta, Napoli, and Avellino. As a result, the European Union (EU) requested that Italy ensure contaminated cheese be recalled and not exported (Reuters 2008, Willey 2008). Out of 130 mozzarella production sites checked by Italian officials, 25 showed dioxin levels above EU limits (BBC 2008b). Dioxins are by-products of a wide range of manufacturing processes including smelting, chlorine bleaching of paper pulp, and the manufacturing of some herbicides and pesticides (WHO 2007). In the Calabrian cases however, authorities suspect pastureland may have become contaminated by toxic industrial waste, illegally dumped by the organized crime syndicates that dominate the waste disposal industry in Italy (Saviano 2007, Willey 2008).

Exposure to low levels of dioxins is not uncommon in our environment under normal circumstances. Small amounts of dioxin are consumed daily via contaminated foodstuffs and environmental exposure (Sato and others 2008). While the effects of long-term, low-level exposure are not well understood, acute exposure to high concentrations can have severe consequences. Short-term exposure of humans to high levels of dioxins may result in skin lesions and may alter liver function, while long-term exposure can damage the immune system, the developing nervous system, the endocrine system, and reproductive functions. Chronic exposure of animals to dioxins has resulted in several types of cancer (WHO 2007). In areas of the Italian region of Campania, where toxic dumping has been a particular problem, cancer mortality and congenital malformations show significantly increased rates in comparison with national rates (Comba and others 2006).

In September 2008, Chinese citizens learned that government tests found melamine, a toxic chemical that can artificially boost reading of protein content in standard tests, in liquid milk used to manufacture different dairy products. The contaminated milk in China sickened nearly 53 000 young children: 47 000 were hospitalized, 6 240 cases of kidney stones were documented, and at least four babies died from drinking adulterated infant formula (WHO 2008). Studies conducted by China's national inspection agency found that at least 22 dairy manufacturers across the country recorded melamine in some of their products, including infant formula, with levels that ranged from a low of 0.09 milligrams per kilogram (mg/kg) to an astounding high of 6 191.0 mg/kg. Late in the year, the World Health Organization (WHO) announced the tolerable daily intake of melamine as 0.2 mg per kg of body weight (WHO 2008).

At least two companies exported their products to Bangladesh, Burundi, Myanmar, Gabon, and Yemen. In Africa, from the Ivory Coast in the west to Tanzania in the east, national governments joined the list of countries blocking Chinese dairy products rather than risk the prospect of melamine poisoning. Although WHO documented cases only in mainland China, Hong Kong, Macau, and Taiwan, it warned other countries to be cautious (Magnowski 2008).

One month later, in October 2008, two unrelated food scandals swept Japan. First, two major food companies recalled around 0.5 million instant noodle packs when insecticide contamination was discovered (Demetriou 2008). Then, two days later, Japan's largest meat processor voluntarily recalled 13 products after discovering that underground water used in their plant near Tokyo contained high levels of cyanide compounds (Demetriou 2008). This recall covered nearly 2.7 million packages of sausages and pizza sold in Japan. Tests found up to three times the government's limit of cyanide in the well water normally used in the products (Daily Express 2008).

Box 2: E-waste, the cyber nightmare

Electronic waste is now considered the fastest-growing segment of the municipal waste stream in the United States of America. The National Safety Council estimated in 2004 that by 2009, some 250 million computers will have become obsolete. According to the Silicon Valley Toxics Coalition and the Basel Action Network, up to 80 per cent of the material dropped off by North Americans at community recycling facilities ends up packaged for export.

What happens after export can vary: In Nigeria, for example, there is a legitimate and robust market for repairing and refurbishing old electronic equipment including computers, monitors, televisions, and mobile phones. However, computer dealers in Lagos complain that up to 75 per cent of the 400 000 units they receive each month from recycling agencies are not economically repairable or marketable. Subsequently, the e-waste that is a hazardous waste by law is being discarded and routinely burned in an unsafe, unregulated manner.

The situation is even worse in Guiyu, China, an industry town filled with recycling enterprises that receive around 80 per cent of US recycled electronic waste. Guiyu's recycling industry employs workers to recover copper, gold, and other valuable materials from electronics, often without adequate protective equipment. In most cases, the only precautionary measure taken by the workers to reduce exposure to toxic fumes is the use of portable household fans.

In Guiyu, Guangdong, China, a child waits patiently in the midst of waste from electronic components. *Source: Greenpeace/ Natalie Behring*

As a result of this activity, Guiyu's soils record some of the world's highest concentrations of dioxins and heavy metals, seriously affecting the health of its residents. The local environment has been ruined: Water sources are contaminated and drinking water has to be trucked into the village. Villagers cannot grow their own food because the soils are completely tainted. To survive, they must work in the recycling industry—further degrading their health and surrounding environment and making them more vulnerable and more dependent on recycling activities.

The recycling of printed circuit boards is one of the major sources of heavy metal release into the surface environment. In 2008, analyses revealed very high mean concentrations of lead, copper, zinc, and nickel in the dust of recycling workshops and adjacent roads. In the recycling workshops, lead concentrations exceeded the European allowable concentrations by a range of 269–2426 times. Concentrations of copper and zinc exceeded them by ranges of 31–994 and 7–73 times, respectively. Lead and copper in road dust near recycling workshops were found to be 371 and 155 times higher, respectively, than dust in non-e-waste sites in the region. The same study identified that the food markets and public places were also contaminated with high heavy metal concentrations.

This informal e-waste recycling poses a serious health risk to local residents, particularly children, as well as to workers. Compared to adults, the potential health risk to children at all locations was eight times greater, due to higher ingestion rates and smaller body size. The health effects on residents include birth defects; damage to central and peripheral nervous systems; distorted blood composition; damaged lungs, livers, and kidneys; and death.

Sources: Royte 2006, Huo and others 2007, Bi and others 2007, HRA 2008, Leung and others 2008.

On 6 December, the Food Safety Authority of Ireland recalled all pork products purchased since 1 September 2008. Routine testing had detected unacceptable levels of dioxin in the meat. Investigators determined that the compound had been introduced through contaminated animal feed used by 10 farms that together produce 10 per cent of the Irish pork supply (FSAI 2008). Such hazardous compounds and dangerous heavy metals can enter ecosystems and water bodies from numerous human enterprises, including recycling efforts (**Box 2**).

Compounds in water

Cyanide compounds can reach groundwater aquifers and aquatic ecosystems from a large number of industrial processes, including electroplating and case-hardening of metals; extraction of gold and silver from ores; coal combustion and gasification; and fumigation of ships, shipping containers, railroad cars, buildings, and other other structures (WHO 2007b). Between 1975 and 2000, more than 30 large-scale accidental releases of cyanide into water systems were reported due to transportation accidents and pipe failures (Mudder and Botz 2000). Symptoms of acute exposure to cyanide from drinking contaminated water include cardiovascular, respiratory, and neuro-electric alterations (WHO 2007b). The brain seems to be the most sensitive organ to cyanide toxicity.

In contrast to cyanide, effects in humans from drinking water contaminated with arsenic are well documented. This is because severe health effects have been observed worldwide in populations drinking arsenic-rich water over long periods. While most waters in the world have low natural arsenic concentrations, excessive concentrations are known to naturally occur in some areas such as the Bengal Basin (WHO 2001a). Arsenic is stored in fatty tissues faster than it can be processed through the body's digestive and waste systems (Indu and others 2007). As a result of this process of bioaccumulation, drinking arsenic-rich water over 5 to 20 years leads to arsenic poisoning. Arsenic poisoning can cause skin cancer; cancers of the bladder, kidney, and lung; and diseases that affect blood vessels in the legs and feet. Arsenic poisoning can also lead to diabetes, high blood pressure, and reproductive disorders (WHO 2001b).

Over the past two decades arsenic contamination in groundwater has been discovered in a growing number of countries in South Asia (Van Geen 2008). The natural arsenic contamination in this region is dependent on the upstream geology, but can be exacerbated by land-use practices in the catchment areas of the major rivers that carry and distribute sediment and anthropogenic waste materials (Khalequzzaman and others 2008). Across floodplains in Bangladesh and West Bengal, India, groundwater is extracted from millions of private wells dug in response to widespread contamination of surface water with microbial pathogens (Michael and Voss 2008). About 30 per cent of the private wells in Bangladesh show high levels of arsenic, over 0.05 milligrams per litre, and more than half of the country's administrative units are affected by contaminated drinking water (Khalequzzaman and others 2008). Several other countries have identified high levels of arsenic concentration in drinking water including Argentina, Chile, China, Hungary, Japan, Mexico, Mongolia, Poland, Taiwan, and the United States.

Given natural background levels of arsenic, lead, mercury, and other compounds, additions from industrial processes are hardly welcome. And pulses of pollution introduced by industrial accidents can be catastrophic for surrounding communities (**Box 3**).

A HISTORY OF MERCURY CONTAMINATION

Like arsenic, the toxic heavy metal mercury is bioaccumulated. Chronic exposure to mercury-rich water therefore results in eventual mercury poisoning. Mercury also occurs naturally in some ecosystems, though typically at very low concentrations. A variety of industrial and extractive practices used for mining and timber processing discharge toxic concentrations of mercury (**Figure 2**). These threaten people and the environment, especially vulnerable populations in remote areas who are directly exposed to unsafe over-exploitation of natural resources and industrial discharges.

Metallic mercury and other inorganic mercury compounds can lead to serious health problems but the most dangerous form is organic methylmercury. This form of mercury can be produced biologically in aquatic environments, including hydroelectric dam reservoirs. Metallic mercury accumulates in the oxygen-deprived reservoir bottoms where it is transformed by bacteria into bioavailable methylmercury and passed up through the food chain, eventually bioaccumulating in fish (Boudou and others 2005, Pinheiro and others 2007).

Mercury is a profoundly toxic substance (Marques and others 2007). Exposure to mercury is particularly dangerous for growing children and developing fetuses (ATSDR 1999). Even low levels of mercury exposure from a pregnant woman's consumption of methylmercury in dietary sources can cause permanent brain damage and disruptions in the neurological development of children. Impacts on memory, attention, language, and other skills have been found in children exposed to moderate levels of methylmercury in the womb (Heartspring 2008).

Mercury poisoning on record

The case of Minamata, a modest Japanese fishing village, reveals the potential for widespread mercury poisoning. Starting in 1932, mercury was discharged to Minamata Bay by manufacturers of plastic. In the early 1950s, the production of plastics boomed, as did the symptoms of mercury poisoning first in fish, then in cats, and ultimately in humans. By the end of 1956, epidemiological and medical researchers identified the disease—characterized by trouble with walking, difficulty speaking, and convulsions—as heavy-metal poisoning caused by eating contaminated fish and shellfish (Allchin 1999). A generation later, in the 1970s, the effects of 'Minamata disease' persisted, as mothers contaminated in their youth gave birth to children with severe afflictions including gnarled limbs, mental retardation, deafness, and blindness (Kugler 2004).

Mercury contamination has also threatened indigenous people in Canada for many decades. In the late 1960s, exposure and significant risk to health from mercury poisoning was first noticed in two northwestern Ontario Ojibwa communities at Grassy Narrows and Whitedog on the English-Wabigoon river system (Kinghorn and others 2007, INAC 2008). The river system was contaminated with mercury discharges from a chemical plant that supplied a pulp and paper mill upstream in the small city of Dryden. The mercury in the waste was transformed into methylmercury within the aquatic ecosystem and then bioaccumulated to significant levels in the fish eaten by the people living downstream (Wheatley and Paradis 2005). In 1975, mercury concentrations in the fish ranged from 0.47 to 5.98 parts per million—while Health Canada guidelines establish maximum mercury concentrations ranging from 0.5 to 1.0 parts per million for various fish species used for human consumption (Health Canada 2007).

Box 3: The Tennessee coal ash spill

Coal ash is a sooty, particulate residue from coal combustion in power plants and factories. In many regions, coal powered industries are legally required to remove the ash—containing carcinogens, arsenic, lead, selenium, and other compounds—from exhaust smoke before venting through smokestacks. This 'scrubbing' of ash has prevented tonnes of toxic particulate pollution from entering the atmosphere since scrubbing first became commonplace in the 1970s. However, over the years, ash has been accumulating and storage has become a problem.

In the middle of the night on 22 December, a retaining wall around a coal ash containment pond failed in the US state of Tennessee. Nearly 4 billion litres of coal ash slurry spilled out into a network of rivers and a nearby valley, emptying into the floodplain around the Kingston Fossil Plant source with thick sludge more than a metre deep.

The Kingston Fossil Plant submitted a 2007 inventory to the Environmental Protection Agency (EPA) declaring the deposit of 20 000 kilograms of arsenic, 22 000 of lead, 630 000 of barium, 41 000 of chromium, and 63 000 of manganese into the containment pond in that one year. The pond has been accumulating such waste for decades.

The Tennessee Valley Authority (TVA), the public corporation that owns the site, issued a joint statement with the EPA and other agencies recommending that direct contact with the ash be avoided and that pets and children should be kept away from affected areas. Local residents are worried that they could be harmed once the sludge dries and is picked up by winds, or when it filters through to wells and other water sources. The TVA, the EPA, other government agencies, and environmental groups have begun analyzing water samples taken at various sites downstream.

The incident underscores the potential dangers of long term storage of hazardous materials in general and of coal ash in particular. As stricter air quality regulations are applied to the many thousands of coal-fired power plants around the world, safe storage or reuse options for coal ash are becoming an increasingly important priority (See Resource Efficiency, Chapter Five).

Sources: Dewan 2008, EPA 2007, EPA 2008, NRC 2006, Sturgis 2008, TVA 2008

To this day, Canada has dozens of industrial facilities that utilize and discharge mercury near indigenous communities. Environment Canada's 2006 National Pollutant Release Inventory, the most recent inventory available, reports a total of 172 facilities within a 50 kilometre distance of 135 communities across the country (NPRI 2006, Schertow 2008). A preliminary analysis, testing indigenous people in 514 native communities across Canada for methylmercury from 1970 to 1992, indicated that 23 per cent of the individuals showed over 20 micrograms per litre in their blood and 1.6 per cent had levels over 100 micrograms per litre (Wheatley and Paradis 2005). Blood samples of 2 405 umbilical cords showed about 22 per cent had levels greater than 20 micrograms per litre—the maximum acceptable level under Canadian guidelines for adults and more than double the 9 micrograms per litre of blood limit for pregnant women. The highest maternal level found was 86 micrograms per litre (Wheatley and Paradis 2005).

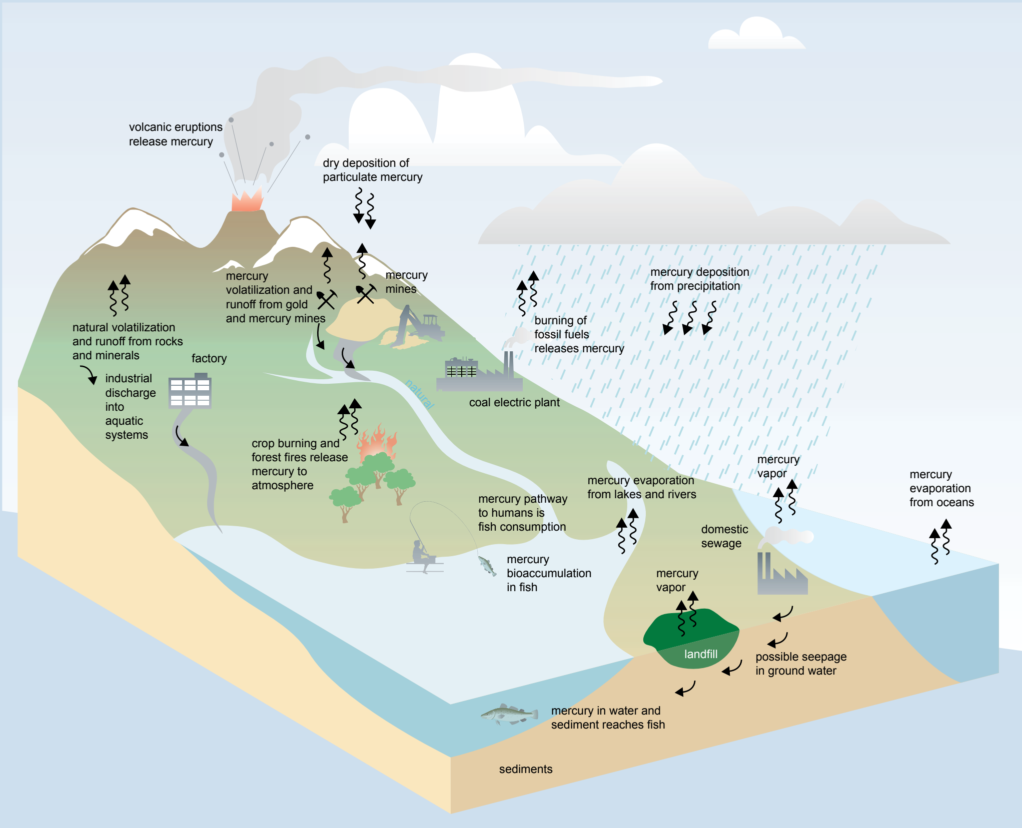
Mercury releases in the Amazon

In 1975 a gold rush started in the Amazon region and in the early 1980s a large increase in gold mining responded to a rise in global gold prices (Sing and others 2003). At the artisanal industry scale, the most common way to extract gold from ore is the mercury amalgamation method. The amalgamation method uses metallic mercury to bind with the gold particles within the finely ground ore. Then the unwanted ore components are separated out. To separate the gold from the amalgam, the material is heated so the mercury will evaporate (Da Costa and others 2008). Small scale gold-mining activities in the Amazon basin that use this method discharge significant amounts of mercury into the environment: Between 5 to 30 per cent is released into waterways and approximately 55 per cent vaporizes into the atmosphere (Sing and others 2003). Formal large-scale gold mining companies no longer use this method because of the health and environmental damages resulting from the mercury processing (Da Costa and others 2008).

The total amount of mercury discharged into the surrounding ecosystems can only be estimated because mercury use in Amazon basin gold mining activities is neither monitored nor regulated. Studies conducted in 1988 estimated that 1.32 kilograms of mercury are lost to the atmosphere for every kilogram of gold produced in the Amazon region (Pfeiffer and Lacerda 1988). Other estimates suggest that artisanal mining activities use three kilograms of mercury for every kilogram of gold, but that 60 per cent of the mercury is then recovered, for total mercury emissions that equal 1.2 kilograms of mercury for every kilogram of gold (Lacerda 2003). Between 1975 and 2002, gold exploration in the Brazilian Amazonia produced about 2 000 tonnes of gold, leaving behind nearly 3 000 tonnes of mercury in the region's environment (Lacerda 2003). Most of the evaporated mercury condenses and falls in rain within 40 kilometres from the source (Bastos and others 2006).

At the same time, mercury concentrations in many Amazonian soils are naturally high (Bastos and others 2006, Kehrig and others 2008). In forest soils, mercury concentrations are 1.5 to 3.0 times higher than in pasture soils. This is attributed to agricultural practices on deforested land that mobilize the mercury in forest soils and biomass through erosion, releasing it to the atmosphere and water bodies (Lacerda and others 2004, Almeida and others 2005, Marques and others 2007, Kehrig and others 2008). Deforestation rates in the Amazon region nearly doubled from 2000 to 2005 due to the opening of the Madeira River waterway, the planning of hydroelectric dams in the Brazilian and Bolivian Amazon, and the soya race that has already resulted in large-scale deforestation in Rondonia and Amazon states (Bastos 2006).

Figure 2: Mercury life cycle



Mercury is transported through soils, water, and atmosphere. While naturals sources do occur, human activities accumulate and concentrate mercury compounds and then disperse them into ecosystems as waste. *Source: UNEP/GRID/Arendal*

Gold extraction, land use changes, and hydroelectric dam projects in the Amazon all contribute to increasing mercury contamination in aquatic ecosystems, in fish populations, and in the human communities that depend on those fish (Kehrig and others 2008, Marques and others 2007). Elevated mercury concentrations in Amazonian fish have been a known threat to wildlife and human health for over 15 years (Kehrig and others 2008). Since the average consumption of fish in the Amazon can reach a quarter kilogram every day, even relatively low mercury concentrations in the fish can result in high exposure and bioaccumulation in the human population (Boischio and Henshel 2000, Bastos and others 2006).

The lack of regulation and monitoring systems for gold mining and land conversion practices in the Amazon region poses a serious threat to Amazonian people and ecosystems. Mercury contamination of soils, sediments, and aquatic biological resources needs to be better assessed and regulated, considering a wide and systematic approach that accounts for all the factors that influence the dynamics of mercury in the Amazonian environment (Bastos and others 200, Barbieri and Gardon 2007, Kehrig and others 2008). Local practices need to be modified towards more sustainable practices to reduce long-term soil nutrient depletion and allow for lower deforestation rates—and ultimately, less natural mercury mobilized to contaminate soils and water bodies (Farella and others 2007). Gold-mining activities in Bolivia and Peru, and subsequent land conversion, are currently expanding into protected areas and indigenous territories that safeguard rich biodiversity hot spots and culturally important resources (**Box 4**) (Earthworks 2006, Conservation International 2002).

Source: Jose Luis Conceicao

Artisanal gold mining operation along the Rio Juma in the municipality of Novo Aripuana, Amazonas, Brazil

Box 4: Mining in a Conservation Corridor

The 30 million hectare Vilcabamba-Amboro Conservation Corridor covers both Bolivian and Peruvian territories. In 2002, a comprehensive assessment of mining concessions located within the protected area showed significant repercussions throughout the corridor: These include water pollution in the rivers; emission of gases, particulates, and noise; biodiversity loss due to habitat fragmentation; and soil degradation. In Bolivia, mining concessions are licensed to operate in protected areas if they demonstrate, through an environmental impact assessment, that their operations would not interfere with the protection objectives of the areas. Despite this legislation, the comprehensive assessment's analysis revealed that 76 per cent of the mining operations were lacking an environmental license, while 24 per cent had a license or were in the process of obtaining one. However, licence or not, the majority of the mining operations did not apply any preventive or mitigation measure to minimize impacts to the environment (Conservation International 2002).

THE FACE OF NANOTECHNOLOGY

Nanotechnology refers to the world of the very, very small. Definitions usually include the manipulation or exploitation of material having at least one dimension measuring less than 100 nanometres. A nanometre is one-billionth of a metre. For illustration, a comma spans about half a million nanometres while a human hair is about 80 000 metres wide (Hester and Harrison 2007) (**Figure 3**).Conceptually nanotechnology has been around for at least twenty years, but the first wave of broad applications is only now breaking through. Today, nanoparticles can be found in cosmetics, sunscreens, and container coatings that deter bacteria and moulds. They make bouncier tennis balls and scratch resistant paints (Jones 2008). In 2006, there were over 600 manufactured goods using nanotechnology on the global market with a value of US$50 billion. At least 20 per cent of those goods were food or food packaging produced using nanotechnology (Bergeson 2008 Osborn 2008). Market analysts foresee a world market for nanotechnologies worth between US$1 050 and 2 800 billion by 2015 and estimate that 10 million jobs related to nanotechnology will be created by 2014 (Bergeson 2008, Friends of the Earth 2008).

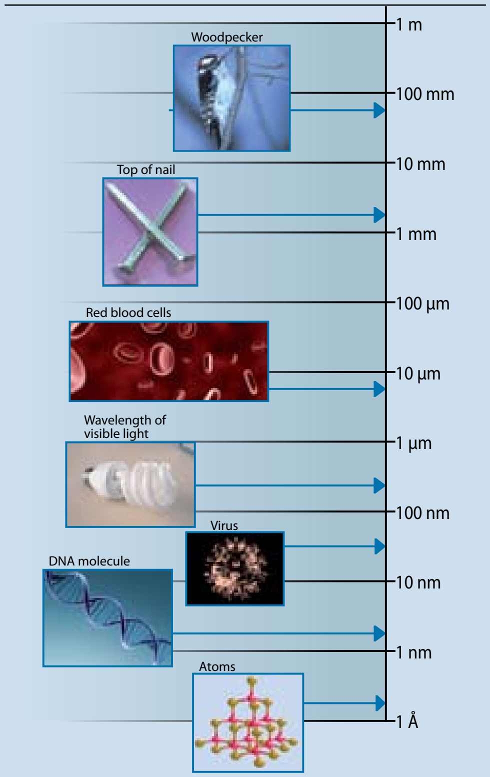
Facing the risks

The potential benefits of nanotechnology are immense, as are the dangers. Nanomaterials are developed for their radically new properties that lead to completely new and sometimes unanticipated results. While there is a broad agreement that nanotechnology holds great promise in materials, medicine, and energy applications, there are also profound uncertainties about the biological, environmental, and safety implications (Bergerson 2008, Heller and Peterson 2008).

Only limited toxicological data are available, but to date no unique or distinctive toxicitiy of nanomaterials have been identified (Stern and McNeil 2008).

The diverse properties and behaviours of nanoparticles have made it difficult to provide a generic assessment of their potential effects on health and the environment (Maynard 2006). However, the same properties that give nanoparticles such commercial promise, including small size, very high surface area to mass ratio, and high chemical reactivity, may also result in greater toxicity than the parent material (Oberdörster and others 2005). Nanomaterials may also be more bioavailable than larger particles, resulting in greater uptake into individual cells, tissues, and organs. Potential routes of nanoparticle exposure include inhalation, swallowing, and absorption through the skin (Stern and McNeil 2008). Studies with human tissue and cell cultures in the laboratory have shown some worrisome results: formation of protein aggregates within nuclei that can inhibit cell replication and transcription, toxicity in the fibroblasts that facilitate wound healing, and DNA damage (Chen and von Mikecz 2005, Dechsakulthorn and others 2007, Karlsson and others 2008). Animal experiments have demonstrated gastrointestinal uptake of nanoparticles causing toxicological effects on kidneys, livers, and spleens (Chen and others 2006, Wang and others 2007).

Figure 3: A guide to nanoscales



Nanoscales exist below the size of visible lightwaves and the largest viruses. *Source: UNEP/ Màrton Bàlint*

One area that particularly worries scientists is the brain, since nanoparticles are small enough to trespass the blood-brain barrier—which in principle acts as a filter to keep out toxins—and accumulate in the brain (Jones 2008). The poor understanding of the biological behaviour of nanomaterials makes it difficult to predict the associated toxicity risks, so some recommend that each new nanomaterial should be subjected to customized health and safety assessments prior to commercial use (Friends of the Earth 2008).

The ecological risks associated with nanomaterials remain as poorly understood as their human toxicology. Titanium dioxide—used in nano form for surface coatings, sunscreens, and cosmetics—has caused organ pathologies and respiratory distress in rainbow trout (Federici and others 2007). While studies indicate that cellular absorption of titanium dioxide is very limited through healthy skin, laboratory studies have demonstrated that when the particles are released in aquatic environments they can harm indicator species including algae and water fleas (Schulz and others 2002, Hund-Rinke and Simon 2006). Another preliminary study found that nanoscale zinc is more toxic to green algae and water fleas than naturally occuring particles and that negative effects can build over time (Luo 2007).

Managing nanotechnology

While nanotechnology is developing rapidly and its use in daily products and life is increasing, environment, health, and safety (EHS) assessments have not kept pace (**Box 5**). Difficulties abound in developing a model of risk for even one type of nanoparticle in different settings, let alone for this whole new class of materials. Studying the EHS implications of nanomaterials will require substantial funding, but that need is not yet being met. A 2006 analysis indicated that the US's National Nanotechnology Initiative allocated about US$13 million in critically important EHS research—only 1.0 per cent of the total US federal research and development investment in nanotechnology (Rejeski 2008). Based on past experiences with substances such as DDT and lead paint, higher spending now on EHS risk studies would forestall future liability and cleanup costs. Most important, research on EHS effects now would allow development of proactive nanotechnology policies to manage benefits and prevent harm (Heller and Peterson 2008).

Wood coated with a nanoparticle surface becomes extremely water repellant or 'superhydrophobic'. Surfaces treated in this way become self-cleaning and require little maintenance.

