The fall of the water

Emerging threats to the water resources and biodiversity at the roof of the world to Asia's lowland from land-use changes associated with large-scale settlement and piecemeal development

Editor

Dr. Christian Nellemann

Contributors

Basanta Shrestha
Suresh Sulise
Gabriel Campbell
Binayak Bhadra
Pradeep Mool
Mandira Shrestha
Lokap Rajbhandari
Surendra Shresta
Purna Chandra Lall Rajbhandari
Dr. Nikhat Sattar
Dr. Ablimit Abdukadir
ErDowlet, I.
Dr. Jiyuan Liu
Dr. Bibhab Kumar Talukdar
Dr. Philip Bubb
Ian May
Lera Miles
Julian Caldecott
Dr. Joseph L. Fox
Thomas Puestow
Robert Alkemade
Michel Bakkenes
Bas Eickhout
Ben ten Brink
Hugo Ahlenius
Kathrine Johnsen
Ingunn Vistnes
Dr. B. P. Kaltenborn
Dr. Jane Uhd Jepsen
Dr. Nina E. Eide

Editor

Dr. Christian Nellemann
Global coordinator, GLOBIO
UNEP GRID-Arendal, C/O NINA, Fakkelgården,
Storhove, N-2624 Lillehammer, Norway
Phone + 47 73801616 / + 47 934 66 713
email christian.nellemann@nina.no
http://www.globio.info/

Contributors

Basanta Shrestha, Suresh Sulise, Gabriel Campbell, Binayak Bhadra, Pradeep Mool, Mandira Shrestha, Lokap Rajbhandari
International Centre for Integrated Mountain Development (ICIMOD)
G.P.O. Box 3226, Jawalakhel, Kathmandu, Nepal
Tel: (977 1) 5525313 Fax:(977 1) 5524509, 5536747
Email: icimod@icimod.org.np
www.icimod.org

Surendra Shresta, Regional Director for Asia and the Pacific
Purna Chandra Lall Rajbhandari
Regional Resource Center- Asia Pacific
United Nations Environment Program
Asian Institute of Technology
GPO Box 4, KlongLuang, Pathumthani 12120, Thailand
Phone: (66-2)524 6238 (direct) 5162124, 5160110
Fax: (66-2)524 6233 5162125
http://www.rrcap.unep.org

Dr. Nikhat Sattar
Head, Emerging and Emergency Programmes
Strategic Planning Team, IUCN Asia Programme, Asia Regional Sub-Office
1, Bath Island Road, Karachi-75530 Pakistan

Dr. Ablimit Abdukadir; ErDowlet, I.,
Xinjiang Institute of Ecology and Geography, Chinese Academy of Science. Urumqi, Xinjiang 830011, China.

Dr. Jiyuan Liu
Director General, Professor
Institute of Geographical Sciences and Natural Resources Research
Chinese Academy of Sciences
Building 917,Datun Road,Anwai,Beijing 100101,P.R.China
Tel:+86 10 6488 9281 Fax:+86 10 6485 1844
Email:liujy@igsnrr.ac.cn
http://www.igsnrr.ac.cn

Dr. Bibhab Kumar Talukdar
Regional Director,
ATREE-Eastern Himalaya Programme
Bungalow No:2, Bhujiapani, PO: Bagdogra, PIN: 734422, India
Tel: 0353-2550093 Telefax: 0353-2551110
www.atree.org

Dr. Philip Bubb, Ian May, Lera Miles, Julian Caldecott
UNEP World Conservation Monitoring Centre (UNEP WCMC)
219 Huntingdon Road, Cambridge CB3 0DL UK,
Tel +44 (0)1223 277314 Fax +44 (0)1223 277136
email: Philip.bubb@unep-wcmc.org

Dr. Joseph L. Fox
Department of Biology, Faculty of Science
University of Tromsø
N-9037 Tromsø, Norway
Tel:+47 77 644386
e-mail: joe.fox@ib.uit.no

Thomas Puestow
Research Scientist
C-CORE
Captain Robert A. Bartlett Building, Morrissey Road
St. John's, NL, Canada, A1B 3X5
Tel: (709) 737-2586 Fax: (709) 737-4706
E-mail: Thomas.Puestow@c-core.ca

Robert Alkemade, Michel Bakkenes, Bas Eickhout, Ben ten Brink
Netherlands Environmental Assessment Agency (RIVM-NEAA)
P.O.Box 1, 3720 BA BILTHOVEN, The Netherlands

Hugo Ahlenius; Kathrine Johnsen
UNEP/GRID-Arendal
Longum Park, Service Box 706, N-4808 Arendal, Norway
ahlenius@grida.no
http://www.grida.no/

Ingunn Vistnes
Agricultural University of Norway, Dept. of Biology and Nature Concervation, P.O. Box 5014, N- 1430 Ås

Dr. B. P. Kaltenborn
The Kalman Group
Lillehammer, Norway

Dr. Jane Uhd Jepsen; Dr. Nina E. Eide
Norwegian Institute for Nature Research (NINA)
Storhove, N-2624 Lillehammer, Norway

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Emerging threats to the water resources and biodiversity at the roof of the world to Asia's lowland from land-use changes associated with large-scale settlement and piecemeal development

Printed November 2004 by Birkeland Trykkeri, Norway. Photos courtesy of Topham/UNEP and ICIMOD.

Preface by the Executive Director of UNEP and the Director General of IUCN

Water means life. Nowhere else on this planet is the dependence of the population on mountains for the water resources they provide as high as in Asia. Here, on the "Roof of the World", nearly half of the world's population relies on the health of mountain ecosystems to supply clean water for drinking, sanitation, food production, livestock and biodiversity.

This report is a result of a collaborative effort between the United Nations Environment Programme, IUCN – The World Conservation Union and local experts across the Himalayan region. It demonstrates that continued unrestrained "piecemeal" development of these vulnerable mountain areas undermines the future availability of water resources to both people and nature. Recent floods have also shown how crucial sound watershed management is to livelihoods and – ultimately – the survival of millions of people throughout Asia.

Satellite images in the report reveal significant changes over the past decades, including deforestation, erosion and salinization. It is therefore of particular concern that only a few percent of these watersheds are currently protected. The report makes a powerful statement that if we fail to assess the impacts of uncontrolled large-scale development, we may indeed lose what we gain locally. This is especially important as the human and financial costs of reversing established settlement and infrastructure development in environmentally sensitive regions are very high.

While there are many promising steps towards improved environmental governance in the region, for example in Nepal and in parts of China, much more is needed. Options for action include increasing the number and extent of protected areas and providing adequate financial resources and enforcement to safeguard these critical habitats and the indigenous communities they shelter.

We hope that this report will help the involved governments and people in the region understand the contribution of conservation to watershed management. UNEP and IUCN welcome increased local and international collaboration on shared water resources and emphasize the need for all governments in the region to expand protected areas in the catchments and basins of the great rivers and seize a unique opportunity for peacefully reaching common goals. We all share a deep personal responsibility and obligation to ensure that future generations can also benefit from the fall of the water from the world's tallest mountains.

Klaus Toepfer,
Executive Director, UNEP

Achim Steiner,
Director General, IUCN

Executive summary

This report illustrates several of the cumulative environmental impacts of piecemeal infrastructure development, population growth, water shortage and climate change in the Greater Asian Mountain region. The scope of this report is the broad, regional scale land use change.

The Hindu-Kush Himalayas and adjacent mountain ranges comprise extremely important water towers of large capacity and of great strategic importance, sustaining basic needs of close to one half of the World's population. Despite the large reservoirs of glacial systems and upland watersheds, seasonal water scarcity and supply variability are increasing problems. Until recently, the extreme topography including the tallest mountains of the world, has served as a physical barrier to development. This is rapidly changing.

- Piecemeal infrastructure development has resulted in increased mining, hydro power development, poaching, deforestation of water sheds, agricultural expansion with increasing irrigation, redistribution of domestic animals into more marginal grazing lands and drainage of wetlands.
- Satellite images from 1960-2000 reveal great changes in environmental pressures both in urban, rural and even highly remote areas with progressing development.
- Impacts include overgrazing, erosion and deforestation following settlement along road corridors.
- A major cause of increased sediment load in rivers in wet seasons and decreases in water flow in dry seasons is unsustainable human land use practices.
- Unsustainable land use has resulted in reduced capacity of watersheds to manage monsoon and snowmelt driven floods.
- Expansion and population pressures have lead to increased settlement in flood-risk areas along lakes, behind former flood dikes, in drained wetlands, deltas or on steep slopes subject to land slides and erosion.
- Unsustainable land use practices are increasing both likelihood and impact of floods, especially for impoverished people.

Modelling of the cumulative impact of a range pressures appear to provide a new tool for facilitating and improving cost-effective environmental policies. In spite of a broad range of scenario conditions:

- In 2000, biodiversity was impacted in 46 % of the land area in the region as a result of infrastructure development and associated human exploitation.
- Currently less than 3% of the watersheds in the region are protected by parks and reserves against erosion and deforestation.
- Four different scenarios show that up to 73% of the land area may be impacted by 2030, indicating substantial reductions in abundance and diversity of wildlife and in the ability of catchments to filter water and reduce impacts of floods.
- All model outputs suggest a reduction in the original abundance of wildlife[1] between 40-80% in lowland areas, and 20-40% in upland areas by 2030.

Scenarios of the significance of different threats to abundance of biodiversity including climate change, different land use practices, development and N-deposition show that the significance of different pressures may change over time.

- The most significant threats consist of unsustainable land use practices primarily related to road development, deforestation and unsustainable agricultural practices.

Although numerous local examples of successful halting or even reversal of environmental degradation exist throughout this region, the overall picture is alarming. Environmental impacts are generally poorly controlled through existing policy and management systems. Most of the larger infrastructure projects fail to complete environmental assessments, and those that do, fail to encompass the cumulative social and environmental impacts of piecemeal development. There are currently no international policies in place to reduce the long-term impacts of this development. Water and participatory programmes are contributing to sustainable development in many regions locally. However, a strong increase in the extent and network of protected areas will be needed in order to divert the currently unchecked tide of resource exploitation in the water sheds in order to safeguard the water supply and biodiversity. China is among the countries facing major environmental challenges, but has also recently revealed impressive and successful initiatives in development of protected areas and combating desertification and deforestation. Careful management of the land and its water resources may play a major role in social and geopolitical stability in the long-term in the region. To a great extent this will depend on region-wide policies aimed at coordinating efforts towards better protection of upland watersheds inside and outside of protected areas.

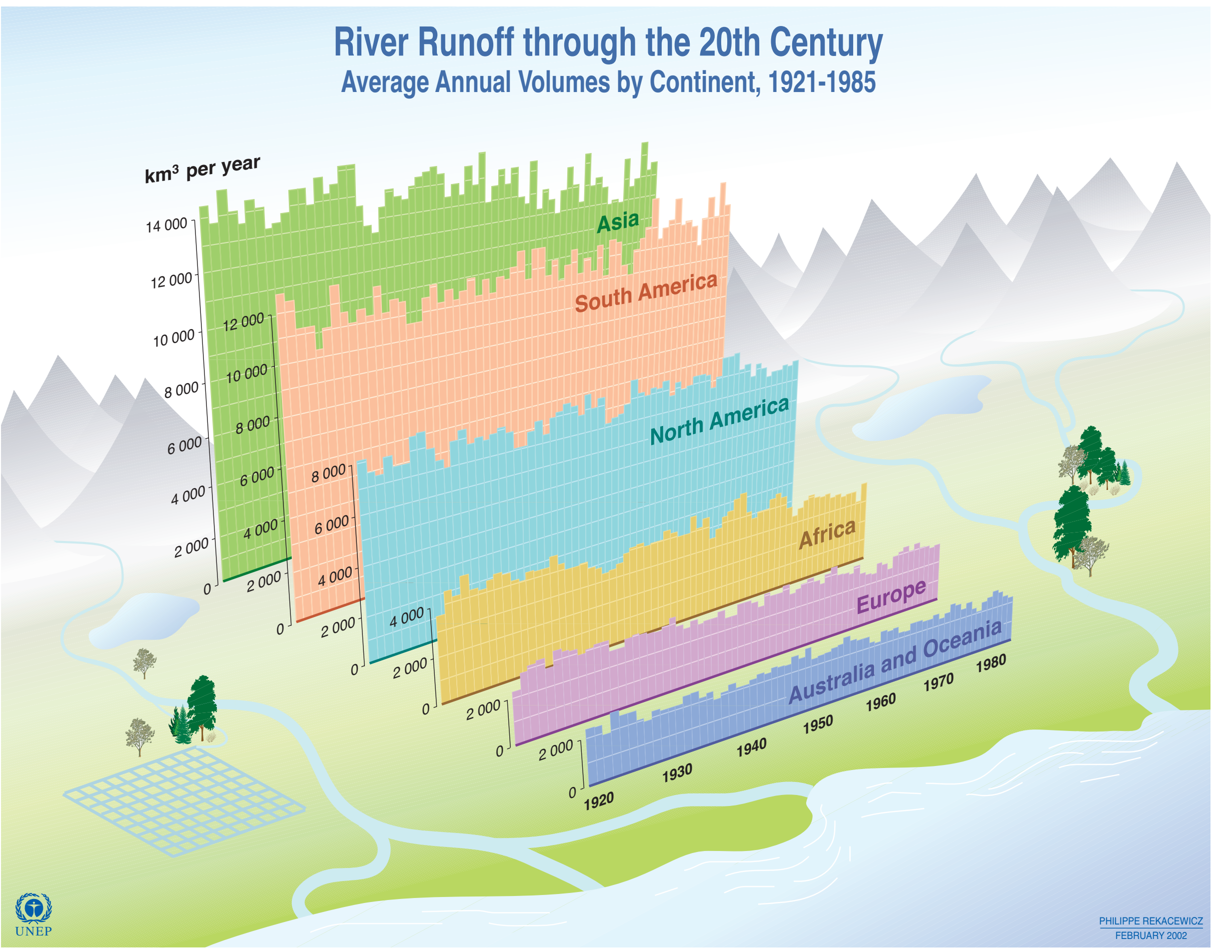
1. Biodiversity loss is calculated here as the average reduction in the abundance of the original species. The abundance of a species means the number of individuals or population size of a species, for instance 20.000 Whooper swans.

Introduction

At the roof of the world, the Tibetan plateau supplies, together with the Himalayas, Hindu Kush and the Tian Shan mountain ranges, water to people in Central, Southern, Western and South-east Asia, the largest river run-off from any single location in the World (UNEP, 2002a) (Fig. 1). Major rivers originating from these mountain regions include the Syr Darya, the Amu Darya; the Ganges, the Indus, the Arun, The Sankosh, the Manas, the Yarlung/Brahmaputra, the Chindwin, the Salween/Nu Jiang, the Lancang Jiang/Mekong, the Jinsha Jiang, the Huang He and the Yangtze, in addition to numerous other rivers. While the mountains are homes to some 170 million people, the water resources influence the lives of close to half of the world's population downstream. The region comprises unique biodiversity, ranging from desert, steppe and high-altitude fauna to tropical rainforests with global biodiversity hotspots, such as in South-Western China.

While mountains traditionally have been considered the major water sources of the region, there is great diversity, particularly between north-western and south-eastern regions in the hydrological significance of mountains for water supply further downstream (Viviroli et al., 2003). For several of the rivers from the Tian Shan and Hindu Kush into Central Asia and Pakistan, such as the Amu Darya and the Indus, the mountain sections are responsible for >90% of the estimated discharge, while rivers like the Mekong also receive substantial water from lowland catchments and the monsoons. There is also extreme variability within this region with regard to vulnerability to land use patterns, land slides, floods, drought or glacial outbursts (Semwal et al., 2004; Gautam et al., 2003; Blyth et al., 2002; Gurung and Gurung, 2002; Chettri et al., 2002,; Dongol et al., 2002). In spite of the vast water supply, water scarcity is a major problem in the region, both up- and downstream, including both drinking water and irrigation (Merz et al., 2003). Desertification is a major problem in north-western parts of China, such as in parts of Xinjiang, particularly as a result of intensified land use along road corridors. The rivers form basic lifelines to people including access to

Figure 1: While Asia has the highest share in the run-off of all the World's rivers, it holds an estimated 60% of the World's population (~3, 675,000,000 people in 2000), but only 36% of its river run-off (UNEP, 2002a).

