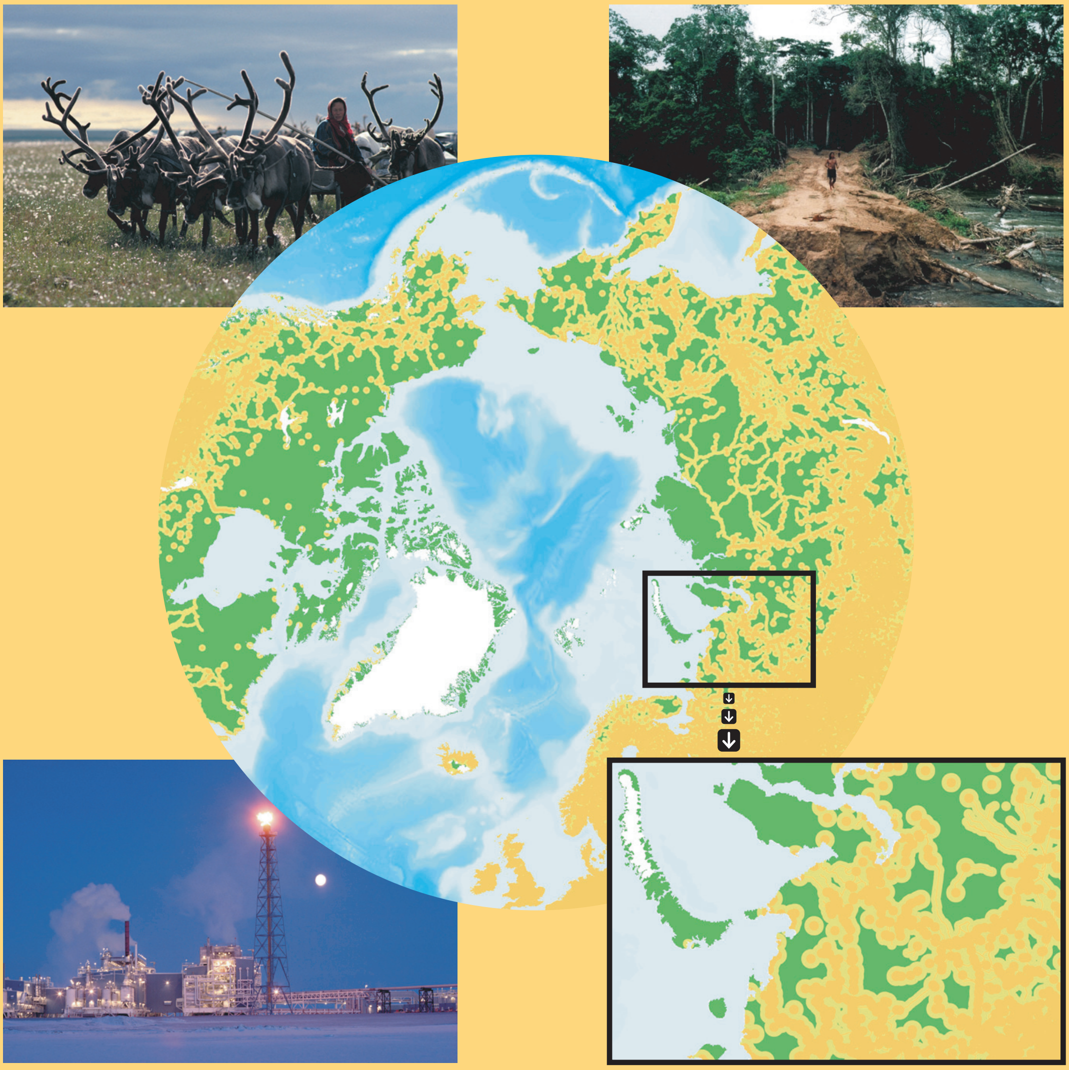
Environment Information and Assessment Technical Report

3

UNEP/DEWA/TR.01-3

GLOBIO GLOBAL METHODOLOGY FOR MAPPING HUMAN IMPACTS ON THE BIOSPHERE



UNEP

A word from the Executive Director

For thousands of years, humankind has relied and depended upon the Earth's resources to meet growing demands for food, medicine, shelter and water. Our entire existence and the diversity of cultures and economies has been built upon goods and services from nature. However, far too often, these activities have taken a heavy toll on our environment.

Waste, desertification, pollution, deforestation, loss of biodiversity and the degradation of land and fresh water are continually putting greater and greater strain on sustainable economic, cultural and environmental development. We are becoming increasingly aware that we not only rely on the environment for its many services, in fact, our health, economy and political world is largely built on the Earth's resources. What happens to the Earth, happens to humankind. So far, however, we have not had sufficient foresight to fully understand and communicate to the public, policymakers and state leaders the future impacts of the choices that are being made today. With 10-30 million different species and complex ecosystems in existence, our knowledge of the environment is fragmented into several thousand scientific journals, reflecting millions of reports and papers, allowing policymakers to make only best-guess solutions or to take no action.

Our greatest challenge today is to plan better for our common future. And one of our chief problems lies in communication and foresight. We simply need to clearly visualize and communicate the long-term impacts of the growth in human resource use in a manner that is understandable. Not by predicting the future, but by scientifically documenting the likely future impacts of the choices that are being made today.

The impacts of growing human resource demands are now seen in all parts of the world. Without foresight, the future is, at best, highly uncertain. GLOBIO is a pioneering attempt from UNEP to help us all see the possible outcomes of what may happen to our globe with the policies we make today. State leaders across the world have a personal responsibility for the destiny of future generations.

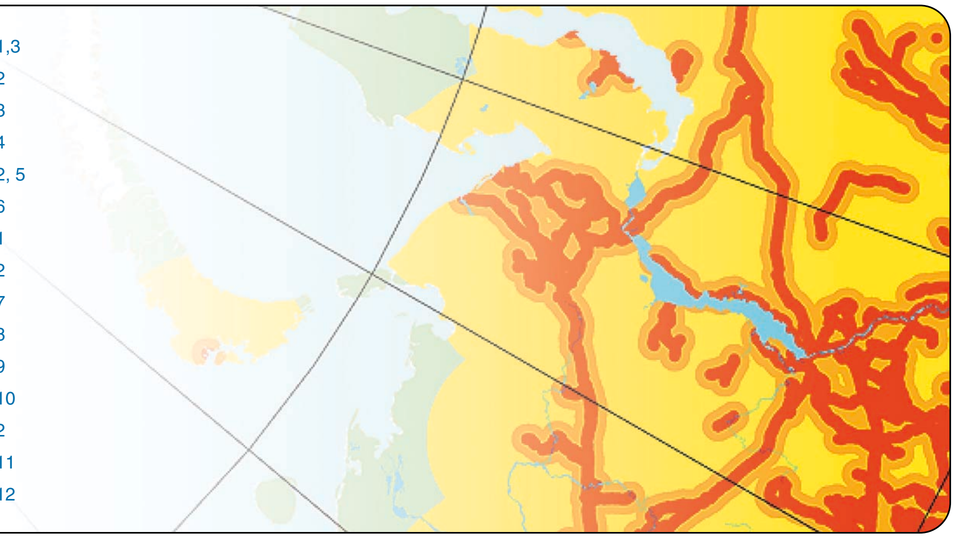
The application of the GLOBIO principles at all levels and in all regions on Earth makes it suitable for developing a common platform for protocols and international agreements as they relate to humans and biodiversity. And, hence, help us form our common future.

Klaus Topfer
Executive Director, UNEP

GLOBIO GLOBAL METHODOLOGY FOR MAPPING HUMAN IMPACTS ON THE BIOSPHERE

THE ARCTIC 2050 SCENARIO AND GLOBAL APPLICATION

C. Nellemann[1,3]
L. Kullerud[2]
I. Vistnes[3]
B. C. Forbes[4]
E. Husby[2, 5]
G. P. Kofinas[6]
B. P. Kaltenborn[1]
J. Rouaud[2]
M. Magomedova[7]
R. Bobiwash[8]
C. Lambrechts[9]
P. J. Schei[10]
S. Tveitdal[2]
O. Grøn[11]
T. S. Larsen[12]



1 Norwegian Institute of Nature Research (NINA), Pressesenteret, N-2624 Lillehammer, Norway
2 UNEP/GRID-Arendal, Longum Park, P.O. Box 1602 Myrene, N-4801 Arendal, Norway
3 Department of Biology and Nature Conservation, Agricultural University of Norway, P. O. Box 5014, N-1432 Ås, Norway
4 Arctic Centre, University of Lapland, P. O. Box 122 SF-96101 Rovaniemi, Finland.
5 Powel Gemini, Storetveitsveien 98, 5072 Bergen, Norway
6 Institute of Arctic Studies, Dartmouth College, 6214 Fairchild, Hanover, NH, 03755, USA
7 Institute of plant and Animal Ecology UD RAS, 8 Marta str., Ekaterinburg, 620144, Russia
8 Center for World Indigenous Studies (Canada), P.O. Box 19001, 360-A Bloor St. W. Toronto, ON CANADA M5S 1X1
9 UNEP, Division of Environmental Information, Assessment and Early Warning, United Nations Environment Programme, P.O. Box 30552, Nairobi, Kenya
10 Directorate of Nature Management, Tungasletta 2, 7005 Trondheim, Norway
11 Norwegian Institute for Cultural Heritage Research (NIKU), Box 736 Sentrum, N-0105 Oslo, Norway
12 Noragric, Centre for International Environment and Development Studies, Agricultural University of Norway, P. O. Box 5001, N-1432 Ås, Norway

© 2001 United Nations Environment Programme
ISBN: 92-807-2051-1

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

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

For bibliographic and reference purposes this publication should be referred to as:
UNEP (2001). C. Nellemann, L. Kullerud, I. Vistnes, B. C. Forbes, E. Husby, G. P. Kofinas, B. P. Kaltenborn, J. Rouaud, M. Magomedova, R. Bobiwash, C. Lambrechts, P. J. Schei, S. Tveitdal, O. Grøn and T. S. Larsen. GLOBIO. Global methodology for mapping human impacts on the biosphere. UNEP/DEWA/TR.01-3.

UNEP-DEWA
Division of Early Warning and Assessment
P.O.Box 30552, Nairobi, Kenya
Tel: +254 2 62 32 31 / 62 40 28
Fax: +254 2 62 39 43
http://www.unep.org

Additional copies of this report are available at
http://www.earthprint.com

Cover photos by Bryan and Cherry Alexander *(migrating reindeer; Prudhoe Bay Oilfield)* and by UNEP *(logging road in rain forest)*. All UNEP photos throughout courtesy of Topham Picturepoint.