Source: BASF Aktiengesellschaft

Box 5: Nano food products and packaging

Nanotechnology will likely have significant consequences in the food industry—from how food is grown, produced, and processed to how it is packaged, transported, and consumed. Already nanoparticles are added to food to improve flow properties, colour, and stability during processing or to increase shelf life. Nanoparticles act as anti-caking agents in granular or powdered processed food and as a whitener and brightener in confectionery sugar, cheeses, and sauces. The current lack of labelling standards for identifying nanomaterials in food makes it impossible to know whether a given product contains nano-ingredients, however.

The European Union's Scientific Committee on Emerging and Newly Identified Health Risks recognized in its 2005 report the many systemic failures of existing regulatory frameworks to manage the risks associated with nanotoxicity. Nevertheless, recent reviews of regulatory measures in the United Kingdom, the United States, Australia, and Japan found that none of these countries require manufacturers to conduct nanotechnology-related safety assessments of nano food products and packaging before they are delivered to the market.

Sources: Friends of the Earth 2008a, SCENIHR 2005, Bowman and Hodge 2007

CHALLENGES TO A NUCLEAR POWER REVIVAL

Since the mid 1970s, France has pursued a strong policy of nuclear power use and by 2004 it had the second largest nuclear generating capacity after the United States (WEC 2004). France derives over 75 per cent of its electricity from its 59 nuclear plants (WNA 2008). Nuclear power development in France is often cited as evidence that nuclear power can be used safely and efficiently. However, recent industry problems have called into question the desirability of a global nuclear power revival.

Safety concerns at a critical moment

The most recent series of worrying incidents began on 7 July 2008, when uranium leaked from a waste management plant near the southeastern French town of Tricastin, 40 kilometres north of Avignon. Initial reports from Socatri, a subsidiary of the government-controlled nuclear company Areva, estimated that 30 thousand litres of solution containing 12 grams per litre of un-enriched uranium leaked when a storage tank overflowed (BBC 2008). Socrati later revised that to only six thousand litres, but the spill still exceeded the permitted annual quantity of radioactive effluent from the site by 100 times (Kay 2008). The liquid soaked into the ground and then passed into the Gaffiere and the Lauzon, two nearby rivers that flow into the Rhone (Ward 2008). Although the Nuclear Safety Agency estimated that uranium concentrations in one of the contaminated rivers were about one thousand times World Health Organisation guidelines, the experts stated that the risk to the public was low (Ward 2008, Kay 2008). Nonetheless, local authorities enforced an emergency plan in the three villages surrounding the plant. A ban was placed on drinking water from private wells, swimming in the rivers, and irrigating fields. Eating fish caught in the contaminated rivers was also outlawed.

The nuclear power complex at Tricastin in southeastern France *Source: Stefan Küh*

Then, on 18 July, Areva detected an enriched uranium leak at a nuclear fuel processing site in Romans-sur-Isère, about 100 kilometres north of Tricastin (Mabe 2008). The leak came from a buried pipe transporting liquid uranium from the nuclear fuel fabrication facility to the treatment station. Discovered during a maintenance operation, the leak could have been active for years.

Also on 18 July, the utility company Electricité de France (EDF) reported that 15 employees had been exposed to low levels of radiation at a nuclear plant in the Rhône Valley south of Lyon (Mabe 2008). Two weeks later, 100 employees at an EDF nuclear plant in Tricastin were also exposed to low-level radiation. Exposure sensors detected a rise in the radiation level while maintenance work was being carried out at a reactor that had been shut since a leak forced its temporary closure only a few days before (BBC 2008). The incident was rated at level zero on the seven-point scale used to gauge the severity of nuclear accidents and EDF alleged none of its employees faced serious health risks (Mabe 2008).

This is not the first time radioactive leaks have posed a risk to populations in France. In May 2006, leaks at the dumpsite Centre Stockage l'Aube in eastern France resulted in low levels of radioactive contamination of groundwater less than 10 kilometres from the famous Champagne vineyards. That dumpsite, which contains waste mostly from EDF and Areva, showed fissures in the storage cells. The same month in 2006, another dumpsite run by France's National Radioactive Waste Management Agency in Normandy had leakage problems. The levels of radioactivity in underground water used by farmers were estimated at up to ninety times European safety limits (Greenpeace 2006).

Far from close

Nuclear energy has recently been heralded as a potential champion in the fight against climate change and new nuclear developments are being planned around the world. But safety issues related to nuclear production and radioactive waste management, as well as to terrorism and accidents, constitute a a significant downside. Risk is closely related to issues of trust, competence, and accountability (Bickerstaff and others 2008).

Box 6: Agricultural chemicals

Synthetic fertilizers are relatively inexpensive, simple to use, easily absorbed by plants, and they have helped boost global crop outputs dramatically over the past half century. Similarly, synthetic pesticides are relatively inexpensive and—initially, at least—effective means of killing insect pests, plant diseases, and weeds. Of course, the pesticides work because they are poisonous, so it is no surprise that their manufacture and use, especially in excess with fertilizers, of these agrochemicals can damage ecosystem and human health. However, the consequences of their use to ecosystems and humans are often ignored because those consequences are not directly or immediately felt by end users.

The massive influx of nitrogen into many aquatic ecosystems, driven largely by the intensified use and subsequent waste of synthetic fertilizer over the last several decades, has created an increasingly recognized challenge for farmers, scientists, governments, and investors. Despite the observed increases in short-term crop yields from heavy chemical use, we have routinely failed to account for the resulting long-term damage to agricultural lands, water bodies, global ecosystems, and human health. We also do not consider the massive energy inputs and carbon footprint of agrochemicals.

Synthetic fertilizers use now totals approximately 210 million tonnes per year, creating serious distortions in Earth's natural nitrogen cycle. On land, nitrogen oversaturation has disrupted soil chemistry and created a depletion of other critical nutrients including calcium, magnesium, and potassium. Ironically, the addition of one nutrient out of balance with others can result in an overall decline in soil fertility, leading to diminished productivity of both cultivated and natural landscapes.

In aquatic ecosystems, nitrogen overload stimulates excessive algae growth. When these plants die, they consume the water's available dissolved oxygen, essentially suffocating other organisms and creating massive zones characterized by low concentrations of oxygen and hardly any marine life. The largest dead zone is the Baltic Sea, with a northern section of the Gulf of Mexico off the Mississippi Delta the second largest of the more than 150 major dead zones identified throughout the world's oceans. The effects of increased proportions of CO_2 in the oceans as they absorb excess concentrations from the atmosphere may exacerbate this growing threat from ocean dead zones.

Many countries continue to increase subsidies to their nitrogen-based synthetic fertilizer industries despite the lack of obvious justification. In India, the world's second fastest growing economy after China, government subsidy expenditures to the fertilizer industry reached US$23 billion in 2008, representing more than three per cent of India's GDP. While India's consumption of nitrogen fertilizer grows at an exponential rate, the country's reliance on imported fossil fuels—a key ingredient in the production of synthetic fertilizers—has risen in similar measure. Consequently, petroleum products and energy needs in India have become yet another unduly subsidized industry.

Petroleum products are the raw material for many synthetic pesticides, as well as the fuel for their manufacture. Over the past five decades, 'pre-emptive' applications of pesticides have produced resistance in targeted pest species and their excessive use has accelerated the rate of nonpoint source pollution. Approximately 3 million people worldwide suffer from severe pesticide poisoning, which can lead to cancer, birth defects, and damage to the nervous system. Exposure to these contaminants is directly attributable to pesticide runoff into drinking water sources and to chemical residues in foods.

Curbing the world's addiction to synthetic fertilizers and pesticides will be a formidable challenge on several fronts. From an ecological perspective, management options must consider transitions to an eco-agriculture approach and more stringent protocols for efficient use of agrochemicals (See Ecosystem Management, Chapter One). These challenges are further complicated by institutional and governance failures, which mask these agrochemicals' high cost to human and ecosystem health. Effective solutions will require strict, prudent regulations on counterproductive investments and swift measures to dismantle perverse subsidy policies, particularly in the context of high-growth developing country economies.

Sources: Astill 2008, Kapoora and others 2008, Lie 2007, Science News 2008, WHO 2007, Wu and others 1999, WWI 2008

Source: Associated Press/ Rajesh Nirgude

The recent leakages in France, far from showing that safety issues have become less of a problem in the nuclear industry with experience and over time, undermine the public's trust in the nuclear power industry. The High Commission for Transparency and Information on Nuclear Safety, for instance, concluded that the handling of the incident in Tricastin revealed "...a chain of malfunctions and human neglect…" on the part of Socatri (Laurent 2008). Such incidents also suggest that the working conditions at power facilities are examined for safety and accountability. Public trust has been undermined by the findings that indicate faults in the construction process of new facilities. In March this year, France's nuclear safety authority identified shortcomings during an inspection of the new Third Generation European Pressurised Reactor that is being built in Flamanville, Manche. The agency uncovered several chronic faults in construction and ordered construction work to be halted (AFP 2008). The future of the nuclear industry now seems to depend on the balance between people's fears of nuclear contamination and the growing need for carbon neutral energy. Where that balance will settle is not yet known.

CONCLUSION

Rapidly increased industrialization, extensively globalized food supply chains, and pervasive extractive processes combine to introduce many and varied harmful substances into the environment (**Box 6**). It is the acute events—oil and chemical spills, episodes of food contamination, and the recall of toxic toys—that gain most of our attention. But the cumulative effects of pervasive, low-level contamination and the slow accumulation of many poisons and biologically active compounds could ultimately have a much deeper negative effect on both human and ecosystem health, especially in terms of resilience aginst additional threats. It is certainly important to control and respond to acute episodes of harmful contamination. But it is just as crucial to anticipate, regulate, and control the slow steady poisoning. Prevention of the slow poisoning, as well as the acute episodes, can be attained through rational means: Minimizing production of hazardous substances, controlling their distribution and ultimate disposal, and substituting with more benign substances and practices (See Resource Efficiency, Chapter Five).

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Climate Change

The changing climate is pushing many Earth systems towards critical thresholds that will alter regional and global environmental balances and threaten stability at multiple scales. Alarmingly, we may have already passed tipping points that are irreversible within the time span of our current civilization.

A storm front passes over Bribie Island, Queensland, Australia. *Source: Barbara Burkhardt*

INTRODUCTION

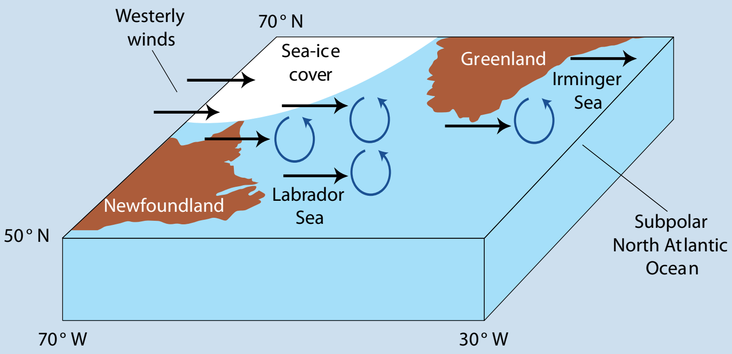
Climate change has long since ceased to be a scientific curiosity, and is no longer just one of many environmental and regulatory concerns. It is the major, overriding environmental issue of our time, and the single greatest challenge facing decisionmakers at many levels (Ban 2008). It is a growing crisis with economic, health and safety, food production, security, and other dimensions. Shifting weather patterns threaten food production through increased unreliability of precipitation, rising sea levels contaminate coastal freshwater reserves and increase the risk of catastrophic flooding, and a warming atmosphere aids the pole-ward spread of pests and diseases once limited to the tropics.

The news to date is bad and getting worse. Ice-loss from glaciers and ice sheets has continued, leading to the second straight year with an ice-free passage through Canada's Arctic islands and accelerating rates of ice-loss from ice sheets in Greenland and Antarctica. Combined with thermal expansion—warm water occupies more volume than cold—the melting of glaciers and ice sheets from the equator to the poles is contributing to rates and an ultimate extent of sea-level rise that could far outstrip those anticipated in the most recent global scientific assessment (IPCC 2007).

There is alarming evidence that important tipping points, leading to irreversible changes in major Earth systems and ecosystems, may already have been reached or passed. Ecosystems as diverse as the Amazon rainforest and the Arctic tundra may be approaching thresholds of dramatic change through warming and drying. Mountain glaciers are in alarming retreat and the downstream effects of reduced water supply in the driest months will have repercussions that transcend generations. Climate feedback systems and environmental cumulative effects are building across Earth systems, demonstrating behaviours we cannot anticipate.

The potential for runaway greenhouse warming is real and has never been more clear. The most dangerous climate changes may still be avoided if we transform our hydrocarbon-based energy systems to renewable energy systems and if we initiate rational and adequately-financed adaptation

Figure 1: Deep convection in the subpolar ocean



An extensive sea ice cover insulated the strong, cold westerly winds from the warmer ocean until they reached the central basin of the Labrador Sea in winter 2007–08. There, these unusually cold winds rapidly cooled the surface water, leading to mixing of the water column to depths that had not been reached in the last 15 years.

Source: Lozier 2009

programmes to forestall disasters and migrations at unprecedented scales. The tools are available but they must be applied immediately and aggressively.

DETECTION, OBSERVATION, ATTRIBUTION

The Intergovernmental Panel on Climate Change publishes its comprehensive assessment reports on climate change science every five or six years (IPCC 2007). But scarcely a week passes without new research appearing in peer-reviewed literature and news reports that adds to the story. For instance, the IPCC was unable to formally attribute to human influence the climate changes observed in Polar regions because of the regions' natural variability and the insufficient coverage. In 2008 researchers using place-specific gridded data sets and simulations from four different climate models found that changes in Arctic and Antarctic temperatures are not consistent with natural variability and are directly attributable to human influence (Gillett and others 2008). They conclude that human activities have already caused significant warming in both Polar regions with likely consequences for indigenous communities, biological systems, ice-sheet mass balance, and global sea levels.

Arctic ice loss

Evidence grew in 2008 that the areal extent of Arctic sea ice is declining more rapidly than previously expected in response to higher air and ocean temperatures. The USA's National Snow and Ice Data Center reported that the year's minimum sea-ice cover occurred on 12 September, when it extended over 4.52 million square kilometres of the Arctic Ocean (NSIDC 2008). This is the second lowest figure for the area of ice surviving the summer thaw since satellite monitoring began in 1979. While 2008 saw 10 per cent more ice cover than in 2007, the lowest figure on record, it was still more than 30 per cent below the average for the past three decades. Taken together, the two summers have no parallel.

For the second year in a row, there was an ice-free channel in the Northwest Passage through the islands of northern Canada. But this year also saw the opening of the Northern Sea Route along the Arctic Siberian coast. The two passages have probably not been open simultaneously since before the last ice age, some 100 000 years ago (NERSC 2008). Theoretically, in 2008 the Arctic ice cap could have been circumnavigated.

A possible unanticipated consequence of sea-ice loss in the Arctic is the apparent return of strong ocean convection in gyres of the sub-polar North Atlantic. This is where surface water sinks to depth as a distinct mass, driving circulation patterns in the Atlantic Ocean (**Figure 1**). The strong mixing documented in the Irminger Sea to the east of Greenland's southern tip and in the Labrador Sea to the southwest is attributed to cold air arriving from Canada that initiated a heat transfer from the ocean to the air, with a sinking mass of cold water as the consequence. In recent winters the cold air from the west has been warmed by higher temperatures of water flowing south through the Davis Strait. However, in the winter of 2007 to 2008, the surface water flowing south was sea-ice melt, colder and fresher than usual, so with winter it froze quickly over Davis Strait. The cold air from the west stayed chilly until it reached the relatively warm water off Greenland, where the subsequent energy exchange triggered the gyres' renewal (Vage and others 2008).

The overall declining trend of sea-ice in the Arctic has now lasted at least three decades. The loss is greatest in summer, but is also evident in winter ice packs—in the thickness of the ice. With less ice surviving the summer, the amount of thick ice that has built up over several years is decreasing. This leaves the whole sea-ice system more vulnerable to future warming and brings closer the prospect of an ice-free Arctic (Kay and others 2008, NSIDC 2008).

In the Arctic the atmosphere is warming twice as fast as in most other regions of the world. In the far north warming is amplified by a decrease in the reflectivity of the Earth's surface as ice and snow melt. Ice and snow reflect solar energy back into space, while darker surfaces like bare tundra and open ocean absorb more solar energy and then radiate it to heat the air above. So as the reflective surfaces disappear, the darker surfaces release heat into the immediate environment that results in more melt.

However, there may be other factors contibuting to accelerated warming in the Arctic Ocean. In 2007, there was an especially large loss of ice in the Beaufort Sea, north of Canada and Alaska. This was due to incursions of warm water from the south that melted the ice from beneath (Perovich and others 2008). Also local atmospheric conditions amplified ice loss. 2007's clear sunny skies increased melting in the 24-hour sun, and strong winds during the early part of the summer drove ice into seasonal packs, creating enlarged patches of open ocean (Kay and others 2008). In 2008, winds dispersed the ice that resulted in a larger ice area, but of thinner ice (NSIDC 2008).

Evidence for the role of more systematic natural variability in the Arctic also grew during 2008. New research showed that the region's normal variability, dominated by the Arctic Oscillation and the North Atlantic Oscillation, presents warm and cold phases that alternate—with each phase persisting through several years (Keenlyside and others 2008, Semenov 2008). The phases are triggered by changing patterns of ocean currents that allow more or less warm water into the Arctic which alters air movements (Graversen and others 2008). In recent years, the region has been in a warm phase, accentuating the effects of global warming. While phase changes in the Arctic Oscillation and the North Atlantic Oscillation may mask incremental climate change trends, some scientists are asking how climate change affects these oscillations and others, such as the El Niño Southern Oscillation (Goodkin and others 2008, Goelzer and others 2008).

Greenland and Antarctica ice sheet loss

The largest mass of ice in the Arctic covers the island of Greenland. In places, the ice sheet is three kilometres thick. If it melts, it will raise sea levels by an estimated six metres. Until recently, glaciologists presumed that the ice would thaw slowly over millennia, as warming at the surface of the ice sheet permeates downward and gradually melts the ice. That thinking is reflected in the IPCC fourth assessment report (IPCC 2007).

But the ice sheet is currently losing mass much faster than would be expected if melting alone was to blame. Current losses are more than 100 cubic kilometres a year. New findings in 2008 revealed that the flow into the ocean of the Jakobshavn Isbrae glacier in western Greenland, one of the most important routes for ice loss, has doubled since 1997 (Holland and others 2008).

It appears that physical processes are destroying the integrity of parts of the Greenland ice sheet. The precise mechanisms remain disputed but two possibilities are being discussed. One is that warm ocean waters are destabilising the mouths of major glaciers like the Jakobshavn Isbrae, speeding their flow. A second arises from the discovery that meltwater forming at the surface of the sheet is draining down crevasses and moulins to the bottom of the ice sheet. This meltwater lubricates the previously frozen contact between the ice and underlying bedrock, again causing glacier flow to accelerate. In 2008, researchers reported on one of the thousands of melt-water lakes that now form on Greenland each summer (Joughin and others 2008, Das and others 2008). The four-kilometre-wide expanse of water that formed in 2006 completely drained into the icy depths in 90 minutes, at a flow rate greater than Niagara Falls.

Scientists walk along the edge of a large canyon carved out by over a decade of meltwater flow across the surface of the Greenland ice sheet.

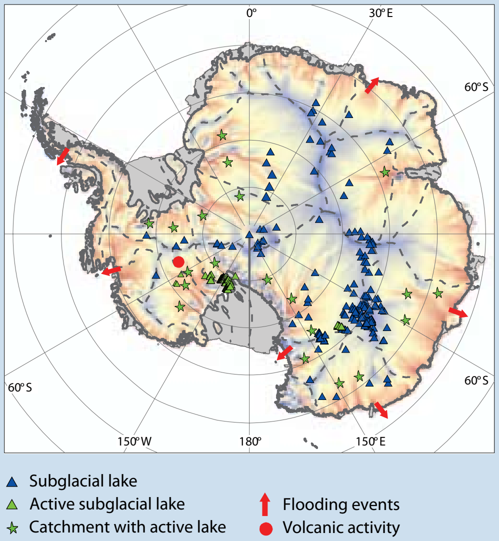
Source: Sarah Das/ Woods Hole Oceanographic Institution

But the significance of this process for ice loss remains unclear. There has long been discussion about the extent and the effects of subglacial water drainage and how those influences vary with the size and the temperature of the ice mass (Bell 2008, O'Cofaigh and Stokes 2008). Some researchers argued that the subglacial rivers formed by moulin drainage in Greenland are ephemeral, that the water swiftly disperses and the flowing ice grinds to a halt against the bedrock. According to this argument, such events may only be responsible for 15 per cent of the annual iceberg formation from Greenland (Van der Waal and others 2008). But the evidence is based on only a handful of sites. And even if Greenland's subglacial water proves less important than some believe, this leaves open the question of why the great ice sheet is losing mass so rapidly.

Whatever the processes involved, it is now clear that Greenland can lose ice at rates much faster than previously supposed and has done so frequently in the past. A new analysis of historical data on the extent of the Greenland ice sheet shows that total meltdown is quite possible as a result of warming on the scale that is being forecast for the next few decades (Charbit and others 2008).

Antarctica is losing ice, too, particularly from the West Antarctic ice sheet. This sheet contains enough ice to raise sea levels by about five metres. It sits like a wrecked ship with a frozen weld to submerged mountains and has always been considered potentially unstable—particularly because warmer ocean waters could melt the frozen link between ice and rock. Researchers estimated in 2008 that loss of ice from the West Antarctic ice sheet increased by 60 per cent in the decade to 2006 (Rignot and others 2008). Ice loss from the Antarctic Peninsula, which extends from West Antarctica towards South America, increased by 140 per cent.

Box 1: Subglacial drainage in Antarctica



The International Polar Year, which started in March 2007 and will draw to a close in March of 2009, is a scientific programme that focuses on changing Arctic and Antarctic conditions. Some of the most exciting work studies the dynamics of ice sheet water drainage. New data showing the existence of large scale water drainage systems beneath the polar ice sheets have renewed concern about ice sheet stability.

Beneath the Antarctic ice sheets over 150 subglacial lakes evolve, including Lake Vostok, a basin the size of Lake Ontario. High-resolution imaging of the ice sheet surface has allowed scientists to monitor the movement of water through previously unrecognized interconnected hydrologic systems that include large lakes and rivers. While the extent and degree of interconnection are unknown, the potential drainage system in Antarctica is larger than that of the Mississippi River basin.

In the coming decades, significant changes in the polar regions will increase the contribution of ice sheets to global sea level rise. Under the ice streams and outlet glaciers that deliver ice to the oceans, water and deformable wet sediments lubricate the base, facilitating rapid ice flow. In Antarctica, subglacial lakes have the capacity to modify velocities in ice streams and outlet glaciers and to provide sources of lubrication for new ice-flow tributaries.

Subglacial fluvial systems of Greenland and Antarctica provide a valuable modern analogue for former ice sheet dynamics. Prehistoric glacial lake outbursts sculpted the topography of vast regions in North America, Europe, and Asia. These floods also delivered enormous quantities of sediment and freshwater to deltas and to the oceans—possibly contributing to temporary disturbances in oceanic thermohaline circulation.

Sources: Allison and others 2007, Bell 2008, Shaw 2002, Toggweiler and Russell 2008

The processes affecting the peninsula involve accelerating glacier flows caused by both warmer air and higher ocean temperatures (Rignot and others 2008) (**Box 1**).

An additional factor in Antarctica that could undermine the integrity of the great ice sheets is the recent disappearance of a number of ice shelves. These shelves float on the ocean but are attached to the ice sheets indirectly. The shelves often act like corks in a bottle, holding back glaciers on land whose loss will raise sea levels.

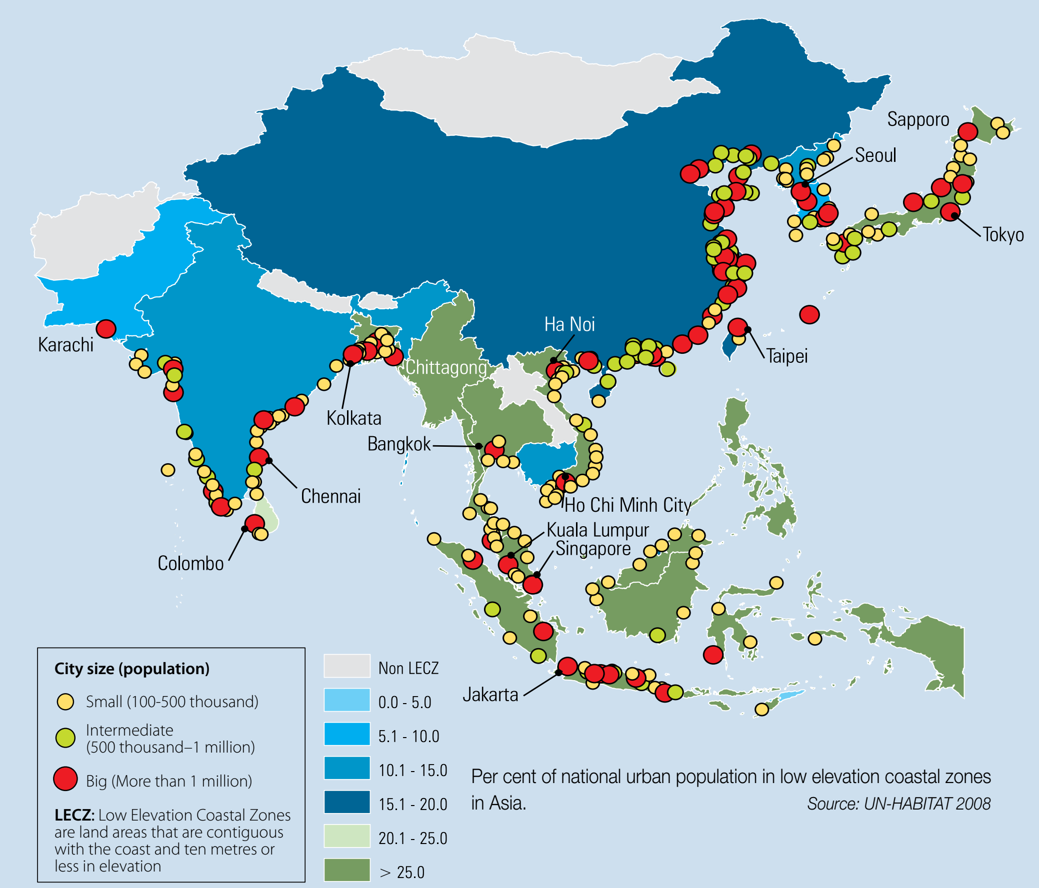
A large part of the Wilkins Ice Shelf collapsed in February 2008 (Braun and others 2008). At that time the British Antarctic Survey said the shelf is in imminent danger of collapse (BAS 2008). As of December 2008, satellite radar imagery shows more cracks within the Wilkins Ice Shelf itself, especially at the head of the ice bridge stabilizing the shelf edge. The ice bridge has diminished in width from 6.0 kilometres to 2.7 kilometres since the February collapse (ESA 2008).

Sea level rise

The last IPCC assessment forecast that global sea levels would rise by between 18 and 59 centimetres in the coming century—just from the thermal expansion of warmer oceans and the melting of mountain glaciers (IPCC 2007). But since the report was completed, many researchers involved in that assessment have predicted that a much larger rise is possible, indeed probable. The new prediction originates in part from reassessments of the potential for physical break-up of the ice sheets of Greenland and Antarctica.

For instance, a study presented at a conference of the European Geosciences Union at Vienna in

Figure 2: Asian cities at risk from sea level rise



Per cent of national urban population in low elevation coastal zones in Asia.

Source: UN-HABITAT 2008

April suggested that a rise of between 0.8 and 1.5 metres was most likely (Schiermeier 2008). Another study on the dynamics of ice-sheet loss argued that sea levels could rise by as much as two metres in the coming century as a result of outflows of ice from Greenland alone (Pfeffer and others 2008).