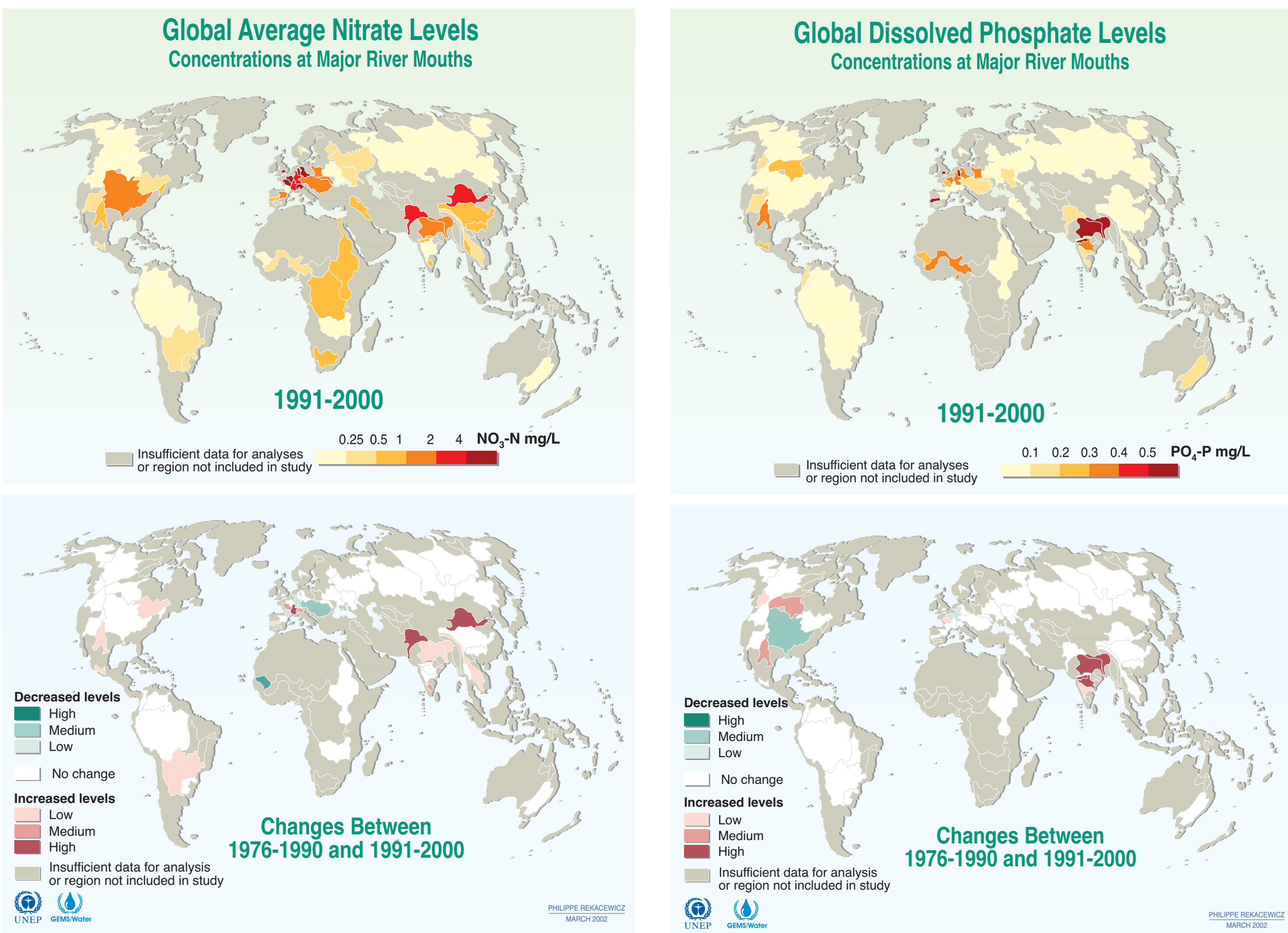


Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999.

household water, food, fisheries, jobs and cultural traditions. Changes in the catchments and the rivers could be detrimental not only to individuals, but also to nations and welfare of several billion people in the region (Lu et al, 2003; Viviroli et al., 2003). Currently, both natural and human driven disasters are common throughout the region, including floods, land slides, earthquakes and glacial outbursts (Gerrard and Gardner, 2002; Yong and Yiqian, 2003). Problems are currently being exacerbated by climate change which speeds up meltdown of high altitude glaciers at unprecedented rates.

To the last part of the 20th century, the topography of the region largely functioned as natural protection to large-scale development, thereby providing unique gradients from largely untrammeled areas with only minimal impacts from pastoralism and subsistence type agriculture, to some of the most densely populated regions of this planet, thus preserving the precious water resources in the catchments. However, development of the infrastructure network in recent years has greatly increased the access of industry to forest products, minerals, hydro power, oil and gas. Environmental pressures and threats include nuclear waste, toxic tailings from industry, pollution, sand storms, deforestation, overgrazing and erosion from increases in domestic animals, reduction in nomadism, unsustainable agricultural practices and loss of seasonal pastures and natural flood-buffers. Growing populations result in intensified land use practices along road corridors, increased water consumption and increased vulnerability to climate change. This has resulted in increases in both nitrate and dissolved phosphate levels in the rivers across the last decades (Fig. 2). While numerous water and participatory programs have been developed and some successfully directed towards individual and local issues, there are currently few, if any assessments of the large-scale long-term changes of human settlement and resource exploitation in the region. Such major long-term changes may play a major role for the functioning of ecosystems and their services to people and should of particular interest for policy making as they may exhibit trans-boundary patterns. Such

Figure 2: Increases in nitrate and dissolved phosphate levels between 1976-1990 and 1991-2000 in some of the major watersheds in the World show particular high changes in Asia.



Source: United Nations Environment Programme (UNEP) - Global Environment Monitoring System (GEMS) Water Programme 2001; National Water Research Institute Environment Canada, Ontario, 2001.

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research has also been compounded by the extreme diversity of the region from tropical rainforests to deserts, steppe and high-altitude environments.

In this report we present case studies revealing that piecemeal infrastructure development may produce un-foreseen environmental impacts across most landscape types and ecosystems and exacerbate a common policy deficit throughout the entire region. We present possible outcomes and overviews of what unchecked development may lead to for the water resources and biodiversity in the region given today's policies.

Objectives

The purpose of this report is to assess the risk to the water resources and biodiversity of the Greater Asian Mountain region of large-scale piecemeal infrastructure development. Specifically, the report intends to provide evidence for how unchecked infrastructure development across a broad range of ecosystems from tropical forests to alpine steppe may provide serious environmental impacts as a result of associated changes in land-use along road corridors. This information is used to present an overview of the current and possible future extent of threats to the water resources and biodiversity in the region in the context of growing populations, water shortages and climate change.

Methodology

The methodological approach of this assessment is based upon presenting evidence on the impacts of infrastructure for a range of ecosystems, secondary data and compiled overviews of the current situation of the water resources and finally overviews and scenarios on the cumulative impacts of piecemeal development now and in the future using GLOBIO-modeling.

The GLOBIO methodology is based on a broad review of impacts to wildlife from infrastructure and associated development in a variety of landscapes from Arctic and alpine steppe and tundra, to savanna, forests, tropical rainforests, wetlands, croplands and near-urban environments ranging from pure wilderness regions to densely populated rural and urban environments. It thus provides a perfect setting for creation of alternative scenarios for piecemeal development across such a diverse region as the Greater Asian Mountain region.

Many major environmental assessments rely on an evaluation of direct effects, indirect effects and cumulative impacts. Direct effects include the impact of the actual infrastructure such as physical loss of habitats; indirect effects refer to impacts such as land use alterations in the local or regional neighborhood of the infrastructure, avoidance by wildlife of the areas in the vicinity of the infrastructure etc.; and cumulative impacts include the long-term effects of several pressures or effects combined.

Here we first present an overview of regional land cover and the current extent of piecemeal development in the region. We then present an analysis of indirect changes in land use exemplified by an analysis of satellite images in different ecosystems of the region affected by development. We use satellite imagery derived from Landsat, IKONOS and Corona satellites. Images were used to assess changes in land cover from the 1960'ies to current. We present satellite images or other data for five of the major human and natural environments in the region including tropical forests (The Mekong subregion), urban areas (Kathmandu in Nepal), deserts (The Taklamakan and Tarim river basin, Xinjiang, China), temperate hills (Galiat in Pakistan) and finally high-altitude mountain steppe (Bayanbulak, Tian Shan, Xinjiang, China). The landscapes represent some of the variety in human and natural environments found in the region.

The GLOBIO method

The GLOBIO consortium consists of UNEP GRID Arendal, UNEP World Conservation Monitoring Centre and the Netherlands Environmental Assessment Agency at RIVM (NEAA-RIVM). The institutions work together with a large network of experts and institutions to develop quantitative scenario techniques to assess the impacts of human activity on biodiversity and ecosystems. The GLOBIO 2.0 model specifically addresses the biodiversity impacts of infrastructure development using internationally established scenarios of projected growth from the GEO-3 scenario work (UNEP, 2001; 2003).

Recently, the institutions have jointly developed a new Global Biodiversity Model – the GLOBIO 3.0 – which is a combination of GLOBIO 2.0 and the climate and biodiversity model IMAGE-2.2 including new pressure-biodiversity relationships to more fully assess the cumulative impacts of different human pressures on biodiversity. Rather than just assessing the pressures alone, the new model has its basis in a very extensive literature survey of empiric peer-reviewed scientific studies on effects on biodiversity. From this a series of dose-response curves has been generated. By combining these with different scenarios – using established scenario frameworks from IPCC and GEO, projections of future biodiversity compared to the original state (given no human impact) can be made. In GLOBIO 3.0 biodiversity has been slightly different defined as in GLOBIO 2.0, and has been made coherent with one of the state indicators as agreed upon under the Convention on Biological Diversity (UNEP, 2004[2]). The definitions are explained in the text.

In the following we employ the GLOBIO 2.0 model framework to specifically address the environmental impacts of infrastructure development in the greater Asian mountain range of the Himalayas-Hindu Kush, Tibet and Tian Shan, including the effects down river. In addition we use the GLOBIO 3.0 model framework for a comprehensive assessment of the cumulative impacts of human development and climate change on biodiversity. The details of the models are given in the appendix.

1. Biodiversity loss is calculated here as the average reduction in the abundance of the original species. The abundance of a species means the number of individuals or population size of a species, for instance 20.000 Whooper swans.

What is biodiversity, biodiversity loss and how can we measure it?

Biodiversity is a broad and complex concept that often leads to misunderstandings. Biodiversity encompasses the overall variety found in the living world: it includes variation in genes, species and ecosystems. Here, we will focus on species, considering the variety of plant and animal species in a certain area (species richness) and their population sizes (species abundance). Population size is the number of individuals per species, generally expressed as the abundance of a species or briefly "species abundance". The various nature types in the world, also called "biomes" vary greatly in the number of species, their species composition and their species abundance. Obviously a tropical rainforest is entirely different from tundras or tidal mudflats. The loss of biodiversity we are facing the last century is the -unintentional- result of increasing human activities all over the world. The process of biodiversity loss is generally characterized by the decrease in abundance of many original species and the increase in abundance of a few other -opportunistic- species, as a result of human activities. Extinction is just the last step in a long degradation process. Countless local extinction ("extirpation") precedes the potentially final global extinction. As a result of human development, many different ecosystem types are becoming more and more alike, the so-called homogenisation process. Decreasing populations are as well a signal of biodiversity loss as strongly expanding species, which may sometimes become even plagues in terms of invasions and infestations.

Until recently, it was difficult to measure the process of biodiversity loss. "Species richness" appeared to an insufficient indicator. First, it is hard to monitor the number of species in an area, but more important it may sometimes for a shorter period increase as original species are gradually replaced by new man-favored species. Therefore the Convention on Biological Diversity has chosen to use -amongst others- species abundance as indicator for this degradation process. In line with the above in this report and in the GLOBIO model biodiversity is defined as a tangible and quantifiable stock entity: the whole of original species and their corresponding abundance. Even for a relatively small area in e.g. tropical forest, an area may contain several million species. Thorough mapping and monitoring across larger areas is therefore simply not feasible or possible. However, luckily, there are numerous thorough peer-reviewed empiric studies available that quantitatively link changes in habitat, such as fragmentation, to biodiversity loss. By extensive reviews of the literature for specific habitat types and the extent of the pressures present, we can model the potential loss in biodiversity compared to the undisturbed state by projecting the impact of changes in different pressures over time. By comparing and analyzing also historic changes in habitats, including use of as satellite imagery, records in changes can be projected out in time using different types of scenarios and assumptions.

Biodiversity loss is here expressed as the average species abundance of the original species compared to the natural or low-impacted state. To avoid masking of the process increasing populations do not compensate for the loss of decreasing populations in the indicator. If the indicator is 100% then the biodiversity is similar to the natural or low-affected state. If the indicator is 50% then the average abundance of the original species is 50% of the natural or low-affected state, and so on. To avoid masking, significant increased populations of original species are truncated at 100%, although they should have actually a negative score. Exotic or invasive species are not part of the indicator. See appendix for further information on calculations and modelling.

Piecemeal urban and infrastructure development

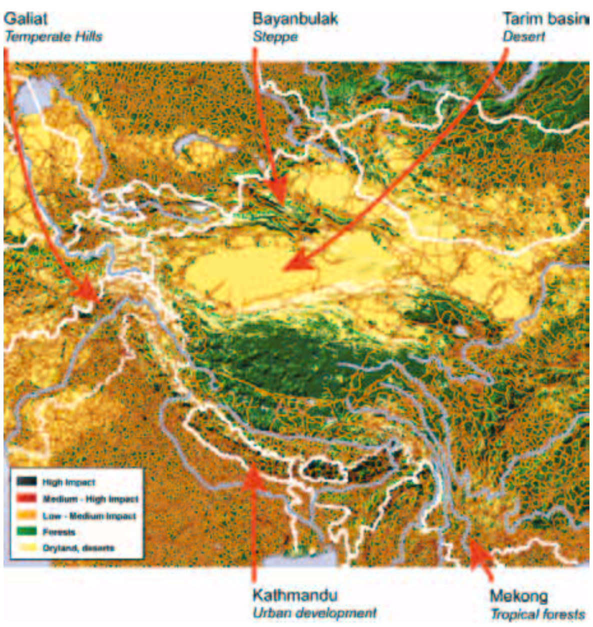


Figure 3: The area where infrastructure development, intense land use or agriculture has resulted in biodiversity loss in the Greater Asian Mountain region. The locations illustrate some of the great variety in the region and are presented elsewhere in this report.

During the past century, population growth, trans-migration, political changes, opening of certain borders between countries and globalization of markets has accelerated resource exploration. This, in turn, has resulted in massive development of the infrastructure network. By 2000, biodiversity was affected by infrastructure (medium-high level) in an estimated 46% of the region (Fig. 3). This indicates a substantial loss of biodiversity within this area.

The projected pressures resulting from growing human populations and intensifying land use is particularly evident in Northern India, Bangladesh, Southern Nepal and South-West China. This development has taken place through decades and is also well reflected in changes in population density in I.e. Nepal (Fig. 4), which is the most densely populated mountain country in the World.