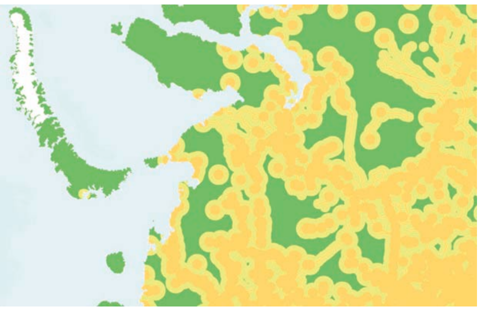
http://www.grida.no/prog/polar/globio/

GLOBIO GLOBAL METHODOLOGY FOR MAPPING HUMAN IMPACTS ON THE BIOSPHERE

THE ARCTIC 2050 SCENARIO AND GLOBAL APPLICATION

CONTENTS

At the backside of the report, quotes from reviews are presented as a summary



Preface

For millennia, humans have altered the world's ecosystems to meet their growing demands for food, fiber and water or to build cities, roads or other infrastructure. Many of these changes to ecosystems have unquestionably benefited humanity - through for example vast increases in food production - even if they transformed "natural" ecosystems. But with the benefit of hindsight we can see that many were ill advised. Many dams have created more poverty than development, the expansion of agriculture in some regions has increased the frequency of floods without substantial gains in food production, everywhere we are losing "option values" as species go extinct, and in some regions entire cultures have disappeared. Today, the sheer magnitude of the human impact on Earth ecosystems, combined with growing human populations and consumption, means that the challenge of meeting human demands for ecosystem goods and services is growing dramatically. Everywhere countries are facing profound trade-offs: We can increase the amount of food produced by ecosystems but only at a cost to the ability of those systems to meet our needs for clean water. We can build more roads and expand or cities, but only at a cost to food production and the protection of biodiversity.

Until now, our approach to managing ecosystems has been largely one of trial and error, with hindsight our most powerful tool. We have sometimes learned from our mistakes, but our mistakes have exacted a tremendous toll. It is time to arm policymakers and the public with foresight about the potential consequences of choices we face. Advances in ecological sciences, combined with improvements in monitoring and data gathering over the past decades now provide a sound scientific basis for exploring the future consequences of policy choices we make today. But there have been remarkably few attempts to actually apply science in this way. GLOBIO has taken up this challenge.

GLOBIO is a pioneering attempt to meet the needs of decision-makers and the public for scientifically-based information about the consequences of their choices today for the future of biodiversity, sustainable development, and local cultures.

Scenarios such as those used in the GLOBIO study are not predictions of the future. Instead, they are tools that decision-makers can use to explore possible outcomes of choices they make today. GLOBIO examines the potential consequences of different scenarios of infrastructure development in the coming decades. Any scientist would be quick to note that infrastructure is only one of many factors affecting ecosystems. But the elegance and strength of the GLOBIO approach lies precisely in its focus on a simple and straightforward relationship between infrastructure and ecosystems. Though the impacts of infrastructure development on ecosystems and local communities are mediated through myriad causal routes, they are nevertheless profound and in the aggregate highly predictable. GLOBIO gives us all a chance to explore where the road we are following will lead us. And in doing so, it gives us a chance to explore the options of taking a different road. Or not building a road at all.

Dr. Walter V. Reid
Director, Millennium Ecosystem Assessment.

Executive summary

GLOBIO was initiated to provide an inexpensive, simple scientifically based communication tool for mapping, at large scale, the likelihood of human impacts on the biosphere resulting from increasing growth in resource utilization. GLOBIO is intended to bring scientific evidence on human impacts into a format suitable for policymaking.

Conventional assessments of environmental impacts have usually been made through studies focused on specific ecosystems or species. Due to the complexity of the world's ecosystems and the ecology of the Earth's 10-30 million species, the conventional approach has led to the undertaking of a considerable number of case studies at various scales. Such a large number of studies render long-term planning and decision-making very difficult, as the latter would require the appraisal of all relevant studies at once in order to assess cumulative impacts. The different scales at which studies were undertaken compound this difficulty. Furthermore, most models require unrealistic amounts of input-data in order to be effective, and are not practical in national, industrial, or social planning procedures.

To ensure the realization of the objectives of sustainable development, there is a critical need for tools that help assess the likelihood of environmental impacts of different developmental proposals. This is particularly relevant for infrastructure development, the central nervous system of our modern world. Towards addressing this need, this pilot report presents a methodology that relates probability of impact on biodiversity and ecosystems to distance to infrastructure, based on existing impact assessment studies. Infrastructure brings primary industrial development, but also secondary, more uncontrolled development in terms of increased human immigration and settlement, with increased risks of deforestation, overgrazing, desertification, social conflicts, and water and land degradation. The methodology is applied to the Arctic region. This Arctic pilot study is intended to be the forerunner of a global scenario report.

In the last part of the 20th century, the Arctic has been increasingly exposed to industrial exploration and exploitation as well as tourism. The growth in oil, gas, and mineral extraction, transportation networks and non-indigenous settlements are increasingly affecting wildlife and the welfare of indigenous people across the Arctic. A considerable number of species of birds, mammals, and plants have already undergone a reduction in their populations or breeding success, or have been subjected to other types of impact in 15-20% of the land area of the Arctic. A 2050 scenario was made using reduced, stable, or increased rates of infrastructure growth as compared to the growth between 1940-1990. The scenario revealed that at even stable growth rates of industrial development, 50-80% of the Arctic may reach critical levels of anthropogenic disturbance in 2050, rendering most of these areas incompatible with traditional lifestyles of many subsistence-based indigenous communities. As most of these impacts are related to the establishment of permanent infrastructure and the exploitation of non-renewable resources, the reversibility of the estimated changes in the near future is most unlikely.

If similar patterns of human impacts apply at the global scale, the land area impacted significantly by human activities (such as reduced abundance of flora and fauna) may increase globally from 15-20% to 50-90% within 50 years. This will most likely result in a substantial increase in environmental problems related to habitats, biodiversity, food production, water resources and health in 2050, thereby impacting both ecological, social and economic aspects of the global environment. The rapid growth of infrastructure with its associated secondary human impacts underlines the urgency for scenarios and appropriate methodological improvement to provide the necessary platform for holistic policymaking and international agreements.

More than 1 billion people rely on the well-functioning of the Himalayan ecosystem for their water resources outside of the mountain range. Construction of roads into pristine areas often unintended results in deforestation, followed by erosion, with subsequent impacts on water and drainages far down-stream. The fate of the remaining forests in the Himalayas bears destiny for many people.

1.0 Introduction

There is a growing understanding and awareness that our basic resources, in particular food, water, and land products, are largely dependant upon the well-functioning of our ecosystems. Ecosystems also serve as important buffers to absorb pollution and mitigate the effects of global changes. They also provide natural response to pests. The disruption of these ecosystems may seriously threaten our health, food production, and economy.

Population growth and expanding human activities encroach increasingly on natural ecosystems disturbing wildlife and disrupting essential environmental services. Considerable efforts are being made in many countries to assess the impacts on ecosystems caused by human activities. Most environmental impact assessments have, however, a narrow approach as they usually focus on one individual activity and its impacts on one species or the local environment. As such, they fail to fully assess the overall cumulative impacts of smaller, consecutive developments in a region [42].

references page 26 - 35

In the area of long-range air pollution, international scenarios of likelihood of impacts at large scales within a defined time span have been developed to help decision-making [163]. However, no methodology has been elaborated for scenario assessment of the cumulative impacts of human activities on biodiversity and ecosystems at a large scale.

In order to help address this gap, the GLOBIO methodology was developed. This report presents the main features of GLOBIO and the outcome of its application in the Arctic region.

Roads are often built through forest for industrial purposes, such as mining/mineral exploration, oil and gas interests. Secondary, more uncontrolled development, result in deforestation, with subsequent erosion and loss in biodiversity. Sustainable development planning should therefore take into consideration the effects of the entire road network, not just the individual new segments that are continuously added on.

2.0 Goals

The purpose of GLOBIO is to develop a global methodology for mapping risk of human impacts on the biosphere. GLOBIO is intended to bring scientific evidence on human impacts into a format suitable for policymaking.

The requirements set for the methodology are: a low-cost, quantitative, scientifically sound, logic and simple communication tool linking development to environmental impacts. The methodology should moreover be directly suitable for:

- assessing ecological, cultural and socio-economic aspects of developmental activities
- providing guidance for conservation
- providing guidance for development planning with minimum impacts
- analyzing impacts at various scales, including local, national, regional, and global scales
- undertaking scenario assessments
- assessing impacts with complex multiplicative effects such as fragmentation

3.0 Background

Natural resources exploitation and anthropogenic activities have expanded rapidly in the Arctic, particularly during the last decades of the past century. These activities include oil and gas exploration, mineral exploration, mining, marine fisheries, waste dumping, shipping, and tourism [35, 41, 105]. The Arctic is considered to hold large reserves of hydrocarbons and minerals [99]. Today oil and gas exploitation development is the keystone to many northern economies. Various plans are underway to extend the infrastructure and development network to new regions, such as the Yamal Peninsula of Russia, the National Petroleum Reserve and the Arctic National Wildlife Refuge of Alaska, and the Barents Sea region 137, 140.

Tourism is another activity with major economic interests and a important market globally. It is one of the fastest growing activities in the Arctic and is difficult to control 107. Many prospective travellers perceive the Arctic as one of the last wilderness areas and among the least exploited regions by tourism in the world. Pristine landscapes and wildlife are the major attractions in the Arctic 79, 106, 205. As a highly mobile activity, tourism is likely to add to the impacts of the more stationary industrial activities of the Arctic in the years to come.

So far, no large-scale mapping methodology has been presented relating industrial development and tourism to probability of impact on biodiversity and ecosystem function. Such a large-scale quantitative assessment could enable us to model and predict impacts more directly on some of the most essential products, such as food, medicine, and services provided by ecosystems. This kind of mapping would help define critical levels of disturbance, and would monitor and predict changes in our global environment as a result of human activities.

The critical level concept for mapping purposes used in this pilot study has been adapted from the one used in relation to emission control under the UN-ECE Convention on Long-range Transboundary Air Pollution in Europe 163.

3.1 Infrastructure: a leading cause to environmental disturbance

Globally, there is increasing evidence that infrastructure, such as roads, transportation corridors, airports, pipelines, power lines, utilities, and dams lead to substantial environmental impacts, even with low levels of transportation traffic.

New infrastructure will accelerate other development activities due to the increased access afforded by infrastructure 56, 67. Hence, the impacts associated with infrastructure may vary not only with the climate and ecology of a region, but also largely with the social, political, and economic situation in a country.

Roads and other infrastructure also impact wildlife by modifying animal behavior and species distribution in areas with infrastructure 194. Wildlife is impacted directly by infrastructure through collisions with vehicles (considerable even at population levels in some instances), substantial noise, disruption of the physical environment, alteration of the chemical environment, and introduction of exotic species 194.

Infrastructure, an important key to human development and economic growth, also brings many environmental risks. The impacts vary with social and climatic conditions, but may be classified into 3 major phases:

1) The primary development phase, including impacts associated with primary industrial development and associated potential pollution of water, air and land;
2) The secondary development phase, including secondary, more uncontrolled human immigration and settlement with risks of deforestation, overgrazing and desertification, sometimes illegal crops and hunting, social conflicts and water and land degradation;
3) The third development phase, including the regional cumulative impacts of the addition of infrastructure to the already existing infrastructure network. This includes social, economic, and environmental effects within the region, positive as well as negative.