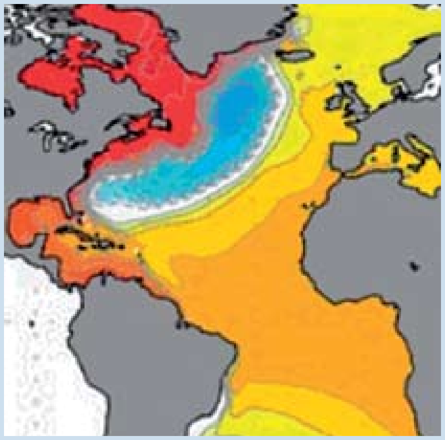
Such a rise would be far beyond anything seen in the recent past. Sea levels rose 2.0 centimetres in the 18th century, 6.0 centimetres in the 19th century, 19.0 centimetres in the 20th century, and what is projected as an equivalent to 30.0 centimetres for the 21st century based on rates observed in its first few years (Jevrejeva and others 2008). These predictions are not unprecedented: The magnitude of scale for sea level rise now being forecast would be in line with what happened at the end of the last ice age. Then, as ice sheets disintegrated, sea levels rose by between 70.0 and 130 centimetres per century (Carlson and others 2008).

A one-metre rise in sea levels worldwide would displace around 100 million people in Asia, mostly eastern China, Bangladesh, and Vietnam; 14 million in Europe; and 8 million each in Africa and South America (**Figure 2**). However, a new study of how a sudden release of meltwater, or its ice equivalent, from ice sheets into the oceans would influence sea levels shows that, in the first years, the rising waters would not flood with equal speed everywhere. It would take several decades for a pulse of rising sea levels to spread around the world.

From the Greenland ice sheet, most of the melted water would initially stay in the Atlantic (**Figure 3**). Fifty years after release, sea level rise would be thirty times greater in parts of the North Atlantic, including the Gulf of Mexico, than in the Pacific. Similarly, the study found that water from a collapsed Antarctic ice sheet would swamp coastlines in the southern hemisphere, while being barely measurable in the northern hemisphere for at least 50 years (Stammer 2008).

But whatever the detailed modelling may reveal, research in 2008 indicates that sea level rise—from thermal expansion, mountain glacier retreat, and ice sheet melt—is likely to be much greater and to arrive much sooner than believed even two years ago. No matter how quickly climate change is mitigated, sea level will rise. So, efforts to adapt to rising seas are more urgent than ever.

Figure 3: Global ocean response to Greenland ice sheet melt



The map shows the response of the ocean over ten years to localized freshwater forcing associated with Greenland ice sheet loss with variance measured in millimetres. The spreading and redistribution of the freshwater in the ocean starts wih an initial boundary wave with associated negative sea surface heights depicted in shades of blue and positive sea surface heights shown in shades of red and orange, moving southward from the Labrador Sea toward the equator. It continues to cross the Atlantic toward the eastern side and further poleward.

Source: Stammer (2008)

SINKS, SOURCES, AND FEEDBACKS

Future climate change will depend largely on how fast greenhouse gases accumulate in the atmosphere. That in turn will depend on how much we emit into the atmosphere—and also on how much nature is able to absorb.

Since 2000, anthropogenic carbon dioxide emissions have been increasing four times faster than in the previous decade. Most of the emissions came from burning fossil fuels and manufacturing cement (See Resource Efficiency, Chapter Five). These emissions are now 38 per cent above those in 1992, the year governments attending the Earth Summit pledged to prevent dangerous climate change (Global Carbon Project 2008).

At the same time, natural carbon sinks that absorb some of our emissions are unable to perform this function with their former efficiency. The main carbon sinks are the oceans, frozen tracts in the Arctic, and forest ecosystems—all these sinks are losing their absorption capacity. Analysis of a variety of studies suggests that the uptake of carbon by the oceans fell by 10 million tonnes in 2007. It is not yet clear whether this is part of a longer-term trend (CDIAC 2008).

Carbon in the Arctic

The Arctic is warming faster than any other region of the planet. The Arctic also contains very large stores of carbon in the form of methane that may be released as the planet warms. Large-scale methane releases would provide a major positive feedback to global warming and could turn natural ecosystems from carbon sinks to carbon sources, triggering uncontrollable global warming.

The carbon is contained in soils, including frozen permafrost, and beneath the bed of the Arctic Ocean. Two studies in 2008 revised upwards the amount of soil-carbon believed to be held in permafrost. One study of North America concluded there was 60 per cent more than previously supposed (Ping and others 2008). A second international study doubled previous estimates for the carbon inventory of the entire Arctic permafrost (Schuur and others 2008). These findings suggest there is presently twice as much carbon in the northern permafrost as there is in the atmosphere.

Researchers investigating how Arctic sea-ice loss affects temperatures on land predict that future warming in the western Arctic could be 3.5 times greater than the global average. This accelerated warming would be most pronounced in the autumn season and would lead to further rapid degradation of permafrost in northern peatlands (Lawrence and others 2008).

The Arctic region stores very large amounts of methane in the form of hydrates locked in ice lattices in permafrost or beneath the bed of the Arctic Ocean. During 2008 there has been growing interest in tapping offshore methane in hydrates as a source of energy. But climate scientists are concerned that methane hydrates could escape into the atmosphere either as permafrost melts or as warmer waters destabilize frozen offshore deposits (Bohannon 2008).

In 2008, marine researchers discovered more than 250 plumes of methane bubbling up along the edge of the continental shelf northwest of Svalbard (Connor 2008). The International Siberian Shelf Study reported elevated methane concentrations offshore from the Lena River delta (Semiletov 2008). Meanwhile, researchers showed that, once under way, thawing of east Siberian permafrost—thought to contain 500 billion tonnes of carbon—would be irreversible: 250 billion tonnes could be released in a century (Khvorostyanov and others 2008).

Northern peatland soils that are not frozen also contain large amounts of carbon and are vulnerable to warming. The peat's ability to store carbon is highly dependent on its moisture content. Warming will dry out the peat, lowering water tables. A new modelling study showed that this would lead to massive loss of organic carbon in the soil. In northern Manitoba, Canada, a 4.0° Celsius warming would release 86 per cent of the carbon sequestered in deep peat (Ise and others 2008).

In 2007 and 2008, methane concentrations in the atmosphere began to show an upward trend after nearly a decade of stability. At first researchers assumed that the higher concentrations would be limited to the northern hemisphere and could be attributed to peatland degassing. But similar findings were detected in the southern hemisphere also to reveal a global increase (Rigby and others 2008). Scientists await more data before they can determine whether the reading is a blip, a spike, or the beginning of a worrisome new trend.

Forest sequestration

One reason for fears about the ability of forests to soak up carbon dioxide is that forest cover itself is declining and contributing to emissions—1.5 billion tonnes of carbon a year enter the atmosphere from changes in land use, almost entirely from deforestation in the tropics (Global Carbon Project 2008, Canadell and Raupach 2008). Another reason is that even intact forests may be in trouble: The ability of forests to store carbon may have peaked and rising temperatures may already be decreasing carbon uptake by vegetation in the northern hemisphere. Higher temperatures impose significant stress on trees during the summer season and photosynthesis halts sooner. Once the photosynthesis comes to a halt, carbon is no longer sequestered. And stressed forests are vulnerable to damage from pollution, pests, and disease that can turn them into carbon sources (Piao and others 2008) (See Ecosystem Management, Chapter One).

Amazon on the edge

The Amazon rainforest, which covers 5 million square kilometres and contains a quarter of the world's species, could be on a climatic edge. In 2008, one of the world's leading climate models, run by the Hadley Centre at Britain's Meteorological Office, predicted that the Amazon may be close to a crucial tipping point. Beyond that point, the almost daily rainfall that sustains the jungle will become less dependable, soils will dry out, and much of the forest will die (Harris and others 2008) (**Box 2**).

One reason for the Amazon rainforest's vulnerability is that its rainfall is critically dependent on a pattern of tropical ocean temperatures that is threatened by climate change. When this pattern is disrupted by a warmer eastern Pacific and a tropical North Atlantic that warms faster than the South Atlantic, these new conditions are known to cause drier conditions in Brazil. For instance, a major drought in the Amazon in 2005 was in 2008 diagnosed as being the result of unusually warm temperatures in the North Atlantic (Harris and others 2008). A doubling of carbon dioxide levels in the atmosphere could warm the oceans sufficiently to decrease rainfall in the Amazon basin by 40 per cent. Such a decline in rainfall would reduce the rate of growth of rainforest vegetation by 30 per cent. This would be in addition to the predicted decrease in growth of 23 per cent directly attributable to the higher air temperatures (Harris and others 2008).

According to this scenario, the combination of heating and drying in the Amazon basin would initiate a runaway loss of forest. Forest loss would raise temperatures, doubling local warming this century from an anticipated 3.3 to 8.0° Celsius. Even if temperatures did fall to former levels, the rains would not return because there would be no forest to process them through evapotranspiration. Finally, soils would have dried out when exposed to sunlight and be more susceptible to erosion, accentuating the drought conditions (Betts and others 2008, Malhi and others 2008).

Box 2: A river runs through it

The pivotal role of the Amazon region in global climate was underlined in a study of the impact of outflows of the Amazon River into the Atlantic on the ocean's carbon cycle. The Amazon, the world's largest river, carries about a fifth of all the world's river water. It sends a muddy freshwater flow for thousands of kilometres into the Atlantic, taking rainforest nutrients like nitrogen with it. Microbes contained in the flow feed off the nutrients and fertilize the ocean, increasing plankton growth that results in the oceans absorbing carbon dioxide from the atmosphere.

The findings provide a new perspective on the ability of the overall ocean system to soak up man-made emissions. But they also underline how the ocean carbon sink could be vulnerable to changes on land, such as deforestation and drought. Drought in the Amazon would both damage the rainforest and reduce the river flow, cutting the flow of nutrients and reducing the ocean's ability to capture carbon dioxide from the air.

Source: Subramaniam and others 2008

The Amazon River delivers a plume of sediment to the Atlantic Ocean. *Source: NASA*

Black carbon and other feedbacks

There are other important anthropogenic influences on climate besides greenhouse gases. Evidence is mounting for significant consequences to climate variability from soot, aerosols of black carbon that originate from fires on the landscape. Global emissions of black carbon are rising fast and Chinese emissions may have doubled since 2000. The warming influence of black carbon could be three times greater than estimates from the IPCC's latest report, making it the second most importance climatic agent after carbon dioxide (Ramanathan and Carmichael 2008).

These findings remain controversial—not least because black soot can cool as well as warm. But when black carbon falls onto ice it darkens the surface, absorbing more of the sun's energy which leads to local warming and melting. Soot may be a contributor to the disappearance of glaciers in some regions and could even explain the accelerated rates of melt in the Himalaya-Hindu Kush (Ramanathan and Carmichael 2008) (**Box 3**). But soot released from the increasing number of wild fires in North America and Siberia is also shading the Arctic from direct sunlight, causing cooling (Stone and others 2008).

Another air pollutant with known cooling properties was reassessed in 2008. Sulphate aerosols, often the main component of acid rain, cool the atmosphere by scattering sunlight back into space. The new studies suggest that efforts to curb acid rain by cutting sulphate emissions, particularly since 1980, have contributed substantially to the very rapid warming over Europe and the North Atlantic since 1980 (Ruckstuhl and others 2008, Van Oldenborgh and others 2008).

In another unexpected finding, increasing fallout of acid sulphates in China has been suppressing natural methane production from bacteria in rice paddies, slightly reducing global warming (Gauci and others 2008). These feedbacks in no way undermine the argument that man-made pollution is warming the planet, but they remain significant uncertainties. Most importantly, they demonstrate the complexities inherent in Earth systems, as well as the intricate balances of cumulative effects under varying circumstances and at multiple scales.

IMPACTS AND VULNERABILITIES

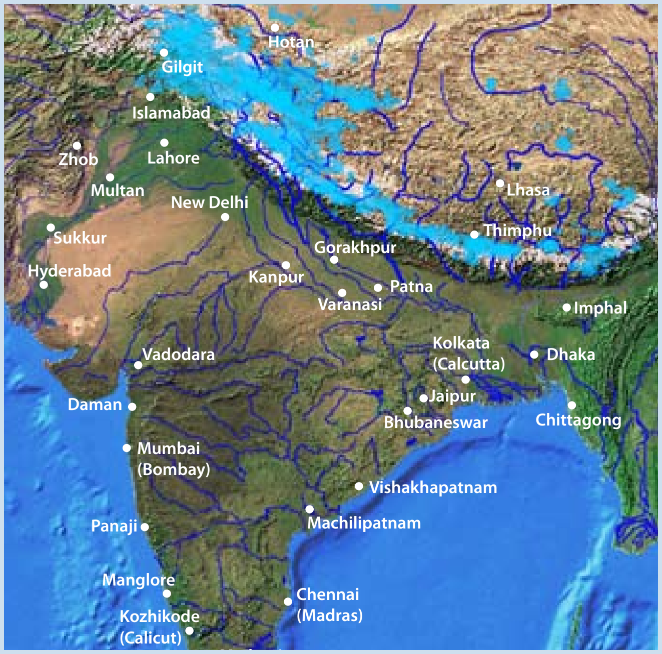
New research demonstrated that winds in the strongest cyclones have become more intense in all oceans (Elsner and others 2008). The increase has been greatest in relatively cool ocean basins that have seen the largest increases in sea temperatures, notably the North Atlantic, but also the eastern North Pacific and southern Indian oceans.

Tropical cyclones only form when ocean temperatures exceed about 26° Celsius. Therefore it is likely that warmer oceans will generate more tropical cyclones. But things may not turn out so simply. Most potential storms never turn into tropical cyclones even above that temperature, because other atmospheric conditions exert significant influences.

A major new modelling study forecast that a further warming of the North Atlantic could in fact discourage formation of hurricanes, the regional name for tropical cyclones. The study forecast an 18 per cent decline in the annual hurricane count by later this century. It commanded attention because the same team had previously produced a remarkably accurate 'hindcast' of hurricane numbers over the past 30 years (Knutson and others 2008).

The paper argued that, along with ocean temperature itself, what matters most for hurricane formation is the temperature difference between the surface of the ocean and the top of the troposphere, the region where hurricanes reach their greatest height. The authors argued that the recent increase in North Atlantic hurricanes arose because of unusual warming in the tropical North Atlantic with normal temperatures in the troposphere, probably due to short-term natural fluctuations. If this combination proves anomalous,

Box 3: Meltdown in the mountains



One of the most explicit signs of the Earth's warming is the near-universal retreat and thinning of mountain galciers in temperate and tropical regions, as well as in Polar latitudes. New data from the World Glacier Monitoring Service at the University of Zurich tracked 30 reference glaciers in nine mountain ranges and underlined the extent of this phenomenon. The reference glaciers were in equilibrium in the early 1980s, accumulating the same amount in precipitation each year as they lost during melt season. But in the past two decades, they have been losing ice rapidly.

This loss is accelerating. From 2005 to 2006, the most recent collated data set, the reference glaciers showed an average thinning of 1.4 metres, almost five times the annual loss in the 1980s and 1990s. Among those glaciers dissipating the most, Norway's Breidalblikkbrae thinned by more than 3.0 metres in the year, France's Ossoue glacier thinned by almost 3 metres, and Spain's Maladeta glacier thinned by nearly 2 metres. Of the 30 reference glaciers, only one thickened, Echaurren Norte in Chile. The report concludes that up to 750 million people could be seriously affected as Himalayan glaciers disappear and the rivers they feed become seasonal, especially in northern India.

Hazardous substances—transported through the atmosphere, condensed with water molecules, deposited on ice surfaces, and encased within glaciers—are now being released back into the environment as glaciers melt. Currently restricted-use DDT is turning up in unanticipated amounts in Adélie penguin populations that occupy parts of the Antarctic coast. Organic pollutants such as insecticides have been well documented as they melt out of glaciers in North America's Rocky Mountains and polychlorinated biphenyls, or PCBs, can be found downstream of European glaciers. As temperate mountain glaciers disappear they will deliver unwelcome chemicals to ecosystems and communities struggling to cope with expected floods and then, eventually, droughts (See Harmful Substances and Hazardous Wastes, Chapter Two).

In South Asia alone, nearly a billion people depend on glacier melt water from the Himalaya/HinduKush mountain system.

Sources: WGMS 2008a, WGMS 2008b, Geisz and others 2008, Blais and others 2001, Schindler and Parker 2002, Branan 2008 then the recent rising trend in strong hurricanes may cease.

The study was controversial, however. Some reviewers pointed out that the model could not reproduce the strongest hurricanes—the ones people care about the most and that have become more frequent. Others pointed out that the findings were restricted to the North Atlantic. Apparently, different rules will apply in the Pacific and other basins, where global warming is still expected to produce more, and more dangerous, cyclones.

The year 2008 saw a series of other significant predictions for future extreme weather as researchers attempt to deliver relevant insights at regional and subregional scales. One such finding predicts that daily high temperature extremes are set to rise twice as fast as average temperatures (Brown and others 2008). Another suggests that there are likely to be many more extremely intense rainfall events in a warmer Europe (Lenderin and van Meijgaard 2008).

Growing concern about world water shortages highlight new findings on the possible impacts that climate change will have on the hydrologic cycle, including rainfall, soil evaporation, and loss of glacial meltwater flows in rivers. New findings predict empty reservoirs in the Mediterranean and American midwest, dry rivers in China and the Middle East, and less predictable river flows chracterized by flash floods in a glacier-free South Asia (Barnett and Pierce 2008).

Several researchers warned during the year about the dangers of communicating what are likely over-precise predictions of local climate change, especially rainfall and river flows. Uncertainty about some aspects of climate change has to be accepted. But unpredictability is no reason to delay taking action on climate change. Far from it. Its unpredictability is part of what it makes it so dangerous (Smith 2008).

TIPPING POINTS

With possibilities of collapsing ice sheets, methane bubbling out of permafrost, desiccated rainforest ecosystems, and sporadic ocean circulation patterns, concern is growing that Earth's life-support systems are approaching thresholds that contain tipping points. Such fears are reinforced by growing evidence that it has happened before. Past climatic shifts, such as the end of an ice age, have happened abruptly. Studying these past changes could help predict whether anthropogenic climate change is about to precipitate irreversible changes.

In early 2008, a team of scientists published the first detailed investigation of vulnerable Earth systems that could contain tipping points. The team introduced the term 'tipping element' for these vulnerable systems and accepted a definition for tipping point as "...a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system..." (Lenton and others 2008).

The team examined nine of these elements and assigned transition times to emphasize policy relevance. They also suggested average global temperature increase that approaches a critical value within each tipping element.

The elements they considered as policy relevant include the Asian monsoon, the West African monsoon, Arctic sea ice, Amazon dieback, boreal forest loss, thermohaline circulation, El Niño Southern Oscillation, collapse of the Greenland ice sheet, and loss of the West Antarctica ice sheet (**Box 4**) (See Environmental Governance, Chapter Six). The study warned against a false sense of security delivered by projections of smooth transitions of climate change. Instead, too many critical thresholds could be crossed within this century because of the changing climate. Scientists hope to establish early warning systems to detect when these suggested tipping elements become unstable (Lenton and others 2008).

The goal of early warning may be complicated by the cumulative effects the different Earth

Hurricane hitting Cuba in 2008.

Source: Associated Press/ Eduardo Verdugo

Box 4: Tipping point in Africa?

Debate continues about whether the Sahel, one of the world's regions most vulnerable to climate variability, is about to pass a tipping point. Some studies suggest that the Sahel region of West Africa could see a sudden revival of rains if global warming and changes in ocean temperatures in the North Atlantic combine to trigger a strengthening of the West African monsoon. This tipping point has been crossed in the past: From 7000 to 3000 before the common era (BCE) large parts of the Sahel were verdant after an exceptionally dry period around 8500 BCE. Evidence published in 2008 suggested that even if this revival occurs it may not be as abrupt as some suggest. A study of pollen and lake sediments in the Sahara investigated how the Sahel went from wet to dry conditions over a one thousand year period that began six thousand years ago. Other studies suggest this shift happened within a few decades. The search for a reliable means of predicting future precipitation patterns in the Sahel region of Africa continues, with one study suggesting that links to sea surface temperatures that held in the 20th century might not apply in the 21st century. However, even if the Sahel did become a lush landscape, only good governance could promise that it would not be a source of conflict and mismanagement (See Ecosystem Management, Chapter One; See Disasters and Conflicts, Chapter Four).

Sources: IPCC 2007, Kropelin and others 2008, Brovkin and Claussen 2008, Cook 2008

Source: Mike Hettwer

Cast from the archaelogical site of Gobero, Niger on the shoreline of Mega Lake Chad, hundreds of kilometres from the current lake shore. These remains of a mother and two children date to about 3300 years before the common era.

systems have on each other, given the complexities at multiple scales and under various circumstances. In 2008 such complexities were demonstrated when early warning efforts resulted in observations of unexpected enhanced thermohaline circulation in the Labrador and Irminger Seas (Vage and others 2008). Another new study found links among El Niño, the Asian monsoon, and the south equatorial Atlantic's sea surface temperature. These teleconnection clues hold out the prospect of more accurate seasonal forecasts of the Asian monsoon, including its possible failure (Kucharski and others 2008).

CONCLUSION

Uncertainties remain in climate change science, especially regarding the operation and interaction of Earth systems over various timeframes and how subsystems react to feedbacks. In particular, more work is required to understand the nature of possible tipping points in systems operating at various scales. For now, the evidence suggests that we may be within a few years of crossing tipping points with potential to disrupt seasonal weather patterns that support the agricultural activities of half the human population, diminish carbon sinks in the oceans and on land, and destabilize major ice sheets that could introduce unanticipated rates of sea level rise within the 21st century (Lenton and others 2008, Schellnhuber 2008).

The basic scientific building blocks behind forecasts of widespread and damaging climate change are irrefutable (IPCC 2007). Unless action is taken soon to stabilize and then decrease concentrations of greenhouse gases in the atmosphere, these changes will cause widespread damage to ecosystems, natural resources, human populations, and their fragile economic activities. Such damages could certainly end prosperity in developed countries and threaten basic human livelihoods in developing countries (**Box 5**).

Box 5: Managing the unavoidable

Until very recently, technology transfer to address climate change has dwelled on mitigation issues. Given that the overwhelming majority of global greenhouse gas emissions are from the energy sector, energy alternatives became the dominant focus for technology transfer. Since energy technologies have been promoted as centralized and infrastructure dependent, it has been a priority on the part of developing country decision makers to emulate developed country models by promoting infrastructure development, modernizing energy delivery, and stimulating private sector investment in large scale installations. So technology transfer in the climate context has come to focus squarely on flows of experience, know-how, and equipment installation arrangements between countries, especially from developed to developing countries, and less on deployment and dissemination within countries (See Resource Efficiency, Chapter Five).

Now that the question of technology for adaptation has moved towards centre stage, some of the ideas about technology transfer for mitigation have been carried forward into the adaptation domain. However, this approach will likely not work.

First, adaptation is not new in the way that modern energy infrastructures are new. Second, the sectors that need technology for adaptation are ubiquitous—not dominated by one sector like energy. Third, many technologies for adaptation, and techniques for adaptation that foster shifts of behaviour and approach, are already available in developing countries. And fourth, the most needed technologies and techniques for adaptation are unlikely to be as capital intensive as those for mitigation, meaning there will not be huge short-term profits to be made by corporate interests.

The selection of technologies for adaptation can be a delicate matter: Caution must be exercised in the introduction of some technologies to avoid possible unintended side effects. The development and application of suitable criteria, motivated by the immediacy of the adaptation challenge, will help to avoid some of these problems.

There are three essential criteria—efficiency, equity, and effectiveness. First, any chosen technology should be subject to some efficiency criterion. Before adopting any specific adaptation measure or set of measures it is important that the benefits exceed the costs, especially at the local level. Second, it is important that the choice of technology for adaptation is equitable in its distribution. In choosing among alternatives, decisonmakers may wish to consider which segments of the population will particularly benefit and where and upon whom the full costs will be incurred. Third, although they may be efficient and equitable, some adaptation options may be politically, socially, or legally unacceptable and lead to negative effects. Perhaps a simple change of an existing regulation may be sufficient to facilitate needed effects. Too often, alterations in cultural values and attitudes are involved: These can be much harder to change. But if approached with respect and rationality, social and cultural obstacles can be negotiated, especially when community leaders can be convinced of the advantages emerging from effective adaptation techniques and technologies.

Five sectors require particular emphasis for adaptation planning. They present challenges, but also offer some lessons learned that could be considered:

In many coastal locations technology has been instrumental in reducing society's vulnerability to perennial weather related hazards. Traditional and recently developed techniques and technologies that have proven to be effective in reducing vulnerability to weather-related hazards will also be important as technologies for adaptation to climate change.

For water resources, climate change induced variability in the hydrologic cycle imposes additional challenges on planning and management. The development of appropriate adaptation strategies to cope with this added uncertainty requires a broad, integrative approach given the multidimensional roles that water plays in sustaining human life, society, and the ecosystems on which they depend.

For agriculture, it is important to consider a diverse toolkit for adaptation because there are a number of uncertainties regarding the range of impacts associated with climate variability and climate change. This is essential to retain the flexibility to transfer and adopt appropriate site-specific techniques and technologies.

Source: Strait Crossing Bridge Ltd.

The Confederation Bridge links the Canadian provinces of New Brunswick and Prince Edward Island. Along its 13 kilometre length the piers and road surface were built a metre higher than required to accommodate for expected sea level rise and associated variable ice conditions over its one hundred year lifespan.

There is along history of dealing with the impacts of climate variability in the sector of public health. Incorporating consideration of where, when, and how extensively climate change could affect future disease burdens is important for increasing resilience. In facing climate change health issues it is especially important to design interventions in collaboration with practitioners addressing the full spectrum of public health challenges.

Finally, an integrated and exhaustive governance structure is central to the success of adaptations, particularly in infrastructure projects and in urban settings. The broader the scope of the adaptation intervention, the greater the need for good governance to ensure efficiency, equity, and effectiveness. Awareness-building and involvement of community groups is essential, as is honest involvement of public and private sector interests, in the successful transfer of technologies for adapting infrastructure systems to the changing climate.

Source: Klein and others 2006

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Disasters and Conflicts

In recent decades, the growing threat of climate change is demonstrated by a significant increase in the number and severity of storms, floods, and droughts while the average number of seismic disasters, as devastating as they are, remained steady. New and ongoing conflicts can be both the result and the cause of environmental degradation.

In Eldoret, Kenya, two children stand together as heavy rain falls at a temporary shelter for about 19 000 people displaced during post-election violence. *Source: Reuters/Georgina Cranston*

INTRODUCTION

The year 2008 was marked by images of violence and destruction, from election disputes and food riots to ongoing wars and internal strife—through violent storms, vicious floods, relentless drought, and savage earthquakes. With growing populations and increasingly stressed resources, with the intensifying specter of significant climate change and globalized financial crises, and with persistent political instability in many regions, significant numbers of people are becoming more vulnerable to physical shocks, political and economic crises, and armed conflicts.

Natural disasters such as earthquakes, tropical cyclones, and drought can be devastating to humans and to critical infrastructure. But nature itself can be another casualty in a natural disaster: Environmental devastation results directly from damage to natural systems and indirectly from damage by accidents, oil spills, sewage overflow, and other infrastructure failures. Later, subsequent damages can include increased exploitation of resources by displaced or otherwise affected populations and re-assignment of support away from environmental protection, in the name of an emergency (WRI 2003).

There is hope, however, in the increasing evidence that disaster prevention and preparedness programmes work. Sound management and concerted public outreach and preparedness efforts can prevent the devastating destruction that characterized natural disasters in the 20th century. Such management

Box 1: Insecurity and environmental consequences

The threatened species of Eastern Lowland Gorilla (*Gorilla beringei graueri*) and Mountain Gorilla (*Gorilla beringei beringei*) have been under increased pressure in the eastern provinces of the Democratic Republic of the Congo (DRC). The region has been subjected to 'resource wars' for decades. In this region, the disputed resources range from charcoal to supply continuing demand from neighbours in Rwanda, where charcoal production is banned on environmental grounds, to the mining of columbite-tantalite or coltan, a rare mineral essential for the manufacture of most modern electronics.