It is important to realize that changes in population density in more urban areas, in addition to intensifying land use in nearby or more remote rural areas reflect long-term trends. There is no indication that populations are likely to stabilize or even decline in most parts of the region. Established infrastructure is likely to be near permanent as settlement often takes place along new road corridors. The current consumption of

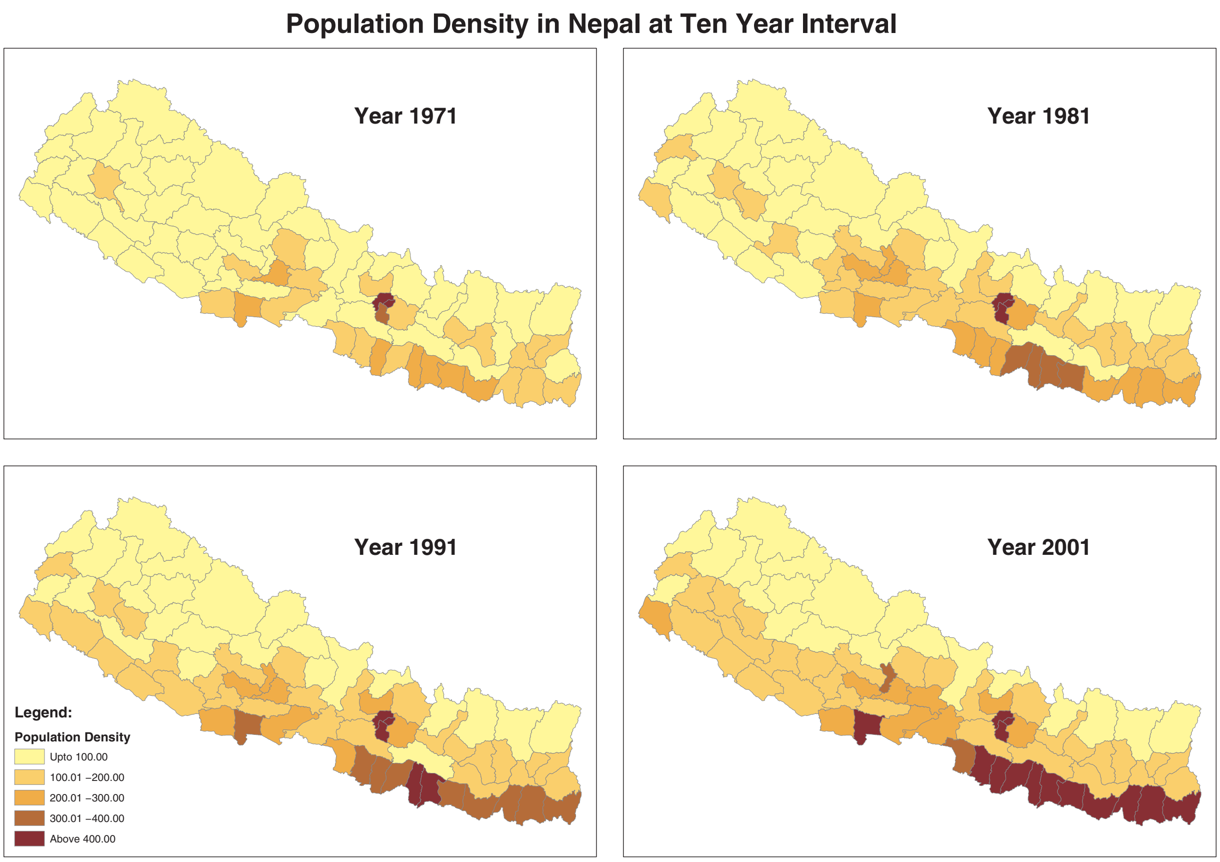


Figure 4: Population pressures are increasing rapidly in low-lying slopes and foothills. The maps depict changes in population density in Nepal 1971-2001. Note that the observed changes 1971-2001 correlate well with projected changes in infrastructure development and land use pressure for the coming decades (Shrestha et al., 2003).

wood, water and exchange of forests for cropland has not reached equilibrium and will likely continue for decades ahead.

The development is also reflected at finer scales in increased urbanization and development of temperate hills, tropical forests, deserts and in highland steppe.

Urban development

Across the region, urbanization is increasing. The impact of the expanding and intensifying land use is well reflected around urban areas, such as Kathmandu (Fig. 5). Even though Kathmandu is a small city by Asian standards, this case is illustrative for much of Asia. Most large Asian cities have expanded greatly during the last few decades and have reached proportions where most public services and amenities are exhausted and of inferior quality. Partly due to Kathmandu's location in a valley, the pollution problems are immense. The supply of adequate drinking water is a major problem, and sewage treatment presents a serious health threat. Lack of urban planning compounds the problems of population growth and immigration to the city.

The high rate of settlement is even visible in land cover changes and settlement within a decade in i.e. Kirtipur (Fig. 6).

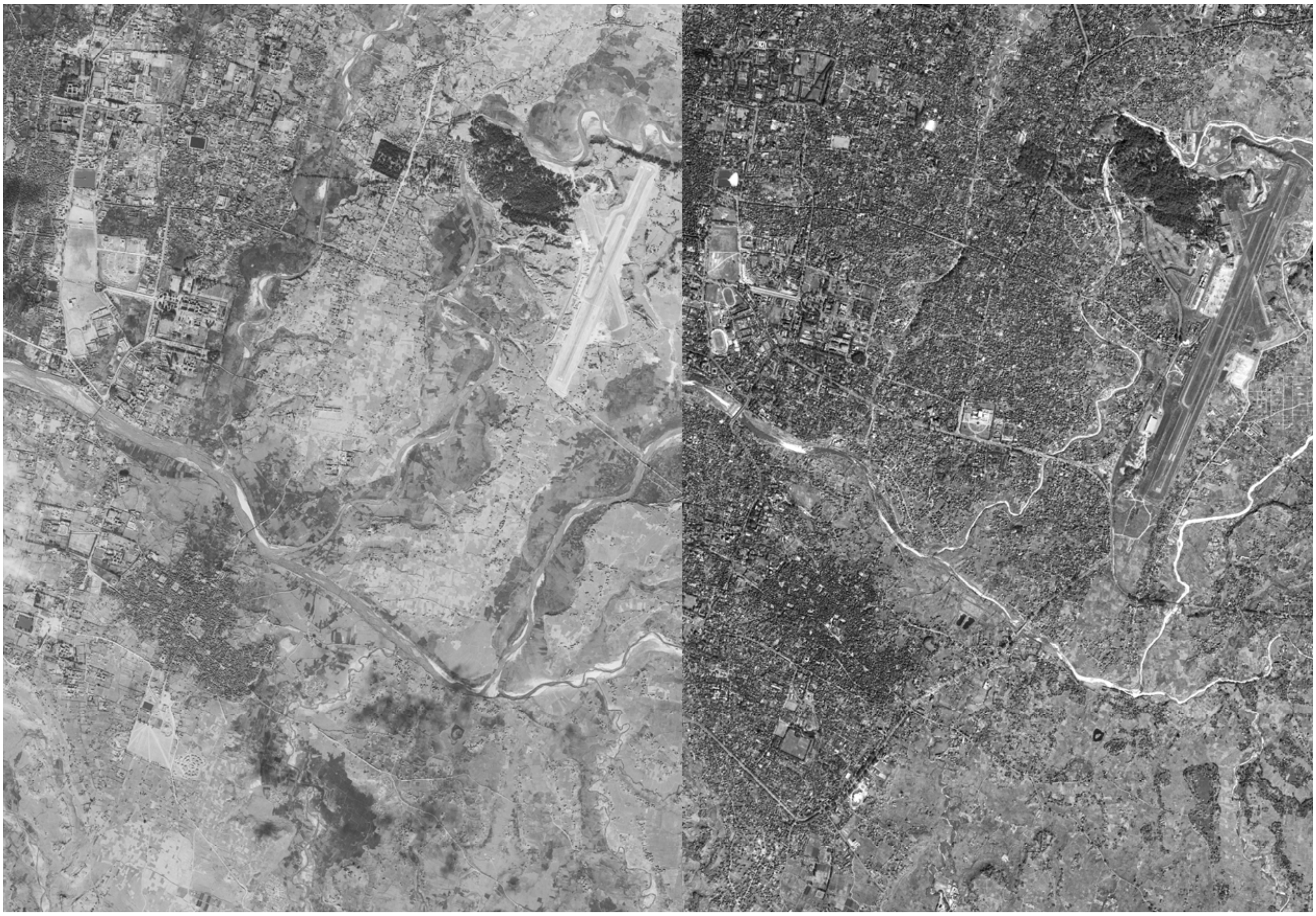


Figure 5: Growth in urban settlement and land pressures around Kathmandu 1960 (left) and today (right) using Corona and IKONOS images. Corona was an American spy satellite that was in use between 1959 and 1970. Notice how the light-coloured (left) croplands, mainly rice on terraces, have been developed with urban housing (dark areas) (right).

Land Use and Land Cover Change in Kirtipur Municipality

Land Use and Land Cover 1992 | **Land Use and Land Cover 1998**

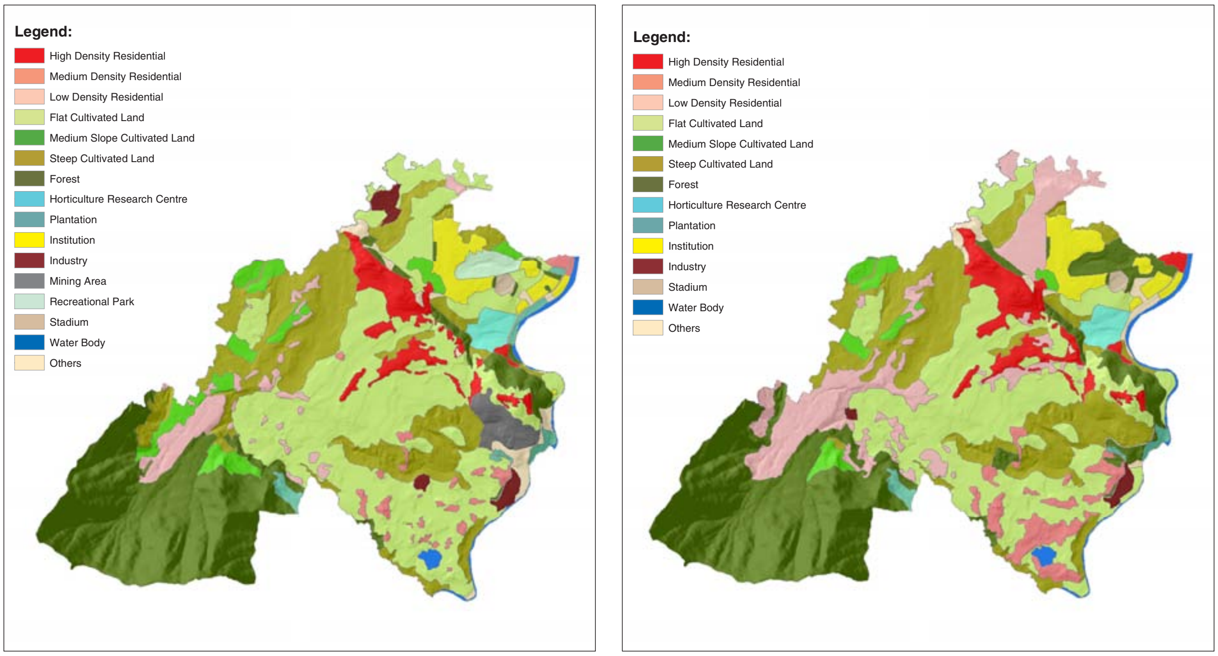


Figure 6: Land use and settlement changes in Kirtipur, Nepal. Notice settlement in terms of medium to low density populated areas (pink and dark pink areas) increased between 1992 and 1998. Such rapid growth put great pressures on sanitation and water resources (Shrestha, 2003).

Rural upland areas in temperate hills

Similar patterns of intensifying land use can also be found in more rural areas all across the Greater Asian Mountain region. Galiat is a part of Abbottabad Tahsil of Abbottabad District, Northwestern Pakistan. The area is located in the lesser Himalayan ranges between 33° 55' and 34° 20' North latitude and 73° 20' and 73° 30' East longitude and is home to 3,250,000 people. The main ridge of Galiat is running from North-West to South-East with big spurs in North-South directions. The main valleys also run in the direction of the spurs. The topography is rugged with steep slopes and narrow valleys with elevations ranging from 1000-3000 m. A mosaic land use pattern exists through out Galiat. The local population in the Galiat area is dependent on natural resources. The rapid population growth during the last 3-4 decades has resulted in a fragmentation of land holdings, clearance of vegetation and breaking of new land and terracing for agriculture, increased competition for scarce resources, steep slope cultivation, degradation of land due to overuse and soil erosion. The degradation of the environment is essentially caused by heavy pressure on the vegetative cover by an ever-increasing density of both livestock and humans.

The area drains into the Jhelum, Kunhar, Haro and Daur rivers. The forests are generally located above 2000 meters. Valley bottom and moderate side slopes are inhabited having scattered and conglomerate patterns of houses. Land slips and land slides are found on steep bare slopes. Rock falls, scree deposit and mud flows are also common on precipitous slopes.

Unplanned developmental activities such as construction of buildings and roads (widening of Abotabad to Murree Road and construction of Kuza Gali to Malkot and several rural access roads) have resulted in considerable environmental degradation. Evidence of forest degradation (except Ayubia National Park area), deforestation, poor logging practices, sparse pastures, uncontrolled grazing, erosion, geological instability and poverty is visible. The deforestation is particularly evident along the road corridors (Fig. 7).

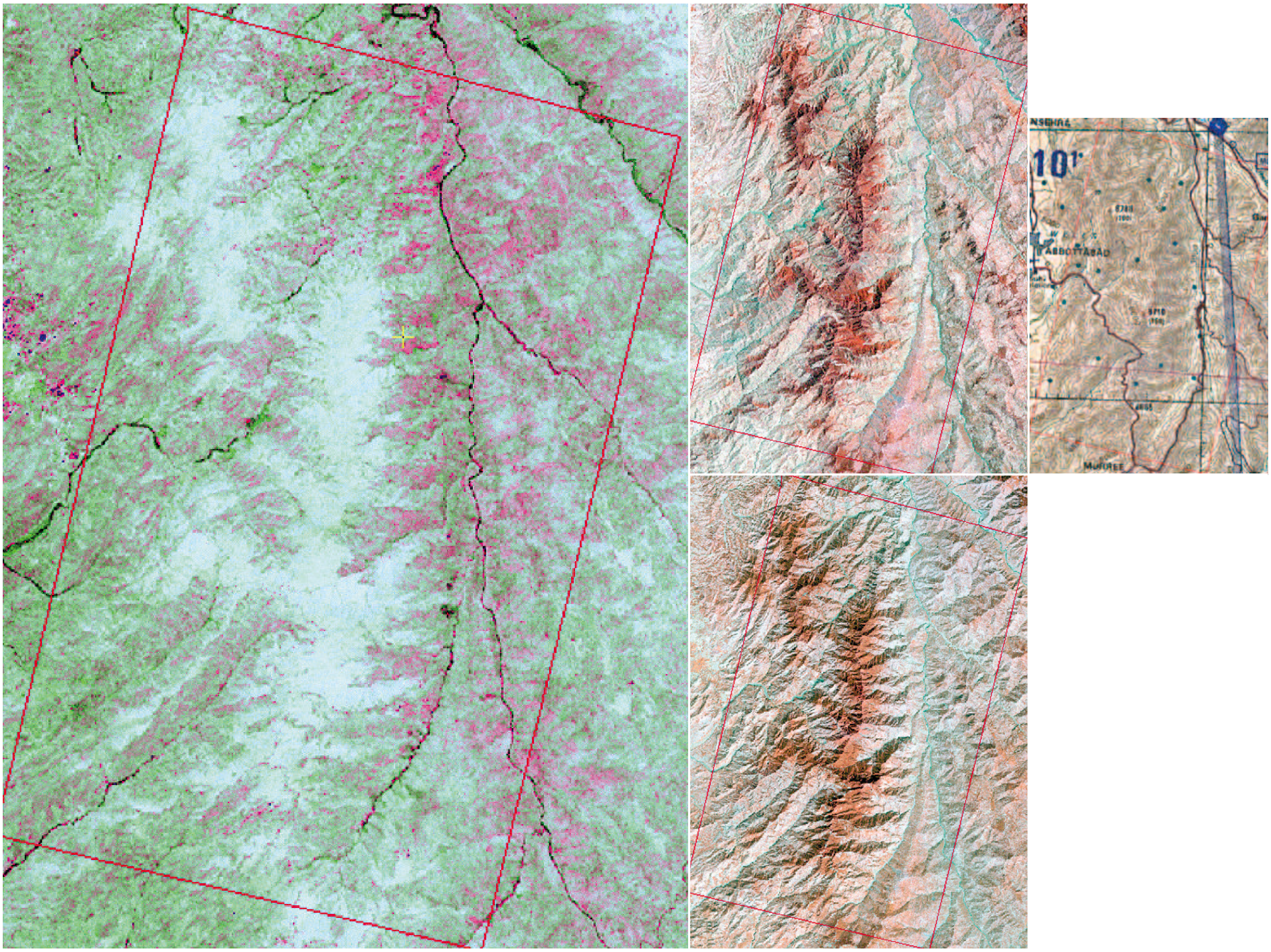


Figure 7: Deforestation, grazing and erosion along road and river corridors in Galiat, Northwestern Pakistan. The two small images to the right show the vegetation cover in 1979 and 2001. The pink color in the large image indicates the reduction in vegetation cover observed from 1979 to 2001. Notice that deforestation and land use changes primarily takes place along roads and rivers (see small insert of roads in image).