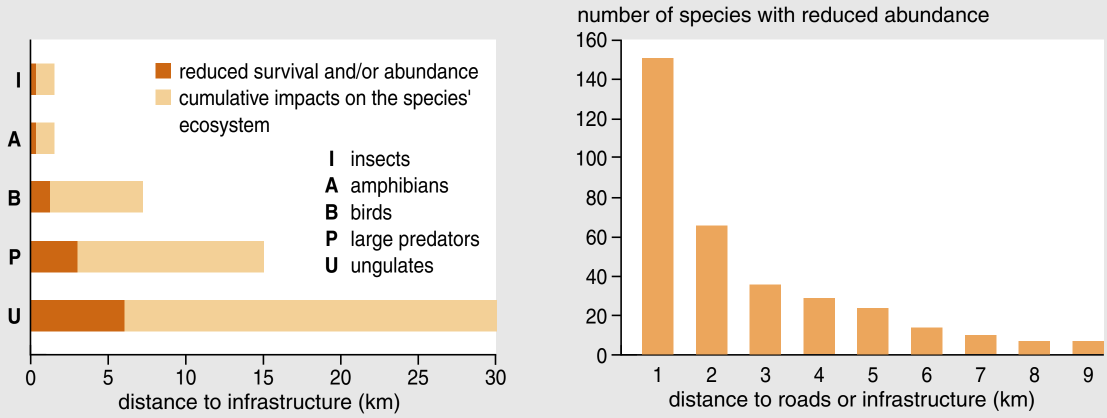


Figure 1a-b: Distances from roads and other infrastructure within which reduced survival or abundance of wildlife has been observed, synthesized from >100 studies and a total of 151 species, mainly birds and mammals.

Impacts can be expected on most fauna families. Examples include insects 82, 83, 117, 184, am-phibians and reptiles 212, birds 11, 94, 160, 170, 171, 176, 178, 186, 212, small mammals 8, 12, 89, 98, caribou and reindeer (*Rangifer tarandus*) 35-37, 88, 148-151, 210, 221, arctic fox (*Alopex lagopus*) 74, elk (*Cervus canadensis*) 43, 130, 180, wolves (*Canis lupus*) 72, 102, 142, 192, black bears and brown bears (*Ursus americanus and Ursus arctos*) 23, 134, 141, mountain lions (*Felis con-color*) 204, bobcats (*Lynx rufus*) 129, elephants (*Loxodonta africana*) 14-16, and primates 21, 179 (Figures 1-2).

Animals avoid areas near infrastructure, breed-ing success decreases in developed areas, and habitats become fragmented 9, 66-69, 117, 194. The ecological impacts of losses of habitats and redistribution of animals away from develop-ment may again affect foraging success or survival substantially in areas beyond these initial zones of disturbance, and, hence, result in overgrazing, erosion, changes in predation pressure and breeding success. Avoidance of developed areas therefore affects much larger areas than that of the physically altered footprint of development.

The extents of the zones within where wildlife will become affected by infrastructure vary according to species, season, type of disturbance, habitat, and other environment factors. The effect of anthropogenic development is thus species specific; while specialist species seem to avoid developed areas, generalists are more tolerant and may even benefit from human development 45, 80, 91. While some studies have suggested that wildlife and industrial development are highly compatible 46, 47, 139, all in all, however, studies including both specialist and generalist species conclude that total species diversity declines with increasing anthropogenic development (see appendix) 38, 56, 91, 117, 122, 186, 121.

Sensitivity is particularly high in the Arctic. Reindeer and caribou (Rangifer tarandus) are among the most sensitive species in the Arctic to human activity, often reducing the use of grazing grounds by 50-90% within 3-10 km of roads, power lines, or resorts (Figure 1) 49, 88, 148-151, 221.

Large Arctic carnivores abandon areas when road densities reach a certain level, typically around 0.5-0.6 km/km2 (Figure 2) 142, 144, 192, 203.

Birds may be highly sensitive not only to drainage of wetlands (Walker et al. 1987), but also to noise from traffic 169-172. Reijnen et al. (1996) found reduction in populations of 14-44% up to 1500 m from roads for a series of bird species. The net result is serious impacts on ecosystem function, even at considerable distances from infrastructure (Figure 1).

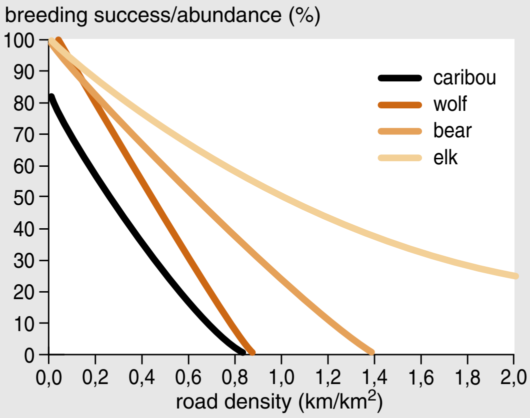


Figure 2: Reproductive success or abundance of caribou/reindeer, wolves, bears and elk as a function of distance from infrastructure or road density, as estimated from 20 studies. Note that a different sensitivity and size of impact zones, generally 25-75% lower, apply to warmer climate zones.

The probability of impact on vegetation also varies with type of disturbance involved. The impact on vegetation and hydrology of the tundra is relatively limited from power lines and pipelines; generally related to changes in snow distribution, ablation patterns, and minor disturbances of soils etc. within 500 m 13, 58-65, 120, 123, 137, 138. From roads, the impacts on vegetation are considerably greater, at close ranges (<1 km) because of road dust, but primarily through effects on water discharge, changes in albedo, and possible thermokarst. These effects can be substantial up to 5 km 209, 213. The most significant impacts on vegetation are related to human settlements 74, 137-138. Here, the much higher levels of anthropogenic activity, gravel pads, borrow pits, and extensive use of off-road vehicles can substantially affect or disrupt vegetation patterns and hydrology (with resultant thermokarst) up to 20 km from the actual location of buildings 1, 10, 58-65, 110, 137, 138, 146, 165, 166, 173.

Construction of roads, flooding, and/or changes in vegetation composition may also affect fledging success of birds and nesting waterfowl 194, 213, which in turn may disrupt predation patterns and long-term productivity of smaller predators. The impacts on soils, vegetation, and wildlife are therefore often linked. The cumulative effects of these disruptions in ecosystem function are thus likely to exacerbate the impacts associated with changes in use and abundance of selected species.

Very many animals are migratory or travel significant distances, including both insects, reptiles and amphibians, mammals and birdlife, often finely tuned to seasonal variation in food and water abundance. Thousands of wildebeest and other animals, including also endangered species, died from thirst when fences were built – intended to reduce the spreading of the foot-and-mouth disease in domestic cattle - across their traditional migration routes to water holes.

Photo **Alan Brown, UNEP**

Many bird species are migratory, and the damming of rivers for hydro-electric power and irrigation purposes results in the draining of wetlands, with global impacts on migratory species. The pattern is recognized worldwide.

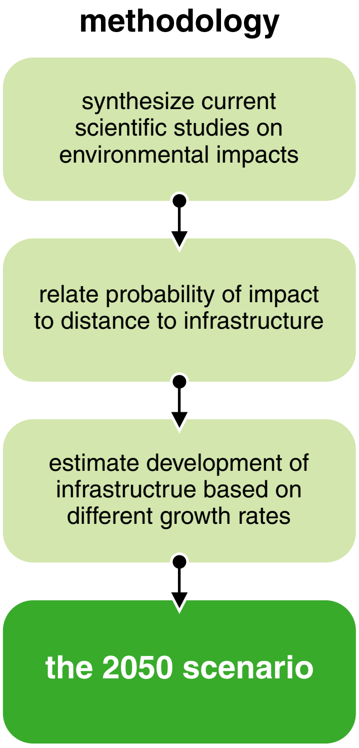
Collecting medical herbs. Mentawai, Indonesia. For many people, even the modern pharmaceutical industry, biodiversity is the leading source to all medical supplies.

4.0 Methodology

Following the initial stage of literature review, the main elements of this methodology are based upon 3 major steps: 1) Synthesis of studies on impact zones of infrastructure (see above); 2) Review of historic growth in infrastructure, and 3) Scenario assessment (see right). To obtain a simple framework for assessing probability of impact in function of the distance from infrastructure, four levels of degree of likelihood of impact were defined (see below).

4.1 Synthesis of impact zones from infrastructure

Based upon some 200 scientific studies, an attempt was made to summarize the extent of the impact zones of infrastructure on flora and fauna in the Arctic. Studies on vegetation, soils and wildlife, referred to in this report, were used to derive the probability of impact in function of the distance from 1) power lines or pipelines; 2) roads; and 3) settlements, cabin resorts, or construction-related facilities (Tables 1-2). These zones were then extrapolated to produce a circumpolar map of current development and probability of disturbance in the Arctic.



The extent of the impact zones are likely to vary considerably with traffic volume; small country roads obviously produce less impacts than highways for comparable habitats [66]. Noteworthy, some Arctic species adapted to open areas with high natural predator awareness have been documented avoiding human structures even in the absence of traffic [148, 149].

A similar pattern has been observed for vegetation. The impact zone of power lines and pipelines on vegetation and hydrology of the tundra is relatively limited, typically within 500 m; greater for roads (<1 km), and most significant for settlements due to gravel pads, borrow pits, and extensive use of off-road vehicles (<20 km). The data are given in Table 2.

The sensitivity will vary depending upon species, season, and type of impact. In general, insect fauna and rodents have the smallest impact zones, whereas large mammals have the greatest. The

Criteria for defining environmental impacts:

1) ***Reduced survival and/or abundance of birds:*** A zone within which there is high risk of reduced survival or abundance of birds based upon studies of >50 bird species.

2) ***Reduced survival and/or abundance of large mammals:*** A zone within which there is high risk of reduced survival or abundance of larger mammals based upon studies of most of the larger predators and ungulates.

3) ***Cumulative effects on flora and fauna:*** A zone within which there is high risk of cumulative effects on ecosystem function, such as changes in proportions of organisms affecting food chains, increased numbers of generalist ("pest") species, vegetation changes, overgrazing, increased risk of predation etc.

4) ***Low levels of disturbance:*** No or few studies have documented or reported possible impacts. Increase in hunting pressure, tourism and human traffic must, however, be expected.

Table 1: Extent of zones of impact on Arctic fauna caused by power-/pipelines, roads, and settlements. The impact zones designate the probability that habitat availability is reduced substantially, or that breeding success, abundance, or survival has decreased as a result of infrastructure or associated activity. Note that different, generally 25-75% lower, sensitivity and impact zones apply to warmer climate zones.

Type of disturbance	**Type of impact**		
	Reduced abundance	Cumulative impacts on ecosystems	Low disturbance
Power-/pipe lines	0-4 km	4-16 km	> 16 km
Roads	0-5 km	5-20 km	> 20 km
Settlements	0-10 km	10-40 km	> 40 km

Table 2: Extent of zones of impact on vegetation caused by power-/pipelines, roads, and settlements. Impacts include both direct (like road dust out to 0.5-1 km) and cumulative impacts (changes in hydrology, ATV-tracks etc.). Note that different, generally lower, sensitivity and impact zones apply to warmer climate zones.