Virunga National Park is Africa's oldest park and is situated in a region that hosts the greatest diversity of vertebrate species on the continent. In September of 2007, armed rebels occupied the Park's specifically designated gorilla sector, forcing rangers to abandon their conservation activities within that sector. Then in September 2008, rangers were forced to abandon the rest of the park when the park headquarters in the town of Rumangabo, from which conservation operations were run, was overrun by advancing rebel forces. Finally, in late November, rangers were allowed to return to the Park and to the gorilla sector as well.

Virunga's gorilla sector spans forested hills on DRC's border with Uganda and Rwanda and is home to about 200 of the last remaining 700 mountain gorillas in the world. The first task for the returning rangers was to begin a month-long census of the mountain gorillas to update information last collected in August of 2007. Early reports tell of five female gorillas nursing infants, certainly a small sign of hope for a sometimes grim and often discouraging conservation effort.

More than 150 rangers have been killed in eastern DRC in a decade of conflict that has claimed more than 5 million lives—more than any conflict since World War Two—through violence, hunger, and disease.

Source: Maguwu 2008, Holland 2008, Mongabay 2008

practices include proper siting and safety codes for development projects, as well as restoration of protective ecosystems including coastal mangroves to combat storm surges and hillside plants to control erosion. It has also become clear that poor disaster prevention, preparedness, and response can intensify the background devastation and long-term displacement and disenfranchisement of affected populations even in the most developed countries.

Armed conflicts present a still greater prevention challenge, but here too, there is increasing evidence that relatively simple measures can make devastating events considerably less likely or less severe. Every disaster and every conflict offers lessons for those who seek to save lives, landscapes, and settlements in the future. Some of these lessons, whether taken as inspiration or as cautionary tales, will be fully appreciated only after years. However, many lessons can be applied and valued today.

DISASTERS, CONFICTS, ENVIRONMENT—2008

The year began with a disputed election in Kenya that then broke out into violent unrest. The host country of the headquarters for the United Nations Human Settlements Programme (UN-Habitat) and the United Nations Environment Programme sunk into chaos with inter-ethnic killings, sexual assualts, and mutilations. Estmates put the death toll at 1 200 while at least 300 000 victims, mostly women, children, and the elderly, sought shelter in temporary camps when their homes in both rural settlements and urban slum areas were destroyed and their lives were threatened (IRIN 2008a).

A number of local conservation initiatives were damaged or destroyed, as often happens when social order breaks down. North and South Nandi forests and parts of the Cherengany ecosystem were areas where the damage was greatest. Some reforested plantations were burnt. There were also instances of burning of forest stations and subsequent displacement of forest staff. As part of a project funded by the Government of Finland, an extensive inventory of the damage was initiated by WWF, Kenya Forests Working Group, Nature Kenya, IUCN, Forest Action Network, and the Kenyan Forest Service, to be followed up by peace building and rehabilitation components.

In Zimbabwe, continuing deterioration of civil society has led to increased poaching of wildlife and clearing of forested areas for fuel. The environmental consequences of political unrest maintained a chronic profile throughout the year—especially in eastern parts of the Democratic Republic of the Congo (FEWS 2008, Bird and Prowse 2008) (**Box 1**).

Chinese New Year

In late January and early February 2008, a series of severe snow, sleet, and ice storms hit a vast area of China, west of Sichuan through east-central Anhui Province to Guangdong Province in the south (Stone 2008a) (**Figure 1**). The affected regions include many of China's remaining natural forests: Significant reserves such as the 58 000 hectare Guangdong Nanling National Nature

Figure 1: Chinese New Year's Storm covers a vast area

Unusual cold, heavy snow, sleet, and ice affected at least 19 provinces of China during January and February 2008 in what was one of the worst winter storms in memory to hit the central, eastern, and southern provinces of China.

Source: Màrton Bàlint and Jason Jabbour/ UNEP; adapted from IFRC 2008

Reserve were heavily damaged by the 'Chinese New Year's Storms'. All told, a staggering 20.86 million hectares of forest were ravaged by the storms, according to the Chinese State Forestry Administration. The affected area represents one tenth of the country's forests and tree farms.

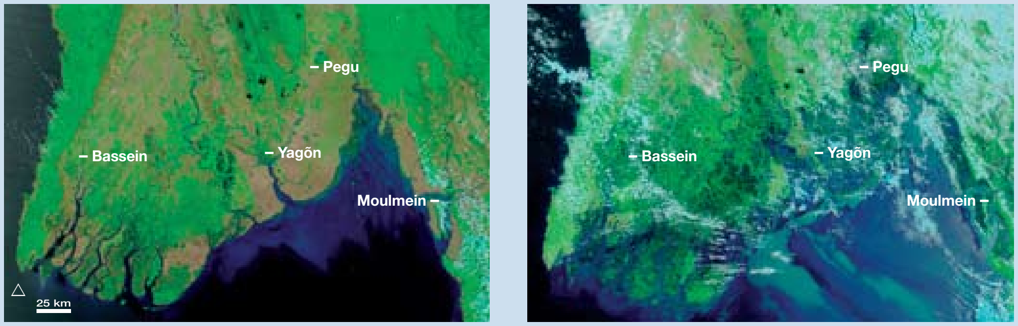
The economic cost of the storms is estimated at more than US$21 billion. One hundred and twenty-nine people were killed in the storms, and another 1.7 million were displaced, while 8.6 million were stranded when parts of the transportation system faltered. Many more millions suffered through fuel shortages and power outages for weeks after the storms had settled. The environmental damage is harder to judge, although it is worth noting that the damaged area is approximately equivalent to the area planted in national reforestation schemes between 2003 and 2006. Early assessments indicated that introduced species, such as slash pine from the southern United States and Australian gum trees, fared significantly worse than native trees, though the damage to native Chinese species was also significant. The devastating storms came at a time when China was attempting to control illegal logging and implement monitoring and conservation plans on a wide scale (Stone 2008a).

Cyclone season

On the 2nd of May, Cyclone Nargis hit the coast of Myanmar at its peak intensity, with wind speeds recorded at 215 kilometres per hour. With more than 140 000 people missing or dead in the storm and at least 2.4 million homeless or otherwise catastrophically affected, many aid agencies had difficulty reaching victims for weeks after the disaster (Stover and Vinck 2008). Most of the thousands of people who perished when Cyclone Nargis hit are believed to have drowned in the 3.5 metre storm surge that swept nearly 40 kilometres inland (OCHA 2008a) (**Figure 2**).

Coastal populations in Myanmar have grown substantially in recent decades, as farmers seek fertile land and space for fishponds. As has been the case throughout the tropical world, this coastal development has spurred the large-scale clearing of mangrove forests. Similar to the case in the 2004 tsunami, the loss of the protective fringe of trees substantially increased the damage resulting from Cyclone Nargis (FAO 2008).

Figure 2: Irrawaddy River delta washes away



Satellite images of the Myanmar coast on 15 April 2008 (left) before Cyclone Nargis and 5 May 2008 (right) after Nargis hit the region, showing the devastation of flooding over the coastal plain. *Source: NASA/ MODIS Rapid Response Team*

Early in the 20th century, mangrove forests were estimated to cover more than 242 811 hectares in the Irrawaddy River delta. By the end of the century, only 48 562 hectares remained. Much of this loss was due to a boom in the charcoal industry in the 1970s, when urban demand for fuel led to a rapid degradation of the country's forests. In the 1990s, agricultural encroachment and the introduction of shrimp farms further cut into the mangrove forests (IRIN 2008a). According to a disaster assessment report, 16 800 hectares of native mangrove forest were destroyed and about 21 000 hectares of forest plantations were damaged (PONJA 2008).

This further loss of mangrove forests and associated ecosystems will have a significant impact on those segments of the rural population that depend on forestry for their livelihoods. A large number of artisans, fishers, marginal farmers, and landless poor rely on the surrounding forests as a source of direct and indirect income (IRIN 2008b). As well, the delta supports many micro-enterprises that typically represent easy-entry, subsistence activities for poor households, including those headed by women (PONJA 2008).

The small-scale salt production industry that occupies the lowest part of the delta was also devastated by the storm and its powerful surge wave. Estimates suggest 35 000 farms, mostly private, were hit, resulting in a loss of livelihoods for thousands. More than 9 712 hectares or 80 per cent of all salt fields in the delta were damaged. As well, the storm destroyed warehouses storing over 24 000 tonnes of newly-harvested salt (IRIN 2008c).

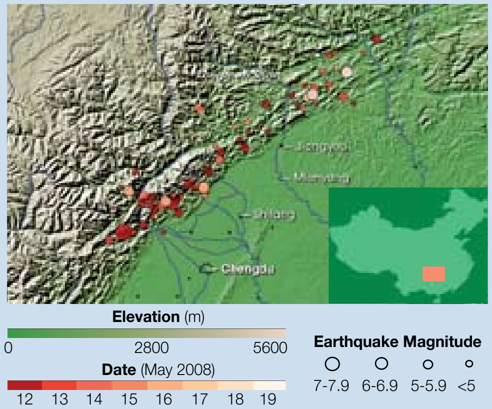
An estimated 20 000 salt farmers and their families were living in the delta at the time of the disaster. By some accounts, as many as 8 out of 10 salt industry workers were killed in the storm, leaving dependent families in search of alternative livelihoods (IRIN 2008d, PONJA 2008).

Rip in the Earth

On 12 May 2008, a 300 kilometre-long seam in the bedrock under Sichuan Province, China, was violently ripped apart. Starting at 2:28 PM local time, pent-up seismic energy was released from a fault between the Qinghai-Tibet plateau and the Sichuan basin (USGS 2008). The rupture itself lasted for just 120 seconds, but the consequences of the resulting magnitude 8.0 earthquake will persist for years or decades to come.

With over 87 000 people missing or dead in the disaster, over 350 000 were injured, 5 million were left homeless, and 15 million were evacuated from the region, with direct costs estimated to be at least US$73 billion (Xinhua 2008a). More than five million buildings collapsed—7 000 of them schools—with another 21 million buildings sustaining damage, not only in Sichuan province, but also in Chongqing, Gansu, Hubei, Shaanxi, and Yunnan provinces. Several towns and cities were almost completely destroyed, including Beichuan, Dujiangyan, Wuolong, and Yingxiu. The earthquake's maximum intensity was centred in the area of Wenchuan, but it was powerful enough to be felt through much of China as well as parts of Bangladesh, Thailand, and Vietnam (USGS 2008).

Figure 3: Shock and aftershocks



Overlaid onto the map are earthquake magnitude indicators. The size of the circle indicates the strength. The earthquake's epicenter was approximately 90 kilometres west-northwest of the city of Chengdu; it is the largest dot on the map. Smaller magnitude events occurred northeast of the epicenter, and generally followed the edge of the Longmen Shan mountain range. As recently as 9 December, aftershocks were still occurring in the region.

Source: NASA, GLCF, Jesse Allen

The Wenchuan earthquake struck in one of the most seismically active regions of Asia. It was a deep rupture, about 19 kilometres below the surface and centred 90 kilometres west-northwest of Chengdu, the capital of Sichuan Province and an important transportation and communications hub (Burchfiel and others 2008, USGS 2008).

Chengdu itself was spared the worst damage, but many smaller centres and rural areas were not so fortunate. A series of violent and destructive aftershocks began immediately, complicating the relief efforts and multiplying the stress and worries of the local population. Two powerful aftershocks on 27 May destroyed a further 420 000 homes in Qingchuan County, Sichuan. Continuing aftershocks plus the loose rocks and very steep terrain of the surrounding area combined to create additional dangers for rescuers and residents alike (MCEER 2008) (**Figure 3**).

Beyond the significant direct damage caused by the shocks and falling boulders and debris, the landslides blocked highways, hampering relief efforts, and also dammed rivers and streams throughout the region. The result was a series of 'quake lakes', rapidly filling reservoirs along major waterways such as the Qing and Jiang Rivers (Stone 2008b, NASA 2008a).

More than 30 temporary lakes were formed behind these unstable earthen dams, flooding upstream areas and threatening downstream regions with flash floods should the temporary dams suddenly breach. The largest reservoir on the Jiang, named Lake Tangjiashan, threatened as many as 1.3 million people downstream, from the town of Beichuan, immediately below, to Mianyang city, 100 kilometres downstream (NASA 2008a). By early June, soldiers managed to excavate a drainage sluice across the top of the blockage and on 9 June used explosives to widen the channel, allowing the water to start draining from the lake (Xinhua 2008b) (**Box 2**).

In western Sichuan Province, the 70 million hectare Hengduan Mountain Region was damaged by both the spring storms and the Wenchuan quake (Morell 2008). Efforts are underway to control overgrazing of grasslands and to protect, replant, and restore forests through large areas of western China, at least in part to help control erosion and the sort of landslides that proved so deadly after the Wenchuan earthquake (Xin 2008). The area has also been subject in past years to severe flooding of the Chang Jiang, or Yangtze River, attributed to deforestation of the surrounding watershed. The Sichuan government banned logging in native forests after the 1998 Yangtze floods in an effort to prevent future disasters, and the Chinese government implemented national forest preservation and replanting efforts shortly afterward. Nationally, Chinese planned for the planting of 2.5 billion trees in 2008 (Morell 2008).

Hurricane swathes

During a four week period from mid-August to mid-September, the eastern Caribbean was pounded by Tropical Storm Fay and then by three hurricanes—Gustav, Hanna, and Ike—with devastating effects throughout the area. However, Haiti suffered most. Haiti is considered the least developed country in the Americas and years of poverty, social instability, and periods of near-chaos have led to massive deforestation. This year, the deforestation combined with perennial overuse of steep hillsides to produce severe slope instability and catastrophic landslides during heavy rains. In this particularly vicious hurricane season, the city of Gonaïves was especially hard hit, with relief efforts slowed by the continuing sequence of storms and washed out bridges (OCHA 2008b).

Box 2: Draining a quake lake

Source: Liu Jin/ Agence France-Press - Getty Images

Top: A view of the earthquake-damaged city of Beichuan on 12 May. Below: The view on 10 June, after a controlled drainage operation flooded parts of the damaged city.

Hurricanes Gustav and Ike also hit the neighboring nation of Cuba particularly hard. Gustav had sustained Category 4 winds of almost 240 kilometres per hour when it made landfall in southwestern Cuba in late August, while Ike's winds were 193 kilometres per hour when it hit Holguín province in eastern Cuba just one week later. Together, the storms damaged more than 100 000 buildings, and left more than 200 000 people homeless, while a quarter of a million people were evacuated from the most threatened regions (NASA 2008b). The capital, Havana, and important industries including tourist resorts, oil installations, and nickel mining operations were largely undamaged; however, damage to housing, agriculture, and the electrical grid was estimated at US$5 billion (OCHA 2008b).

An aerial view of houses in Gonaïves, devastated by floods from Hurricane Hanna on 3 September 2008. *Source: Marco Dormino/ UN Photo*

The hurricane season of 2008 tested disaster preparedness throughout the Caribbean. During those four weeks, nearly 800 lives were lost, at least 2.8 million people were affected, and more than 600 000 houses were damaged or destroyed (OCHA 2008b).

Resilience in both natural and socio-economic systems is essential for disaster mitigation and recovery. Ironically, the most deadly of the storms was Hanna, one of the weaker systems, which hit Haiti after the cumulative effects from Fay and Gustav had left the country extremely vulnerable (OCHA 2008b). The early evidence is that Cuba's intact ecosystems and functional government have helped the country avoid the debilitating loss and chaos suffered by Haiti.

HUMAN FLAWS AND DISASTER PREVENTION

If the destructive force of the hurricanes hitting Haiti was intensified by poverty, environmental degradation, and lack of infrastructure, the impacts of Cyclone Nargis were made worse by the lack of warning and of appropriate response. Due in part to the government's downplaying the threat and the delay in admitting international aid agencies in the aftermath, Nargis was 2008's most destructive natural disaster (Stover and Vinck 2008, OCHA 2008a, Webster 2008). The effect on the winter rice crop—a mainstay of the national diet and economy—was devastating. Myanmar is usually a net exporter of rice and the loss of the crop came during a year dominated by global shortages of rice and other staple foods. While most of the inundated land will recover its fertility, helped by subsequent freshwater flooding, at least 200 000 hectares were rendered unfit for planting during the 2008 monsoon season (IRIN 2008b).

Effective planning, response, and resilience-building programmes rely on effective forecasting and prediction of adverse events including tropical cyclones, winter storms, and periods of prolonged drought or flooding. Significant strides have been made in the prediction and tracking of tropical storms and cyclones, and all major cyclone-generating regions are covered by forecasting services organized by the World Meteorological Organization. But as the devastation caused by the Cyclone Nargis and by hurricanes and storms in the Caribbean demonstrate, there is an essential need for disaster mitigation on the ground immediately following the initial forecast. According to storm disaster analysts, there are three main improvements needed to make tropical storm forecasting and warnings more effective in developing regions: Extended forecasts, to allow more response time; inclusion of storm surge forecasting along with storm forecasts; and development of robust, comprehensive national disaster plans (Webster 2008).

The most vulnerable populations in the North Indian Ocean region live along river deltas and other low-lying coastal areas with little access to communication and transportation networks (O'Hare 2008) (**Box 3**). The standard three-day time horizon for cyclone track and intensity forecasting may be sufficient for complex, large-scale responses in developed regions, as was seen with the evacuation of coastal areas of Cuba. However, in rural, developing areas, where telecommunications are limited and people move mostly by foot with their livestock, food, and belongings with them, a three days' warning may not be sufficient (Webster 2008).

Box 3: The most vulnerable populations

The people who suffer most from cyclones are generally the poorest and most vulnerable populations in an area. A 2008 study of the effects of natural disasters on vulnerable populations, conducted in the aftermath of 2007 Tropical Storm Noel in the Dominican Republic, found that the household's poverty level affects its capacity to prepare and respond to a natural disaster. This relationship holds true even in developed countries. Over one thousand people, mostly poor, died when Hurricane Katrina struck New Orleans and the US Gulf Coast in 2005—despite several days' warning that the hurricane's path would make landfall near the city.

Vulnerable populations can include the poor, children, women, the elderly, people with disabilities, and persons living with HIV/AIDS. Other contributing factors to high vulnerability include low levels of technology; lack of necessary information or skills; limited or no access to transport, communication, and health services infrastructure; and unstable or weak political institutions. Overall, a lack of resources and external support leaves these vulnerable populations unable to fully anticipate, prepare for, or protect themselves from disaster.

Whether uprooted by flooding or by fighting, the displaced often must endure family separation and the death of family members; loss of homes and possessions; and the experience of assault, physical injury, emotional trauma, and depression. In the face of disaster, it is the weak in a population who suffer most. For example, globally, for every adult male who drowns in a flood disaster, there are three to four women who die.

Sources: Ferris 2008, Huq 2008, O'Hare 2008, UN-INSTRAW 2008

In responce to Cyclone Sidr's approach in 2007, hundreds of thousands of Bangladeshis were evacuated and many sought refuge in emergency shelters like this one near Mongla port, around 320 km south of Dhaka.

Source: Farjana Khan Godhul/ AFP

Getting it right, just in time

Several studies in recent years have indicated that tropical cyclones may be intensifying under climate change (Emanuel 2005, Webster and others 2005, Elsner and others 2008) (See Climate Change, Chapter Three). Although this remains disputed, conditions in the North Indian Ocean are already well suited to generating powerful, destructive cyclones. This is particularly true during the periods immediately before and after the South Asian monsoon, typically April-May and October-November, when warm surface water temperatures combine with low vertical wind shear conditions.

Over the long term, these major tropical cyclones have not often made landfall in the countries bordering the North Indian Ocean. But recent years have been an exception. There have been four major tropical cyclones in the basin since 2006, compared to just eight similar storms over the preceding quarter century. There isn't sufficient data to determine whether this represents an ongoing trend or an acute anomaly (Webster and others 2005, Webster 2008). But as is the case along other cyclone-generating basins, it may not matter. Vulnerability to storm damage would be increasing even without an increase in storm frequency or intensity, due to growing populations and other development in vulnerable coastal areas (O'Hare 2008).

Bangladesh is considered to be one of the region's most vulnerable countries to possible effects of climate change including sea level rise, increased flooding, and intensified storms. In September, the country announced a comprehensive action plan to address the impacts of climate change over the coming decade (Antony 2008). Bangladesh, which has three densely populated mega-deltas opening to the Bay of Bengal, has already been a leader in cyclone damage remediation efforts. Some 300 000 people were killed by Cyclone Bhola in 1970, and at least 138 000 perished during a 1991 cyclone—about 80 per cent of them women and girls (Ikeda 1995). When Cyclone Sidr hit in November 2007, with storm and landfall characteristics that were very similar to the 1970 event, only about 3 500 lives were lost (AlertNet 2007) .

A national emergency network—including a series of storm shelters, coastal dikes, a radio and mobile phone warning system, and volunteers

As Cyclone Sidr moved northward in the Bay of Bengal over 40 000 Red Cross and Red Crescent volunteers spread the word that evacuations were necessary.

Source: International Federation of Red Cross and Red Crescent Societies

who communicate warnings via megaphones and on bicycles—had been established under a national disaster plan. Combined with extended-range cyclone forecasts and storm surge forecasts generated by Louisiana State University in the USA, as well as the Indian Meteorology Department's forecasts of the storm's track and intensity, the networks allowed Bangladeshi authorities to oversee the successful evacuation of over 2 million people during the Sidr event (AlertNet 2007, Webster 2008).

Preparing for earthquakes

Earthquakes tend to strike in the same regions over time. Although the likely location of destructive tremors can be mapped with considerable accuracy along Earth's network of seismic faults, the precise timing of the events themselves remains stubbornly difficult to anticipate. Improvements in weather forecasting and cyclone prediction have made a dramatic contribution to disaster mitigation in recent decades. Is there any hope that similar advances could some day help reduce the physical damage and loss of life from earthquakes as well?

The answer is maybe—and depends heavily on the time scales under consideration. Earthquake prediction on the scale of hours, let alone days, is not expected anytime soon. But such long lead times might not be necessary for warnings to have a significant beneficial impact, and after decades of effort some promising signs are emerging. Earthquakes have probably been the most deadly disasters of the last century; gaining even seconds of advance notice could help cut the death toll in the future (Malone 2008). In Japan an earthquake early warning system was launched in 2007, using immediate electronic signals that travel faster than the earthquake itself The signals are triggered by a network of seismographs to slow trains, stop elevators, and warn civilians that a tremor is moments away (JMA 2008).

While there has been increasing research effort aimed at earthquake prediction over the past 15 years, the goal of advance warning remains elusive (Panakkat and Adeli 2008). Several recent refinements are helping deduce changes in future earthquake risk from analysis of past earthquakes. Already, several groups have conducted such analyses for the Sichuan basin area and more broadly.

Working with computer models of the stress on faults in the area surrounding the Wenchuan rupture, an international team of collaborators calculated significant stress increases along three neighboring fault systems. Noting that portions of the surrounding faults have gone more than a century without rupturing, the authors conclude that there is a 57 to 71 per cent chance of another earthquake of magnitude 6 or greater in the area within 10 years and an 8 to 12 per cent chance of a magnitude 7 or greater quake during the same time period. These probabilities are nearly double those for the decade before the Wenchuan earthquake (Toda and others 2008).

Using a computer model of the many active faults in the Sichuan basin and surrounding areas, another team calculated changes in seismic stress along those faults. They mapped stress changes to locate fault sections with relatively high odds of producing large aftershocks (Parsons and others 2008). This 'stress-transfer analysis' has been used successfully in the past, notably in the case of the 26 December 2004 Sumatra earthquake that caused the devastating tsunami. When a magnitude 8.7 aftershock hit three months later, it occurred in a region successfully calculated to be under greater stress as a result of the 26 December event (McCloskey and others 2005). Aftershocks can continue for years but increased-stress calculations can be completed within days. The maps produced from these models can identify potential future rupture zones for focusing mitigation efforts (Parsons and others 2008).

In Ying Xiu Township, China, children were trapped when this Middle School collapsed during the 12 May Wenchan earthquake. An estimated four thousand of the township's ten thousand residents died here at the earthquake's epicentre. *Source: UN Photo/Evan Schneider*

As important as earthquake prediction may turn out to be, it cannot supplant careful disaster planning and public awareness, as well as rigorous, strictly enforced building codes. The poor construction of many buildings, especially schools, was blamed for the large numbers of deaths in the Wenchuan earthquake, supporting a common saying among seismologists, that earthquakes do not kill people, buildings do (Stone 2008e). Ongoing analysis of the complex geophysics of the Wenchuan event will no doubt help refine risk assessment and hazard maps for the region and elsewhere, but a more basic lesson is immediately applicable. As much as geophysicists and seismologists have learned about our planet's shifting crust, there is much left to be discovered. As a result, safety in a seismic zone can never be assumed nor assured. Planners, agencies, and especially residents forget that lesson at their peril.

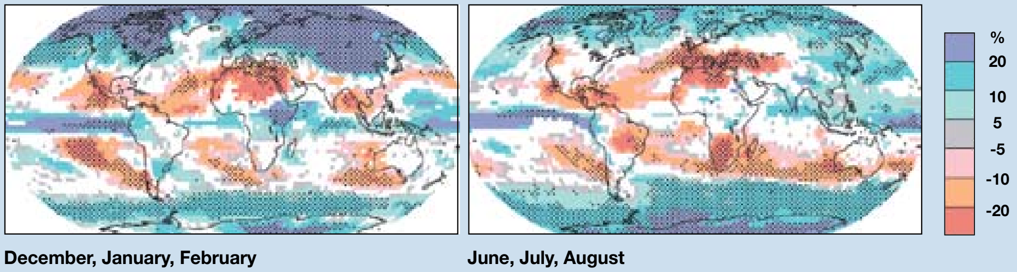
Slow onset disasters

Storms and earthquakes, and even floods, occur on short time scales, while droughts and famines are known as slow onset disasters. There is growing evidence that floods and droughts are two extremes in an oscillating pattern, with famine as a consequence (Eltahir and others 2004). However, as global climate change intensifies, disruptions in both weather patterns and the general dynamics of the hydrologic cycle are likely to play increasingly significant roles in disastrous droughts and floods. Given the global distribution of fresh water resources, patterns of population growth, and the anticipated disruptions in water supply—added to geopolitical divisions and existing conflicts—hydrological instabilities will continue to initiate or exacerbate political tensions and armed conflicts.

The expected shifts in precipitation patterns and water availability due to changing climate are complex and have been documented by the Intergovernmental Panel on Climate Change (Bates and others 2008). In many regions of the world, water is already scarce and likely to become more so as global climate change advances (IWMI 2007, IPCC 2007) (**Figure 4**). Areas expected to be affected by persistent drought and water scarcity in coming years include the southern and northern tiers of Africa, much of the Middle East, a broad band in Central Asia and the Indian subcontinent, southern and eastern Australia, northern Mexico, and the southwestern United States (IPCC 2007). This context of change makes planning for future water use and disaster mitigation particularly challenging: The changing climate currently underway defies entrenched assumptions about capacities and supplies that have been adopted as water management schemes in many societies by default (Milly and others 2008).

Notably, Afghanistan and surrounding areas have been in a serious drought since at least the turn of the century (ICRC 2008). Much has been written about the particular role of water scarcity in spurring armed conflicts and hostilities in arid regions around the world and there are growing worries that Afghanistan is one more example (IRIN 2005, Gall 2008a). In September, aid agencies reported a growing threat of widespread hunger through central and northern Afghanistan. Poor harvests were blamed on very harsh winter weather early in 2008, followed by serious drought conditions over the summer growing season, potentially putting five million Afghans at risk of severe food shortages (Oxfam 2008). Not only does the ongoing conflict in Afghanistan hamper efforts to provide aid and development support to drought-stricken regions, but the increasing pressure of the drought may be undermining the overall security situation (Banzet and others 2007, Gall 2008b).