Wilderness areas and high-altitude steppe

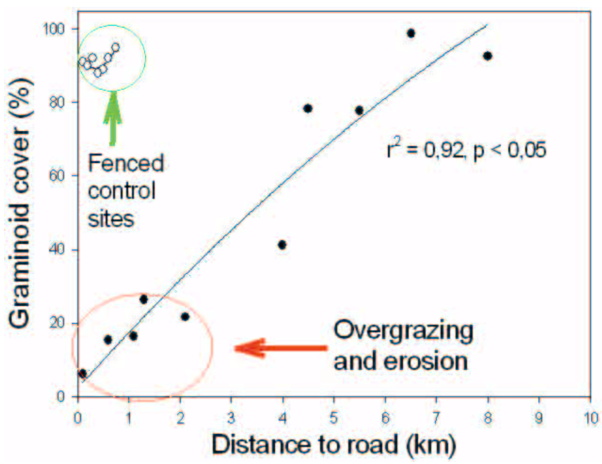
Wilderness areas of the Greater Asian Mountain region are characterized by either desert or very dry high-latitude environments including steppe. Most of these areas are typified by great clustering and concentration of biodiversity and resources commonly around water (oasis), glacier fed rivers and in south facing slopes. The highly patchy nature of natural resources in such landscapes makes them particularly vulnerable to development. Most of these areas are characterized by either scattered villages as in rural areas, crucial to many nomadic indigenous people. Many of these nomadic people have adapted a life form that enables them to utilize scattered and sparse resources in a more or less sustainable manner.

Unfortunately, the development of infrastructure such as power lines and roads intended to increase the standard of living, trade and health of locals, often leads to increased immigration of non-locals, bringing in different lifestyles and unsustainable land use practices.

Growing dependency on new goods and services and increased demands for meat from domestic animals, especially sheep and cattle, often results in more sedentary lifestyles and increased concentration of domestic animals along road corridors and settlement. Grazing, along with intensive use of forests and shrubs for firewood, often leads to increased erosion and risk of flashfloods (Fig. 8).

In many areas, such as in the Bayanbulak range of the Tian Shan mountains of Xinjiang, China, immigration of Han-Chinese have resulted in larger local settlements, with increasing pressures on the environment. The area contained the largest concentration of Whooper swans (Cygnus cygnus) in the world. As a result of growing number of domestic sheep and partly cattle to support the settlement and for export made possible through the road system, overgrazing has taken place across much of the low-lying parts of this high-altitude mountain plain. The result has been increasing erosion and loss of much of central Swan foraging and nesting habitat. The Swan population has declined from near 20,000 swans in 1975 to less than 2,000 in 2000 (Zhang et al., 2002). Furthermore, the nomadic Kazaks, with a long history of sustainable nomadic grazing, have lost some of their traditionally richest grazing areas near the settlements, and are left with intensified grazing in less productive ranges.

Figure 8: Overgrazing by domestic animals concentrates along road corridors and new settlements, with resultant drop in grass coverage and increase in erosion on plains and slopes close to roads. Each black dot represents a randomly selected site (with five vegetation plots each) on the Bayanbulak range, East Tian Shan, Xinjiang, China. Fenced control areas protected against grazing across a 20 year period are shown as open circles. Areas impacted can however in some instances be up to 30 km from major settlements as those people that still retain more traditional lifestyles are forced to use more marginal lands in dry seasons 15-30 km away from their traditional now-occupied ranges close to new settlements.



Arid lowland areas

Much of the arid and semiarid land surrounding the Tian Shan mountains depend entirely on snowmelt for their water resources. With growing settlement, the demand for irrigated cropland has increased dramatically, and rivers like the Tarim have been increasingly drained to support ever-growing irrigation projects. The agricultural expansion has resulted in an increase in salinization, a loss of riparian habitat for wildlife, and the destruction of previously rich grazing and nesting habitats for numerous wildlife species. In absence of alternative water sources wildlife decrease in abundance. Perhaps even more importantly, the development and land use changes leads to shifts in species composition, favoring generalist species at the expense of local and more specialized species. The region suffers under desertification and overgrazing, great drop in the swan population and intensification of croplands in former pastures.

Salinization refers to a build up of salts in soil, eventually to levels toxic for plants and soil invertebrates. Increased soil salinity decreases the osmotic potential of the soil and the root complex, inhibiting the water uptake of the plants. Salinization is typically a result of excessive water application, such as frequent floods or irrigation. Remote sensing analysis from the 1960'ies to 2000 reveal that the major land-cover changes in the Tarim river ecosystem are caused by land reclamation for agriculture. Housing started at the end of the 1950s and the old poplar forest around the Tarim river was gradually degraded due to a decline of the underground water levels as a result of water overuse for agriculture. From the 1950s to early 80s, the extent of the forest di-

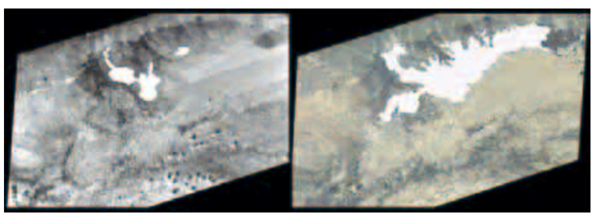
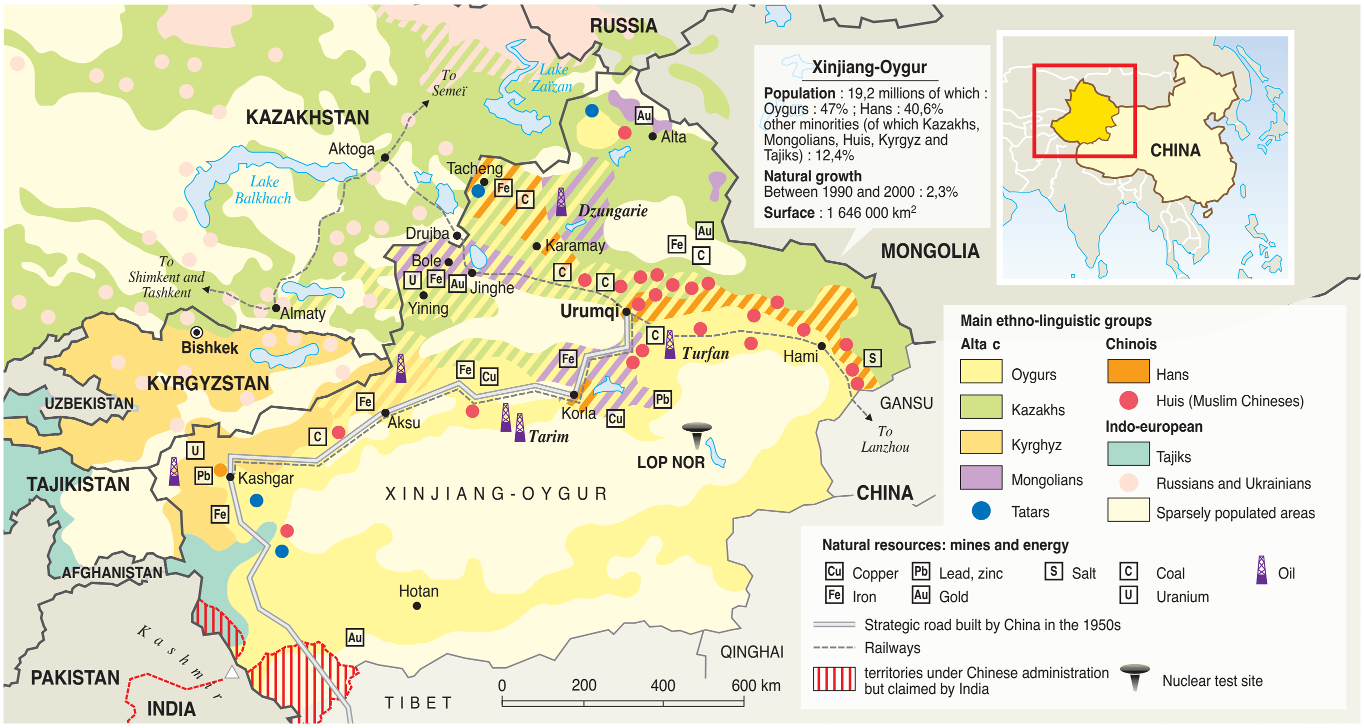


Figure 9: Satellite images indicating the increase in salinization of soils (white) in Northern Taklamakan along the Tarim river, Xinjiang, China between the 1950's and 1990's.



Sources : *Atlas of the People's Republic of China*, Foreign languages Press, Beijing, 1989 ; Jacques Leclerc, *Aménagement linguistique dans le monde* (http://www.tlfq.ulaval.ca/axl), universit de Laval, Qu bec, Canada ; Central Intelligence Agency (CIA), Maps and publications, Washington DC ; Chinese census, November 2000 ; ChinaOnline, Chicago (http://www.chinaonline.com).

PHILIPPE REKACEWICZ

Figure 5: Xinjiang and the Taklamakan desert have been found to hold vast resources of minerals and oil. The development and immigration however puts increasing strain on the very patchy biodiversity, so dependant upon the same water resources as the expanding human populations. Most of the lowland shrub areas and scattered forests are used for irrigated agricultural production, with loss of important wildlife habitats.

minished by 3000 km². Areas affected by salinization increased by thousands of km² from 1964 to 1994 (Fig. 9). This was due to a secondary salinization caused by the increase of the local water table following overuse of water for irrigation. This process came to stagnation from 1994 to 2000. The agricultural land surface during the whole period has been stable, since the largest scale land reclamation was done in 1950s. Water is becoming short (Courtesy of E. Lambin, 2004).

The 1,321-km-long Tarim River, the longest inland river in China, runs west to east along the northern edge of the Taklimakan Desert, and flows into Taitema Lake. Taitema lake and the lower reaches of the Tarim river (approx. 320 km section) dried up during the early 1970's. This resulted in a severe environmental degradation of the region. The Chinese government has spent 10.7 billion yuan or ca. 10,2 billion USD since 2001 on a long-term project to restore the environment along the Tarim River. The restoration project was intended to have effect by 2005, a goal unlikely to be met. Development pressures in Xinjiang (Fig. 10) is also affecting settlement patterns and demands for agricultural production, which, in turn, put pressures on local biodiversity.

Lowland and mountainous tropical areas

The Greater Mekong sub-region is a major recipient of water from the mountains and the monsoons, and includes some of the World's largest biodiversity hotspots. The region is highly diverse in terms of culture, resource management, governance and pressures. Recently, the Stockholm Environmental Institute (SEI) and the Asian Development Bank performed an evaluation of the major infrastructure projects in the region with emphasis on the transport and water resource sectors. The case studies included the Bangkok-Phnom Penh-Ho Chi Minh City-Vung Tau Road Improvement Project; the Chiang Rai-Kunming Road Improvement Project, the Kunming-Lashio Road System Improvement (Chuxiong to Dali portion), the Theun-Hinboun Hydropower Project, Lao PDR, the Tonle Sap Conservation and Sustainable Development Project and the Kinda Dam Multi-Purpose Project (SEI-UNEP, 2003).

An overview of the current (2000) status of some of the major road projects are given in Fig. 11.

The evaluated projects were highly variable both in extent and quality of the environmental impact assessments (EIAs) performed. None considered cumulative impacts of the prospected developments. Despite potentially affecting several thousands of people directly, and tens of thousands indirectly, assessments of the environmental and social consequences of the projects were limited.

Economic Corridors in the Greater Mekong Subregion

Figure 11: Major road projects in the Mekong region.

In general, poor or central governance and trans-boundary projects seem to reduce probability of proper environmental assessments. Common to all projects is that while some sectors, such as trade, transport and energy, it happens at the expense of biodiversity, wildlife and quality of and access to water sources.

The positive effects of development typically affect traders, merchants, and transport operators that may benefit from the greater access and reduced transportation costs provided by improved road systems They also include market access for farmers as the road opens a wider vent for surplus, but only if such surplus is available. Employment alternatives to subsistence agriculture may expand by virtue of the opportunities supported by a new road. Representatives of official and NGOs may be better able to serve client populations, and easily preventable communicable diseases may decline as the road will facilitate access to public health services. Opportunities for training and education may expand as the road reduces the isolation of communities in the area. Commercial investment may increase in response to the better economies of production and marketing associated with an all-season road.

Negative impacts however, tend to include population migrations and disruption of successful patterns of environmentally sound highland agriculture. Migrants from highlands may suffer the adverse health consequences associated with population movements to lowlands, and increased numbers of unwanted pregnancies may result from improvements in health status and economic well-being associated with better road access. Communicable diseases, such as HIV, may increase as a result of greater contact with workers and travellers from other areas. Poaching, logging and intensified grazing often take place along new road corridors. The reasons for building a road are decisive for its effects. Most road development projects are not large-scale routes of more strategic nature, but secondary roads to support logging or mining operations. These roads also result in most of the negative impacts, and rarely in positive ones, as no programmes or strategies tend to be in place to ensure mitigation or implementation. This particularly applies to cloud forests that are not only important biodiversity hotspots, but also very important for the hydrology of tropical forests.

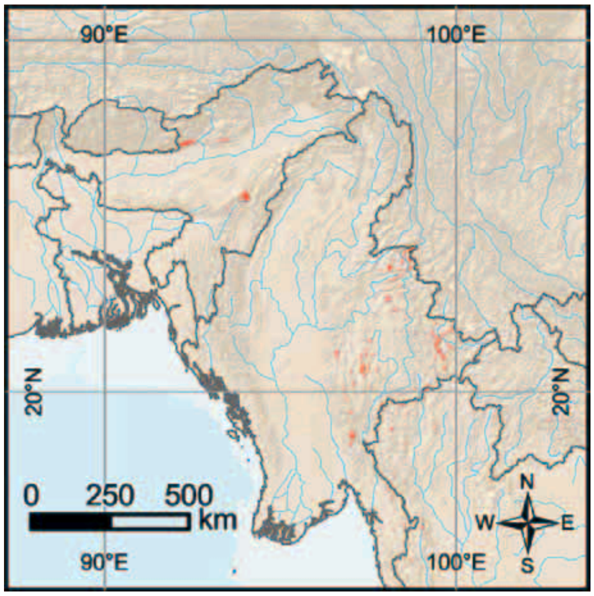


Figure 12: The distribution of tropical montane cloud forest in South-east Asia (red areas) (Bubb et al., 2004). TMCFs are under particular threat due to logging and development in South-east Asia and play an important role as biodiversity hotspots and the hydrology of the ecosystems. They play a particular hydrological role in regions where the monsoon, rather than snowmelt water from the mountains is the main water source.

Tropical Montane Cloud Forests (TMCFs) are rare and fragile ecosystems under particular threat due to logging and development in South-east Asia. Cloud forest typically consist of a belt of vegetation over an altitudinal range of about 500 m, and on large inland mountain systems cloud forests may occur between 2,000-3,500 m.These mountain forests are defined by the persistent presence of clouds and mists, which provide an input of water in addition to rainfall which significantly influences the hydrology, ecology and soil properties of cloud forests (Bubb et al., 2004). Their lush, evergreen vegetation includes an abundance of ferns, orchids and other epiphytic plants. In continental south-east Asia TMCFs have a naturally fragmented distribution on mountain ranges and peaks. They are found in the Indian states of Arunachal Pradesh, Assam, and Manipur, in eastern Myanmar, northern Thailand, Laos, and Vietnam. Sub-tropical cloud forests are also found in eastern Nepal, Bhutan and Yunnan Province of China (Fig. 12).

All mountain forests play important roles in stabilising water quality and maintaining the natural flow patterns of the streams and rivers originating from them. Tropical montane cloud forests have the additional unique value of capturing water from the condensation of clouds and fog. This “stripping” of wind-blown fog by the vegetation becomes especially important during the non-rainy season and in areas with low rainfall but frequent cloud. In addition evaporative water loss from cloud forests is low as vegetation is continuously wetted by rain or fog. This results in stream flows from cloud forest areas that are greater and more stable in dry periods. Under humid conditions the amount of water directly intercepted by the vegetation of cloud forests can be 15-20% of the amount of direct rainfall, and can reach 50-60% under more exposed conditions. These values tend to increase in higher altitude cloud forests. In areas with lower rainfall, or during extended dry periods, these percentages can be higher still and equivalent to 700-1000 mm of rainfall per year (Bubb et al., 2004).