Type of disturbance	**Type of impact**		
	Reduced abundance/ shift in composition	Cumulative impacts on ecosystems, such as thermokarst, off-road traffic	Low or no disturbance
Power-/pipe lines	0-0,5 km	0,5-2 km	> 2 km
Roads	0-1 km	1-10 km	> 10 km
Settlements	0-10 km	10-30 km	> 30 km

variation in response is presented in Figure 1, based upon the studies assessed (see Appendix 1). Four categories of impacts were defined for the Arctic (Figure 3):

1) Reduced abundance of birds (0-1 km from infrastructure);
2) Reduced abundance of large mammals (0-3 km);
3) Cumulative impacts on flora and fauna, including shifts in insect composition, food chains, hydrology, predation patterns etc. (0-20 km);
4) Areas with low or no disturbance (> 20 km).

Note that some species, like reindeer and caribou, are impacted at greater distances, and 50-90% reduced abundance compared to undisturbed areas have been observed up to 15 km from development. In Arctic areas with permafrost, roads may lead to changes in hydrology and habitats several kilometers away from development, thereby affecting areas considerably beyond these estimates.

Data from the Digital Chart of the World (DCW) at an approximate scale of 1:1 million were used to produce the circumpolar map. The primary source for this database is the US Defense Mapping Agency (DMA) Operational Navigation Chart (ONC) series that are produced by the United States, Australia, Canada, and the United Kingdom. The ONCs have a scale of 1:1,000,000 (1 inch equals approximately 16 miles) and include details of technical structures. The DCW database was originally published in 1992. Data currency varies from place to place depending on the currency of the ONC charts. Chart currency ranged from mid 1960s to the early 1990s. DCW has proved to be inaccurate compared with higher resolution regional and national mapping databases in the Arctic. However, it provides the best available coverage for the whole Arctic region[68].

GLOBIO - scientific estimates of impact zones of infrastructure and associated human activity

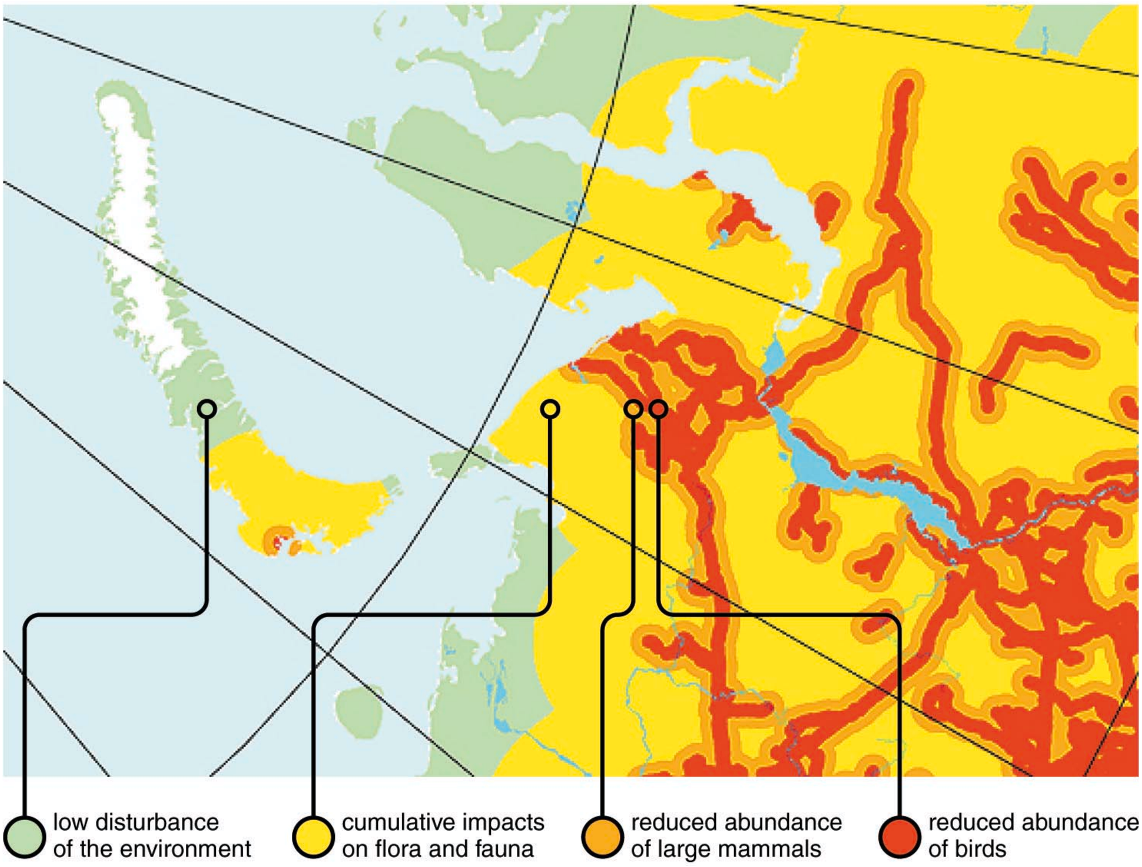


Figure 3: GLOBIO requires only baseline information on infrastructure. Impact zones are derived through a synthesis of numerous scientific studies, and adjusted according to climate, eco-zone, and type of infrastructure. Overlays with additional information, such as pollution, can be supplemented to the overviews.

4.2 Historic growth in infrastructure

Changes in infrastructure between 1940 and 1990 were used to create scenarios of future development. The entire Arctic was divided into 25 by 25 km grid squares ("plots") and these again into 250 by 250 km grid squares ("sites"). The buffer zones from infrastructure outlined above were applied to the 1940 situation where available and similar analysis done for the 1990 DCW situation. All 25 by 25 km grid squares with >50% of the area having buffer zones 1-3 (practically speaking: any plot with any significant amount of infrastructure at these scales) was classified as being "impacted" e.g. having reduced abundance of wildlife or other cumulative impacts on the ecosystem. The scale of 250 by 250 km grid with 25 by 25 km plots was used in order to monitor, depict and visualize the expansion of new infrastructure at regional scales.

Infrastructure is often built into the most productive regions, with subsequent immigration of non-indigenous populations and growth in resident farmlands. Nomadic and semi-nomadic people are often forced into more marginal grazing lands previously used only seasonally. The result is overgrazing and high vulnerability to periods of drought, often with tragic results. The driving pressures of development that initially started these processes, often with social conflicts, are too often overlooked.

To derive with an estimate of the growth in areas impacted by infrastructure across the 50-year period from 1940 to 1990, the following approach was applied based on the assumption that new infrastructure primarily spreads out from existing infrastructure.

1) 30 random, non-overlapping grid cells of 250 by 250 km, covering areas with existing infrastructure (roads, power-/ pipelines, or railroads) in 1940, were selected across the Arctic.
2) Within the grid cell, the area with the highest concentration of infrastructure around 1940 (roads/km2) was located. If no concentration was found, any random point in the existing infrastructure was selected (see Figure 4a).
3) The selected point was then “revisited” in the 1990 situation (Figure 4b).
4) A circle was drawn around the selected point (Figure 4c). The radius of the circle was expanded until ca. 75% of the circle area was located within 3 km from of the roads existing in 1990. (e.g. having < 75% “impacted” plots of 25 by 25 km)
5) The radius of the 1990 circle minus the radius of the 1940 circle was then calculated (D_{max}) (Figure 4d). This radius is an estimate of how far infrastructure has spread away from existing infrastructure in the period 1940-1990.
6) The procedure was replicated across all 30 grid cells, and a mean value calculated (Figure 4e and Table 3).

The availability of good maps from around 1940 is very limited. Furthermore, maps are updated at irregular schedules. Reliable maps are available for parts of Scandinavia and North America. However, many parts of the Arctic were still undeveloped before World War II, and most development occurred throughout the 1960-1970s. Hence, most of the development, excepting parts of Russia and Scandinavia, are the result of changes from near 0 to the situation in 1990. Examples include the Prudhoe Bay oilfield of Alaska, the trans-Alaskan pipeline, and the oil fields of Yamal, Russia.

a.
1940:
A random point in infrastructure is located.

b.
1990:
The same point is re-located in 1990. (New infrastructure now visible).

c.
1990:
A circle with center point in the 1940 location is expanded until ca. 75% of the circle area is within 3 km from infrastructure.

d.
The radius (1940-1990) is measured (D_{max}), an estimate of growth in infrastructure in that region between 1940 and 1990.

e.
This procedure is replicated within 30 non-overlapping random regions, each 250x250 km, across the entire land-covered Arctic. The mean is then used for scenarios at 50-200% of this growth rate.

Figure 4a-e: Principles of estimating growth in areas located within 3 km from infrastructure.

Table 3: The average distance (D_{max}) from infrastructure existing in 1940 within which >75% of the areas are <1 km (reduced abundance of birds) and <3 km (reduced abundance of large mammals), respectively, away from infrastructure 50 years later, based upon 30 random 250x250 km grid squares across the Arctic.

	D_{max} (km) (reduced abundance of birds)	D_{max} (km) (reduced abundance of large mammals)
Mean	18	55
S.E.	2	6
95% CF	15-21	44-66
n	30	30

For analysis of changes in growth of infrastructure in more populated regions or at finer scales, changes have to be based on satellite imagery and aerial photos and regression analysis of changes over time. There is an extensive coverage of aerial photos, CIR photos, and numerous types of remote sensing data available now to assess changes in infrastructure development. This data can be used not only for assessing historic growth rates, but also for monitoring changes in the future.

4.3 Scenario modeling

There is considerable uncertainty related to the estimate in growth in infrastructure, economic development, and the future demand for oil, gas, and minerals in the Arctic. Three scenarios were therefore used based on three different growth rates: reduced growth rate of 50%, current growth rate, and an increased growth rate of 200% compared with the growth rate recorded between 1940 and 1990. Maps were created showing the extent of impact zones in the year 2050 for each of the three growth rates.

5.0 Results

5.1 Overview of the impacts

In the first part of the 20th century, <5% of the Arctic was affected by infrastructure. In the last part of the century, this proportion had increased to 20-25% of the Arctic, mainly as a result of petroleum development in Alaska and Russia (Figure 5). Currently, parts of Alaska, most of northern Scandinavia, and large parts of Siberia are developed. For Siberia, the development consists mainly of winter roads and pipelines, in addition to railroads and industrial complexes. The far majority of infrastructure in the Arctic has been related to oil, gas, and mineral extraction, with associated transportation corridors.