Figure 4: Projected patterns of precipitation changes



Relative changes in precipitation projected for 2090 to 2099 compared with 1980 to 1999, according to multimodel analyses. White areas indicate that less than two thirds of the models agree on any trend, while stippled areas indicate that more than nine tenths of the models agree on the trend. *Source: IPCC 2007*

Once a source of irrigation for thousands of hectares of land, and a feeding source for several power reservoirs, Kabul's central river has turned into a predominantly dry ditch due to persistent drought conditions.
Source: Catherine McMullen/ UNEP

Resources and security

The interplay among disasters, environmental challenges, and conflict is complex. As in Haiti, the impacts of a natural disaster can be exacerbated by pre-existing environmental degradation, with the potential that it will aggravate societal tensions and civil strife. In Afghanistan and other regions experiencing persistent drought, the challenges of survival can drive accelerated environmental damage, as well as produce a cohort of dissatisfied, angry potential warriors with limited options—a dangerous recipe in regions where conflict is already endemic (Kaplan 1994, Henriksen and Vinci 2008).

There is every possibility that disasters and resource scarcity will exacerbate existing conflicts, if they do not cause them outright. A substantial body of evidence shows robust links between resource scarcities and potential for conflict (Smith and Vivekananda 2007). Rapidly growing populations and resource stress make significant contributions to the likelihood of violence and conflict in any given situation, such as the ongoing hostilities in Sudan and elsewhere (UNEP 2008). Persistent drought and a shortage of fertile land have been shown to contribute to the ongoing conflict in Darfur, where water resources have always been limited, but where 16 of the 20 driest years yet recorded have occurred since 1972 (UNEP 2007).

An opposite effect, sometimes termed 'the resource curse' has also been debated (Ross 2008). Scarcity of essential resources is almost always a cause of social tension and perhaps conflict. But an abundance of high-value, marketable resources is also recognized as a potentially significant source of tension or an exacerbating factor in armed conflicts, including at least 18 civil wars over the past two decades that have been fuelled by natural resources (UNEP 2008). There are several modes of resource curse, including use of profits from high-value commodities such as gemstones, timber, or drugs to support insurgencies and conflicts that arise from perceived inequitable sharing of natural resource revenues. The resource curse can act as a spark that initiates hostilities, as a source for financing to sustain ongoing conflicts, or as a disincentive to conflict resolution as long as outstanding issues of resource ownership remain unresolved (Le Billon 2007). While this pattern does emerge in some instances, more recent analysis concludes that the resource curse is not predestined. Instead, managed natural resource use should be a valuable part of a nation's sustainable development strategy (Brunnschweiler and Bulte 2008) (See Environmental Governance, Chapter Six).

GREAT EXPECTATIONS

Clearly, the incidence and severity of natural disasters can change over time and on local and global scales. The evidence suggests that the incidence of disasters has been increasing for more than half a century, and is likely to continue doing so. More specifically, while geological disasters such as earthquakes and volcanoes have remained fairly constant over the past century, hydro-meteorological disasters such as storms, floods, and droughts have increased dramatically since 1950 (Eshghi and Larson 2008). The frequency of these events has increased by an average of 8.4 per cent per year between 2000 and 2007, inflicting an average cost each year of at least US$80 000 (CRED 2008). According to another analysis, the total number of disasters has increased from about 100 events per decade in the period 1900-1940 to almost 3 000 per decade by the 1990s (O'Brien and others 2008). A third opinion put the total number of disasters between 2000 and 2005 at 4 850—and attributes the chilling increase to 'technological' disasters such as train wrecks and building failures, as well as weather events (Eshghi and Larson 2008).

Studies of various disasters and prevention options show the role of intact ecosystems in resilience to disaster, the crucial importance of properly-designed buildings and infrastructure, and the potential contributions of forecasting and early warning systems. But as the cases of Haiti and Myanmar demonstrate, there are factors beyond the physical and logistical realities, the earthquake's magnitude, or the evacuation speed of a population that contribute to the scale of a disaster. Researchers studying vulnerability and resilience to natural hazards and disasters use the term 'social vulnerability' to describe this constellation of factors that affect human vulnerability to environmental change (Cutter and Finch 2008). For a given population these factors can include socioeconomic class, gender, age, racial or ethnic backgrounds, migration status, and housing tenure—whether the affected individuals rent or own their homes.

Human vulnerability to environmental change can increase or decrease over time, in step with shifting demographic and socioeconomic factors. A nation's overall vulnerability can also increase or

Source: Tim McKulka/ UN Photo

After fleeing heavy fighting in Sudan, internally displaced persons receive rations of emergency food aid distributed by the World Food Programme.

decrease in response to large-scale patterns of development and migrations. Globally, there has been an increasing concentration of population density in coastal areas and the concomitant increase in susceptibility to and losses from coastal flooding and tropical storms (Webster and others 2005). A quantitative assessment of shifting vulnerability to disasters in the USA over the last half-century reveals more subtle impacts of population movements (Cutter and Finch 2008). During this time of dramatic demographic and socioeconomic shift, the authors found an overall national decrease in vulnerability to natural disasters, but with increasing regional variability. The factors most consistently contributing to increased vulnerability were urban density, race/ethnicity, and socioeconomic status. Intriguingly, age also was a significant factor in many locations, including in the northern states of North Dakota, South Dakota, and Montana. Many areas of these and other states have aging populations caused by out-migration of young people seeking employment and opportunity elsewhere, leaving their more vulnerable elders behind.

Such detailed studies have been conducted for a few other regions, including the Yaqui Valley of Mexico and parts of India, but for most areas of the world in-depth studies of changes in human vulnerability to environmental change are lacking (Luers and others 2003, O'Brien and others 2004). In what has been called the greatest mass migration in human history, perhaps 200 million people have relocated from rural to urban settings in China in recent decades (MN 2008). Much of this movement has been from the interior to increasingly crowded coastal cities, where increased vulnerability to typhoons, flooding, seismic events, and other factors has been recognized. Extrapolating from the experience in the US northern states or Mexico's Yaqui Valley, a dramatic out-migration of youth will result in increased vulnerability in the source regions for China's mass migration. In the specific case of flood disaster mitigation efforts, researchers conclude that emphasizing structural and regulatory approaches to flood mitigation and neglecting human vulnerability factors can actually increase long-term flood risk, through a process of risk transference (Wilhelmi and Kelman 2008). In anticipating current and future vulnerability to natural disasters, planners and managers must pay close attention to the physical correlates of disaster, such as seismic zones and the shifting patterns of rainfall and storm activity. However, research evidence and logic indicate that social, geographic, and demographic changes must also be taken into account (Wisner 2003).

CONCLUSION

International aid has been a critical element in disaster response and recovery efforts in many situations, especially for developing countries. Of the estimated 62 million deaths from natural disasters during the 20th century, more than 85 per cent occurred before 1950 (CRED 2008). Social scientists attribute a significant portion of that impressive decline in mortality to the efforts of the global humanitarian community, but also ask whether the international disaster response has unintended consequences on national disaster preparation priorities. They focus in particular on the balance between national spending on disaster prevention versus relief and recuperation after the fact. Using a new quantitative model of the incentives and outcomes arising from international disaster aid, they suggest that the expectation of international aid after a natural disaster can cause a 'bailout' effect, in which poor, corrupt, or otherwise unresponsive governments neglect investing in disaster prevention in the expectation that free foreign aid will arrive quickly after any natural disaster (Werker and Cohen 2008).

This disturbing theoretical conclusion—that the presence or expectation of outside relief can actually increase the severity of the initial disaster—is not to be taken as an argument against international disaster aid. Instead, relief aid policies must take the possibility of the bailout effect into account. These include decentralizing relief delivery, encouraging local political development, and rewarding non-disasters, all components contributing to disaster preparedness and prevention on the part of governments. While disaster relief is one of the most basic and important transfers of wealth between developed and developing countries, like all transfers it can distort incentives or be manipulated by self-interested leaders: Domestic policies and the actions of international relief should be designed to mitigate, rather than exacerbate, the wrath of nature (Werker and Cohen 2008).

Disaster researchers draw a distinction between the precipitating event, the 'shock' which would be an earthquake, a storm, a fire, a drought, or a war, and the consequential disaster which which would be the lives lost or the damage caused (Werker and Cohen 2008). There is growing evidence that the frequency and severity of some shocks, especially those influenced by the global climate system, are increasing. There is certainly no reason to think that the global burden of shocks is decreasing. It is also increasingly recognized that natural disasters, environmental stress, and access to resources can spark or exacerbate civil and military conflicts (UNEP 2008). Besides acting to mitigate climate change, there is little that planners, managers, and local populations can do about the incidence of natural shocks. But the path from initial shock to full-blown disaster or conflict wends its way through the social, political, and physical spaces we can populate with good planning and responsible decisions. The path is determined by thousands of official reports, management plans, and individual decisions. It is these plans and decisions that science and experience can inform, and that good governance can determine, if we are going to minimize the damages of disasters and avoid the futility of violent conflicts.

Significant environmental events 2008

Source: Please see http://www.unep.org/geo/yearbook/yb2009/significant_map


In early 2008, researchers discovered more than 250 plumes of methane bubbling up along the edge of the continental shelf northwest of Svalbard.
In September, Arctic sea ice shrank to its second-smallest extent since satellite measurements began in 1979.
The International Siberian Shelf Study reported elevated methane concentrations offshore from the Lena River delta.
In July, a large number of strong thunderstorms with heavy rain, tornadoes, and hail storms struck Germany, with some casualties and significant damages.
Errata in Progress
Severe winter storms affected over 78 million people in southern and central China in January/February 2008.
Early in the year, Central Asia experienced lowest temperatures in decades.
More than 54,000 infants and young children have sought medical treatment in relation to the melamine-contaminated dairy products in China
4 496 cases, with 22 deaths, of hand, foot and mouth disease occurred since March among infants and young children in Fuyang City, Anhui Province, China.
The first snow in a century fell on Baghdad on January 11 causing deaths of about 50 people and 15 000 animals.
In May, the the Chengdu magnitude 8.0 earthquake hit Sichuan province, China, killing over 69 000 people. It was the nineteenth deadliest earthquake of all time.
In mid June, torrential rains hit southern China, triggering flash floods and mudslides that killed 57 people and resulted in economic losses of about US$4 billion.
Heavy snow and freezing temperatures in January left more than 300 dead throughout Afghanistan.
Northern Nigeria is currently affected by a new outbreak of wild poliovirus type 1, which has begun to spread internationally.
In May, tropical cyclone Nargis swept through the Irrawaddy delta and Myanmar's largest city Yangon, bringing with it heavy rain, strong winds, and a storm surge. It was the world's worst 2008 disaster, with more than 140 000 persons missing or dead and millions of lives affected.
In June, typhoon Fengshen created havoc in the Philippines. Among other tragedies, it was responsible for capsizing a ferry with 800 people on board.
January post election unrest in Kenya resulted in humanitarian crisis with 250 000 displaced citizens and damage to infrastructure and conservation schemes.
In DRC's Virunga National Park, rare images were relased in September of the Okapi – a shy animal related to the giraffe with zebra-like stripes on its rear. It is so elusive that it was once believed to be mythical.
The Sumatran Muntjac, a lost species of deer, has been re-discovered in the remote mountains of western Sumatra, Indonesia some eighty years after it was last seen.
2008 saw an alarming increase in rhinoceros poaching in Zimbabwe; rhino horns bring high prices as an aphrodisiac.
Dry conditions in south-eastern Australia reinforced long-term drought over much of that region, with Victoria having its ninth-driest year on record.

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Resource Efficiency

Industrial and environmental mismanagement is not a necessary component of development. Tools to minimize overexploitation and pollution are available. Using principles of industrial ecology, such as life cycle analysis and industrial symbiosis, can serve the public good and cultivate healthy communities.

Steam pipes from a power plant and ethanol upgrading facility for reuse at the Kalundborg Symbiosis Industrial zone in Denmark. *Source: Ove Andersen*

INTRODUCTION

We are consuming more than nature can regenerate and we are producing wastes faster than Earth's systems can process. Studies released in 2008 reinforce the message clearly: Human consumption of Earth's resources outstrips the planet's capacity to regenerate by about 30 per cent (WWF 2008). As a result of continuing population growth and increasing material demands in many parts of the world, this ecological deficit is amplified each year.

The fundamental problem stems from the way we mismanage our system of production and consumption—resulting in natural resource depletion, material waste, pollution, and climate change. A significant transformation in the patterns of production and consumption, including innovative technologies and dramatically improved resource-use efficiencies, will be needed if we are to avoid driving the resource deficit ever closer to the tipping point of ecosystem collapse at regional and planetary scales (IEA 2008a).

Improved resource efficiency is also essential for achieving the sustainable development and economic wellbeing called for in the Millennium Development Goals (MDGs). MDG 7, for example, defines the four targets for ensuring environmental sustainability—reversing the loss of environmental resources, reducing biodiversity loss, increasing access to safe drinking water and basic sanitation, and improving the lives of at least 100 million slum dwellers. Each one of these targets will require resource efficiencies to succeed.

Box 1: A rich vocabulary for components

There are a number of definitions used for different approaches and aspects of resource efficiency. Here are a few explored in this chapter:

Industrial ecology is the shifting of industrial processes from open loop systems with resources and capital emptying from the system to become waste, to a closed loop system where wastes become inputs for new processes.

Industrial symbiosis is the flow of by-product resources among one or more industrial actors to conserve resources. It is a subset of industrial ecology, with a particular focus on material and energy exchange.

Biomimicry is the science that studies nature's models, systems, processes, and elements and imitates or takes creative inspiration from them to solve problems presented by unsustainable practices.

Life cycle analysis involves compiling an inventory of environmental exchanges and impacts over the lifetime of a product with the objective of minimizing them.

Dematerialization is the absolute or relative reduction in the quantity of materials required to serve economic functions in society.

Source: UNEP 2008, SCORE 2008, Ausubel and Waggoner 2008

Improving resource efficiency requires not only improved technology, but also new frameworks and new behaviours on the part of governments, businesses, and civil society. It means more than cutting emissions from the 'low hanging fruit' in easy sectors or re-designing obviously inefficient processes. Fortunately, opportunities exist to adopt sustainable consumption and production practices, allowing the goals of development, increased economic wellbeing, and improved environmental stability to be achieved in concert. It will require significant oversight and conscious, coordinated efforts, but the potential benefits of action far outweigh the risks of continued complacency (**Box 1**) (**Figure 1**).

DOING MORE, WASTING LESS

Depending on the level of economic development, trade patterns, and industrial structures, growth rates and extraction intensities vary among three regions: the countries of the Organisation for Economic Co-operation and Development (OECD); newly industrialized countries such as Brazil, Russia, India, Indonesia, China, and South Africa; and the rest of the developing countries. Strongest growth and extraction intensities are expected in the newly industrialized countries, while the share in total global resource extraction in OECD countries will shrink. This surge of resource use intensity is rooted in the rising expectations of growing populations as emerging economies influence world markets (OECD 2008, IEA 2008b). These expectations challenge the requirements for resource efficiencies in building construction and use, in transportation, in food production, and in water use.

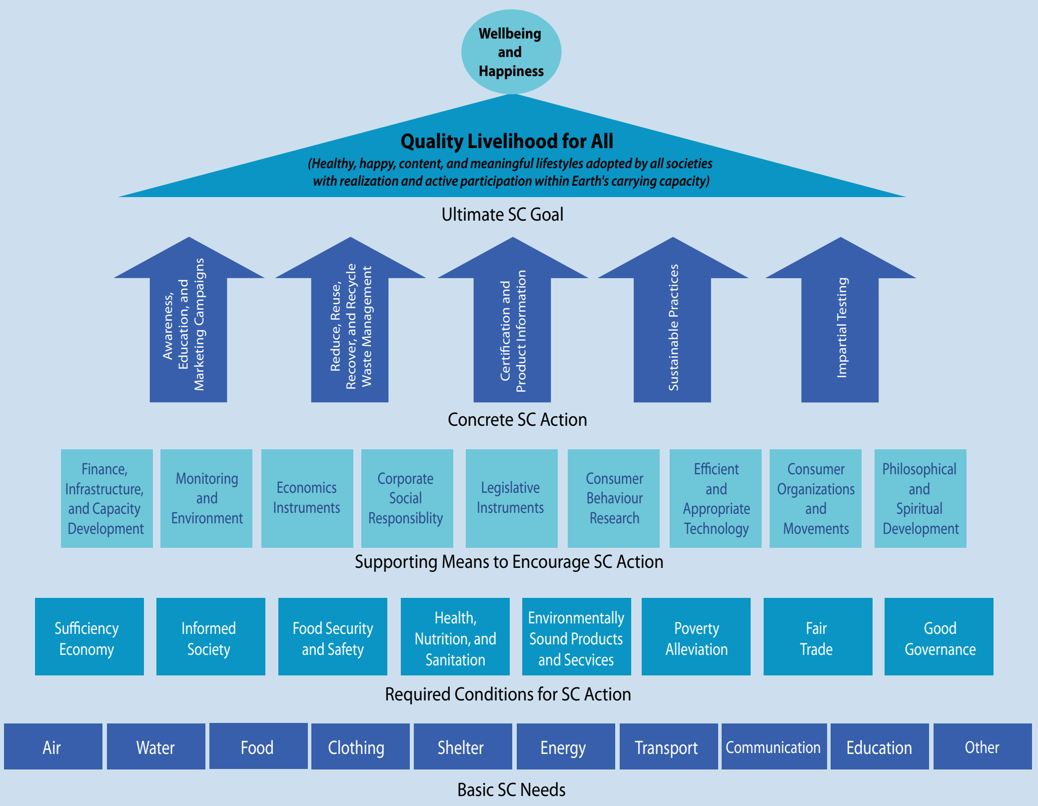
Over two billion tonnes of waste were dumped throughout the world last year. Rich countries are the most wasteful, with each person throwing away 1.4 kilogrammes of solid trash every day, but this has levelled off in recent years as some citizens try to create less waste and recycle more.

As poorer nations develop, they are expected to produce more waste. In 2004 China surpassed America as the largest producer of rubbish: By 2030 it will be churning out nearly 500 million tonnes a year (Medina 2007) (**Figure 2**).

Built environment

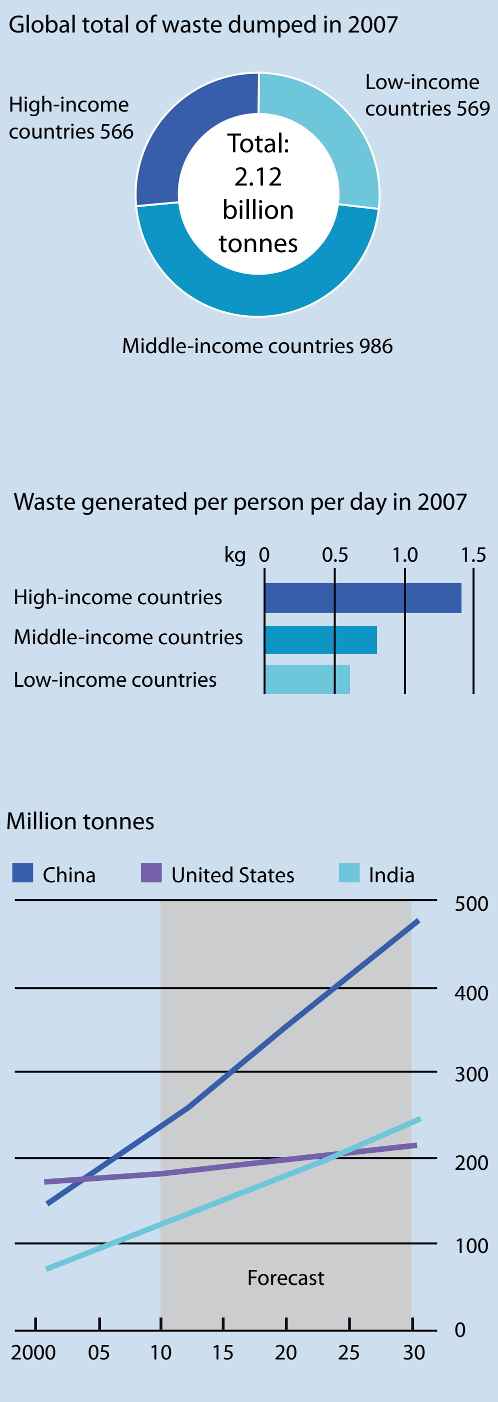
The built environment—including buildings, roadways, and other structures, as well as the energy and materials used to produce and run them—accounts for a large portion of primary material use and for 30 to 40 per cent of the total energy use in developed economies (WBCSD 2007). Efforts to improve resource efficiency in the building sector must consider construction materials and methods; energy-consuming installations such as lights, fans, and pumps; and products that influence energy use, including windows and insulation.

Figure 1: Model to achieve sustainable consumption in Asia



Source: Centre for Environment and Development 2008, de Zoysa 2007

Figure 2: What a waste



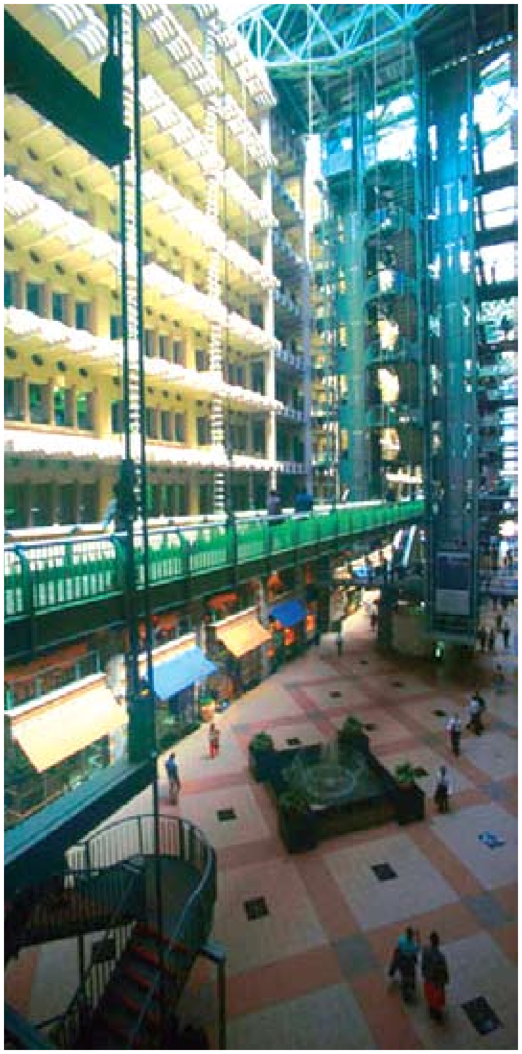
Source: Medina 2007

Biomimicry principles were famously applied to the built environment in 1996 by architects and builders who modelled the Eastgate Building in Harare, Zimbabwe on the self-cooling systems of termite mounds. The design derived from the observation of compass termites building wedge-shaped towers that always point north. This allows the broad sides to capture heat in early morning and late day while the point of the wedge exposes only a small surface to the mid-day sun. All surfaces contain ventilation holes. As the air inside warms, it rises and exits through upper holes, creating an automatic draw of cooler fresh air through lower holes. The Eastgate Building uses a passive cooling system that operates on the same principles and is complemented by other features such as broad window overhangs (Webb 1994). Since it opened, the commercial structure with 5 600 square metres of retail space, 26 000 square metres of office space, and parking for 450 cars used an average of 90 per cent less energy than other buildings of similar size—saving more than US$3.5 million in air-conditioning costs alone (Biomimicry Guild 2008).

Applying resource efficiencies in construction has become a global phenomenon. In a worldwide survey, an average of 32 per cent of construction industry professionals across all regions estimated that more than 10 per cent of domestic construction output is already moving towards resource efficiencies. A further 53 per cent of respondents said they expect to be dedicated to these principles on more than 60 per cent of their projects in the next five years. (McGraw-Hill Construction Analytics 2008). Several countries, including Canada, France, and the United Kingdom, have initiated programmes to make the built environment energy neutral—while occupied, the buildings should generate as much energy as they consume (WBCSD 2007).

Construction waste is also a challenge for improving resource efficiency. In the United Kingdom alone, the construction industry consumes more than 400 million tonnes of material each year and is responsible for nearly 120 million tonnes of waste from demolition, excavation, and construction—this makes up about one third of the UK's total waste production (WRAP 2008). An estimated 25 million tonnes of construction waste, with a potential value of nearly US$2 billion, ends up in landfill without any form of recovery or reuse. In October 2008, the UK's Waste & Resources Action Programme launched a voluntary industry agreement aimed at reducing construction waste by 50 per cent by 2012 (WRAP 2008).

Many buildings last for at least a generation, so it is important to improve construction standard efficiencies in the built environment before business-as-usual practices produce a new generation of resource wasting buildings. Rapid expansion of the construction sector in developing



The Eastgate Building is designed to optimize climate comfort through the use of methods based on models from nature.

Source: Mick Pearce

countries, projected to double existing floor space by 2030, makes it critically important to adopt sustainable products, systems, and materials (**Box 2**) (IEA 2008b). Governments can establish building codes that require a large-scale shift to sustainable construction practices, to solar power

Box 2: Material improvements for the built environment

Concrete is the most common construction material in the world: Global production reaches about 2.35 billion tonnes per year—one solid cubic metre for every person on the planet. Concrete is only water and calcium-based cement mixed together with gravel or crushed stone. But making the cement is a high temperature, often coal-fired, process. It involves cooking calcium carbonate, or limestone, in a kiln until it burns at about 1000° Celsius, releasing large amounts of carbon dioxide both from the heating process and from separating out the desired calcium oxide compounds. All told, cement production worldwide contributes about five per cent of total global CO_2 emissions (See Chapter Three, Climate Change).

Strong, long-lasting, mouldable and relatively inexpensive, the concrete that cement makes possible is an ideal construction material—except for the CO_2. Given its widespread use and significant emission contribution, cement production is a key target for mitigation efforts, including resource efficiency initiatives, modified production protocols, and substitute materials. If CO_2 emissions from cement could be reduced by even 10 per cent, one-fifth of the Kyoto Protocol goal of an overall reduction in emissions of 5.2 per cent would be reached.

Cement's strength and durability are due to its core calcium-silicate-hydrate particles' tendency to organize naturally into the most densely packed structure possible for spherical objects. As one example of material substitution, researchers at the Massachusetts Institute of Technology in the USA are currently attempting to design an alternative mineral with the same packing density that does not require high-temperature firing. They are particularly interested in using compounds of magnesium, a waste material of many other industrial processes.

Another substitution in the basic cement recipe has potential to mitigate another persistent environmental problem—coal ash disposal (See Harmful Substances and Hazardous Waste, Chapter Two). Concrete that incorporates coal ash—the inorganic particles captured from the smokestacks of coal-fired power plants—has the double benefit of using what otherwise would be waste, without requiring additional burning. Newer geopolymer concrete substitutes, based on silicon and aluminium from coal ash and iron slag, could cut CO_2 emissions from cement production up to 20 per cent of their current values and utilize an industrial waste, while also providing a product less prone to chemical weathering.

Sources: Worrell and others 2001, Constantindes and Ulm 2007, IPCC 2007, CSI 2008, Climate Change Corp 2008, Geopolymer Institute 2008

Solar water heaters are getting popular in Ho Chi Minh City, Vietnam. The Vietnamese government set up a programme in 2008 that subsidizes part of the installation costs of solar water heaters, supporting local manufacturers as well as saving 57 million kWh or 4 900 tonnes of oil equivalent per year. *Source: Dong Ngo/ CNET.com*

for heating, to compact fluorescent lighting, and to the most energy efficient household appliances and office equipment (IEA 2008b).

Transportation: smarter and more rational

The transportation sector is uniquely dependent upon liquid hydrocarbon fuels, as a matter of both practicality and design tradition (IEA 2006). In 2006, transport accounted for 23 per cent of world energy-related CO_2 emissions (IEA 2008b).

Anticipated growth in transport and associated pollution comes from two factors, increased use of private motor vehicles in developing countries and increased international transport of both passengers and freight. A survey of recent studies shows that automobiles and other private motor vehicles account for about 80 per cent of transport-related environmental degradation—despite major improvements in environmental performance in recent years (Tukker and others 2006). In addition to the familiar direct costs of increased use of motor vehicles—respiratory problems, traffic accidents, noise, and emissions—indirect costs from traffic volume and congestion include lost productivity (WBSCD 2001). Estimates indicate that there were 650 million vehicles on the road in 2005, a number that is predicted to more than double by 2030 (IEA 2008b).