Cloud forests have exceptional biodiversity value because a high proportion of their species are restricted to this habitat and have very local distributions on isolated mountain ranges. These high levels of endemism also make cloud forests home to many threatened species, as well as the regular discovery of new species. A new genus of the cow family and two new barking deer species were discovered in the Annamite cloud forests of Lao and Vietnam in 1996.

Cloud forests face many of the same threats to their existence as other tropical forests, but the unique ecology and location on mountain slopes makes them particularly vulnerable to some deforestation forces, land conversion and especially to climate change (Still et al., 1999; Bubb et al., 2004). A wide range of potential negative impacts have been identified. It is predicted that the optimum climatic conditions for many mountain habitats will increase in altitude by hundreds of meters in the second half of the 21st century. This will be a direct result of temperature and rainfall changes caused by a doubling of CO_2 levels. This will result in the replacement of cloud forests by lower altitude ecosystems and the extinction of cloud forests currently found on mountain peaks from where they are unable to spread upslope. Cloud forests are also likely to be affected by climate change, due to a reduction in cloudiness at lower altitudes as temperatures increase (e.g. Loope and Giambelluca, 1998; Foster, 2001).

Conservation and sustainable management of the cloud forests of continental south-east Asia first requires greater recognition of the existence of these forests amongst policy makers and development planners. Accessible information is required on the unique watershed and biodiversity values of these forests. Conservation and restoration measures can then be developed in partnership with the local communities and the cities that depend on the water and other products from the cloud forests.

The examples presented above illustrate the complexity of environmental impacts deriving from unchecked development, and their severe impacts on biodiversity and water resources locally. However, the cumulative impacts of such piecemeal development may also seriously impact overall biodiversity and ecosystem services, as well as the stability, quantity and quality of water resources.

Water resources affected by development

South-east Asia contains immense diversity with regard to the hydrological significance of the mountains for the water flow, the size of the river catchments, population density, pressures and biodiversity (Table 1). Currently, only a few percent of the water sheds are protected against exploitation (Table 1; Fig. 13). The ma-

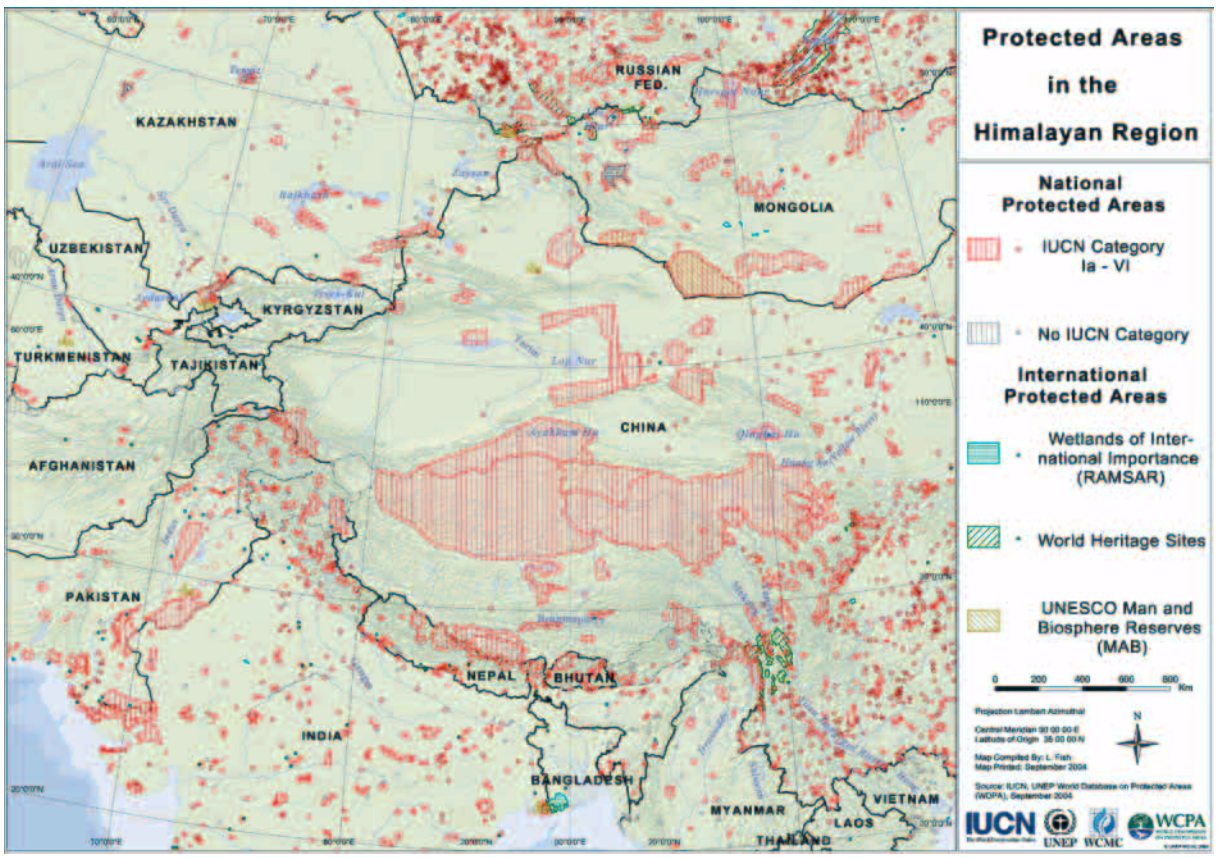


Figure 13: The extent of major protected areas in the study region. China has made impressive efforts in protecting vast areas including major parts of the Chang Tang and the Kunlun Shan, home to the Chiru antelopes and other wildlife and indigenous nomads. Organised poaching still remains a major challenge. Overall, however, the crucial water sheds are vastly underrepresented, less than 3% of the water sheds in mountainous Asia are currently protected, though supporting life to over 3 billion people.

Table 1: An overview of the major rivers in the Himalayas-Hindu Kush-Tian Shan-Tibet region (Source: Viviroli et al., 2003, IUCN/WRI 2003).

River	Basin km²	Population /km²	Total population	Water m³/person /yr	% cropland	% irrigated
Tarim	1,152,448	7	8,067,136	754	2.3	0.6
Syr Darya	762,617	27	20,590,659	1,171	22.2	5.4
Amu Darya	534,739	39	20,854,821	3,211	22.4	7.5
Indus	1,081,718	165	178,483,470	830	30.0	24.1
Ganges	1,016,124	401	407,465,724	1,700-4,000	72,4	22,7
Brahmaputra	651,335	182	118,542,970	1,700-4,000	29.4	3.7
Irrawaddy	413,710	79	32,683,090	18,614	30.5	3.4
Salween	271,914	22	5,982,108	23,796	5.5	0.4
Mekong	805,604	71	57,197,884	8,934	37.8	2.9
Hong (Red river)	170,888	191	32,639,608	3,083	36.3	3.9
Yangtze	1,722,193	214	368,549,302	2,265	47.6	7.1
Huang he (Yellow river)	944,970	156	147,415,320	361	29.5	7.2

*Number of dams > 15 m high. Numbers in parenthesis indicate new dams > 60 m under construction

jor rivers influence an estimated 1,398 billion people living in the basins, and perhaps close to 3 billion in surrounding areas through food production from irrigated croplands.

Along the Tarim river emerging from eastern Tian Shan in Xinjiang, China, into the Taklamakan desert, >20% is protected, and 7.7 million people inhabit the basin. In comparison, the Indus, Ganges, Brahmaputra, Yangtze and Huang He support more than one billion in their water sheds, but have only 1.3-4.4% of their basin protected. The Huang He now has a meager supply of 361 m³/person/year, whereas the Salween, originating from nearly the same area, has >23,000 m³/person/year (Table 1). Overall, with the exception of the Tarim river, only 2.7% of the basins are protected in spite of their vital role for the economy, health and survival of one-fifth of the world's population.

Extent of ecosystems with reduced biodiversity as a result of development

Close to half (46%; fig. 14a) of the Greater Asian Mountain region suffered a medium to high impact by development in year 2000. This figure is likely to increase substantially in the coming decades. Scenario analyses indicate that with continued growth and unchecked infrastructure development and resource exploitation, dramatic changes may occur in the watersheds across the next 30 years (Table 2 and Fig. 14a-e). By 2030, up to 73% of the area may have experienced substantial impacts on biodiversity and habitats, the largest proportion in productive lands. There was great variation among the individual countries in the study area (Fig. 15). Deserts and semi-deserts comprised ca. 2.93 million km² of the region in 2000. The greatest and most dramatic increases in environmental pressures on catchments, wildlife habitats and biodiversity will most likely take place along the Karakoram highway, Kashmir, along the Indian and southern side of the Himalayas and in South-eastern Tibet, the Yunnan and Sichuan provinces of southwestern China. However, intensification of grazing and croplands may increase risks of further desertification and pressure to semi-arid lands in Northern Xinjiang and Qinghai provinces, including the areas surrounding the Taklamakan desert, Qinghai lake and the Gobi desert. The uplands and water sheds of the Syr Darya, Amu Darya, Indus, Brahmaputra, Ganges, Yangtze and Huang He will receive some of the highest pressures and subsequent impacts in the coming decades. In other regions throughout the Tian Shan, Hindu Kush, Himalayas through northern Nepal and through Bhutan, as well as inner Tibet (The Chang Tang plateau) benefit widely from protected areas (Fig. 14).

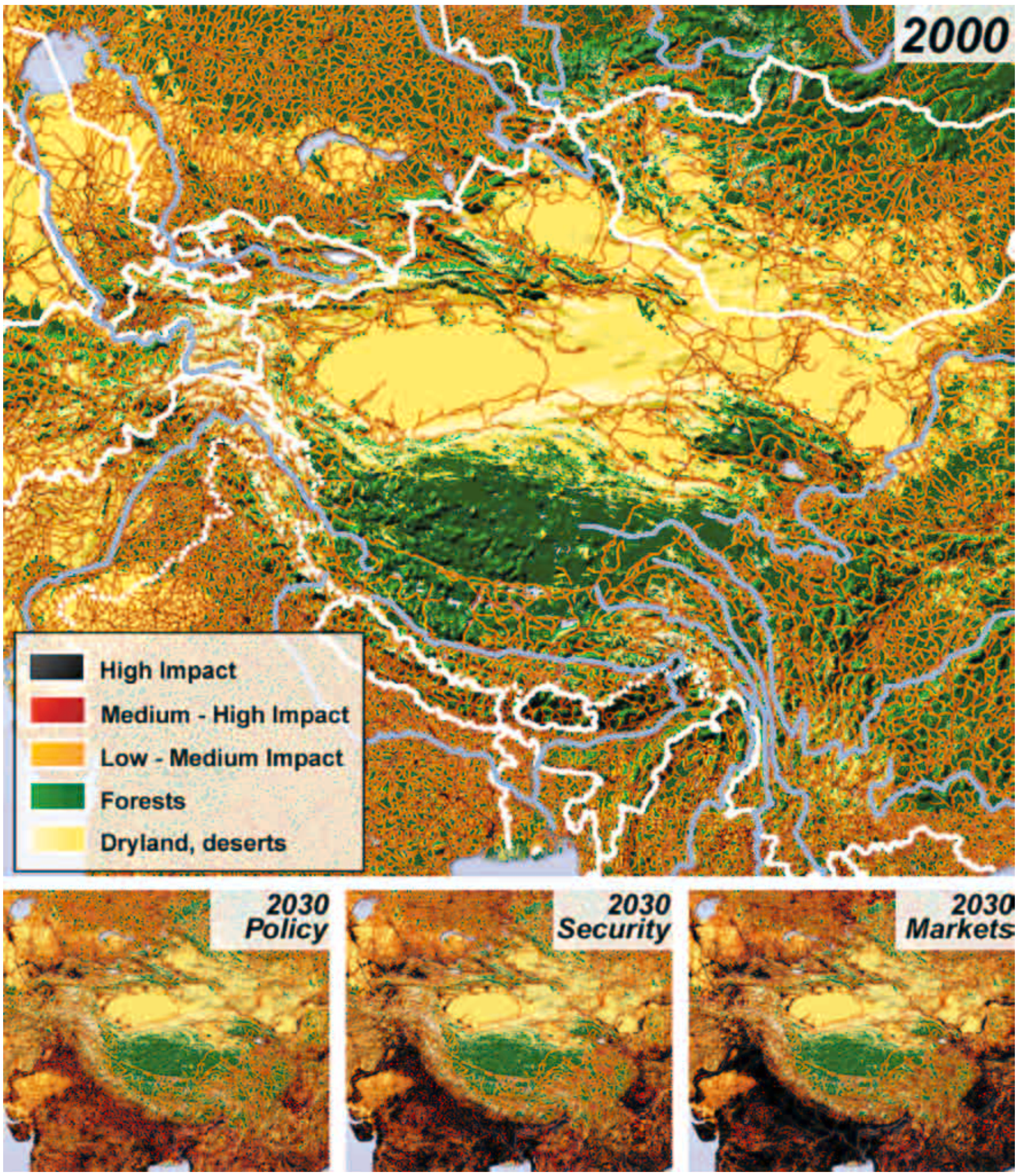
Table 2: The projected area with ecosystems impacted by infrastructure development* in the study area of Asia's mountains and surrounding lowland basins (ca. 15,6 million km²) (GLOBIO 2.0).

Year - scenario	Ecosystem area with reduced biodiversity (km²)	% of total area
2000	7,303,130	46
2030 - Sustainability first	8,826,094	57
2030 - Policy first	9,801,702	63
2030 - Security first	10, 531,973	69
2030 - Markets first	11,114,845	73

*The area within which 5-100% of wildlife species known to be impacted by human development are suspected to decline by >50%.

% forest	% original lost	% basin protected	Dams in basin*	Hydrological significance of mountains
<1	69	20.9	-	Very high
2.4	45	1.0	7(11)	Very high
0.1	98.6	0.7	6(8)	Very high
0.4	90	4.4	(3)	Very high
4.2	85	5.6	(5)	High
18.5	73	3.7	(3)	High
56.2	61	0.6	0	Moderate
43.4	72	2.2	4(5)	Moderate
41.5	69	5.4	4(7)	Moderate
43.2	80	3.8	22(25)	Moderate
6.3	85	1.7	63(101)	High
1.5	78	1.3	40(47)	High

Figure 14a-d: Changes in the area with reduced biodiversity and ecosystem function as a result of human development in infrastructure and associated resource exploitation between 2000 and 2030, given different scenarios. Security first and Markets first indicate situations where market-driven forces determine rate and extent of development, while policy first represents a more moderate growth rate.



Piecemeal development intensify land use

The scenarios project a substantial increase in the pressures on the environment and loss in biodiversity with continued development. Infrastructure causes impacts far beyond those of direct use or disturbance close to the actual infrastructure. The impacts of infrastructure and associated exploitation are seen through the cumulative impacts of the human expansion, resource and land use along road corridors and not the actual infrastructure in itself. Proximity to infrastructure, such as roads, is therefore a primary indicator of risk of habitat conversion, fragmentation and subsequent reduction in species abundance (UNEP, 2001). The cumulative environmental impacts of piecemeal development cannot, and has not been, effectively prevented through the traditional national levels of environmental planning and assessment (UNEP, 2001).

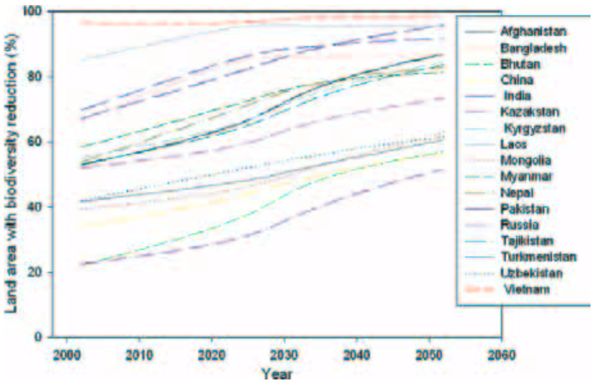


Figure 12: The areas projected to experience reduced biodiversity as a result of human development of infrastructure and associated land use pressures for the countries within the study region (Source GLOBIO 2.0). The graph includes only the medium development level ("Policy first"). Notice that for some areas deserts or high mountains put a limit on development. The productive land area of some countries impacted may therefore be considerably higher than shown, such as in China where deserts limit development. The figures provide area statistics for the areas of the countries included in the study area only, not the entire countries.