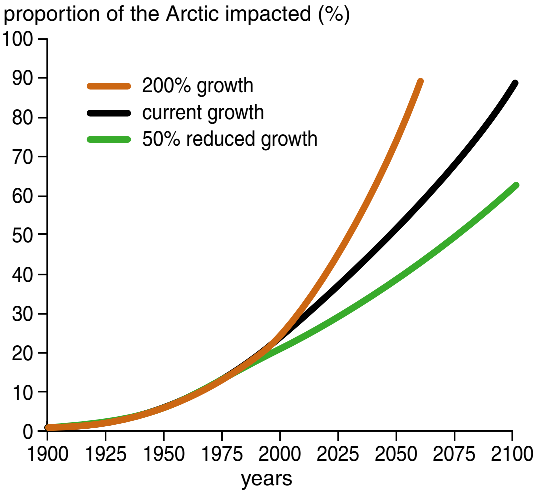
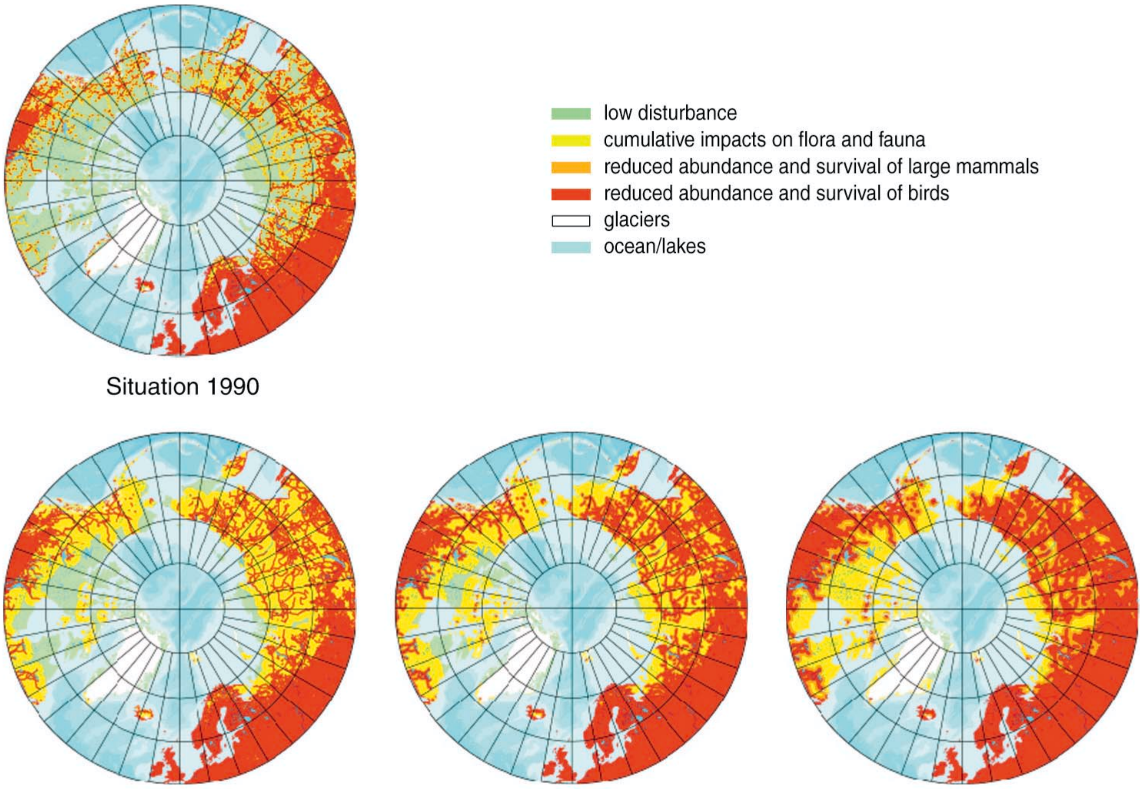


Figure 5: Changes in the proportion of the Arctic being significantly impacted by human activities between 1900 and 2100 based on growth rates of 50%, 100% and 200% of the recorded growth rates in infrastructure between 1940 and 1990.

By assuming only continued development of existing infrastructure and new opening of areas to oil and gas development, estimates show that few areas in the Arctic will be left undisturbed within 50 years. In 2050, 50-80% of the Arctic is likely to have high levels of anthropogenic disturbance, depending upon growth rates (Figure 6). For Scandinavia and parts of Russia, these levels will occur within 20-30 years (Figure 7). This development will accelerate with the possible opening of parts of a Northern Sea Route through the Northeast Passage [153], where development of infrastructure and upgrading of harbors will facilitate extraction rates. These figures will, correspondingly, depict an ecological transformation of traditional lands for many Arctic indigenous people dependent upon reindeer husbandry and caribou hunting. In 2000, Greenland and northern Canada are the two regions most unaffected by industrial development.


Photo **UNEP**

While infrastructure does not depict long-range transported air pollution, it often well depicts degree of local land and water pollution, as most of the industry is located at concentrations of infrastructure near cities. Heavy development of infrastructure into previously undeveloped areas, or heavy expansion of existing network locally, therefore indirectly often leads to increased waste and water pollution. Often not considered, but unless controlled, part of the long-term pattern and development globally.



Situation 1990

Situation 2050 - 50% scenario

Situation 2050 - 100% scenario

Situation 2050 - 200% scenario

Figure 6: Changes in human impact on biodiversity and ecosystems between 1990 and 2050 using three different rates (50-100-200%) of growth in infrastructure and resource utilization compared to 1940-1990. Temperate parts of USA, Europe and Russia will appear more impacted on these maps than what actually is the case. A global scenario would use different impact zones in different climatic regions. See the Barents Sea map for finer resolution.

5.2 Impacts on biodiversity and ecosystem function

The fragmentation of Arctic habitats will, at the levels of development predicted, seriously threaten biodiversity and ecosystem function. Considerable scientific research in the 1990s confirm that fragmentation of landscapes by infrastructure and related activities of human resource utilization (logging, farming, mineral extraction etc.) directly result in reduced productivity and survival of many species, and hence, in reduced species richness 38, 56, 117, 122, 186. Terrestrial infrastructure development will also substantially affect aquatic systems not only by i.e. pollution, but also through the construction of new transportation routes and settlements along the coast, thereby affecting also sea and freshwater ecosystems indirectly. Stream and lake ecosystems are also affected through the building of dams, wetland drainage, channelization, and groundwater exploitation. This will impact fish, invertebrates, sea mammals, and other organisms through increased harvesting or disturbance 174, 194. Infrastructure therefore causes impacts far beyond those effects directly induced by the physical foot print.

Even more serious may be the long-term effects on ecosystem function as a result of altered proportions between predator and prey organisms. Certain groups of species may benefit from lowered survival of other otherwise competitive species. Fragmentation may result in reductions in populations of natural enemies for "pest insects", thereby increasing the number of "pest insects" 117, 122. Fragmentation of habitat may also lead to a crowding of species in remaining habitat patches, making the species more vulnerable to predation. Under these conditions, fragmentation may favor small and medium sized predators and corvine birds. Species vulnerable to fragmentation include species dependent on large, continuous areas, species with poor dispersal abilities, species with low fecundity or short life cycles, and species with specialized habitat requirements. Several studies also document disrupted natural mechanisms and food chains due to development. The changes in natural food chains and buffer mechanisms as a result of development of infrastructure will seriously exacerbate the direct environmental impacts on populations and ecosystems at regional scales.

5.3 Impacts on indigenous cultures

Living as herders, hunters, and gatherers, Arctic indigenous people have adapted their lifestyle with reindeer/caribou systems through thousands of years of co-evolution 28, 100, 113, 158. Today's Arctic

In Siberia and the Yamal peninsula, like in the rest of the Arctic, the growing infrastructure related to oil, gas and mineral interests often conflict with the traditional lifestyles of indigenous people and their interactions with the land.

Photo **Bryan and Cherry Alexander**

Photo **Bryan and Cherry Alexander**

Reindeer and caribou are crucial to many indigenous people in the Arctic. The saami of the Barents Sea region, once nomadic, are now struggling to retain their traditional grazing ranges, that are encroaching rapidly due to hydro power development, large cabin resorts, roads, forestry and mineral exploration. Most of the fragmentation is done by continuous, small-scale expansion from the already existing network of roads and settlements.

indigenous settlements are commonly located in resource-strategic positions, with territoriality and social networks adapted to the movements of reindeer or caribou [28, 29, 126, 187]. While caribou hunters and reindeer herders have embraced aspects of modernity, many also retain their close relationship with wild and domesticated populations of Rangifer. This resource has and continues to be the most important terrestrial subsistence resource for Arctic indigenous peoples of the Circumpolar North [114]. Indigenous culture groups that herd and hunt reindeer/caribou include (but are not limited to): in Eurasia, Saami, Nenets, Komi, Khanti, Dolgan, Nganasan, Yukagir, Even, Evenk, Sakha (Yakut), Chukchi, Koryak, and Chuvan; and in North America, Gwich'in, Iñupiat, Dogrib, Koyokon Dene, Metis, Cree, Chipewyan, Innu, Naskapi, Yupiit, Inuvialuit and Inuit.

The impact of infrastructure development on reindeer and caribou potentially threatens the cultural traditions of Arctic indigenous people and their chosen way of life. Changes in the size, distribution, and movements, or overall behavior of Rangifer populations may, accordingly, have a significant impact not only on the subsistence-based economies of Arctic hunting people, but also on their social organization and cultural systems as a whole [64, 154]. Therefore, a focus on this keystone species serves as an indicator of future possibilities for those peoples who depend on this resource [181].

Northern Scandinavia and parts of Russia are examples of areas where the current growth of infrastructure related to transportation, oil, gas, and mineral extraction is increasingly incompatible with land requirements for reindeer husbandry [64, 222]. In these areas infrastructure growth is associated with the loss of traditional lands, and conditions forcing indigenous people to abandon nomadic herding patterns for more sedentary life styles. Infrastructure development is often concurrent with changes in regional economic activity, inviting southern-based resource extraction companies interested in short-term economic gains. Such socio-economic changes not only affect cultural practices directly related to traditional reindeer husbandry, but also conflict with the use of traditional homelands for hunting, fishing, and gathering.

Due to the simplicity and compressed food chains of Arctic wildlife and their dependence upon slow-growing forage resources, long-term disruptions in the productivity of primary species like nesting waterfowl and reindeer/caribou may seriously affect ecosystem function and sustainability of these northern systems. In addition to these biophysical impacts comes multiplicative effects that may follow from changes in related human land-use patterns, such as increased public access, intensive resource harvesting, and the full array of social costs typically associated with the transformation of longstanding local cultural traditions.

The rates of change and their potential impacts on northern reindeer herders and caribou hunters are therefore significant. Utilization of fugitive resources like caribou and waterfowl are critical not only as food, but also for identity and spiritual values of herders and hunters. Through numerous fora, Arctic people now seek to define a sustainable balance in their participation in the cash economy with traditional pursuits. Infrastructure development is closely associated with greater changes in economic activity, and is accompanied with a loss of rights for use of subsistence resources. Thus, the study of cumulative effects of infrastructure development must be linked to analysis and implementation of institutional arrangements that sustain a meaningful role for local resource users in development planning and management [19]. Extending the cumulative effect assessment to socio-cultural elements of the system broadens the scope of impacts on development trends. Policies that support external interests in resource extraction in the Arctic need to account for indigenous resources into the full array of impacts related to development activities.