In 2005, the American Society of Civil Engineers predicted that transportation infrastructure would be one of the great challenges of the 21st century and that single fix approaches—new technologies, new fuels, new pricing mechanisms, or new policies—would not solve urban transportation problems (ASCE 2005). The complexity of the problem suggests that sophisticated problem-solving approaches and new business models are needed for the transportation sector. If more people and products can move efficiently to their desired destinations using less materials and less fuel per capita while producing less pollution, resource efficiencies are achieved (**Box 3**).

One intriguing application is the Sustainable Mobility and Accessibility Research and Transformation initiative (SMART) based at the University of Michigan in the United States. It is partnering with diverse stakeholders to improve urban infrastructures in Bangalore and Chennai in India, nine cities in South Africa, and in several US cities. The initiative's strategy is to promote public transportation by creating hubs that facilitate the onward flow of individuals through the most efficient and environmentally sound means possible (Zielinski 2008).

Box 3: Renting transport

Commuters in Paris, France have adopted the Vélib bicycle rental scheme with enthusiasm. Since the programme began in July 2007, the number of available bicycles doubled to 20 000 available at 1 400 sites. That success has inspired a new programme offering an automobile equivalent. In June 2008 the city's mayor announced that the city will place 4 000 small electric cars at 700 Autolib pickup points around Paris and the suburbs starting in 2010. The French railroad company SNCF hopes to operate the Autolib points out of its train stations.

Some critics, however, see the plans as a retrograde step that will simply add to the congestion the Vélib scheme was supposed to be reducing. Others say it will end up being nothing more than a self-driven taxi service.

Advocates say that computerization will ensure users are told exactly where they will be required to drop the cars off, guaranteeing there is always a free space available and eliminating parking issues. There are also plans to integrate payment for the bike and car hire schemes with the ticketing systems for traditional modes of public transport.

Source: Fairley 2008, Appleton 2008

The first phase of the Chennai project focuses on reducing traffic congestion and pollution by targeting the individuals most likely to own personal vehicles and to be technologically adept, the thousands of computer and software industry commuters who travel the same route daily. The railway and bus systems will be equipped with wireless technologies to enable employees to work en route, to improve productivity, and to shorten the commuter's workday. At the stop closest to their workplace, commuters can switch to privately-run low-polluting shuttle buses or taxis, rental bicycles, or walking paths. The project uses the commuters' mobile phones to collect passenger movement data, which is then used to forecast transportation and traffic conditions and needs. Eventually, commuters will be able to use their mobile phones to check current conditions on any aspect of the system and choose the most efficient mode and route of travel (Cherubal 2008).

The SMART project in South Africa is, in part, an effort to deal with transportation challenges anticipated for the FIFA World Cup in 2010. But it is also intended as a legacy to improve living and working conditions for South African citizens into the future. The SMART project hopes to contribute to reducing poverty and unemployment by providing affordable and accessible public transport (South African Department of Transport 2008).

Aviation efficiency represents a special case in transportation. Each year, more than 30 million flights take to the skies (WTO 2006). Aviation accounted for 11 per cent of world transport emissions in 2006 and contributed less than two per cent of total greenhouse gas emissions (IEA 2008b, IPCC 1999). At present, air transport emissions represent a relatively small contribution to global warming but their impact is stronger because harmful emissions enter upper layers of the atmosphere directly (Kimber 2007).

Recent increases in public concern, the largely discretionary nature of air travel, and the fluctuations in fuel prices have combined to put resource efficiency at the top of the agendas of the aviation industry. Airplane manufacturers are testing algae-based bio-fuels, while airline companies are optimizing altitudes and flight plans to reduce jet fuel consumption. Early retirement of low-efficiency aircraft will also play an important role, particularly as new aircraft should be 50 per cent more efficient per passenger per kilometre. These are positive initiatives, but most will make a difference only in the medium to long term and the overall scale of possible improvements remains questionable (IEA 2008b).

Some stakeholders in the aviation industry argue that quicker results could be achieved by allowing consumers to make more informed choices when purchasing tickets. In the early years of the 2000s, 20 per cent of aviation capacity flew empty and company-specific use of aircraft resulted in multiple planes flying similar routes, particularly in Europe. Moreover, indirect flights emit nearly 30 per cent more CO_2 than direct routes because of multiple take-off and landing procedures. As much as 9 per cent of total trip emissions can be produced during taxi to and from the runways; significant savings in jet fuel and emissions could also be realized by using tug vehicles. For the most part, these inefficiencies are unknown to travellers. Eco-labelling on airline efficiencies would allow flyers to make routing choices that would ultimately steer the market toward more efficient practices (Kimber 2007).

In reality, even these measures may have limited impact. The number of commercial aircraft is expected to rise from 18 000 in 2006 to 44 000 by 2030. The increase in volume of traffic could potentially offset any efficiency gains (IEA 2008).

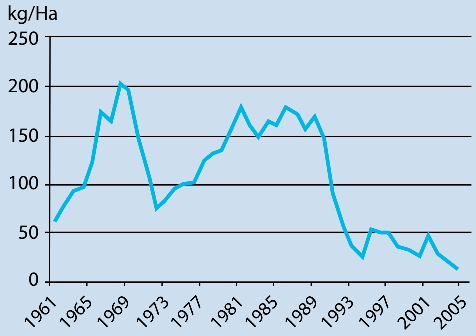
Food: A world of difference across the food supply chain

Modern agricultural systems use more energy to produce food than the food energy that is produced (Stout and Best 2001, FAO 2003). Meat and meat products have the greatest environmental impact: The estimated contribution of meat products to global warming is in the range of 4 to12 per cent of all food products (Tukker and others 2006). Civil society, companies, and governments around the world are already taking steps to improve resource efficiency in the food supply chain (See Ecosystem Management, Chapter One).

As the world rethinks a new and more sustainable model for agriculture and food security, it can draw crucial lessons from Cuba's recent past. In the wake of the Soviet Union's break up in 1991, Cuba has taken a radical departure from large-scale conventional monoculture systems to the wholesale de-industrialization of food and farming systems. Previously, the nation's agricultural production was largely dependant on imported and heavily subsidized inputs of petrochemical fertilizer, pesticides, fuel, and advanced machinery (Raffensperger 2008, FAO 2003). In the year preceding the Soviet Union's final break-up, Cuba suffered an 80 per cent loss in its trade and the sudden disappearance of nearly 1.3 million tonnes of fertilizer, causing agricultural production to drop by half (Ewing 2008). The collapse catalyzed an important paradigm shift away from heavily subsidized agricultural production systems towards integrated pest management and organic, low-capital, small-scale farming systems (**Figure 3**) (See Harmful Substances and Hazardous Waste, Chapter Two).

A new study confirms that Cuba, against all odds, managed to avoid its own food crisis by launching a semi-organic urban agricultural revolution. The results of the study, which represents the first systematic and empirical research on Cuba's radical agricultural transformation, revealed valuable insight into the institutional structures and widespread changeover in management dynamics that were required (Wright 2008). Today, Cuba enjoys a thriving and virtually self-reliant system of agricultural production. As a side benefit Cubans have also become leaders in soil conservation,

Figure 3: Synthetic fertilizer use in Cuba



Cuba was compelled to give up the use of artificial fertilizers after the Soviet Union broke up.

Source: Earth Trends 2008, FAOSTAT 2008 organic farming methods, biopesticides, and worm composting (Wright 2008). By challenging the conventional globalized and privatized food security strategies—even if it was from circumstantial necessity rather than choice—Cuba has effectively broken the policy barriers that seem to inhibit the adoption and mainstreaming of a sustainable eco-agriculture system.

FROM CRADLE TO GRAVE

Life cycle analysis—compiling an inventory of environmental exchanges and impacts over the lifetime of a product—is a key tool in industrial ecology. Traditional life cycle analysis considers three processing stages from 'cradle to grave': cradle to entry gate, the raw material extraction and refining; entry gate to exit gate, product manufacture; and exit gate to grave, product use and disposal (USEPA 2003). An industrial ecologist examines each of the processing stages to consider how to introduce efficiencies.

Until recently, both industrial ecology and life cycle analysis were applied primarily to industrial processes. Now there is increased recognition that they apply to the overall supply chain of material goods: mineral resource extraction and refining are energy intensive and are prone to releases of gas, liquid, and solid by-products that can either pollute or serve as raw materials for other processes. Applying industrial ecology and life cycle analysis to mining and mineral processing is a logical step (Pearce 2007).

Of all the materials currently used by society, metals have the greatest potential for unlimited recycling. The durability and recyclability of metals reduce their total life cycle impact, sometimes to below that of non-metallic materials. In theory, metals have an unlimited lifespan, but they are non-renewable and the supply is finite. Analyses suggest that we may be reaching a point at which detecting metal left as waste on earth's surface for recycling may be economically competitive with primary extraction (Gerst and Graedel 2008).

A recent cradle to exit gate life cycle analysis of six widely used metals—copper, nickel, lead, aluminium, titanium, and steel and stainless steel—reveals trends that warrant careful consideration in relation to resource efficiency strategies. Light metals, titanium and aluminium, had the greatest cradle to exit gate environmental impacts in terms of gross energy requirements, global warming potential, and acidification potential; steel and lead had the lowest impacts in these terms. Nickel and copper had the greatest impacts in relation to solid waste burden, which includes mining waste, tailings, slag, and power station ash (Norgate and others 2007) (See Harmful Substances and Hazardous Waste, Chapter Two).

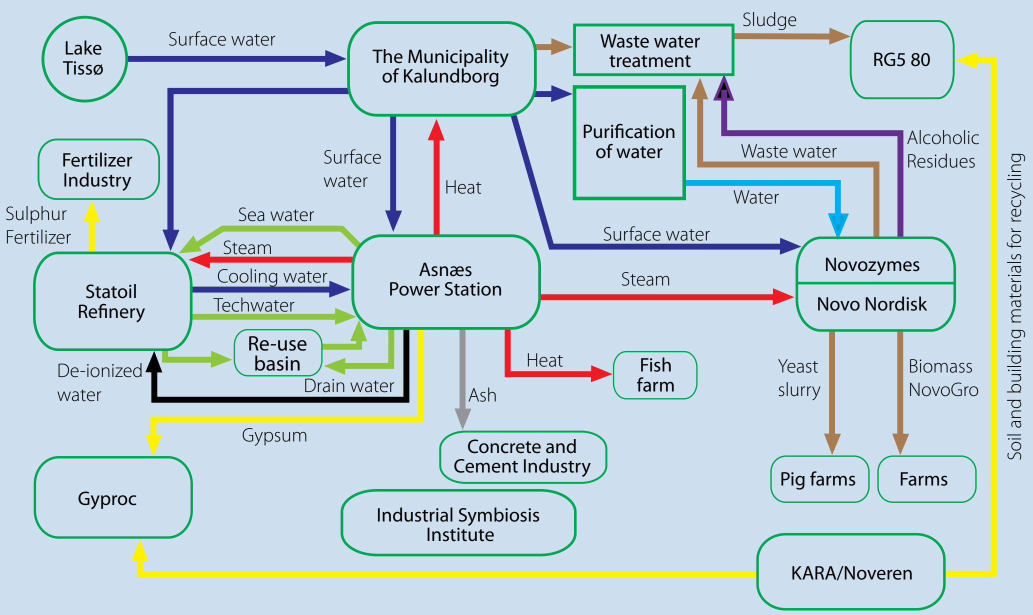
Experts anticipate that as demand for raw material increases, high grade ores will become depleted and the environmental impacts associated with extracting and processing lower grade ores will rise. Thus, it may become necessary to re-assess existing cradle to grave analyses. In the future, it may be more resource efficient to replace the high-impact light metals with lower impact heavier metals in some products, especially those products that are not modes of transport (Norgate and others 2007).

Dematerialization

Some of the efficiencies an industrial ecologist might look for when examining processing stages involve dematerialization: What isn't necessary and what can be left out? But dematerialization occurs outside the formal life cycle analysis by recognizing unlooked for efficiencies under changing conditions or by rethinking a process when a resource becomes expensive. Dematerialization also results when informed buyers exercise the option to demand some product or service that consumes less material. Turning down the offer of packaging communicates disdain for unnecessary consumption of material. Dematerialization may also result from decisions by a producer who supplies the demand for less consumption. A manufacturer of unbleached cotton uses fewer resources and could charge a higher price. The objective is to get more for less and some researchers propose that dematerialization may be the key to decoupling development from environmental degradation and to achieving an environmentally sound economy (Ausubel and Waggoner 2008).

Another consideration an industrial ecologist might look for in life cycle analysis is opportunities

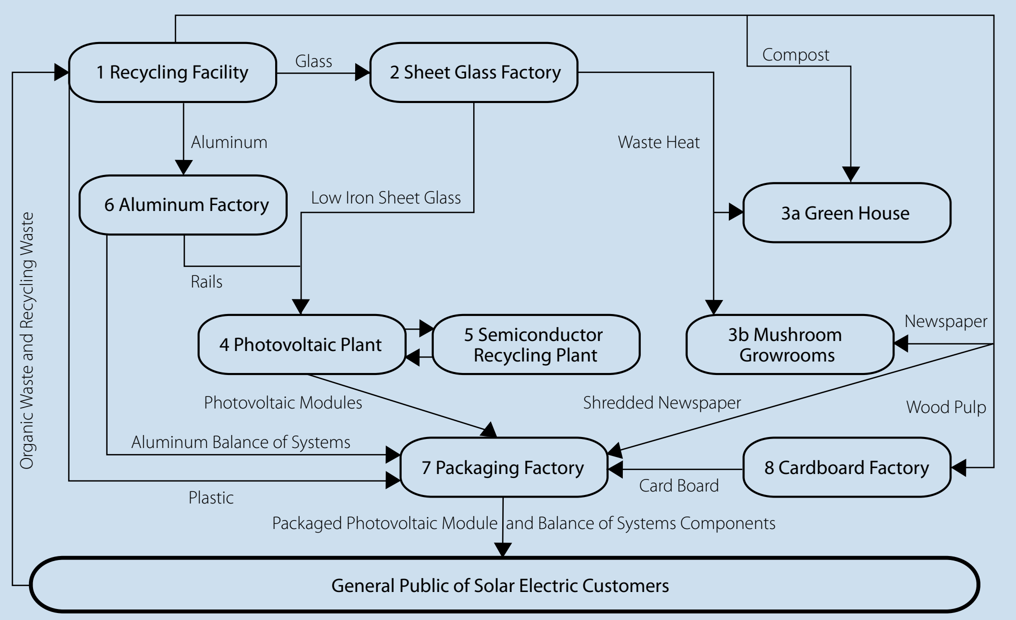
Figure 4: Industrial symbiosis in Kalundborg, Denmark



Innovative waste management through Industrial Symbiosis network in Kalundborg, Denmark. More than 25 symbiosis processes are currently active—some have been operating since 1983.

Source: Ove Andersen

Figure 5: Industrial symbiosis for environmentally sound production of photovoltaic modules



Designing manufacturing loops according to industrial symbiosis principles could make new technologies more environmentally sound. A system integrating the processes in eight factories could be an economically feasible medium-term government investment to promote broader implementation of photovoltaics as energy sources.

Source: Pearce 2008

for by-product symbiosis—using industrial wastes from one process to supply raw materials to another process. This industrial symbiosis attempts to close loops within one company or among several companies (**Figure 4**). In the United Kingdom, the National Industrial Symbiosis Programme involves more than 8 000 participant companies and has diverted more than 4.1 million tons of business waste from landfills. The programme has eliminated 351 000 tonnes of hazardous waste from the environment, saved 9.3 million tonnes of water, and avoided the use of 6.34 million tonnes of virgin material (See Harmful Substances and Hazardous Waste, Chapter Two). It has reduced carbon emissions by 4.6 million tonnes, generated US $208 million in new sales for members and saved them nearly US$170 million (NISP 2008). Many cities, including Chicago and Shanghai, have recently adopted similar industrial symbiosis projects, typically involving both public and private sector participants (**Figure 5**) (Managan and Olivetti 2008).

WATER: URGENT NEED FOR BETTER SYSTEMS

For the first time in 2008, the Living Planet Report includes new measures of global, national, and individual water footprints (WWF 2008). The report states that, on average, each person in the world consumes 1.24 million litres of water each year. But the disparities are enormous: Per person consumption in the United States is double the average, 2.48 million litres per year, while individual consumption in Yemen is about half this amount at 619 000 litres per year. The OECD Environmental Outlook 2008 projects that by 2030, 3.9 billion people will live in areas under severe water stress, mostly in South Asia and China (OECD 2008). This will be an additional one billion people over the number living under severe water stress today. In most developing countries, particularly in rural Africa and Asia, the demand for water simply exceeds what is available.

A major report released in 2008 confirms the probability of a looming water crisis—if current food production and environmental trends continue (See Ecosystem Management, Chapter One; Climate Change, Chapter Three; and Disasters and Conflicts, Chapter Four). For many, the calamity has already arrived. Today, 879 million people, the majority in rural areas, lack adequate access to clean water and 2.5 billion people are without improved sanitation in their homes (Serageldin and Masood 2008). If current trends continue, any hopes we have to avert a full-scale water crisis will require urgent strategies to reform water policies, particularly in relation to agriculture which accounts for 70 per cent of water withdrawals worldwide. The most pressing need is to improve food production wherever rain falls and thus to improve water productivity (Serageldin and Masood 2008).

Current approaches to water policy focus on allocating withdrawals and managing run-off water flows, considered as surface flow in rivers, lakes, wetlands, aquifers, groundwater, and constructed storage facilities (Röckstrom and Barron 2007). In reality, rainfall that infiltrates and remains in soil sustains 80 per cent of the world's agricultural land and generates 60 to 70 per cent of the world's food (Serageldin and Masood 2008). In the absence of any form of rain water management, vast numbers of small-hold farmers are engaged in a high-risk, weather-dependent business. In sub-Saharan Africa, more than 95 per cent of agriculture is rain fed; in India, approximately 60 per cent of agriculture is still rain fed, despite recent irrigation development (Röckstrom and Barron 2007). In many of these areas, lack of water at critical points in the

Women in Masai Mara, Kenya, next to their rainwater tank. Rainwater harvesting is a simple and low cost technique that has been practiced for hundreds of years. Africa has very low water storage per person per year which is inadequate for sustaining livelihoods depending mostly on agriculture. *Source: Elizabeth Khaka/UNEP* growing season creates chronic gaps in crop yield—average savanna grain yields are about 25 per cent of estimated yield potential. Low yields and frequent crop failures prompt farmers to focus on minimizing risk rather than maximizing yield. They are also disincentives to investing in more effective techniques or technologies. According to a 2008 assessment by the International Water Management Institute, in the absence of a drastic increase in water productivity, particularly with respect to rain-fed agricultural crops, the world will require approximately twice the current supply of water by 2050 (Molden 2008).

Mathematical modelling and on-farm studies demonstrate that integrated approaches to farming, coupled with capture of rainwater for supplemental irrigation, can significantly increase plant water availability and plant water uptake capacity (Röckstrom and Barron 2007). In semi-arid parts of southern India, adding just 50 millimetres of supplementary irrigation to mitigate dry spells resulted in crop yield increases of 70 to 120 per cent (Sivannapan 1992). In Mwala, Kenya, increasing rain water retention in rain fed maize systems provided a 40 per cent increase in yield; supplemental irrigation in combination with other practices provided a 50 per cent increase in yield over a five-year period compared to current practices (Röckstrom and Barron 2007).

More research is needed to better understand crop, soil, water, and atmosphere relations in rain-fed systems, but early work suggests that the largest productivity gains can be achieved in the lowest yield range (Serageldin and Masood 2008, Röckstrom and Barron 2007). Thus, water policies that improve rainwater access throughout the growing season, perhaps through investment in water storage containers, could ultimately increase both yields and livelihoods in a sustainable manner.

Another area that is in need of greater specificity of research involves the usage and treatment of toxic wastewater (**Box 4**). In developing countries, urban wastewater is an important source of water for irrigation and if properly treated, it can have a significant impact on reducing fertilizer costs (Serageldin and Masood 2008). However, if left untreated, urban wastewater which contains heavy metals, can find its way into the food chain and contribute to serious health problems including skin disorders and diarrhoeal infections (See Harmful Substances and Hazardous Wastes, Chapter Two). A recent study examining wastewater in 53 cities in Africa, Asia, Latin America, and the Middle East found populations in 80 per cent of cities surveyed are consuming food grown with contaminated wastewater (Raschid-Sally and Jayakody 2008). And while policymakers in developing countries are well aware of this reality, very little is being done (Serageldin and Masood 2008).

Box 4: Improving water management in industries

While industrial use of water is much lower than that of agriculture, it increases with country income, going from 10 per cent of national consumption in low- and middle-income countries to 59 per cent in high-income countries. Several OECD countries have managed to decouple water use from economic growth, largely through better technologies and general awareness about the need to conserve water. Over the medium term, promoting more water-efficient industrial processes represents the best opportunity for water saving. Thus, governments need to take steps to improve efficiency, encourage waste water reuse, and collection and use of rainwater.

Case studies published by the World Business Council for Sustainable Development demonstrate that diverse industries can realize significant water savings in production processes. A modern paper mill in Finland switched from chemical to thermo-mechanical pulp and installed a biological wastewater treatment facility; these initiatives have helped the company reduce water consumption by more than 90 per cent over the past 20 years. A textile manufacturer in India began using zinc rather than aluminium in synthetic fabrics and cut water consumption by 80 per cent while also providing cleaner wastewater reused for irrigation by local farmers. A Mexican sugarcane plant improved housekeeping and separated process water from sewage water, realizing a 90 per cent savings in water consumption.

When Spanish company Obrascon Huarte Lain S.A. (OHL) won the franchise to manage 300 km of highways in Brazil's São Paulo State, it set out to do so in a way that would mitigate the roadway's impact on the world's largest aquifer. Estimated to contain more than 40 000 km^3 of water, the Guarani aquifer extends more than 1.2 million km^2 beneath the borders of Brazil, Paraguay, Uruguay, and Argentina. OHL designed the roadways to direct water toward 520 containment dams along the highway network with a total storage capacity of 2 million m^3. This system slows the speed of run-off water, allowing it to seep slowly into the ground and replenish the aquifer. OHL realizes no profit from the dams, but saves significantly in terms of reduced road maintenance and the avoidance of major washouts.

Source: Molden 2008, WBCSD 2008

CONSTRUCTIVE PROGRESS

In its *Action Plan for Sustainable Consumption and Production*, the Sustainable Consumption Research Exchange network raises five questions that would have been considered controversial before the current economic crisis and modern environmental consciousness (SCORE 2008):

- Is the market system fundamentally flawed?
- Should we be striving for de-growth?
- How can markets contribute to fairness and equity?
- Should we accept consumer sovereignty if it is harmful to the environment or society as a whole?
- How can we realize development aspirations in dematerialized ways?
- How can we maintain fair balance among business, consumers, and government?

An approach known as the sufficiency strategy or the 'economics of enough' focuses on dramatically reducing overall consumption by convincing producers and consumers to act in relation to need, rather than desire. As it is unlikely that this level of altruism will spontaneously arise among consumers, proponents argue that governments need to take radical steps to influence the behaviour of producers and and consumers (Alcott 2008).

China steps up to the challenge

In 2008, China's National People's Congress adopted the Circular Economy Law of the People's Republic of China—scheduled to come into effect on 1 January 2009. A circular economy (CE) promotes industrial symbiosis and exchange of material as opposed to straight-out consumption (Pintér 2006).

This new construct defines the responsibilities of various administartive levels in relation to promoting CE, as well as their power to address non-compliance. It calls on all parties to engage in activities that promote CE, effectively making everyone a stakeholder and a steward (Squires and others 2008).

To complement these efforts, China is developing a labelling system to indicate the resource consumption level of products and will issue a catalogue that assigns techniques, equipment, materials, and products to one of three categories—encouraged, restricted, or eliminated.

When items from the eliminated list are used, the government can confiscate equipment or material, impose fines up to US$30 000 or shut down an enterprise. If eliminated items are imported, they must be returned and a fine of up to US$150 000 can be imposed. If the importer is unidentified, the carrier can be made responsible for returning the goods or paying the relevant disposal costs. No financial institution may provide any form of credit to support enterprises that produce, import, distribute, or use items on the eliminated list.

International legal analysts acknowledge the significance of the law in announcing China's pursuit of sustainable development. However, if it remains only a policy statement, it will have little actual effect. Major challenges include no specific time-frame for enacting CE measures. As well, it is generally assumed that the provincial and local governments will continue to favour development over the environment—and stifle grassroots efforts that challenge their authority (McElwee 2008).

If China is successful in implementing the CE concept, it could set new standards for productivity and competitiveness on the global scale (Pintér 2006). To assess whether China is achieving its CE aims, China's National Development and Reform Commission is working with various agencies to develop an appropriate set of indicators to measure energy and material flows. These indicators will improve understanding of two aspects of the CE system—the aggregate environmental impact of material production and consumption and the physical efficiency with which the economy transforms raw materials into useful products with minimum waste (Pintér 2006).

The CE model sees the economy as embedded in Earth's biophysical and geophysical systems and acknowledges that the economy is doubly dependent upon them. First, for securing the necessary raw materials needed for production, and second, for absorbing or processing waste that results from production and consumption (McElwee 2008, Ayers and Simmons 1994, Robert and Eriksson 1991).

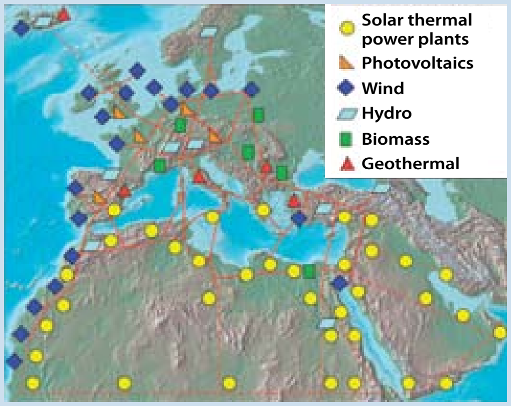
CONCLUSION

Living sustainably requires that we manage resources on nature's terms and at nature's scale (WWF 2008). This implies that decisions in each sector must be taken with consideration of the broader ecological consequences and that human beings must find ways to manage resources across man-made boundaries—across property lines and political borders—to cultivate ecosystem health as a whole.

Human beings, human societies, and the human economy are entirely integrated into the economy of the Earth's systems—the geosphere, the biosphere, the atmosphere, and the ecosystems that knit it all together. If we can learn how Earth systems function to produce resources and recycle subsequent by products, we can learn to live with nature rather than struggle against it (**Box 5**).

The Chinese dyke-pond system evolved over the past two thousand years, perfected by generations of farmers into a circular economy of intensive agriculture integrated with the culture of carp and other freshwater fishes. It depends on maximizing internal inputs between land and water, optimizing the efficient use of resources, and minimizing wastes. *Source: M. Harvey/ Still Pictures*

Box 5: Powerful Earth systems



An integrated multisource power grid envisioned for North Africa, the Middle East, and Europe *Source: TREC*

In 2000, global wind-energy potential was about 72 000 gigawatts—nearly five times the world's total energy demand and seven times its electricity demand. In one hour, enough solar radiation falls on the Earth to supply a year's consumption by the human species. Looking at the big picture makes our energy worries seem trivial perhaps—the challenge is to literally harness that power.

Wind and solar power are attractive because they are renewable sources of energy. They aren't subject to scarcities and to the machinations of cartels: Once the turbines, the mirrors, or the panels have been installed, the only fuel they consume comes directly from nature. The only sources of pollution, whether greenhouse gas emissions or production of harmful substances, originate in their manufacture. This Resource Efficiency chapter has shown how principles of industrial ecology such as biomimicry, symbiosis, and dematerialization—as demonstrated by the Eastgate Building ventilation, the environmentally sound manufacture of solar panels, and the use of excess heat to maintain fish farms in Denmark—can serve energy efficiency. They can also serve energy production.