Expansion of roads into previously undeveloped areas open these areas for industrialization such as oil, gas and mineral exploration, logging, tourism and primary immigration, but also more uncontrolled, secondary immigration that often leads to legal and illegal hunting, squatter settlements, deforestation, land and water degradation, sometimes growing of illegal crops, and land conflicts (Skole et al., 1994; Houghton, 1994; Johnston, 1994; Chomitz and Gray, 1996; Reid and Bowles, 1997; Mäki et al., 2001).

Development of roads in semi-deserts and grasslands are often intended for mineral extraction, but also result in increased human immigration and occupation of dry-season pasture land traditionally used by nomadic pastoralists (Sheehy, 1992; Katoh et al., 1998; Li et al., 2000; Wang et al., 2002; Pan and Zhang, 2002; Su and Zhao, 2002). The result is often an increase in sedentary livestock densities in the vicinity of roads or adjacent back-country, changes in nomadic systems and composition of grazing ungulates, with resultant desertification or land degradation (Mwalyosi, 1992; Ayoub, 1998). Indeed, overgrazing is one of the primary causes of desertification in semi-arid zones of China and Central Asia (Sheehy, 1992; Li et al., 2000; Wang et al., 2002). However, China has invested large resources in combating desertification, such as the NAP programme (Zhao et al., 2002) and in spite of enormous environmental pressures, China has successfully reversed desertification and deforestation trends in many regions (Runnstrøm, 2000; Wang et al., 2003). However, while results are encouraging, huge efforts are still needed (Liu et al., 2003) and water scarcity is a severe and growing problem. Dust storms are a considerable environmental problem that is largely attributable to overgrazing and unsustainable land practices.

Piecemeal development is taking great tolls on biodiversity

Habitat loss associated with intensified land use, deforestation, influx of settlers and livestock, and subsequent overgrazing and poaching are severe threats to biodiversity (Turner 1996; Turner and Corlett 1996; Grau and Brown 2000; Fahrig 2003). The process is driven chiefly by the establishment of infrastructure associated with extractive industries. In addition infrastructure may disrupt the physical environment, alter the chemical environment, introduce exotic species, and in particular modify animal behavior and induce changes in land use (Andrews 1990; Kruess and Tscharntke 1994; Forman and Hersperger 1996; Forman and Alexander 1998; Trombulak and Frissell, 2000). Long-term effects on ecosystem function may occurs as a result of altered proportions of predator and prey organisms and a favouring of generalist species over specialists. While specialist species seem to avoid developed areas, generalist species, such as corvine birds, small predators and pest insects are more tolerant and may even benefit from human development (Cowardin et al 1985; Halme and Niemela 1993; Hill et al. 1997). Fragmentation may result in reductions in populations of natural enemies for pest insects, thereby increasing the number of pest insects (Kruess and Tscharntke 1994; Lawton et al. 1998). Fragmentation may also favour some migratory species at the cost of stationary species. The terrestrial and coastal development in infrastructure will also affect aquatic systems substantially not only through deforestation of catchments, increased erosion and pollution and drainage of wetlands (Woodford and Meyer, 2003), but also through increased shipping and resource extraction in the sea and in fresh-water systems. This activity will have an impact on fish, sea mammals and other organisms through increased harvesting or disturbance (Richardson et al. 1995; Trombulak and Frissell 2000).

For indigenous people, this development often results in conflicts with traditional lifestyles and land use patterns. Furthermore, as such development is assessed mainly as individual projects, the cumulative long-term impacts of the addition of infrastructure to the already existing network, is seldom considered. The pattern is particularly strong in tropical rain forests in the Mekong subregion (Kummer and Turner, 1994; Wilkie et al., 2000). Road construction often triggers entire chain reactions (Skole et al., 1994; Reid and Bowles, 1997). In forests worldwide, from North-American, European and Russian boreal forests to the tropical rain forests of the Amazon, the Congo basin and Southeast Asia, infrastructure development is recognized as one of the driving forces of deforestation, conversion to plantations and threat to biodiversity by propagating human access (Angelsen and Kaimowitz, 1999; Pattanavibool and Dearden, 2002). Grazing by domestic animals can be a major threat to biodiversity by increasing erosion, desertification or impacting floodplains and wetland conditions substantially (Jansen and Healey, 2003).

There are many well-known endangered species threatened by poaching and/or habitat loss in the lowlands, including the rhinoceros, tigers and pandas, but also a much broader range of tropical species, especially birds. The Sichuan-Yunnan region is one of the World's major biodiversity hotspots. However, at higher latitudes, other species are even more sensitive to development and increased poaching:

Black-necked cranes (*Grus nigricollis*)

Black-necked cranes are particularly threatened in Tibet. The population number around 5000 individuals, of which >85% breed on the Tibetan plateau and are extremely vulnerable to drainage of wetlands, hydro power development and overgrazing. The valley along the middle reaches of the Yarlung Zangbo River and the Senyingco nature reserve, two newly-created protection zones in China, are major habitats of rare cranes in Tibet. Thanks to the effective measures that Tibet has taken to protect rare cranes, the number of cranes spending the winter in this southwestern region has grown rapidly in recent years. Black-necked cranes usually stay in Tibet for about six months. Tibet, Yunnan, Qinghai and Guizhou provinces are among the few habitats of black-necked cranes in China.

Whooper swan (*Cygnus cygnus*)

The Whooper swan of Tian Shan in Bayanbulak have declined dramatically from >20.000 individuals in 1975 to less than 2000 in the year 2000, mainly a result of overgrazing associated with increased settlement (Zhang et al., 2002). Although the Bayanbulak swan lake was listed as a Chinese national swan nature reserve in 1986, the pressures including overgrazing and tourism increased with resultant habitat loss of the swans (Zhang et al., 2002). Proposals of dams in the area would further endanger this population.

Snow leopard (*Uncia uncia*)

Snow leopards are endangered mainly by habitat degradation and poaching, which is increasing with increasing settlement in formerly pristine wilderness regions. An estimated 5-7000 individuals are left in the wild (Table 3), mainly in China and Mongolia and scarce occurrences in mountainous regions throughout Central Asia (www.snowleopard.org; Schaller, 1998; Hussain, 2003). As many of the natural prey species decline with incoming human populations and growing livestock numbers, snow leopards shift to livestock for prey. Resultant retaliatory killing with firearms and in particular poison and traps is a growing problem (Oli et al., 1994; Mishra et al., 2003).

Przewalski's gazelles (*Procapra przewalskii*)

At Qinghai Lake, one of the World's currently most endangered ungulates are found. Przewalski's gazelles now number only some 150-300 individuals and their future is critical if measures are not taken immediately to protect them. Przewalski's gazelles were previously known across much larger regions including Inner Mongolia, Ningxia and Gansu. Habitat loss and human expansion has now narrowed their remaining distribution dramatically to the west, east and north of the Qinghai Lake. Predation by wolves and forage competition frm an increasing number of other herbivores, are additional threats to the survival of the Przewalski's gazelles. The most severe threat, however, is the imbalance between the male and female population, which makes its propagation difficult. China's first regulatory document on eco-environmental protection of a whole water system, the Regulation on Ecological Environmental Protection of the Qinghai Lake Valley, came into force on August 1, 2003, which – together with

Table 3: Estimated numbers of snow leopards left in the wild.

Country	Estimated habitat (km²)	Estimated population (1996)
Afghanistan	80,000	unknown
Bhutan	10,000	100
China	400,000	2,000 - 2,500
India	95,000	500
Mongolia	130,000	1,000
Nepal	30,000	300 - 500
Pakistan	80,000	300 - 420
Russia	130,000	120
Kazakhstan	71,000	100 - 120
Kyrgyz Republic	126,000	650
Tajikistan	78,000	< 200 - 300
Uzbekistan	14,000	<50

protected areas hopefully can add help to protect this species, although it's current future must be deemed highly uncertain unless directly targeted programmes to protect it are implemented and enforced.

Chiru (*Pantholops hodgsoni*)

The Chiru or Tibetan antelope has witnessed a decline similar to that of the American buffalo in the 1840-50's. Chiru favour alpine steppe, alpine meadow and desert steppe habitats. The largest remaining Tibetan antelope populations survive in the Chang Tang region of northwest Tibet, southern Xinjiang, and in southwestern Qinghai (Schaller, 1998). The Chiru has been subjected to organized poaching mainly by Hui and Han migrants, as well as previously by Chinese soldiers, primarily because of the value of their fine wool, known as shahtoosh. Shahtoosh is smuggled from China to India for manufacturing in Jammu and Kashmir state. Smuggling routes follow the high mountain passes between Tibet and India, or transit through Nepal. This also applies to poaching of the Snow leopard. Chiru, which are under the protection of the Convention on International Trade in Endangered Species, numbered under 75,000 at the end of the 1990's, down from over a million a century ago. They were being killed at a rate of 20,000 per year, mainly due to the large demand for shahtoosh shawls in Western markets since the 1980s.

Alpine and desert steppe on the western Tibetan plateau, typical habitat for threatened or endangered species such as Tibetan antelope, wild yak, Tibetan argali sheep, Tibetan wild ass, brown bear and, in the more rugged areas, snow leopard.

Four large protected areas in China have been set aside specifically to safeguard Tibetan Plateau wildlife species, including chiru and wild yak and their habitat, and other reserves are proposed, Those established to date include the Chang Tang Nature Reserve and Xianza Nature Reserve (334,000 km^2 and 40,000 km^2, Tibet Autonomous Region), Kekexili (aka “Kokoxili” or “Hoh Xil”) National Reserve (45,000 km^2, Qinghai Province), and Arjin Shan (or “Altun Tagh”) Nature Reserve (45,000 km^2, Xinjiang Autonomous Region). These reserves already have positive effects and the population decline has apparently been halted or even slightly reversed in some areas. Other threats to the chiru and other plateau ungulates include fencing and grazing encroachment by pastoralists, which interfere with chiru migration and foraging and the expanding exploitation of extractive industries that increase immigration and settlement into these areas. Thus, even if large-scale poaching is controlled, the effects of livestock increases and husbandry modernization, as in rangeland ecosystems elsewhere, are likely to be the primary long-term threats to the high plains ungulates such as chiru (Fox et al. 2004). Unfortunately, the calving grounds of some large Chiru populations still remain unprotected, and include areas threatened by road development and mining. While protected areas generally appear to have good effects on species conservation, law enforcement remains weak in many Chinese reserves. This is a common problem throughout most of Asia, but very typical of large parts of Tibet.

As fragmentation and habitat destruction associated with road development and intensified land use along infrastructure corridors continue to play a primary role in relation to biodiversity loss, the relative importance of different pressures for biodiversity may change. While infrastructure will largely increase the accessibility of humans, pests, and invasive species to the few remaining hotspots, climate change and pollution may further reduce the resilience of biodiversity to cope with these or new emerging pressures. Control of piecemeal development and its associated regime of exploitation will therefore be essential for conservation of biodiversity.

Intensified land use impacts water resources

Intensified land use associated with exploitation, immigration, population growth and resettlement along road corridors has major impacts on the water resources and their biodiversity (Dudgeon, 1992; 1995; 2000; Malmqvist and Rundle, 2002; Dudgeon, 2002). The processes are however very variable.

Overexploitation of limited water resources is a growing problem that is not easily solved in interior Asia. If climate change will result in less precipitation as snow or glacial recession, the impacts both on wildlife and human populations may become disastrous. Indeed, as more people have settled in areas prone to desertification even with natural cycles of expansion and contraction of the Taklamakan and Gobi deserts, the result is none the less critical for these people. However, also here human land use seems to play a primary role in aggravating the impacts of such cycles on both people and biodiversity (Liu and Sun, 2002; Lu et al., 2003)). Dust storms and blown sand represent an increasing problem for communication, health and transport in the region (Sun et al., 2000; Xuan and Sokolik, 2002).

Vegetated hills, slopes, wetlands and forests are vital catchments for most rivers, and help purify water and reduce silt content in rivers by natural protection from erosion. With intensified land use along road corridors, forests are cut for firewood or intensified grazing results in overgrazing, deforestation and subsequent increase in erosion, flashfloods and land slides particularly along road corridors (Dudgeon, 1992; 1995; Zong and Chen, 2000; Du et al., 2001). This is particularly true also for abandoned agricultural terraces that are extremely susceptible to erosion unlike well-managed terraces. This leads to increased waste and run-off into drainages and major rivers, including reduced capacity of watersheds to manage monsoon floods (Dudgeon, 1992; 1995; Collins and Jenkins, 1996; Zong and Chen, 2000; Du et al., 2001). The silt content increase and water quality becomes seriously reduced.

Infrastructure development also facilitates increased immigration. Growing land and population pressures lead to increasing settlement in flood-risk areas along lakes, behind former flood dikes, in drained wetlands and partly on steep slopes subject to land slides and erosion. Hence, when upland ability to retain floods is reduced and people simultaneously settle in flood prone areas, the human and environmental impacts of severe or even natural fluctuations in floods become serious. This is well known from the flooding of the Yangtze river which in part was attributed to deforestation and settlement patterns (Dudgeon, 1995; Zong and Chen, 2000; Du et al., 2001; Lu et al., 2003). China has invested large and also successful efforts in reducing deforestation in some of the catchments. Yet, as land use still intensifies in many regions, the high silt content resulting from erosion and the increasing water consumption for irrigation still remains a growing threat that will require further attention.

Infrastructure development and poverty

Infrastructure development is directly and indirectly related to living conditions, welfare and other aspects of the human environment.

Poverty in mountain regions is a complex outcome of interacting processes, where rapid population growth, inequitable access to resources, social and political power struggles, ill-directed policies, lack of food production capacity and basic services and social security systems to name some critical factors, combine to create unsustainable and insufficient living conditions. The widespread lack of access to water of adequate quality is a key component of the global poverty struggle.

A large portion of the population in the Greater Asia mountain region lives in moderate or extreme poverty. All the major problems facing mountain environments and their people's have traditionally failed to attract special attention from the international community. Poverty is one of the most pressing issues in these environments which have never had a prominent position in foreign aid and development projects. It is only recently that mountains have been recognized as particularly important for development, and as especially ecologically and socially vulnerable.

Poverty is largely associated with women and children, i.e. marginalized groups in society (UN 1989, 1992). Poverty among the powerless tends to draw limited attention in international policies. There are many examples that poverty is especially rampant in mountain regions where we also find the most important water sources to people in this region. The Chinese government estimates that the bulk of its 80 million inhabitants below the poverty line are ethnic mountain minorities (Ives 1997).

Poverty has a structure that is also related to the use of water resources. Women are generally impoverished in that they have less access to resources than men, less control over their life, less influence over decision making, but have to carry out the bulk of daily work (UNICEF 1994). Furthermore as economic pressures mount, the world debt crisis increases, and the government-subsidized social programmes are reduced, increasing numbers of men migrate from mountain and other rural regions to urban centers. Finally, the vast majority of bilateral and international aid and development agencies have historically tended to target men in their projects. All in all, this reinforces a poverty structure where social and economic differences are enhanced, resource use remains unsustainable, and local governance and local economies are hindered or undermined. Social and cultural conflicts contribute to poverty, social instability and pressure on basic resources like, water and soil.

Infrastructure development is a driving factor that can affect poverty negatively and positively. Infrastructure is often argued to be important for poverty reduction. This can be the case where development aid, road construc-

tion or water and sanitary investments have been made with poverty reduction in mind. Alas, the great majority of private investments are related to either resource exploitation or allocated to upper and middle-income developing countries. Most infrastructure development in developing countries is a product of international donor policies supporting existing power structures, institutions and elites. The majority of these policies are not effectively sensitive towards gender issues and impoverished groups, although their official goals may say otherwise. However, on the local level there are several notable exceptions like Aga Khan Rural Support Programme in Northern Pakistan.