Consequently, there is a need to advance our understanding of these effects more thoroughly. Recently the International Arctic Science Committee (IASC) concluded that the cumulative effects of current forces changing Arctic grazing systems are of significant concern in the Circumpolar North. In 1998 an international research-planning forum of IASC on the human role in reindeer/caribou systems arrived to this conclusion, noting the paucity of tools for assessment of cumulative effects, and calling for methodological development of assessment tools as critical to human's capacity to anticipate and respond to future conditions [114]. The principles of GLOBIO may help to breach this gap and extend it beyond the North.

5.4 Impacts on the Arctic

Continued growth at current rates in infrastructure, gas, oil, and mineral extraction will, within 20-50 years, seriously impact wildlife populations, vegetation, and ecosystem function across 50-80% of the Arctic. Migratory species, like birds, will carry the impacts with them far beyond the Arctic region. Furthermore, the cumulative impacts are likely to affect many of the indigenous cultures in the Arctic, which are depending upon natural resources for their traditional lifestyles.

The extent of the impacted areas, even with conservative estimates assuming 50% reduction in development rates, ostensibly illustrates the severity of the environmental threat to the Arctic. Although the Arctic is among the least developed areas of the world, the extent of the impact zones is much larger. Changes in the hydrology of the tundra may also affect climate patterns as these areas hold some of the world's greatest carbon reserves.

These risks are more complex to assess and less easily predictable with recent changes in global climate. In Polar regions, the effects of climate change are likely to be the more dramatic than in any other regions. Whilst the effect of climate change is not the focus of this paper, it is important to highlight its potential impacts on Arctic ecosystems, and its need to be considered in combination with the impacts from industrial development and tourism.

5.5 Impacts at a global scale

Early pilot assessments of the Barents Sea, Himalayan region and Amazon region (Figures 7-10), demonstrate that the GLOBIO-mapping techniques can be useful for cumulative impact assessments in most ecosystems. The maps, at very different scales, provide important information on the major driving pressures and changes that, over time, have been the greatest contributors to environmental changes within a region. At fine scales, it may depict the impacts of the contribution of many smaller development projects to the overall development of a region.

At a global scale, a substantial decline in abundance and diversity in fauna, including insects, amphibians, reptiles, mammals and birds, will occur in an estimated 50-90% of the land area in 2050 if growth in infrastructure and exploitation of natural resources continues at the current rate. Some species will increase in numbers, particularly “generalist” species such as smaller predators and “pest” insects, with subsequent impacts on flora and fauna. The environmental impacts of continued growth in infrastructure with its associated resource exploitation will also threaten the production of food and water resources and other essential products from nature. There is a significant risk that the cumulative impacts will lead to the collapse of many natural buffer mechanisms within 50-100 years, and, hence, substantially exacerbate the impacts of pollution and climate change.

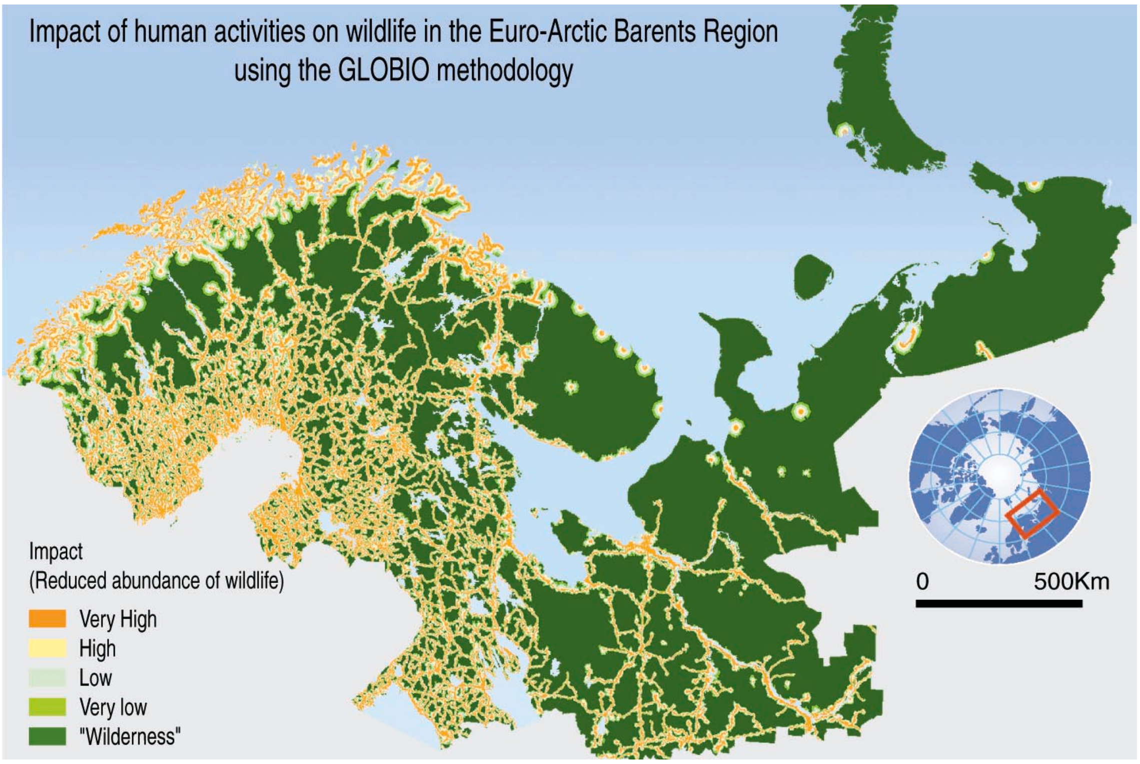


Figure 7: The use of GLOBIO at finer scales for visualizing the cumulative impacts of bit-by-bit encroachment. In the Barents Sea region, it is used to map the encroachment and fragmentation of the ranges used by the Saami people and their livestock of migratory reindeer. Notice that the greater resolution of this map compared to the circumpolar maps provide much more detail on also the variation locally in degree of impacts. The risk of reduction in wildlife is related to the situation before infrastructure was established. Natural rich, but impacted areas may still be higher in biodiversity than e.g. naturally low-productive non-developed inland areas.

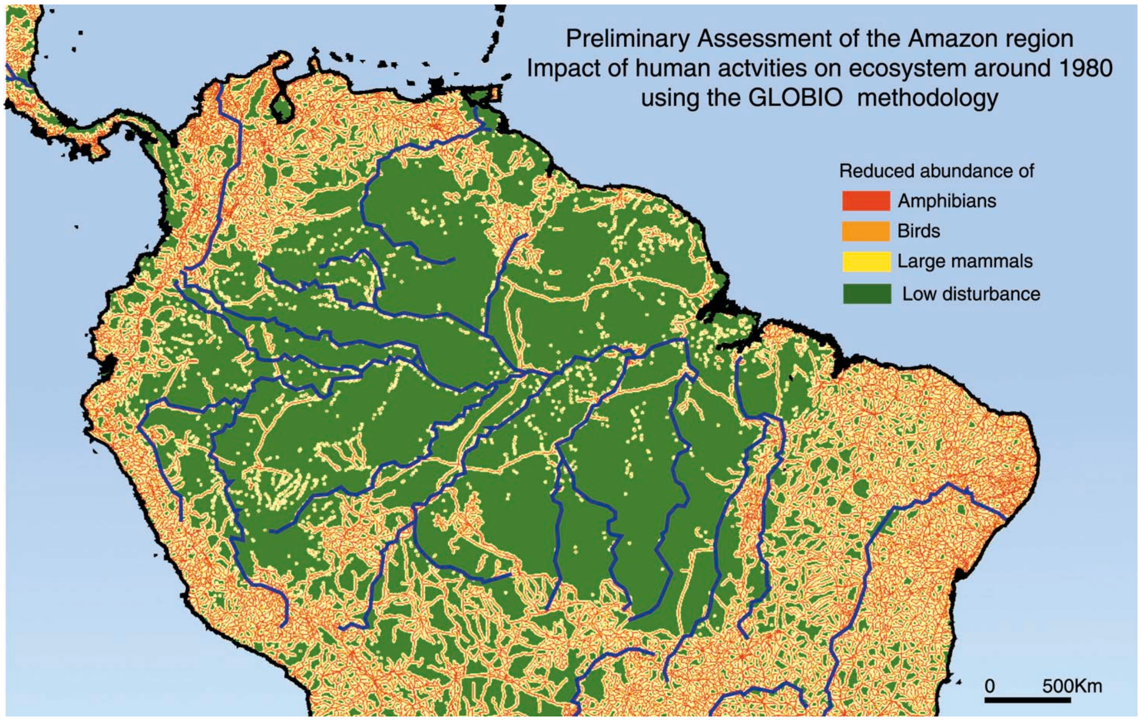


Figure 8: Preliminary assessment of the Amazon region. The map is made for illustration purposes only to demonstrate the application of GLOBIO in other regions of the world. The majority of the deforestation and decline in biodiversity in this region has taken place along the road corridors. Due to the coarse scale of this map, some areas appear more impacted that actually the case.

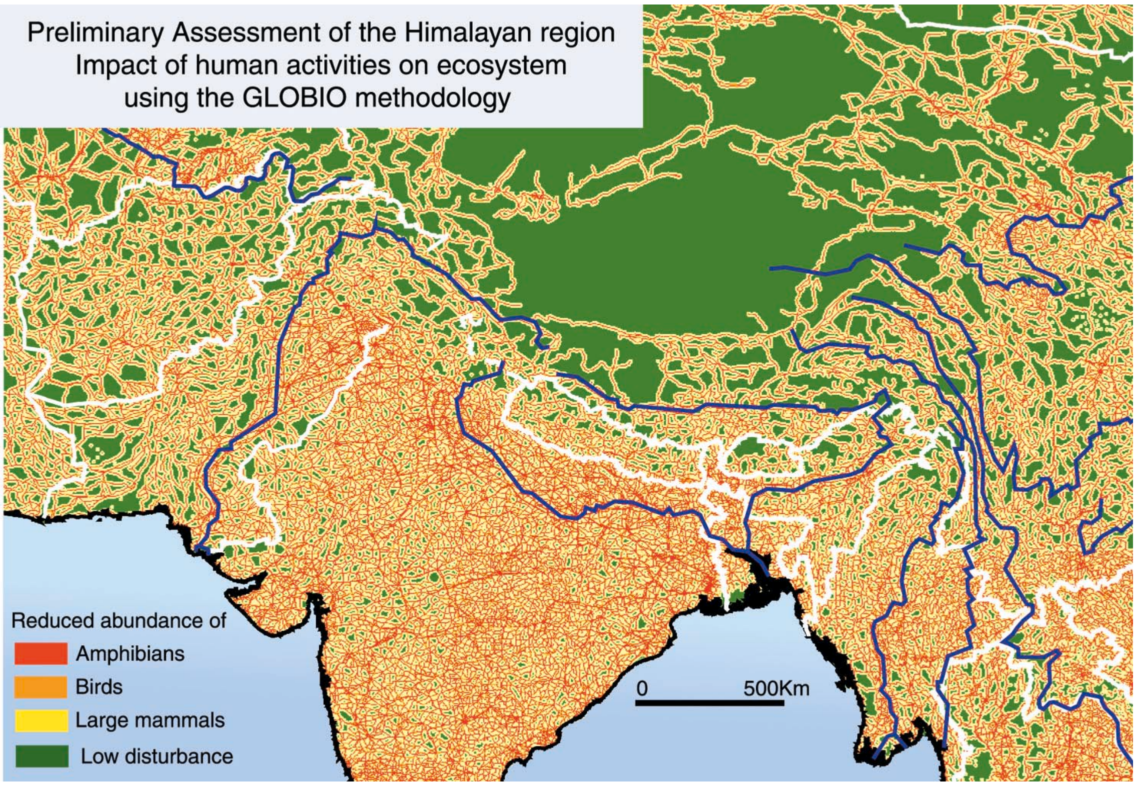


Figure 9: Preliminary assessment of the Himalayan region. The map is made for illustration purposes only to demonstrate the application of GLOBIO in other regions of the world. The density of infrastructure closely resemble much of the original forest cover in parts of the region, now greatly diminished in most places.