The Sahara desert could become a reliable source of power for Europe. In November 2007, European Parliament first considered a proposal presented by the Trans-Mediterranean Renewable Energy Corporation to establish a network of renewable power generating sources. Over thirty years, US$400 billion would build power stations in the desert to meet two-thirds of the energy needs of North Africa and the Middle East and much of Europe's energy demand as well, by 2050. In addition to providing power to partner nations and cutting carbon emissions, additional benefits include excess heat for desalination. Each plant of the solar power generating units has to be cooled and using saltwater to do the cooling could desalinate if properly designed, using principles of resource efficiency.

The scheme goes beyond solar power and incorporates wind, hydro, and biomass power generation capabilities as well. A number of evolving conditions draw these visions closer to reality: Climate change is one of the most motivating.

Sources: Archer and Jacobson 2004, Gramling 2008, Economist 2008, TREC 2008,

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Environmental Governance

Human beings, human societies, and the human economy are entirely integrated into the Earth system and into the Earth systems' economy—the geosphere, the biosphere, the atmosphere, and the ecosystems that knit it all together. Governance of that integration is one of the most important challenges of the 21st century

Allotment gardens offer urban dwellers the opportunity to grow their own food. This small allotment in Bavaria lies on the northern bank of the Danube River near the town of Donaustauf. *Source: Klaus Leidorf*

INTRODUCTION

Earth's ecosystems are under threat. Twenty per cent of the earth's land has been significantly degraded by human activity and 60 per cent of the planet's assessed ecosystems are now damaged or threatened. The irrefutable pattern is one of natural resource overexploitation while creating more waste than ecosystems can process (See Ecosystem Management, Chapter One).

The chemicals we use to produce energy, to control pests, to enhance productivity, to catalyze industrial processes, and to meet human health needs—as well as the chemicals we just discard—continue to weaken ecosystems and to imperil human health (See Harmful Substances and Hazardous Waste, Chapter Two).

The changing climate is pushing many Earth systems towards critical thresholds that will alter regional and global environmental balances and already threaten stability at multiple scales. Alarmingly, we may have already passed tipping points that are irreversible within the time span of our current civilization (See Climate Change, Chapter Three).

In recent decades, the growing threat of climate change is demonstrated by a significant increase in the number and severity of storms, floods, and droughts while the average number of seismic disasters, as devastating as they are, remained steady. New and ongoing conflicts can be both the result and cause of environmental degradation. (See Disasters and Conflicts, Chapter Four).

Industrial and environmental mismanagement is not a necessary component of development. Tools to minimize overexploitation and pollution are available. Using principles of industrial ecology, such as life cycle analysis and industrial symbiosis, can serve the public good and cultivate healthy communities (See Resource Efficiency, Chapter Five).

Human beings, human societies, and the human economy are entirely integrated into the Earth system and into the Earth systems' economy—the geosphere, the biosphere, the atmosphere, and the ecosystems that knit it all together. Governance of that integration is one of the most important challenges of the 21st century.

Environmental degradation and industrial development were coupled during the industrial revolution and into modern times, but that relationship is not necessary and it cannot continue. Firm, informed, and enlightened environmental governance is necessary. The economic system that encouraged overexploitation of natural resources and production of waste is undergoing a complete redesign. This is the moment to ensure the next economic system does not repeat the mistakes of over exploitation and pollution.

ACHIEVING THE MILLENNIUM DEVELOPMENT GOALS

The Global Monitoring Report 2008 on progress towards achieving the United Nations Millennium Development Goals 2008 marks the midpoint toward the 2015 deadline for achieving the Millennium Development Goals (MDGs). The report finds that urgent action is needed to combat climate change that threatens the well-being of all countries, but particularly of poor countries and poor people. It also emphasizes that the goals of development and environmental sustainability are closely related and the paths to those goals have important synergies (World Bank 2008).

In the current global economic downturn, questions have arisen about priorities: Will environment and development objectives be lost in the new economic paradigm? But at a United Nations High-level Event held in September, member states re-committed to the MDGs (UN 2008a). In late December, United Nations member states attending a Conference on Financing for Development to Review the Implementation of the Monterrey Consensus agreed that development aid would not be cut in the face of the current recession. At that conference, the European Union vowed that all its members will provide by 2015 the 0.7% of gross domestic income for official development assistance that OECD countries had first committed to in 1970. Since then, only Denmark, Luxembourg, Netherlands, Norway, and Sweden have all met, and actually exceeded, their 0.7% commitment (UN 2008b, OECD 2008). Despite this renewed commitment on the part of some OECD countries, the Millennium Goals may still be severely challenged by imminent environmental constraints—putting even more importance on responsible environmental governance.

Pressures expected to increase

With business-as-usual policies, the proportion of people who suffer from hunger or whose income is less than US$1 a day will not be halved between 1990 and 2015 as expected in the targets set of the MDGs. The rate at which biodiversity is globally being lost will not be reduced by 2010. The impacts of climate change will not remain within agreed limits. The targets for water supply and especially sanitation will be nearly impossible to reach (UNDP 2008, UNFCCC 1992, World Bank 2008).

The environmental limitations ahead are exacerbated by additional pressures: The continuing growth of the world's population, their increasing material aspirations, and the natural resources that are being and will be exploited to satisfy those aspirations have major implications for ecosystem health, land use, and energy consumption.

Box 1: A parable?

In 2007 a story was told in a meeting on migration and the environment: In one country...

"... agriculture is extremely important because of rapid population growth. Women have an average of twelve to sixteen children each, creating a huge strain on the ecosystem in spite of government programs designed to mitigate environmental degradation.

In the past few decades, the trees that grew on agricultural land belonged to the state, so farmers had no motivation to protect trees. After much discussion, the government transferred ownership of the trees to the users and the number of trees multiplied. Now, trees are protected and the people harvest bark, fruits, and other products. The trees, in turn, retain water, moderate the climate, and shelter the agricultural land from erosion.

However, the average number of children per woman negates the productive capacity of the ecosystem. If you look at the environmental improvement in isolation, the area is a model. When you look at the social system, it is difficult to say that environmental improvements are enough. When the dynamic between the two is considered, the situation is revealed as quite critical."

Source: IOM 2008

The challenge is to meet these growing aspirations while ensuring environmental sustainablity (UN 2004, UN 2006a). Projecting population trends and devising methods to minimize the effects of rising population on resources cannot proceed outside of the environmental constraints or remain oblivious to the approaching thresholds that human activities have already provoked.

These aspirations could be met with less material input. The transition towards dematerialization of consumption could help decouple development from resource exploitation and associated environmental degradation (Ausubel and Waggoner 2008).

Advancements in understanding Earth systems

Process patterns that have emerged from system and chaos theories and that have been applied to ecosystems at various scales over the last two decades show the importance of understanding the dynamism of Earth systems.

Part of that understanding involves Earth system and ecosystem tendencies to cross critical thresholds, to shift regime, to oscillate, or to respond to changing conditions by changing phase—sometimes transitioning to phases that are irreversible within time scales relevant to humanity (Scheffer and others 2001).

For instance, Earth's ice is undergoing a classic phase change: ice is ablating—melting into water and sublimating into the atmosphere. Particles that became airborne during Roman Empire lead mining fell on glaciers and are re-entering the environment in melt water runoff today (Branan 2008). If we stopped all greenhouse gas emissions today, that ice might re-accumulate within 50 human generations, if at all. The effects that climate change is having on species distribution and adaptation may bring a similarly radical transition to ecosystems and to their services (**Figure 1**) (See Ecosystem Management, Chapter One).

Researchers of ecosystem change suggest that the likelihood of a regime shift is increased by lower resilience. The approach of a threshold may be anticipated by the observation of a critical slowing in the recovery rate from a small perturbation (Van Nes and Scheffer 2007). This critical slowing down has been demonstrated in a model of thermohaline circulation approaching a critical threshold (Held and Klienen 2004).

Early in 2008 a review introduced the concept of 'tipping elements' into discussions of abrupt climate induced change. Tipping elements are large scale components of Earth systems that demonstrate a possibility of abrupt change, crossing a tipping point (Lenton and others 2008). Previously, much of the critical threshold work emerged from observations and experimentation at the ecosystem scale of a lake or a savanna or a riparian reach. Now those concepts are being applied at scales of one thousand kilometres and more, and are focused on conditions affected by climate change (**Box 2**).

The Earth system tipping elements examined were chosen in part on whether they could be influenced within a political time frame, a 100 year span assumed for decision makers' concern about their children and grandchildren; whether that influence was called for within an ethical time frame, a 1000 year span assumed for the life time of a civilization; and whether society cared enough, elicited from expert opinion.

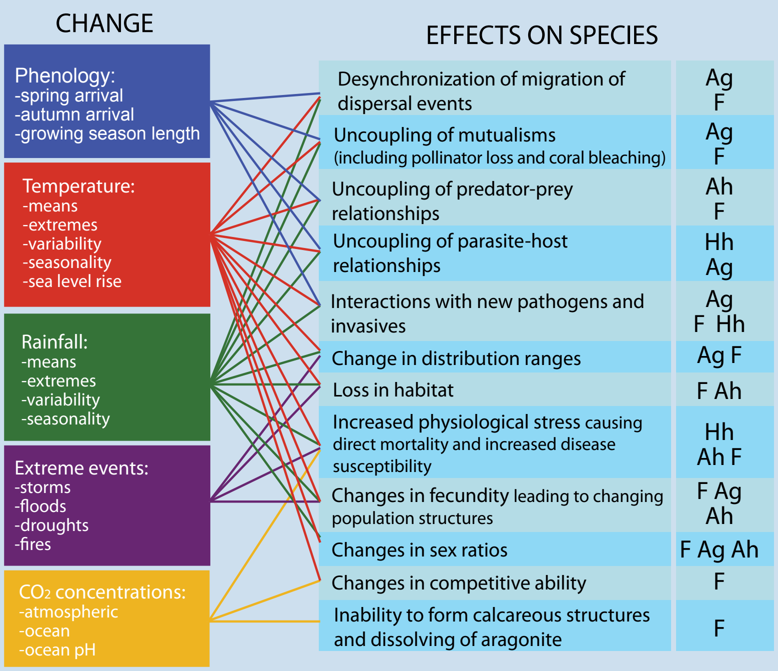
The tipping elements also involve some dependent sequences: For instance, melting Arctic sea ice and Greenland ice sheet loss deliver significant proportions of fresh water to the ocean's surface that affect thermohaline convection. As well, enhanced El Niño Southern Oscillation will affect the dieback of the Amazon rainforest (Lenton and others 2008).

One of the observed and accelerating climate change induced Earth systems that the tipping elements research does not consider is the loss of mountain glaciers. That loss in the Andes will also affect the availability of water and humidity to the Amazon rainforest and influence potential dieback. As well, loss of Himalayan-Hindu Kush ice, attributed to black carbon from the atmospheric brown cloud and to climate change, will likely contribute to Indian summer monsoon phase transition.

The work on weakened resilience was published in 2007 and that on tipping elements was published in January of 2008. Since their writing, a plethora of new scientific information has reinforced and even accentuated the urgent call for environmental governance to respond and to coordinate global and international prevention measures. (See Previous Chapters).

We are already obligated to the loss of mountain glaciers and all the repercussions this entails—loss of irrigation, hydropower, consistent potable water supply, agricultural capacity, and likely onset of conflict and migration. We are already witnessing diminished Arctic sea ice, increased tundra thawing, dissipation of the Greenland ice sheet, and breakups of the West Antarctica ice cover (See Climate Change, Chapter Three).

Figure 1: Interlinkages among climate changes, plant and animal response, and economic activity



Ag - Agriculture, F - Fisheries, Ah - Animal husbandry, Hh - Human health

The changing climate is affecting the timing and quantity of water availablity, the length of growing seasons, and the life cycles of pest and pathogens. These in turn put pressure on various species of plants and animals, with ultimate consequences for a variety of economic and development activities.

Source: Adapted from Foden and others 2008

Box 2: Tipping elements

Nine tipping elements considered as Earth systems subject to possible abrupt change. The time frames presented here will likely be modified as new data and information track characteristics and rates of change:

Indian summer monsoon—The regional atmospheric brown cloud is one of the many climate change-related factors that could disrupt the monsoon. Possible time-frame: One year.

Sahara and West African monsoon—Small changes to the monsoon have triggered abrupt wetting and drying of the Sahara in the past. Some models suggest an abrupt return to wet times. Possible time-frame: 10 years.

Arctic summer sea-ice—As sea-ice melts it exposes darker ocean, which absorbs more heat that ice does, causing further warming. Possible time-frame: 10 years.

Amazon rainforest—Losing critical mass of the rainforest is likely to reduce internal hydrological cycling, triggering further dieback. Possible time-frame: 50 years.

Boreal forests—Longer growing seasons and dry periods increase vulnerability to fires and pests. Possible time-frame: 50 years.

Atlantic Ocean thermohaline circulation— Regional ice melt will freshen North Atlantic water. This could shut down the ocean circulation system, including the Gulf Stream, which is driven by the sinking of dense saline water in this region. Possible time-frame: 100 years.

El Niño-Southern Oscillation (ENSO)—El Niño already switches on and off regularly. Climate change models suggest ENSO will enter a near-permanent switch-on. Possible time-frame: 100 years.

Greenland ice sheet—As ice melts, the height of surface ice decreases, so the surface is exposed to warmer temperatures at lower altitudes which accelerates melting that could lead to ice sheet break up. Possible time-frame: 300 years.

West Antarctic ice sheet—Ice sheet is frozen to submarine mountains, so high potential for sudden release and collapse as oceans warm. Possible time-frame: 300 years.

Source: Lenton and others 2008

Calendar of selected events for 2008

JANUARY

15 January Conservation International, Cozumel's Department of Tourism, and the Florida-Caribbean Cruise Association sign agreement to protect endangered biodiversity in the world's most visited cruise destination. The agreement focuses on awareness, traffic, waste, regulation, and law enforcement.

21 January The US National Oceanic and Atmospheric Administration (NOAA) and Environment Canada sign a cross-border agreement creating a meteorological service partnership. Goals include improving weather and climate monitoring and forecasting, and supporting research in climate change.

FEBRUARY

7 February Norway authorizes a take of 1,052 minke whales in the 2008 season. The Ministry of Fisheries and Coastal Affairs says the quota will not threaten the overall minke whale population.

S.MORGAN/ STILL PICTURES

20-22 February At the 10th special session of the UNEP Governing Council, governments discuss UNEP's Medium-Term Strategy for 2010-2013. Topics include six thematic priority areas as well as the GEO-4 report, chemical and waste management, sustainable development of the Arctic region, and the International Decade for Combating Climate Change.

26 March The First African Water Week opens in Tunis, hosted by the African Ministers' Council on Water and the African Development Bank. Participants agree to accelerate progress on water security and set out plans for the Africa Groundwater Commission.

JORGEN SCHYTTE/ STILL PICTURES

31 March 1 100 delegates from 163 countries meet in Thailand for the first formal talks on a climate agreement to replace the Kyoto Protocol. The new treaty should be in place by the end of 2009, allowing time for ratification before Kyoto's expiration in 2012.

APRIL

8 April The European Parliament's Legal Affairs Committee proposes that damaging the environment be considered a criminal offence. EU member states could apply criminal charges to behavior likely to damage air, soil, waters, plants, and animals.

17 April Australian federal and state environment ministers fail to reach a national agreement, six years in the making, on banning plastic bags. South Australia State will move ahead with a ban from January 2009. Some four billion plastic bags a year go into landfill in Australia.

12-16 May The fourth Meeting of the Parties to the Cartagena Protocol on Biosafety in Bonn agrees on a timetable and framework for negotiations. Legally binding rules and procedures will be established for liability and redress for potential damage from transboundary movements of living modified organisms.

14 May UN Secretary-General Ban Ki-moon addresses delegates at the 16th UN Commission on Sustainable Development. He urges them to offer new ideas and concrete action on land, agriculture, rural development, desertification, and Africa in the quest for sustainable development.

S.P. APIKU/ IRIN

14 May The US lists polar bears as threatened under its Endangered Species Act because their sea ice habitat is disappearing due to climate change. US government scientists predict that two-thirds of the global polar bear population of 25 000 could disappear by 2050.

B. LICHTENBERGER/ STILL PICTURES

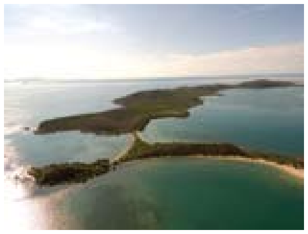
7-12 June The twelfth session of the African Ministerial Conference on the Environment (AMCEN) and first extraordinary meeting of the parties to the Abidjan Convention are held in Johannesburg. AMCEN adopts "Africa's Climate Roadmap, from Johannesburg through Africa to Copenhagen".

24-28 June Scientists and policy makers meet in Uganda at the first international conference on groundwater and climate in Africa After discussing the role of groundwater in improving livelihoods in Africa, they adopt the Kampala Statement urging development of legal and institutional frameworks.

JULY

2-10 July At its 32nd session, UNESCO's World Heritage Committee adds eight new natural sites to its World Heritage List. These include part of the New Caledonia lagoon.

L.G. ROGER / STILL PICTURES



AUGUST

26-29 August UNEP and the World Health Organization (WHO) organize the first African Inter-ministerial Conference on Health and Environment, in Gabon. Goals include building a strategic health and environment alliance, and establishing a network for addressing diseases.

27 September The US Senate approves legislation allowing a longstanding ban on offshore oil drilling to expire on 30 September. Most\ of the US coastline is opened to hydrocarbon exploration as a result.

B. EVANS & P. ARNOLD/ STILL PICTURES

29 September California Governor Arnold Schwarzenegger signs two green chemistry bills, providing a comprehensive program to regulate chemicals linked to cancer, hormone disruption, and other health effects. The new measures encompass 80 000 chemicals now in use.

30 September The inaugural World Ocean Council meeting is held in New York. Representatives from shipping, oil and gas, fisheries, cruise ship tourism, aquaculture, ports, and other ocean industries meet to improve dialogue between industrial sectors dependent on the sustainable use of the world's oceans.

OCTOBER

15 October At the 3rd Summit of the India-Brazil-South Africa Dialogue Forum, leaders stress the importance of access to genetic resources and sharing of benefits, urging a timely and successful conclusion to negotiations on a legally binding international regime.

B. DAEMMRICH/ STILL PICTURES

16-19 November Participants meet at the International Conference on Water Resources and Arid Environments, and the First Arab Water Forum, in Saudi Arabia. Discussions cover climate change and its impact on water resources and arid environments, advancement of Arab water policy, and management of water crises in the Arab world.

17-18 November The international conference Water Unites – Strengthening Regional Cooperation on Water Management in Central Asia is convened in Kazakhstan. The shrinking of the Aral Sea, and need for agreement between upstream and downstream countries on water release regimes and water distribution are discussed.

27 November The UK announces agreement on its Marine and Coastal Access Bill. The Bill will provide the first coherent national legislative framework for marine policy by establishing systems for delivering sustainable development of marine and coastal environments.

S. PARIS/ UN

21 February Costa Rica, Iceland, New Zealand, and Norway become the first countries to join the Climate Neutral Network (CN Net), a joint initiative of UNEP and the UN's Environment Management Group. The global information exchange network is focused on reducing emissions in all sectors of society.

MARCH

9 March Several Asia-Pacific countries announce phase-out of CFCs ahead of the 2010 deadline prescribed by the Montreal Protocol for Substances that Deplete the Ozone Layer. Indonesia reports that illegal import of these ODSs persists.

11 March Australia's ratification of the Kyoto Protocol enters into force, with a commitment to reduce greenhouse gas emissions by 60 per cent under 2000 levels by 2050. Comoros, the Central African Republic, Tonga, São Tomé and Principe, Saint Kitts and Nevis, and Serbia also enter the Protocol in 2008.

KLEIN J.L. & HUBERT M.L. / STILL PICTURES

20 March The Convention on International Trade in Endangered Species (CITES) suspends Nigeria for alleged breaches of its provisions. Nigeria is banned from importing or exporting any animal or plant species under the convention.

J. JABBOUR/ UNEP

19 April The European Commission backs away from its proposal for a compulsory 10% bio-fuel content in petrol and diesel. Scientists warn that the target, a key component of the EU's drive to cut GHG emissions 20% by 2020, could have unintended effects on food production.

MAY

13 May Brazil's environment minister, Marina Silva, hailed as a champion of the green movement but scorned by powerful farming groups, resigns after losing key battles in her efforts to protect the Amazon rain forest.

L.ANTOINE/ STILL PICTURES

12 May The Marshall Islands, one of the world's largest shipping nations, accede to five International Maritime Organization conventions, including the London Protocol. The number of ratifying States reaches 35, accounting for 29.73 per cent of the world fleet's tonnage.

15 May The EU and Ghana announce that they will formalize a Voluntary Partnership Agreement in June to curb illegal logging and promote certification of timber exports. Some US$10 billion in public assets is lost in developing countries due to illegal logging.

19-30 May Delegates at the ninth Conference of the Parties to the Convention on Biological Diversity in Bonn adopt a roadmap for negotiations on access and benefit-sharing, scientific criteria for marine protected areas, and caution against ocean fertilization.

JUNE

3-5 June High-Level Conference on world food security convenes in Rome. It warns that food prices will remain high for years and calls for urgent, coordinated action to combat the negative impacts on the most vulnerable countries and populations.

4 June The US calls for an international agreement for managing Arctic fisheries, and establishes a national policy halting the expansion of industrial fishing into the region, pending better management data.

SEGUIN/ANDIA /STILL PICTURES

27 August Ghana's Environmental Protection Agency bans the import of 25 agrochemicals deemed not suitable to local conditions or posing risks to human health, animals, crops, and the environment. Banned chemicals include toxaphene, aldrin, endrin, chlordane, captafol and DDT.

29 August China adopts law promoting a 'circular economy' coming into force on 1 Jan 2009, to promote energy conservation and reduce pollution. 2010 targets include energy consumption down by 20 per cent per unit of GDP, and major pollutants down by 10 per cent from 2005 levels.

SEPTEMBER

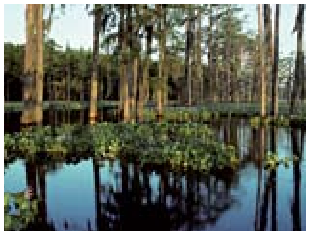
15-19 September The Spoonbill Action Plan is adopted at the fourth Meeting of the Parties to the African-Eurasian Migratory Waterbird Agreement, in Madagascar. Migratory waterbird populations have declined 41 per cent along main migration routes.

H. PIERRE / STILL PICTURES

24 September UN Secretary-General Ban Ki-moon and Norwegian Prime Minster Jens Stoltenberg announce new UN Reduced Emissions from Deforestation and Forest Degradation (UN-REDD) Programme. Tropical deforestation produces nearly 20 per cent of all human-induced carbon emissions.

27-31 October Parties at the 30th consultative Meeting of Contracting Parties to the Convention on Prevention of Marine Pollution by Dumping of Wastes and Other Matter, and the third meeting of its London Protocol, adopt a non-binding resolution to allow ocean fertilization only for legitimate scientific research purposes.

29 October The Ramsar Secretariat, the Danone Group, and IUCN form a partnership targeting climate change at the 10th Conference of Contracting Parties to the Ramsar Convention on Wetlands, in Korea. Danone commits to minimize its emissions and to offset those that remain through wetlands restoration.



J. SIMS/ STILL PICTURES

NOVEMBER

11-15 November Delegates to the first World Conference on Marine Biodiversity, in Spain, discuss progress towards completion of the first-ever census of marine life in 2010. The census will list up to 250 000 named species with maps, DNA barcodes, and biomass estimates.

12 November President elect, Barack Obama announces that energy is going to be one of his top priorities. Once in office, he plans to phase out coal-based electricity generation, switch to renewable energy, and follow Europe's lead on climate change.

29 November Delegates at the International Conference on Financing for Development, in Qatar, stress the need to maintain aid commitments in face of economic downturn. They express concern at the linked challenges of food security, energy and commodity prices, climate change, global financial crisis, and multilateral trade negotiations.

DECEMBER

1-12 December The UNFCCC COP-14 Climate Change Conference in Poland sets the agenda for international efforts to tackle climate change, leading up to COP-15 in Copenhagen, Denmark, in 2009. There, negotiations for a post-2012 climate agreement are set to conclude.

5 December Brazil's new Environment Minister, Carlos Minc, announces plan to combat climate change by reducing deforestation 70 per cent over the coming decade. Goals include reducing the annual rate of deforestation from 7 300 to 1 900 square miles by 2017, preventing some 4.8 billion tonnes of CO_2 emissions.

8 December Protestors from the Maldives tell delegates at the UNFCCC COP-14 that their island country will be destroyed by sea level rise and storms unless global warming is curbed.

C. GLUCK/ OXFAM

Doing the sums

While each of these chapters addressed themes that allow separate entry points for understanding global environmental changes and critical thresholds, relationships among the individual themes continually emerge. Climate change affects disasters and conflicts; ecosystem mismanagement delivers toxic chemicals that harm human and other creatures. Disasters can precipitate regime shifts in ecosystems. Accumulation of harmful substances can create ocean dead zones that wipe out marine ecosystems. Agricultural wastes and climate change destroy coral reefs. Ultimately, lack of resource efficiency is a root cause of all the problems represented in the chapters.

These relationships create difficulties when the individual themes are considered alone. The themes can only be understood as components of the larger Earth systems that support all human activities The cumulative effects originate from the same phenomenon as the recent pulse of globalization: We are no longer isolated and living beyond the influence of others. Today, in our interconnected world, massive social or environmental disruption in one region affects the entire system (Costanza and others 2007). Awareness of such interconnection and even interdependency leads to the requirement for wise environmental governance that considers needs over mutiple scales and many generations: Human beings, human societies, and the human economy are entirely integrated into the Earth's systems and into the Earth systems' economy—the geosphere, the biosphere, the atmosphere, and the ecosystems that knit it all together (Ehrlich and Erhlich 2008).

RE-TOOLING

Recent global environmental assessments have emphasized that new, innovative forms of policy and institutional arrangements have to be developed to deal with persistent environmental problems. Sufficient financial and human capacity is required within countries to implement policy and to monitor and enforce compliance. There needs to be sufficient attention to local situations and local people, for example by strengthening local rights and securing access to and maintaining natural resources to reduce vulnerability of people (WRI 2008). At the international level the improved conditions for this could be created by rationalizing the large number of environmental treaties, by strengthening international organisations, and by developing more coherent international mechanisms (UN 2006b).

Many solutions to these challenges are already known and the measures that could be taken are theoretically affordable. The persistent character of these problems requires consistent long-term policies. This will provide markets with more certainty, so that the private sector can prepare

Table 1: Cumulative effects (constantly under revision with new science and other enquiries)

Themes	Ecosystem management	Climate change	Disasters and conflicts	Harmful substances and hazardous wastes	Resource efficiency
Ecosystem management	Feedback: Deforestation leads to loss of critical mass that initiates further dieback, i.e. Amazon	Agricultural resource inefficiencies from erosion of soils and scarce water resources lead to ecosystem damages	Disasters can precipitate regime shifts in ecosystems; warring parties conduct scorched Earth policies destroying crops and fouling water leads to disaster and famine, etc	Accumulation of harmful substances can create ocean dead zones that wipe out marine ecosystems. Agricultural wastes and climate change destroy coral reefs	Mismanagement of fertilizers leads to over-nitrification and ocean dead zones
Climate change	Ocean acidification leads to coral reef collapse and loss of ecosystem that nurtures fisheries	Feedback: Melting of ice exposes darker surfaces that absorb more solar radiation which further warms local conditions	Slow onset disasters lead to conflicts over scarce resources; increased exposures to pests and pathogens in new locations	Release of hazardous substances into environment as ice melts; scouring of sequestered wastes during flash floods; Flooding of containment receptacles for hazardous, toxic, medical wastes	Need for airconditioning drives power plants to brown-outs and black-outs
Disasters and conflicts	Soil degradation and ecosystem loss propmpts migration and possible conflict	More frequent and intense cyclones hitting populated coasts; More competition for locations beyond sea level rise threat, leading to migrations and conflicts	Feedback: Damage from one disaster increases vulnerability to another	Sudden and massive spills from waste containment sites enter water, soils, and atmosphere requiring immediate and expensive clean-up response	Migrating populations forage ecosystems, leaving swathes visible from observing satellites
Harmful substances and hazardous waste	Release of nanoparticles could threaten ecosystem health, radioactive leaks could affect mutation rates	Flooding of containment fields for hazardous, toxic, and medically dangerous substances	Informal and dangerous mining methods fuel conflicts, wealth discourages legal governance	Feedback: Industrial pollution lowers resistence to other diseases and increases occurances of birth defects and cancers	Resource inefficiencies pollute water, soils, and atmosphere
Resource efficiency	Food production, processing, handling, and distribution leading to contamination and disruptions in the food supply chain	Altered climate patterns lead to desertification and loss of water and soil resources	Civil unrest and political mismanagement lead to malnutrition, cholera outbreaks, breakdown of infrastructrie for water and sanitation	Adding coal ash to concrete cuts amount of GHG producing cement and also sequesters hazardous waste	Feedback: Overexploitation and pollution destroy or foul landscapes and settlements so enterprises and settlements move on when resources are ruined

to make the required investments (OECD 2007). Moreover, such long-term policies need to include concrete ambitious goals and measurable indicators of progress. This also includes those areas of policy in which there are no goals yet, such as energy supply, or areas in which only short-term goals have been set as in the case of biodiversity.