The fact that infrastructure development often acts counter to reducing poverty is reflected on different levels from global to local arenas. The structural and global economic policies of the World Bank, the IMF and other large institutions require the same development responses across widely different contexts and cultures (Stiglitz 2000). These projects are often directed at, or containing large infrastructure components. Frequently, such development approaches disagree with the needs of the poor and instead strengthens local elites and corrupt systems. Secondly, bilateral attempts are almost always influenced by global power games. Thus bilateral, and even multilateral aid officially aimed at alleviating poverty seldom challenge dysfunctional social systems and elites, and may instead strengthen powerful local actors like local politicians and contactors. The resultant infrastructure development usually benefits only a few already powerful interests. Hydropower and road development in the Himalayas is a typical example where great benefits are extracted, and then distributed, and often exported, among a relatively small group of actors. And since infrastructure development mostly reinforces existing power structures locally and nationally, the basic social determinants of poverty, such as gender bias, excessive use of local resources, lack of local control etc. remain unchanged. Albeit there are many instances where privatized infrastructure development have proven more effective and providing better services to the public than public services (Harris /Worldbank, 2003). However, it is crucial to bear in mind that the far majority of the road construction, such as in tropical rainforests are built primarily to serve logging or mining companies, and are not built primarily to improve sanitation or local trade opportunities in rural areas.

As infrastructure development projects to a wide extent are designed to extract resources and capital is widely channeled through economic networks, impoverished rural local populations get very little in return. Many of the areas with extreme exploitation rates of timber and minerals, only the few workers directly involved benefit through employment, while many local populations often are in direct conflict with the companies, as they become exposed to environmental pressures. This said, it is also clear that infrastructure development can be important for poverty alleviation, but only when it is directed towards that purpose, such as to increase local trade opportunities for areas that have the potential for surplus production (Leinbach, 1995), increased access to basic health care provide such will be made available, and also sometimes improved sanitation and education. Once again, this is only the case where the development is an active part of a larger and well-coordinated effort that simultaneously aims to reduce or mitigate the negative impacts. As illustrated from the major larger construction projects in the Mekong, this is too often not the case. Furthermore, most of the piecemeal development takes place by the expansion of the secondary road network, which is often directed towards exploitation opportunities of minerals or timber. If the development does not have economic and welfare development of local populations as a direct objective including actual real-life implementation funds, infrastructure will generally not contribute to poverty alleviation.

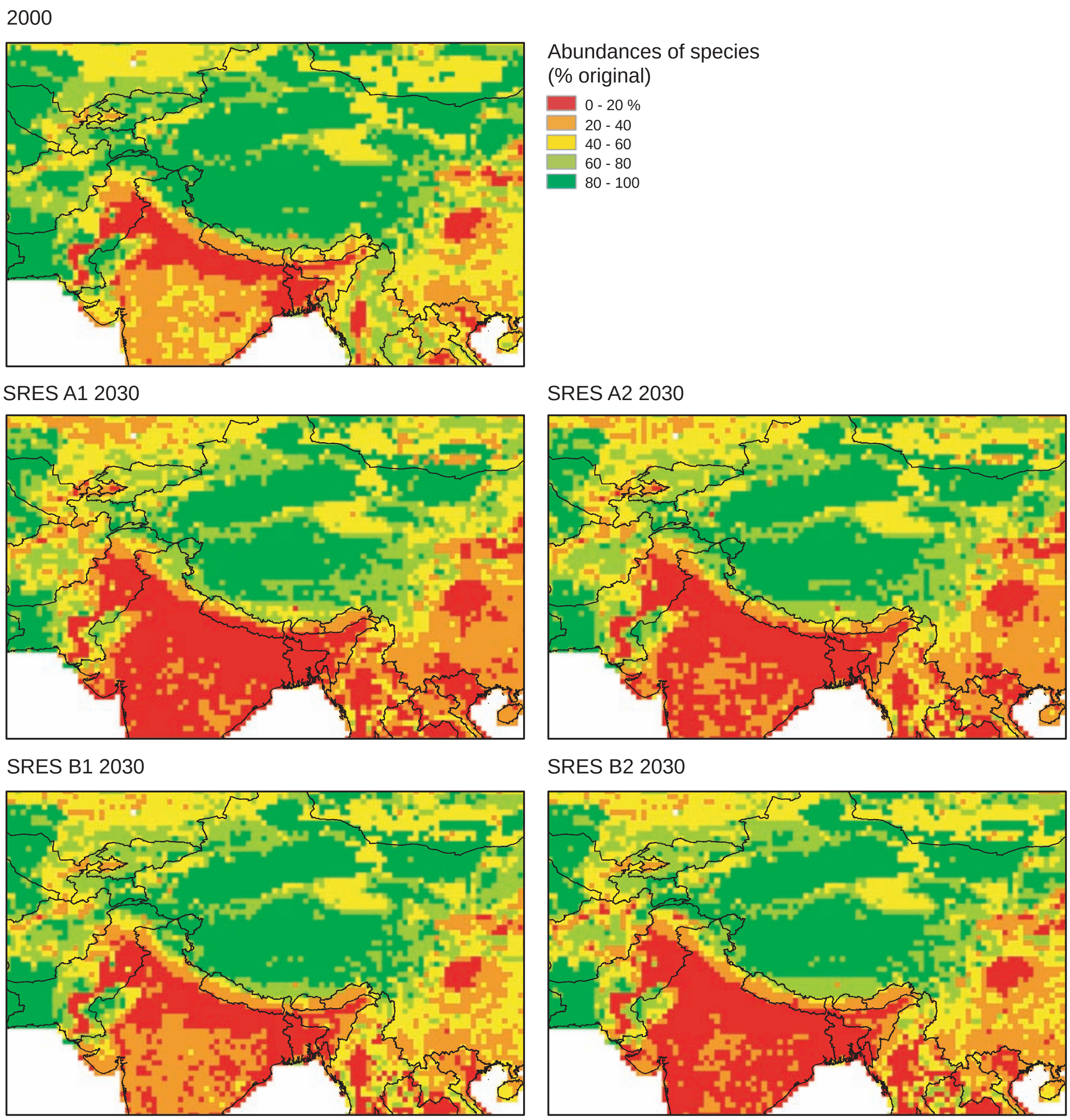
Cumulative impacts of land use and climate change on biodiversity

For wildlife and ecosystems, however, it is the cumulative impacts of numerous pressures that determine actual effect on the abundance of species, including, but not limited to, infrastructure development and associated land use, forestry, agricultural practices, nitrogen pollution and climate change.

In this section biodiversity has been defined as the average abundance of the original species compared with their original abundance when ecosystems were hardly impacted by people. The abundance of a species means the population size of number of individuals of species. This indicator is in accordance with the indicators agreed upon under the Convention of Biological Diversity (UNEP, 2004).

Ecosystem function most generally is closely related to its original species and their abundance. Given dose-

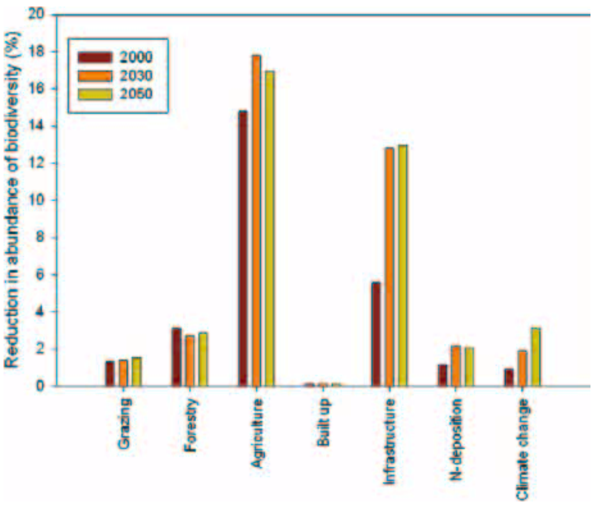
Figure 16: Current and projected reduction in abundance of biodiversity, expressed as percent of original abundance of biodiversity given no human disturbance. The four scenarios depict the cumulative impacts of climate change, infrastructure development, land use, forestry and N-pollution. Notice that the projections are model outputs on very general datasets and should be used with caution for other than depicting trends.



response curves of different human pressures and their subsequent impact on biodiversity, it is possible to model not just the area under pressure, but also provide a range of estimates for what different human pressures may actually mean in terms of reduced species abundance. It is furthermore possible – based on these pressure species response curves to provide estimates on the relative significance of different pressures for biodiversity loss at different times out in the future.

Projections of the relative loss of biodiversity today and in 2030 given different scenarios are presented in Fig. 16. Areas with high human densities and where infrastructure development has been associated with intensive agricultural production and forestry, biodiversity loss has been the greatest compared to less developed areas. This is also evident in all four scenarios. Biodiversity loss is highest in lowland regions, up to more than 80% reduction in the abundances of original biodiversity. Notice that this doesn't mean that 80% of the species are extinct, but that the populations sizes of species – on average – are less than 20% of what they were before human intrusion altered habitats. Few may be extinct, many strongly reduced and a few – human favored – species strongly expanded, by which various ecosystems are becoming more and more alike. The situation is particularly severe in lowlying densely

Figure 17: The relative significance of different pressures for projected biodiversity loss in the study region 2000-2050 (GLOBIO 3.0).



populated areas of China, Pakistan, Bangladesh, India, Myanmar and other parts of Southeast-Asia. These are the areas also exposed to the most extensive human and agricultural exploitation.

While the large protected areas in interior Tibet will largely help protect against biodiversity loss (given control of poaching), many upland areas, such as the expanding areas around settlements and irrigated lands in Xinjiang and Qinghai, and forests in Sichuan and Yunnan of China will experience 20-40% declines in abundances of biodiversity if special attention is not given to these areas. The same applies to mountain ranges Kyrgyzstan, Tajikistan, Afghanistan, Pakistan and lowland Nepal.

Large unproductive mountain ranges have been protected in many of the countries, but the inhabited upforest and mountain slopes remain vastly unprotected. These are also the areas with the heaviest land use and population pressures in the mountains and are critical for water management issues and risk of floods in lowland farmlands.

The scenarios of biodiversity loss also provide interesting information on the relative significance of the different pressures for biodiversity and ecosystem impacts. This is particularly important for policy purposes. While the losses directly attributable to climate change increases from 4 to 8% over a few decades, agricultural expansion and infrastructure development and associated land use pressures are the by far most significant threats to biodiversity. Indeed, those two factors account for a relative 75-78% of the projected loss in abundance of biodiversity up to 2050 (Fig. 17).

Hence, while climate change is likely to produce severe impacts in terms of extreme weather conditions, glacial outbursts (the flash-floods associated with unusual melting of glaciers)(Blyth et al., 2002) and retreats, the immediate threats to ecosystems and biodiversity including risk of floods is primarily related to unsustainable land use practices. By strengthening the resilience of plants and wildlife through the development of protected areas, the risk of floods, land slides, erosion and loss of ecosystem services may largely be reduced. However, it is important to notice that given an overall intensifying land use, the vulnerability of plants to climate change will also increase substantially.

Protected areas and policy needs

Protected areas networks throughout Asia play a critical role for watershed management, conservation of biodiversity and social conditions. Like alluded to earlier in this report, protected areas are often established in areas with precious resources and low levels of human impacts. Quite often protected areas locations coincide with paramount water reservoirs. An extra policy challenge is added through the fact that protected areas are established through national actions, but they often have international effects and implications in terms of resource use.

The network of National Parks in China is extremely important for protecting wildlife, although enforcement of the protected areas needs to be improved in order to produce the expected effects. Here, protection of the calving grounds of the Chiru antelopes, currently outside the parks, may be vital for the future of the Chiru antelope and should be considered further. However, such parks are deeply needed also in the Tian Shan, Pamir, Hindu Kush, Kashmir, Himalayas and southeastern Tibet. A network of parks here could be critical for protecting the water resources to the billions of people and is urgently needed. Protection of water sources is a regional issue that to some extent will require trans-boundary agreements and action. Trans-boundary national parks can play a vital role not only in protecting the resources inside the park, but also in the life sustaining highland – lowland interactions so typical of this region.

Protection of wetlands and river corridors, will in combination with an increased numbers of participatory programmes probably contribute to sustainable development, but only if the current levels of unchecked development is assessed with appropriate policies including new networks of protected areas to levels substantially beyond the current 3%. To achieve this, there current void of effective regional policies focusing on the strategic role of mountains as water towers must be filled. A more sustainable management and use of these precious water sources will depend on an integration of local participatory programmes and broad regional/international policies.

The upper parts of the Indus located in Kashmir in the center between Pakistan, India and China is an area where National parks to protect the water source is of particular importance for both the environment and future geopolitical stability and should be given particular attention by the countries in the region. China has already presented very valuable efforts in the Yunnan –Sichuan provinces, but southeastern Tibet remains a very important region also for large parts of China and Southeast Asia and any development here will hopefully include the necessary foresight to avoid very serious implications on the water resources in terms of quality and quantity further downstream.

Conclusion

The report has presented an overview of some of the current and possible future extent of threats to the water resources and biodiversity in the region in the context of piecemeal development, growing populations, water shortages and climate change.

The growing problems:

1) Desertification is – beyond the natural cycles and the effects of potential climate change – strongly influenced by land use practices along road corridors including overgrazing, salinization of irrigated land and deforestation as an effect of logging, grazing and over-spenditure of water.
2) Growing numbers of sedentary livestock near settlements and road corridors have led to overgrazing, deforestation and subsequent erosion and increase in human vulnerability to flash floods and land slides.
3) Erosion and dust storms are widely associated with overgrazing and abandonment of traditional migratory practices. Land slides are primarily associated with unsustainable land use practices such as deforestation or abandonment of terraces, and further enhanced by tectonic activity and climate change.
4) Deforestation is mainly concentrated along road corridors and lead to increased erosion and growing silt contents in rivers.
5) Infrastructure development lead to growing resource exploitation, local pollution such as tailings from mining operations, logging and construction of dams with further impact on downstream populations.
6) Infrastructure development has led to new and intensified settlement patterns and also substantial growth in poaching.
7) Piecemeal development associated intensified land-use and subsequent secondary uncontrolled immigration has resulted in increased human vulnerability. The increased human vulnerability is the result of combined actions of settlement in high risk areas and growing interactions between unsustainable land use, intensified development, water consumption, ecosystem and wetland deterioration and climate change. Exposure to flash floods, glacial outbursts and periodic desertification from natural or anthropogenic driven desert cycling must be seen in the context of growing populations and piecemeal and intensified land use, not merely natural disasters.
8) There are very few, if any, effective regional policies in place to counter resource degradation and cumulative environmental impacts. There are many promising national and local initiatives, but the fundamental challenge is to unite policy efforts across different management contexts.

The positive responses:

1) Many of the countries in the region, and particularly Bhutan, Nepal and China, are now rising to meet the environmental challenges.
2) However, a substantial increase in resources allocation, coordination and long-term planning is needed for the entire region to reverse the very serious trends identified here. International collaboration is required to address the large-scale changes threatening watersheds.
3) Local participatory programmes have been successful in many areas, such as Nepal, to reverse the environmental degradation. However, such programmes have been insufficient for coping with the large-scale development changes depicted.
4) The development of protected areas in Tibet and increased enforcement has been among the most significant environmental advances in the region. The trans-boundary collaboration between local scientists and international and foreign research institutions should be further strengthened.
5) Other progress includes successful programmes to reverse and combat desertification and deforestation in some local regions, particularly in Nepal and China. This progress clearly demonstrates that if adequate resources and well-coordinated efforts are invested, many of the potential devastating threats can be overcome. Bhutan is one of the few countries that have managed to protect its cultures and biodiversity against unchecked industrial development up until recently, although this may be rapidly changing.

Perhaps the most significant finding here is that the Greater Asian Mountain region and associated lowlands will most likely experience increasing environmental pressures as a result of growing interactions between climate change, intensified and expanding land-use along the infrastructure network and exacerbated by growing populations.

In spite of the tremendous diversity in cultures, climate, governance and population density, the region has two major things in common: The sharing of the water resources and the growing threat from unchecked piecemeal development in the watersheds. This development will increasingly – if no policy is implemented – interact with growing populations and climate change to produce previously unprecedented impacts on biodiversity and billions of people in this region by impacting the ecology and capacity of the water sheds to provide secure water. This challenge must be met.

To reverse the development in established infrastructure, associated exploitation and subsequent settlement is at best extremely difficult. Hence, further development of protected areas and channeling of necessary resources to enforce such areas are needed. This includes funds to combat deforestation, poaching and desertification. Protected areas in the mountain ranges and high altitude plateaus may be the most rapid and effective policy action to be implemented to reverse the trend of biodiversity loss and growing risks to water resources.