The encroachment of road networks in Finnmark, Northern Norway, between 1940 and 2000

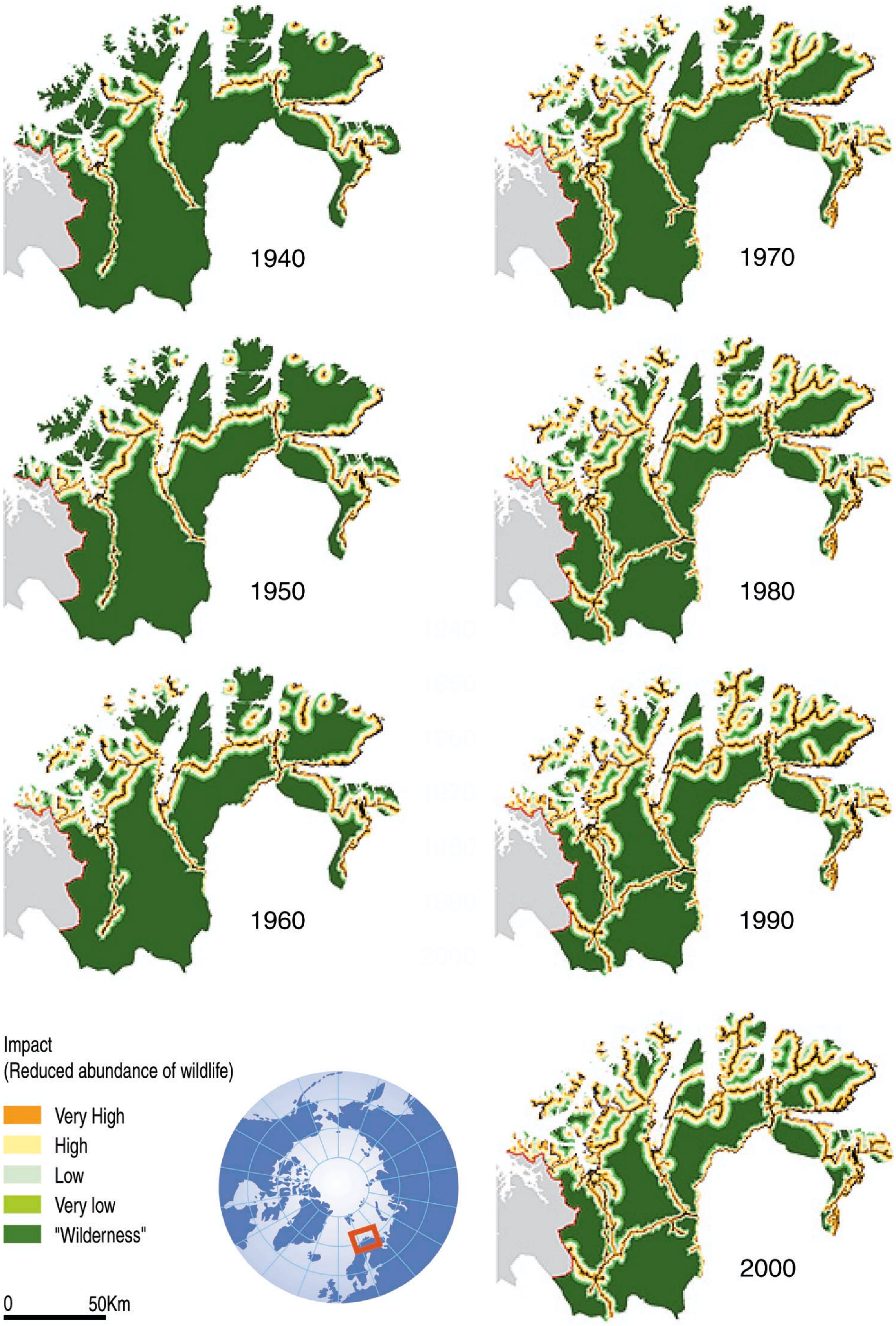


Figure 10: The development of the road network in Finnmark, Norway, between 1940 and 2000. The maps show some of the changes used for the GLOBIO scenario development. The coastal areas of Finnmark are crucial to the Saami indigenous people for calving grounds and summer ranges of their livestock of semi-domesticated reindeer. The same coastal zones, however, have been those subjected to most of the development (see above). The development depicts only part of the encroachment, as the military bombing ranges, resorts, power lines and also major hydro power dams are not included on the maps. Currently, a series of proposed development projects for mineral exploration, power stations, roads and resorts threaten the remaining grazing land and biodiversity in the region.

6.0 Benefits and limitations of GLOBIO

6.1 Supplement to conventional approaches

6.1.1 Traditional wildlife biology approaches

To date, most environmental impact assessments of anthropogenic disturbance of wildlife and vegetation have relied extensively on studies at local scales, or on more theoretic models. Anthropogenic disturbance of wildlife has traditionally been discussed through local studies of fright behavior, flight distances or stress hormone production in animals [4, 54,85, 95, 147, 177, 198, 214], or assessed in relation to direct physical destruction or alteration of habitat [39, 40, 139, 211].

However, assessments of physiological or short-term responses in individual animals or on vegetation at local sites may substantially underestimate regional and global environmental impacts such as changes in species abundance and reproduction, thereby failing to describe fully the cumulative impacts of development [65, 91, 213]. While studies of short-term, local impacts are valuable for understanding mechanisms in ecological responses to human activity, it is difficult to relate physiological stress in individuals and local site-dependent effects on vegetation to impacts at regional levels. Furthermore, such effects cannot readily be linked to the geographic area affected by human activity, and will therefore become difficult to monitor across larger regions. As Arctic indigenous people are largely dependent upon natural resources such as fish and reindeer/caribou, the functioning of the ecosystems at large scales, including successful migration of ungulates, becomes of overriding importance to the wellbeing of these people [18, 64, 111, 154]. So far, however, while isolated, small-scale developments may have only minor impact, the cumulative impacts of consecutive development may seriously endanger not only wildlife, but also the cultural traditions of those depending upon flora and fauna in the Arctic.

6.1.2. Traditional landscape ecology approaches

There are numerous more or less complex biodiversity and landscape indices currently available for more detailed assessments. A review of some complementary approaches is presented elsewhere [191]. Many indices are very sensitive to information on baseline situations or on the state (“quality”) of the ecosystems assessed, thereby requiring rather extensive input information to be reliable. Furthermore, even though roads alter only a small footprint directly (around 1-5% of the land cover), they result in large impact zones by bringing in human activity and fragmentation, as illustrated here. Such indices and models, however, may provide important complementary information to GLOBIO-assessments. Indeed, there are numerous research programs assessing landscape ecological approaches to human impacts at more detailed scales, but many are limited by high requirements of input data. Many are also difficult to relate to socio-economic, cultural, and economic aspects. Such methods should however be explored further to supplement and refine the distance zones, particularly of impacts on ecosystems presented in GLOBIO.

6.2 Data availability

GLOBIO’s only requirement for baseline information is maps of infrastructure. At national scales, updated information on infrastructure is generally readily available. Both current and developing remote sensing techniques holds promise for rapid updating and monitoring techniques that can provide step-by-step information on changes in environmental risks.

New research on impact zones is continuously available through international publication networks, and the size of zones can therefore easily be updated according to new advances and information. At a global scale, growth scenarios must be linked closely to socio-economic models of development to provide the most realistic scenarios. Furthermore, remote sensing may give specific information on changes in land cover, such as changes in forest cover, grasslands etc.

6.3 Data compatibility

The methodology presented in this report relates probability of impact on abundance, reproduction, and survival of wildlife and vegetation to distance to infrastructure. The mapping of impacts may also be combined with diffuse pollution sources such as POP's, acid rain, heavy metals, and other sources of water or air borne pollutants. Based upon the extensive global database from the US Defense Mapping Agency available to UNEP, giving information on transportation network, dams, power lines, utilities and other human physical impacts, the analysis can be conducted for all ecosystems from tropical rain forest to Arctic tundra using a common methodology, but with varying criteria.