Upscaling lessons for multiple benefits

There are new initiatives underway that integrate across sectoral and issue-oriented international agreement concerns attempting to suggest solutions at multiple scales and with diverse positive outcomes. Two of these initiatives, the global marine assessment process and the avoided deforestation scheme, hope to demonstrate lessons learned from smaller scale assessments and projects and to result in benefits at global and local levels.

Seas and oceans provide two thirds of the value of all the natural services provided by the planet, including climate controls and water cycling. Despite the obvious economic benefits, the world's oceans are being degraded and continue to be threatened by factors that include climate change, pollution, physical alteration, and increased pressures on ecosystems from over fishing and from population growth.

The oceans cover seventy per cent of the planet but we do not understand what is happening to them as a whole. In response to commitments undertaken at the 2002 World Summit on Sustainable Development, the Intergovernmental Oceanographic Commission of the UN Educational, Scientific, and Cultural Organization and the UN Environmental Programme are establishing a process to ensure that global marine systems are monitored and assessed on a regular basis.

The reporting process under consideration will define baselines, trends, and outlooks for marine environmental change and set a schedule for regular assessments of the state of the world's ocean system as whole, particularly the interactions between the marine system and society at multiple scales. The process will build on existing regional and global assessments and will provide a framework for integrating sectoral and thematic assessments, especially those carried out at regional and sub-regional levels and that include the influence of rivers on the coastal and marine environment.

The process will organize, analyze, and communicate information so that policymakers and other stakeholders can make informed choices to reduce human impacts on the oceans and preserve future options. It intends to improve ocean monitoring and observing practices and incorporate the use of indicators, including identification of particularly worrisome conditions. Finally it will provide advice, networking, support, and capacity building to strengthen ongoing thematic, regional, and national assessments (UNEP 2008).

Tropical forests are among the most threatened ecosystems on the planet. They provide essential

Table 2: Drivers, themes, and interlinkages (constantly under revision with new science and monitoring and evaluation of projects and programmes)

Themes / Driver	Ecosystem management	Harmful substances and hazardous waste	Climate change	Disasters and conflicts	Resource efficiency	Environmental governance
Population growth	Available cropland per person decrease; population pressures on coastal zones and conservation areas	Toxic substance exposure negatively impact childhood development and pregnant women in particular as well as indigenous people	Displacement of more people due to sea level rise, desertification, intensification and increased frequency of storms	Vulnerable populations in vulnerable area; land reforms; earthquake destroying infrastructures; slow onset disasters	Rapid expansion of the construction sector in developing countries; energy consumption in food production; water stress	Land tenure; equity; improved water access
Increasing resource demand	Factory farming; eco-agriculture;semi-natural landscapes; fisheries collapse; tropical forest loss; destruction of mangrove forests and coral reefs	Nitrification of water; pesticides; e-waste; arsenic in groundwater; mercury contamination; nanotechnology fate;	Biofuel production, forest carbon sequestration, put pressure on availability of food and timber; acidification affects fisheries; no late season water downstream of no glaciers	Destruction from civil unrest; resource wars; mangrove forest loss; changing seasons; extreme weather; landslides; complex emergencies	Consumption growth; biofuel production; China's Circular Economy; dematerialization of industrial output; industrial symbiosis	Rights based catch shares; integrated management systems; Decoupling productivity from environmental degradation; off set payments, REDD; GHG targets; facilitate technology transfer
Economic growth	Rural poor low productivity agricultural practices; valuation of ecosystem goods and services; Amazon rainforest under stress; soaring energy prices; rising food prices	Trade in synthetic fertilizers, pesticides, toxics; export of e-waste; demands for commodities leads to pollution;	Economic loss from disruption of agriculture, shipping, fuel supplies; damages from increased storms affect insurance industry and infrastructure stability	Deforestation induced by poverty and social instability; loss in tourist income; storm taking out crops for loss of food and economic return; technological disasters	Strong growth in extraction of mineral and biological resources in newly industrialized countries; public transportation in urban areas	Financial market downturn; growing biofuel trade; economics of enough
Sustainable development agenda (MDGs)	Deforestation causes loss of forest equivalent in size to Panama or Sierra Leone every year	Economic burden of poor environmental health can be as high as 1.5-4% of GDP annually	Developing countries are most vulnerable to climate change and least able to adapt	Scale up aid and increase its effectiveness; achieve better results in human development	Depletion of natural resources is often associated with declining national wealth	Uneven progress in institutional and policy performance due to gap between policy formulation and capacity to enforce; environment-trade contradictions

Source: adapted from World Bank 2008

environmental functions and ecosystem services upon which all societies depend. They serve as refuge for nearly half of all known plant and animal species, possessing unmatched terrestrial biological diversity. They conserve soil, protect watersheds, and buffer against natural disasters. They provide sources of livelihood to more than 1.5 billion people, many of whom lead subsistence lifestyles and whose very survival hinges on these carbon-rich forests. Aptly termed the lungs of the planet, these ecosystems also play a vital role in filtering and regulating our air, removing carbon dioxide from the atmosphere, and delivering essential oxygen.

Reducing emissions from deforestation and forest degradation (REDD) is one clear way to mitigate climate change. This recognition has given rise to the concept of compensated reduction. The idea was conceived as a way to use new carbon markets to provide a cost-effective and equitable way for developing countries with tropical forests to participate in global efforts to reduce GHG emissions within the UN Framework Convention on Climate Change (UNFCCC) process. The underlying premise is to compensate developing countries that voluntarily commit to reduce and stabilize national deforestation below a previously determined historical level. Thus, REDD may be in part an instrument to enable fair and equitable access to global carbon financing, whether through market or fund-based approaches. Some proponents suggest that REDD offers new incentives for reducing GHGs that could simultaneously accomplish several ancillary goals: biodiversity conservation, watershed protection, poverty alleviation for rural communities, and capacity building in tropical forest nations.

Momentum for REDD has accelerated rapidly in 2008, following a decision in 2007 on the "... urgent need to take further meaningful action..." on an avoided deforestation scheme. This was followed by the formulation of guidance for a two-year pilot phase. While the precise architecture and rules have yet to be settled, it now seems highly likely that an international REDD mechanism of some kind will emerge as a key element of the post-2012 international climate change regime.

2008 saw many demonstration projects and an influx of funding, testifying to governments' and other institutions' increasingly unified position on REDD's potential for delivering multiple benefits. Conversely, as the scientific and political debate evolves, new complexities, uncertainties, and contentious issues continue to surface. One of the most obvious concerns relates to methodological questions. These include how to select and structure deforestation baselines, how to integrate degradation issues into these calculations, how to decide on standards for quantifying and monitoring deforestation rates, how to put the institutional capabilities in place to ensure accuracy, and how to ensure results are available on both spatial and time scales that are relevant to decision-makers.

These all are critical questions and they remain largely unresolved. However, even if they are answered they have the potential to be overshadowed by governance issues. Eventual outcomes may rely less on technical information than on political choices and arbitrations since adopted rules will create winners and losers in what is shaping up to be a new type of ecosystem service payment (Karsenty and others 2008). Thus, the most divisive challenge in REDD implementation may be issues of governance. Pervasive inequities in land use rights and tenure regimes, or limited access to finance and information for marginalized groups, or the appropriation of revenues by elites are but a few governance failures that could effectively nullify both local and global benefits from a REDD scheme (Preskett and others 2008).

Given that REDD will likely be implemented at a landscape scale and that different sites possess varying degrees of ancillary value—biodiversity, fresh water, or local livelihood services—higher implementation costs could disfavor the protection of certain, less immediately lucrative forest values, predicating a need for additional resources (Miles and Kapos 2008). As a result, a small number of recent proposals have focused on valuing the full suite of services provided by the forest utility, not just carbon storage (Gardiner 2008, Trivedi and others 2008). However, these go beyond the scope of the proposed REDD mechanisms under debate and will likely not form part of the upcoming UNFCCC deliberations. Related to this debate is the possibility that carbon-focused forest conservation could shift development pressure to other, lower-carbon ecosystems. If conservation investment is placed squarely on tropical forests while the demand for food and bioenergy crops increases, other locations could come under increased pressure and become new targets for exploitation and land use change.

The potential for REDD to provide innovative and cost effective opportunities to abate GHG emissions while providing biodiversity and social benefits will depend in large part on management and oversight. We may well be approaching an internationally entrenched mechanism to help deliver these multiple benefits by design. It is therefore crucial that scientists, practitioners, and decision-makers recognize, assess, and plan for the unintended adverse side effects of REDD as well as the possible opportunities. While the prospect of REDD in no sense reduces the imperative to address underlying causes of forest degradation, nor can it alone solve our climate crisis, the concept has been a powerful stimulus for new thinking about ecosystem management. To date, forest loss continues and the climate keeps changing, so new ideas need to be discussed, accepted, tested, and rejected or improved. Designing an avoided deforestation scheme to maximize mutiple benefits could set a precedent for meeting environmental challenges with innovative approaches that are efficient, equitable, and effective.

Remains of burnt trees in the Amazon: Deforestation remains a significant contributor to global CO_2 emissions.

Source: UN-HABITAT/ istockphoto

On the benefits of choice

The use of the term 'tipping point' is familiar to most people as there are idioms in nearly every language that describe it: A straw that breaks a camel's back; a drop that makes a container overflow, or a nudge that topples a large object. It presents a system in the midst of a delayed reaction as the 'pressure' builds within the system (Scheffer and others 2001). In geology and engineering, different types of unconsolidated granular material display characteristic angles of repose or stability dependent on the shape of the particles, the density of the material, and other factors. Once this angle is exceeded, slope collapse follows. This concept is applied to the categorization of avalanche threats in mountain regions (Barbolini and others 2004).

This sense of the term was used earlier in sociological circles to include subtle delays, as a causative factor reaches a critical mass before it invokes response within a given population. This phenomenon has been documented in epidemiology, in fashion trends, and in demographic transformation in communities (Gladwell 2000). However the term can be considered from an alternative perspective, one that suggests an opportunity exists to change conditions with minimal effort (Gladwell 2000). In these circumstances a small effort can produce momentum for a desired result. This perspective has inspired a number of projects that aim to create a critical mass to change a larger environment. These include allotment gardens in urban neighborhoods with high crime rates, replanting mangrove swamps, and restoring wetlands (Marten and other 2005).

It is in this sense of a potential opportunity that we argue this is the propitious moment to initiate a deliberate phase transition to an environmentally sound economy. Using 'shock therapy' to pursue macroeconomic objectives is a generally accepted approach (Sachs and Lipton 1990). This economic shock therapy refers to policies that put an economy into free fall, stabilizing only when market mechanisms kick in. It promotes deregulation and the break down of rules and non-market-set standards—an approach severely critiqued in 2007 as 'crisis capitalism' and 'shock doctrine' (Klein 2007).

The current global economy—spurred by cheap hydrocarbon-fueled transportation, globalized goods and services transactions, and split second currency trading—is surely in the midst of a remarkable shock. It presents an unmatched opportunity to revamp and upgrade a system that originated in a world where the industrial revolution had not yet begun, whole continents were divided for colonization, and the total world population equaled that of Europe today.

It is time for a new approach and that opinion is gaining momentum: According to the President of the UN General Assembly, the Follow-up International Conference on Financing for Development on the Implementation of the Monterrey Consensus recognized that the international context has changed profoundly over the past few years. During the Conference, discussants had demonstrated a 'universal rejection' of the model represented by post-World War II arrangements known as the Bretton Woods system or the Washington Consensus (UN 2008b).

This propitious moment calls for an economic system that values those goods and services that keep us alive and enable our wellbeing, based on the thinking and activities from decades of sustainable development efforts. Ecological economics has been applying principles like industrial ecology to the economics sphere for the last two decades. That approach has offered a wealth of data, information, and knowledge about shifting the dominant economic paradigm to one that values ecosystem services, costs the contributions of the commons, and reflects on lessons from history to ensure we have options on whether to relive them or not (Pearce and others 1989, Costanza 2008).

CONCLUSION

If we want to assess the real economy—all the things that contribute to sustainable wellbeing within the economy determined by Earth systems—as opposed to only the market economy as expressed by gross domestic product (GDP), we have to measure and include the non-marketed contributions to human wellbeing from nature and from our society. Ecological economists group these contributions into four basic types of capital that are necessary to support the real economy that produces wellbeing: built capital, human capital, social capital, and natural capital (Costanza 2008).

A better model of an economic system would be based clearly on the goal of sustainable human wellbeing, and It would use measures of progress that explicitly acknowledge this goal. The introduction of a genuine progress indicator (GPI) to replace GDP for tracking economic health is such an alternative measure. This type of measure accounts for the importance of ecological sustainability, social fairness, and real economic efficiency. Ecological sustainability implies recognition that natural and social capital are not infinitely substitutable by built and human capital and that there are real Earth system limits to the expansion of the market economy. Climate change is perhaps the most obvious and compelling of these limits (Costanza 2008).

Social fairness implies recognition that the distribution of wealth is an important determinant of social capital and quality of life. The conventional development model, while ostensibly aimed at reducing poverty, has bought into the assumption that the best way to do this is through growth in GDP. This assumption has not proved to be the case and explicit attention to distribution issues is needed badly (Stiglitz 2008).

Increasing inequality of income actually reduces overall societal wellbeing, not just for the poor but across the income spectrum. Real economic efficiency implies the inclusion of all resources that affect sustainable human wellbeing in the allocation system, beyond current goods and services. Our current market allocation system excludes most non-marketed natural and social capital assets and services, which are huge contributors to human wellbeing (Costanza 2008).

The current development model ignores this fact and therefore does not achieve real economic efficiency. A new, ecologically sustainable development model would measure and include the contributions of natural and social capital and could better approximate real economic efficiency. The new development model would also acknowledge that a complex range of property rights regimes is necessary to adequately manage the full range of resources that contribute to human wellbeing.

For example, most natural and social capital assets are public goods. Making them private property does not work well. On the other hand, leaving them as open-access resources with no property rights does not work well either, as we recognize from incidents of water, soil, and atmospheric pollution. What is needed is an alternative way to propertize these resources without privatizing them (Barnes 2006). Several common property rights systems have been proposed to achieve this goal, including various forms of common property trusts (Barnes and others 2008).

In addition to a role in regulating the market economy, governance for sustainable development should play a significant role in expanding the commons sector in ways that propertize and manage non-marketed natural and social capital assets. At nested scales governance for sustainability acts as a facilitator in society's development of a shared vision of what a desirable future would look like (Daly 1996) (**Table 3**).

The key to achieving sustainable governance in a globalized context is an integrated approach—across scales, disciplines, stakeholder groups, and generations—based on the paradigm of adaptive management where policy making is an iterative experiment acknowledging uncertainty, rather than a static answer. Six core principles were agreed at a 1997 meeting in Lisbon for sustainable governance of the oceans that embody the essential criteria for a comprehensive environmental governance. Over the last decade, these Lisbon Principles have become recognized as basic guidelines for administering the use of common natural and social resources (Costanza and others 1998).

Responsibility: Access to common asset resources carries attendant responsibilities to use them in an economically efficient, socially fair, and ecologically sustainable manner. Individual and corporate responsibilities and incentives should be aligned with each other and with broad social and ecological goals.

Scale-matching: Problems of managing natural and social capital assets are rarely confined to a single scale. Decision-making should be assigned to institutional levels that should maximize input, ensure the flow of information among those levels and other stakeholders, take ownership and actors into account, and internalize costs and benefits. Appropriate scales of governance will be those that have the most relevant information, can respond quickly and efficiently, and are nested—able to integrate across scale boundaries.

Precaution: In the face of uncertainty about potentially irreversible impacts to natural and social capital assets, decisions concerning their use should err on the side of caution. The burden of proof should shift to those whose activities potentially damage natural and social capital.

Adaptive management: Given that some level of uncertainty always exists in common asset management, decision-makers should continuously gather and integrate appropriate ecological, social, and economic information with the goal of adaptive improvement.

Full cost allocation: All of the internal and external costs and benefits, including social and ecological ones, of alternative decisions concerning the use of natural and social capital should be identified and allocated. When appropriate, markets should be adjusted to reflect full costs.

Participation: All stakeholders should be engaged in the formulation and implementation of decisions concerning natural and social capital assets. Full stakeholder awareness and participation contribute to credible, accepted rules that identify and assign the corresponding responsibilities appropriately.

Table 3: A sustainable development model

	Current Development Model the "Washington Consensus"	**Sustainable Development Model** an emerging "Green Consensus"
Primary policy goal	**More:** Economic growth in the conventional sense, as measured by GDP. The assumption is that growth will ultimately allow the solution of all other problems. More is always better.	**Better:** Focus shifts from growth to development in the sense of improvement in quality of life, recognizing that growth often has negative by-products and more is not always better.
Primary measure of progress	GDP	GPI (or something similar)
Scale/carrying capacity	Not an issue because it is assumed that markets can overcome any resource limits via new technology, and that substitutes for resources are always available.	A primary concern as a determinant of ecological sustainability. Natural capital and ecosystem services are not infinitely substitutable, and real limits exist within Earth systems.
Distribution/poverty	Relegated to national policy processes and a trickle down effect: A rising tide lifts all boats.	A primary concern since it directly affects quality of life and social capital and in some real ways is often exacerbated by growth.
Economic efficiency/ allocation	The primary concern, but generally including only GDP-releted goods and services and institutions.	A primary concern, but including both market and non-market goods and services and effects. Emphasizes the need to incorporate the value of natural and social capital to achieve true allocative efficiency.
Property rights	Emphasis on private property and conventional markets.	Emphasis on a balance of property rights regimes appropriate to the nature and scale of the system, and a linking of rights with responsibilities. A larger role for common property institutions in addition to private and public property.
Role of governance	To be minimized and replaced where possible with private and market institutions.	A central role, including new functions as referee, facilitator, and broker in a new suite of common-asset institutions.
Principles of governance	*Laissez-faire* market capitalism.	Lisbon principles of sustainable governance.

Basic characteristics of the current development model and an emerging model based on ecological economics.
Source: Adapted from Costanza 2008

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Acronyms and abbreviations

AFP	Agence France-Presse
AGU	American Geophysical Union
AGRA	Alliance for a Green Revolution in Africa
ASN	American Society of Nephrology
ASCE	American Society of Civil Engineers
ATSDR	Agency for Toxic Substances and Disease Registry
BAN	Basel Action Network
BAS	British Antarctic Survey
BBC	British Broadcasting Corporation
CBD	Convention on Biological Diversity
CCVA	Conservation Corridor Vilcabamba-Amboro
CDIAC	Carbon Dioxide Information Analysis Center
CO2	Carbon Dioxide
COP	Conference of the Parties
CRED	Centre for Research on the Epidemiology of Disasters
CRIIRAD	Commission of Research and Information on Radioactivity
CSA	Centre Stockage l'Aube
DDT	Dichloro-Diphenyl-Trichloroethane
DEPA	Danish Environmental Protection Agency
EC	European Commission
EDF	Electricité de France
EHS	Environment, Health, and Safety
ENSO	El Nino-Southern Oscillation
ESA	European Space Agency
E-waste	Electronic Waste
FAO	Food and Agriculture Organization of the United Nations
FEWS	Famine Early Warning System
FIFA	Fédération Internationale de Football Association
FP6	6th Framework Programme
FP7	7th Framework Programme
GDP	Gross Domestic Product
GEO	Global Environment Outlook
GHG	Greenhouse Gas
GPI	Genuine Progress Indicator
HCTISN	High Commission for Transparency and Information on Nuclear Safety
HFA	Hyogo Framework for Action
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICRC	International Committee of the Red Cross
IEA	International Energy Agency
IMO	International Maritime Organization
INAC	Indian and Northern Affairs Canada
IPCC	Intergovernmental Panel on Climate Change
IRIN	Integrated Regional Information Networks
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
JMA	Japan Meteorological Agency
MA	Millennium Ecosystem Assessment
MCEER	Multidisciplinary Center for Earthquake Engineering Research
MDGs	Millennium Development Goals
mg/kg	Milligram per Kilogram
mg/l	Milligram per Litre
MIT	Massachusetts Institute of Technology
MOE	Ministry of the Environment, Government of Japan
NASA	National Aeronautics and Space Administration (of the United States)
NDRC	National Development and Reform Commission
NERSC	Nansen Environmental and Remote Sensing Centre
NGO	Non-Governmental Organization
NSIDC	National Snow and Ice Data Center
OECD	Organization for Economic Cooperation and Development
OFDA	Office of United States Foreign Disaster Assistance
PES	Payment for Ecosystem Services
PONJA	Post Nargis Joint Assessment
PVC	Polyvinyl chloride
REDD	Reduced Emissions from Deforestation and Forest Degradation
RRI	Rights and Resources Initiative
SCENHIR	Scientific Committee on Emerging and Newly Identified Health Risks
SoVI	Social Vulnerability Index
UCSB	University of California, Santa Barbara
UK	United Kingdom
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	UN Framework Convention on Climate Chnage
UN-Habitat	United Nations Human Settlements Programme
USA	United States of America
US BCSD	US Business Council for Sustainable Development
USD	United States dollar
US$	United States dollar
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WEC	World Energy Council
WGMS	World Glacier Monitoring Service
WHO	World Health Organization
WNA	World Nuclear Association
WRI	World Resources Institute
WTO	World Trade Organization
WWF	World Wildlife Fund

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Ecosystem Management

Lead Author:
Jason Jabbour, UNEP DEWA, Nairobi, Kenya

Contributors:
Traci Birge, UNEP DEWA, Nairobi, Kenya
Carol Hunsberger, Carleton University, Ottawa Canada
Mirjam Schomaker, Consultant, France

Reviewers:
Marten Scheffer, University of Wageningen, Wageningen, The Netherlands
Martin Kijazi, University of Toronto, Toronto, Canada
Marcus Lee, World Bank, Washington DC, USA
Tim Kasten, Elizabeth Migongo-Bake, Matthew Woods, and **Adriaan Tas,** UNEP DEPI, Nairobi, Kenya
Monika MacDevette and **Barney Dickson,** UNEP-WCMC, Cambridge, UK
Martina Otto, UNEP DTIE, Paris, France
Anne-France White, UNEP DCPI, Nairobi, Kenya

Chapter Coordinator:
Jason Jabbour, UNEP DEWA, Nairobi, Kenya

Climate Change

Lead Author:
Fred Pearce, Author and Freelance Journalist, UK

Contributor:
Catherine McMullen, UNEP DEWA, Nairobi, Kenya

Reviewers:
Tim Lenton, University of East Anglia, Norwich, UK
John Christensen, UNEP/ Risoe Centre, Roskilde, Denmark
Olivier Deleuze, UNEP DRC, Nairobi, Kenya
Volodymyr Demkine and **Jason Jabbour,** UNEP DEWA, Nairobi, Kenya
Kaveh Zahedi and **Mark Radka,** UNEP DTIE, Paris, France
Jian Liu and **Anna Kontorov,** UNEP DEPI, Nairobi, Kenya

Chapter Coordinator:
Neeyati Patel, UNEP DEWA, Nairobi, Kenya

Resource Efficiency

Lead Authors:
Catherine McMullen, Susanne Bech, Jason Jabbour, UNEP DEWA, Nairobi, Kenya and **Marilyn Smith,** Science Writer, Paris, France

Contributors:
Bas de Leeuw, UNEP DTIE, Nairobi, Kenya
John Kryger, Industrial Symbiosis Institute, Kalundborg, Denmark
Michael Kuhndt, Christa Liedke, and **Patrick Schröder,** UNEP/ Wuppertal Institute, Wupppertal, Germany
Guido Sonnemann, UNEP DTIE, Paris, France

Reviewers:
Girish Sethi, The Energy and Resources Institute, New Delhi, India
Weishuang Qu, Millennium Institute, Arlington, USA
Jinhua Zhang, UNEP DEWA, Bangkok, Thailand
Surya Prakash Chandak, UNEP DTIE, Kusatsu City, Japan

Chapter Coordinator:
Susanne Bech, UNEP DEWA, Nairobi, Kenya

Harmful Substances and Hazardous Waste

Lead Author:
Tahia Devisscher, Stockholm Environment Institute, Oxford, UK

Contributors:
Thomas Hayden, Stanford University, Stanford, USA
Jason Jabbour, UNEP DEWA, Nairobi, Kenya

Reviewers:
Patrice Jourda, Univeristy of Cocody, Abidjan, Cote d'Ivoire
David Rickerby, European Commission Joint Research Centre, Ispra, Italy

Chapter Coordinator:
Thierry Oliveira, UNEP DEWA, Nairobi, Kenya

Disasters and Conflicts

Lead Author:
Thomas Hayden, Stanford University, Stanford, USA

Contributors:
Catherine McMullen, Jason Jabbour, and **Márton Bálint,** UNEP DEWA, Nairobi, Kenya

Reviewers:
Norberto Fernandez, Peter Gilruth, and **Neeyati Patel,** UNEP DEWA, Nairobi, Kenya
Johannes Refisch, UNEP DEPI, Nairobi, Kenya

Chapter Coordinator:
Volodymyr Demkine, UNEP DEWA, Nairobi, Kenya

Environmental Governance

Lead Author:
Catherine McMullen, UNEP DEWA, Nairobi, Kenya

Contributors:
Jason Jabbour, UNEP DEWA, Nairobi, Kenya
Anna Stabrawa and **Jinhua Zhang,** UNEP DEWA, Bangkok, Thailand
Diana Rizzolio, Jaap van Woerden, and **Ron Witt,** UNEP DEWA, Geneva, Switzerland
Adel Farid Abdel-Kader, UNEP DEWA, Manama, Bahrain
Ashbindu Singh, UNEP DEWA, Washington DC, USA

Reviewers:
Jan Bakkes, Netherlands Environmental Assessment Agency, Bilthoven, The Netherlands
Ian Douglas, SCOPE and University of Manchester, Manchester, UK
Tim Lenton, University of East Anglia, Norwich, UK
Bedrich Moldan, Charles University, Prague, Czech Republic
Marten Scheffer, University of Wageningen, Wageningen, The Netherlands
Marko Berglund, UNEP DELC, Nairobi, Kenya
John Scanlon, UNEP EO, Nairobi, Kenya
Peter Gilruth, UNEP DEWA, Nairobi, Kenya

Chapter Coordinator:
Catherine McMullen, UNEP DEWA, Nairobi, Kenya

PRODUCTION

Nairobi Production Team:

Susanne Bech
Jason Jabbour
Catherine McMullen

Support Team:

Márton Bálint
Audrey Ringler
Cornelius Okello
Neeyati Patel
Matthias Philippi
Beth Ingraham
Nalini Sharma
Harsha Dave
Sylvia Adams
Jospehine Nyokabi Mwangi

Editors:

Catherine McMullen
Thomas Hayden

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Achim Steiner, United Nations Under-Secretary-General and Executive Director, United Nations Environment Programme

United Nations Environment Programme
P.O. Box 30552,
Nairobi 00100, Kenya
Tel: (+254) 20 7621234
Fax: (+254) 20 7623927
Email: uneppub@unep.org

www.unep.org

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