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Appendix 1. The GLOBIO 2.0 methodology – infrastructure scenarios

The GLOBIO 2.0 model is being developed for and together with UNEP (United Nations Environment Programme) to help assess and map the environmental impact of human development (UNEP, 2001). GLOBIO 2.0 is a distance-related multivariable buffer-based model for estimating the extent of land area with reduced abundance and diversity of living organisms, as a result of infrastructural development. The model can also be used to develop scenarios of possible future impacts. The model incorporates buffer zones of probability of reduced abundance of wildlife occurring around infrastructure features, such as roads, major trails, human settlements, industrial features such as power lines, dams, etc.

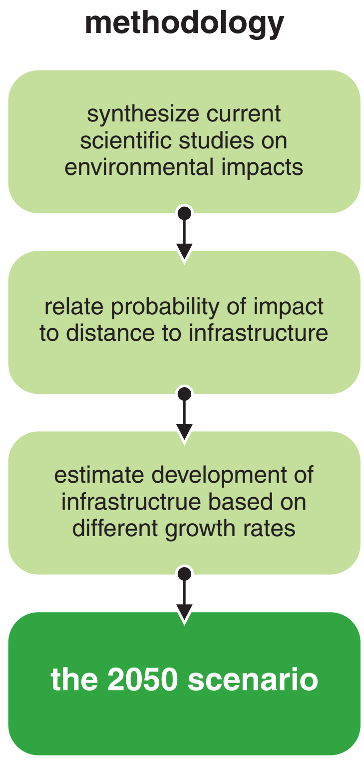
Data sets were compiled on a global 1 x 1° longitude-latitude grid system and included all linear infrastructure (major trails, roads, railroads, power lines and pipelines) in the DCW (VMAP level 0 and 1), land cover from USGS-GLCC2 based on AVHRR data from 1992-1993, and population density from GPW, version 2, and resource databases on oil, gas and mineral reserves from ArctAtlas (see www.globio.info for more information).

For illustrative purposes, four zones of impact are defined based on the functional response of species to disturbance arising from infrastructural development, identified by a review of published research. For the review, the literature covered by the Current contents/Agriculture, Biology and Environmental Sciences database was used as a source. Current contents provides access to bibliographic information from articles, editorials, meeting abstracts, commentaries and all other significant items in recently published editions of over 1,040 of the worlds leading agriculture, biology and environmental sciences journals and books (ISI net 2001). Article titles and keywords were searched for the terms, landscape, habitat patch or patch, forest fragmentation, roads and disturbance from the period January 1987 to October 2001. Of this review, experiments were excluded and only articles strictly based on empirical investigations published in journals, relating to fragmentation or disturbance effects associated with roads, human traffic or activity were included, giving a total of 309 articles on the issue of disturbance from roads. This overview was cross-checked against recent literature reviews (Nellemann et al., 2003a, b).

Based on these articles*, the zones of impact were defined statistically based upon the distribution of declining species within different distance categories to roads:

- "high impact" – upper 50th percentile (i.e. the distance interval within which > 50% of all species that decline by >50% is found);
- "medium-high impact" - 25-50th percentile (the distance interval within which 25-50% of all recorded species that decline by >50% is found),

Figure 1: The GLOBIO methodology principles. Usually several alternative scenarios are produced.



- "medium-low" impact - 1-25th percentile (the distance interval within which 1-25% of all recorded species that decline by >50% is found), and
- "low impact" (for areas beyond those distances).

The GLOBIO model is then applied to provide a series of scenarios which each project alternative development paths. Herein we use 4 alternative growth scenarios based on the GEO-3 scenario work (UNEP, 2003). Specific assumptions for the four GEO-3 scenarios hinge on the development of resource extraction and exploitation in the period 2002-2030, against the background of historic changes in land use and road development for the various continents in the period 1850- 2000.

- *Markets First* is a "let-loose" situation where market forces take control entirely of resource development, and multinational corporations play a primary role in rate, location and impacts of development. This corresponds with a strong acceleration in resource extraction and exploitation. Therefore, up to 2030 an average annual growth of the area impacted by physical infrastructure of 1.5% is assumed. (This is apart from situation-specific adjustments based upon population density, land cover, availability of natural resources etc, see table in appendix). The 1.5% average annual growth is comparable to the average of 1% per year during the preceding 150 years.
- *Policy First* is a continuation of the gradual development trends as experienced during the last century, viz. an average annual increase of 1% in the growth rate of the area impacted by infrastructure.

- *Security First* brings an acceleration of the current regime for exploitation of areas for natural resources extraction. This translates to an annual increase of infrastructure of 1.25 % instead of the current 1% per year.
- *Sustainability First* assumes continued demand for resources, but strategic regional planning reduces and controls effects of human expansions better, thereby minimizing unwanted secondary developments. Networks of protected areas help reduce and direct development into corridors, thereby reducing the extent of areas with reduced biodiversity. However, due to the spatial development pattern inherited from the past, this scenario actually reveals its benefits only after 50 years. Earlier, up to 2030, the annual growth of the infrastructure is assumed to be 0.25 percent point slower than the historic growth rate of 1%. Around 2030, the expansion starts to level out.

For full details of the method including the historical analysis see http://www.globio.info.

Appendix 2. The GLOBIO 3.0 model framework – integrating multiple pressures

Background

GLOBIO was initiated to provide an inexpensive, simple and scientifically based communication tool for large-scale mapping and forecasting of human impacts on the natural environment resulting from increased growth in resource utilisation (UNEP 2001) .To achieve this, the GLOBIO model framework combines several well established models used in assessment of the cumulative effects of human pressures on biodiversity worldwide. The GLOBIO models rest on comprehensive scientific literature reviews used to develop dose-response relationships between biodiversity degradation and various human pressures. The GLOBIO 2.0 model evaluates specifically the impacts of infrastructure development on biodiversity. The more comprehensive GLOBIO 3.0 model integrates GLOBIO 2.0 and the IMAGE 2.2 model (REF on IMAGE 2.2) to allow for a combined evaluation of the impacts of infrastructure development, land use change and land use intensity, climate change and nitrogen deposition on biodiversity. Both the GLOBIO 2.0 and the IMAGE 2.2 models are used in UNEP's Global Environmental Outlook 3 (GEO-3; (UNEP 2002)).

GLOBIO methodology

Spatial data sources
To assess the impacts of the different pressures on biodiversity several different data sources were used. In table 1 a overview of the data sources is summarized.

Indicators of biodiversity
The common indicator of biodiversity used in GLOBIO 3.0 is the mean abundance of species. Hence a change in biodiversity refers to the mean change in the number of individuals of characteristic species of a given ecosystem[1]. The abundance of selected species is one of the key indicators on the state of biodiversity, as agreed upon by the Convention on Biological Diversity (UNEP 2004). The mean abundance of (a selection of) species is expressed as a percentage relative to the mean abundance of (a selection of) species in original or pristine situations.

Developing dose-response relationships
Relationships between the abundance of species and the different pressure factors were established by a meta-analysis of published research. The relationships will be published in (Alkemade and others in prep.)
Land use change and land use intensity:
Many authors compare species diversity between different land use types ((Majer and Beeston 1996; Fujisaka, Escobar et al. 1998; Fabricius, Burger et al. 2003) and many others. The different land use types mentioned in these studies were categorized and the number of species still remaining compared to the pristine state was recorded. For each land use type

1. Species abundance should not be confused with species richness, which is based solely on the number of species per area unit ("species density") or per specified number of individuals ("numerical species richness")

Table 1: Overview of spatial data sources.

Pressure	Data sources	Reference
Land use	Global Land Cover 2000 beta version BIOME from IMAGE 2.2	Millennium Ecosystem Assessment reports (in prep.) (IMAGE-team 2001)
Land use intensity	Global forest resources assessment 2000 Farming systems	(UN-ECE and FAO 2000; FAO 2001) (Dixon, Gulliver et al. 2001)
Climate change	IMAGE 2.2	(IMAGE-team 2001)
Nitrogen deposition	Critical loads	(Bouwman, VanVuuren et al. 2002)
Infrastructure	Digital Chart of the world (DCW based on VMAP level 0)	?

the mean abundance of original species as percentage relative to the pristine state on local scale was calculated. This figure is an estimate of the mean abundance of species on regional scales. Seven different land use classes: pristine; lightly used; degraded; pasture; forest plantation; agricultural land and urban were considered (Fig. 1).
The biodiversity impacts of agricultural management is refined by a study that reviewed literature on the relationship between the intensity of use of pasture and agricultural land and the abundance of wild species. A gradual increase in external inputs in agricultural systems is considered as the basis for different intensity classes.
The relationship between land use and biodiversity, used in GLOBIO 3.0 is based on approximately 70 publications.

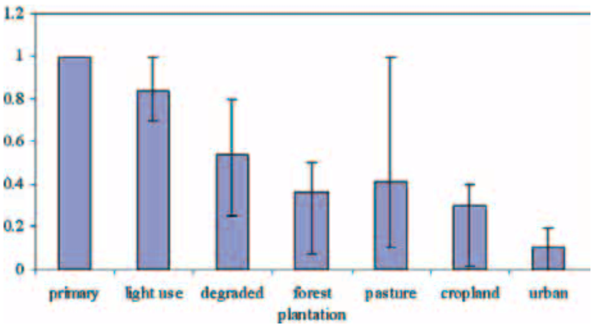


Figure 1: A summary of the results from 70 peer-reviewed and published impacts of different land-use categories on the fraction of original biodiversity

Infrastructure:
The analysis of the impact of infrastructure development in the GLOBIO 2.0 model (UNEP 2001) is based on a synthesis of studies on impact zones of infrastructure (roads, railroads, power lines, pipe lines, settlements, cabin resorts and construction facilities) on species diversity (see UNEP 2001, Appendix 1 for a list of the studies considered in the synthesis). The number of species found to suffer a decline was calculated for each distance zone around infrastructure. A generalized measure of the risk of species decline was then related to distance to infrastructure using regression analysis (fig. 2). Separate distance-impact curves were established for each biome.

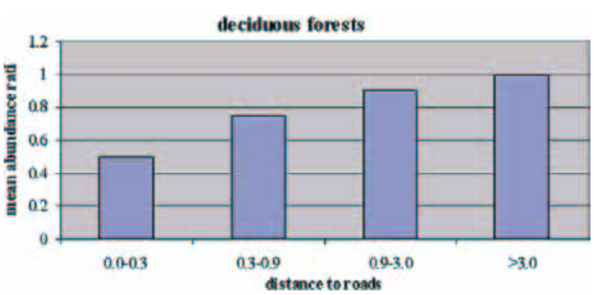


Figure 2: Example of the Effect of road density on species abundance based on review of 204 species and 309 articles (UNEP, 2001; Nellemann et al., 2004)

Climate change:
Very limited field research is available on the decrease in the abundance of original species as a result of climate change. Most authors predict shifts of species or biome distribution caused by climate change (Bakkenes, Alkemade et al. 2002; Leemans and Eickhout 2003; Thomas, Cameron et al. 2004). After the climate had changed the distribution area of a species or biome can be divided in three parts: the area where the biome or species is expected to be disappeared; the area the species is expected to be invaded and the area where the biome or species will remain. The latter is considered to be the stable area. We used the forecasted change in stable area of biomes and of about 1400 European species distributions to derive a dose-response relationship. The percentage of reduction in the stable area is used as a proxy for the mean abundance of species at a regional scale (Leemans and Eickhout 2003) and (Bakkenes, Alkemade et al. 2002) see fig. 3.

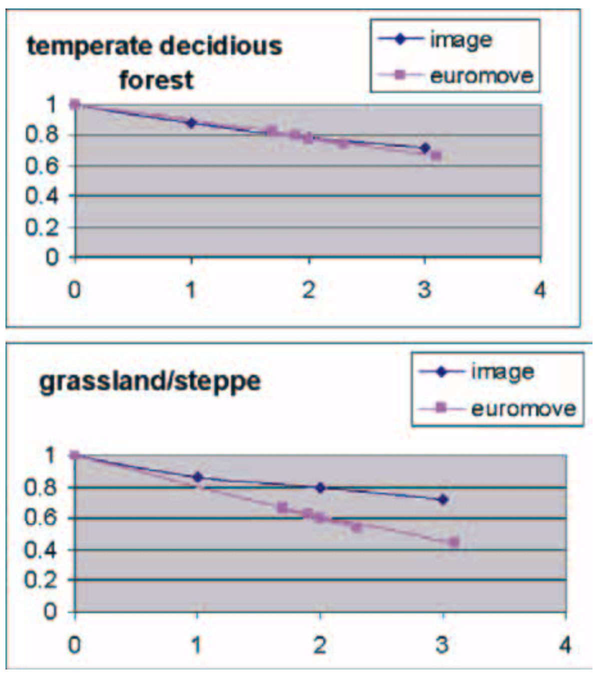


Figure 3: Example of the relationship between the increase of mean global temperature and fraction of stable area.

Nitrogen deposition:
(Bobbink 2004) reviewed some 50 publications the effects of the addition of nitrogen on species richness and diversity was studied, among others: (Pitcairn, Leith et al. 1998; VanDobben, TerBraak et al. 1999; Haddad, Haarstad et al. 2000). Based on the review dose response relationships could be established between nitrogen deposition, exceeding the empirical critical load values, and biodiversity values for a limited number of ecosystems (fig 4.). The critical load values were derived form (Bouwman, VanVuuren et al. 2002). The N-deposition impact factor does not apply for cropland.

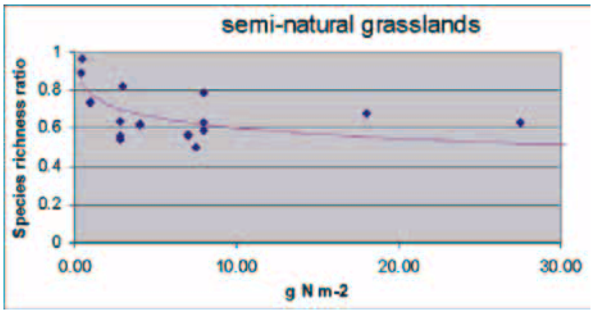


Fig. 4: The effects of exceeding critical loads for nitrogen on species abundance from literature survey of approximately 50 publications (Bobbink 2004) Effects have been extensively reviewed by UN-ECE.

Combining the impacts of different pressures

The resolution of the GLOBIO 3 model is obtained by a combination of the Global Land Cover 2000 map and a 0.5 degree raster. The single unit is the area of a unique land use / land cover category within a 0.5 by 0.5 degree grid cell. The 0.5 degree geographical resolution is used by IMAGE 2.2 and most information is available on that resolution. The biodiversity value of a single unit with known environmental conditions (Bi) is a number between 0 and 1 indicating how close to the original level of biodiversity (Bi=1) a given unit is. Bi is calculated by multiplying the contribution from each of the five pressure types evaluated, hence:

$$B_i = LU_i * LUI_i * CC_i * N_i * I_i$$

Where Bi is the total biodiversity value of the unit i and LUi , LUIi , CCi, Ni and Ii are the biodiversity value contributions from land use, land use intensity, climate change, N-deposition and infrastructure respectively.

The Biodiversity value for a single grid cell (Bg) is then obtained as the area weighted mean of the biodiversity values of the single units within that cell:

$$B_g = \left(\sum_i B_i * A_i \right) / \sum_i A_i$$

With Ai the area of single unit i within grid cell g.

Application and scenario development

The projected changes of pressure factors were calculated using the IMAGE model and were based on the Special Report on Emissions Scenarios (SRES) A1b, A2, B1 and B2 (Nakicenovic, Alcamo et al. 2000; IMAGE-team 2001).

The 'Special Report on Emissions Scenarios' (SRES) are similar to the socio-economic scenarios used by UNEP in the third Global Environmental Outlook (GEO 3) on demography, economic growth and the degree of international co-operation. The SRES A1 scenario is similar to the "Market first" scenario, the SRES A2 scenario is similar to the "Security first" scenario, SRES B1 is similar to "Sustainability first" scenario and SRES B2 is similar to the "Policy first" scenario.

The effects of the socio-economic developments on land use and climate were calculated by the IMAGE model (IMAGE-team 2001). The agricultural land use intensity categories were derived from FAO farming systems typology (Dixon, Gulliver et al. 2001). For each region the percentage of agricultural land that is irrigated, intensively used and extensively used was estimated (Dixon, Gulliver et al. 2001). These regional percentages were applied on every grid cell with agricultural land. For forest use the same approach has been applied: regional percentages of plantations and forest under timber regime were applied on each grid cell with forest. Estimation of percentages plantations, forest under timber regime and natural forest were derived from (Brown 2001). The same percentages were applied on predicted future area of agricultural land and forest, respectively.

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