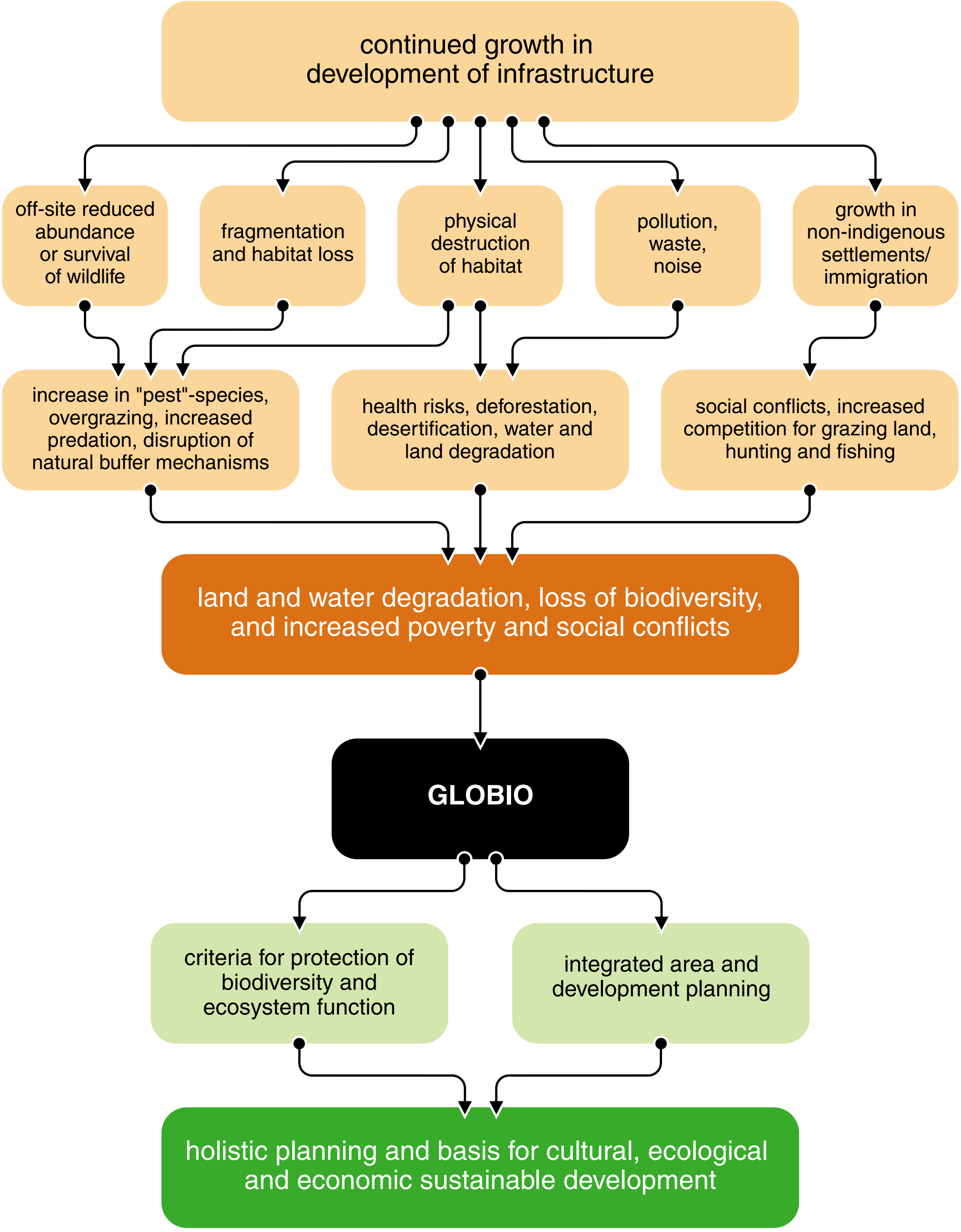


Photo **Ng Chan Chien, UNEP**

The regulation and damming of many rivers for power or irrigation purposes not only impact wildlife, but also the water situation for many people further down stream.

6.4 Sensitivity of GLOBIO to input variables

In many other ecosystems, such as in temperate and tropical regions, the impact zone from infrastructure is substantially lower than in the Arctic; 100-1000 m compared to 4-10 km, respectively [68, 152]. This may partly be explained by a high shrub and tree cover in boreal, temperate and tropical regions compared to the Arctic, as impact zones from infrastructure locally have been shown to be larger in open areas than in areas with cover [179]. As ecological disturbance zones from development are smaller in many parts of for example USA, Europe, South America, Africa, and southeastern Asia, even areas with an apparently high density of infrastructure may clearly have areas with low probability of impact on wildlife. However, the network of infrastructure is far greater in many temperate and tropical regions compared to the Arctic [15, 66, 171]. Reduced survival of numerous species related to density of infrastructure and human resource utilization has been reported in studies undertaken recently from all parts of the world [15, 22, 78, 91, 142, 179, 186, 192, 194]. This provides the GLOBIO approach with the potential for global application.

The statistical factor having the by far greatest impact on the scenarios is the extrapolation of historic development in infrastructure. Indeed, reducing the impact zones by 50% only results in 5-15% difference to the area impacted in 2050, simply because many zones merge due to extensive existing occurrence of infrastructure. By using a range in development of 50-200%, these estimates become statistically far more important than minor variation in impact zones, simply due to the extent of existing infrastructure.

6.5 Scenario modeling

Among the most crucial inputs to GLOBIO are good and realistic scenario-models for development in infrastructure. There are obvious differences in the rates of such development including both socio-economic (urbanization trends) and natural factors, such as low interest in developing desert regions. This part needs to be thoroughly developed for the global scenario work, and currently requires specific attention. New landscape disturbances, which are disconnected to existing infrastructure and may arise in regions previously undeveloped also needs to be addressed in the methodology ahead. For example, this analysis does not include the many mining, power line, and road facilities currently planned for in previously undeveloped regions of the Arctic (e.g., Nunavut and Labrador of Canada).

The major advantage of the GLOBIO-approach of relating environmental risk to distance and density of infrastructure is its simplicity. Global infrastructure holds a key to understanding environmental impacts related to human activity and resource utilization. The likelihood of impact can effectively be linked to existing and planned infrastructure at local scales, as well as to regional, national, and international development scenarios. Herein also lies a disadvantage, namely that GLOBIO mainly provides a risk assessment overview. The many more advanced models and indices available currently should therefore be seen as complimentary to the GLOBIO-approach, as they may provide additional and more detailed information on the impacts of changes in human activity over time.

7.0 Recommendations

The following recommendations are made with regard to progress and improvements:

1) Finalize an initial global scenario report and develop regional assessments in close collaboration with regional institutions.
2) These reports should integrate and synthesize recent advances in relevant fields.
3) Include specific recommendations for actions on integrated area and development planning, mitigation, and protection worldwide, including detailed assessments of specific regions, for example (but not limited to) the Arctic, the Barents Sea region, the Amazon, the Himalayas, and selected regions of Africa, to cover the variety of political, environmental, social and cultural diversity worldwide.
4) Develop further the pilot methodology, particularly with regard to mapping techniques of already fragmented areas, scenarios and critical levels.
5) Recommend a structure for implementation worldwide, including the establishment of expert working groups on mapping, policymaking and key-topics.

8.0 Conclusions

Most of the current environmental problems are the results of excessive human impacts on 10-15% of the land area. Arctic land areas with excessive human impacts (reduced abundance of flora

When infrastructure, such as roads, is established for whatever purpose, areas have historically sooner or later been opened up to industrial development, such as mining. In many parts of the world, roads are often built for industrial purposes directly, but followed by secondary, more uncontrolled immigration, deforestation, illegal hunting etc., thereby producing considerable unforeseen indirect impacts.

and fauna) may increase from 15-20% to 50-90% within 50 years. This will most likely result in a substantial increase in environmental problems related to habitats, biodiversity, food production, and health in 2050. This development will threaten the cultural identity of many indigenous people in these regions.

These problems are not specific for the Arctic, but can be recognized across the world. The approach used in this Arctic case study can be applied at all scales and in any part of the world at low costs.

GLOBIO provides an inexpensive, yet effective and scientifically based communication tool that can provide the international community with overviews of not only current, but also coming environmental threats. Such simple and easily comprehended overviews can then be used and implemented at all scales, either as a common platform in multi-layer assessments, or for integrated area and development planning. Perhaps among the most important potentials of GLOBIO is the link between infrastructure and associated impacts, such as waste, pollution and water and land degradation at local and regional scales, which are often difficult and costly to assess, and even more difficult to predict with conventional approaches.

The methodology developed in this report can link future conditions of air, water, land, and people to a common platform, namely infrastructure. Continued uncontrolled growth in human resource utilization with associated environmental risks is most vividly viewed by the growth of infrastructure. The largest potential of GLOBIO, therefore, lies in communicating scientific evidence of human impacts in a format suitable for policymaking and international agreements to ensure sustainable development.

9.0 References

1) Ahlstrand, G.M. and Racine, C.H. 1993. Response of an Alaska, U.S.A., shrub-tussock community to selected all-terrain vehicle use. Arctic and Alpine Research 25: 142-149.

2) Ahlund, M. and Gotmark, F. 1989. Gull predation on eider ducklings *Somateria mollissima*: effects of human disturbance. Biological Conservation 48: 115-127.

3) Alvo, R. 1981. Marsh nesting of common loons *Gavia immer*. Canadian Field Naturalist 95: 357.

4) Andersen, R., Linnell, J. D. C., and Langvatn, R. 1996. Short term behavioural and physiological response of moose *Alces alces* to military disturbance in Norway. Biological Conservation 77: 169-176.

5) Anderson, A.P., Lindberg, P., Nilsson, S.G., and Petersson, A. 1980. Breeding success of the black-throated diver *Gavia arctica* in Swedish lakes. Vår Fågelvarld 39: 85-94.

6) Anderson, D.W. 1988. Dose response relationship between human disturbance and brown pelican breeding success. Wildlife Society Bulletin 16: 339-345.

7) Anderson, D.W., and Keith, J.O. 1980. The human influence on seabird nesting success: Conservation implications. Biological Conservation 18: 65-80.

8) Andreassen, H. P., Ims, R. A., and Steinset, O. K. 1996. Discontinuous habitat corridors. Effects on male root vole movements. Journal of Applied Ecology 33: 555-560.

9) Andrews, A. 1990. Fragmentation of habitat by roads and utility corrdiors: A review. Australian Zoologist 26: 130-141.

10) Andreyashkina, N.I. and Peshkova, N.V. 1997. Comparative analysis of plant communities reactions on off-road vehicles impact. Botanical Journal. 82.2:97-103.

11) Anthony, R.G., and Isaacs, F. B. 1989. Characteristics of bald eagle nest sites in Oregon. Journal of Wildlife Management 53: 148-159.

12) Apeldoorn, R. C., Oostenbrink, W T., van Winden, A., and van der Zee, F. F. 1992. Effects of habitat fragmentation on the bank vole, *Clethrionomys glareolus*, in an agricultural landscape. Oikos 65: 265-274.

13) Auerbach, N.A., M.D. Walker and D.A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. Ecological Applications 7: 218-235.

14) Barnes, R.F.W. 1996. The conflict between humans and elephants in the central African forests. Mammal Review 26: 67-80.

15) Barnes, R.F.W. 1999. Is there a future for elephants in West Africa? Mammal Review 29: 175-199.

16) Barnes, R.F.W., Barnes, K.L., Alers, M.P.T., and Blom, A. 1991. Man determines the distribution of elephants in the rain forests of northeastern Gabon. African Journal of Ecology 29: 54-63.

17) Bell, D.V. and Austin, L.W. 1985. The game-fishing season and its effects on overwintering wildfowl. Biological Conservation 33: 65-80.

18) Berger, T.R. 1977. Northern Frontier, Northern Homeland – The report of the Mackenzie Valley Pipeline Inquiry, vol 1 & 2, Toronto: Minister of Supply & Services Canada with James Lorimer & Company.

19) Berkes, F. and C. Folke (1998). Linking social and ecological systems for resiliance and sustainability. Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience. F. Berkes and C. Folke. Cambridge, Cambridge Universtiy Press.

20) Boellstorf, D.E., Anderson, D.W., Ohlendorf, H.M., and O'Neill, E.J. 1988. Reproductive effects of nest-marking studies in an American white pelican colony. Colonial Waterbirds 11: 215-219.

21) Boinski, S., and Sirot, L. 1997. Uncertain conservation status of squirrel monkeys in Costa Rica, *Saimiri oerstedi oerstedi* and *Saimiri oerstedi citrinellus*. Folia Primatologica 68: 181-193.

22) Brocke, R.H., O'Pezio, J.P., and Gustafson, K.A. 1988. A forest management scheme mitigating impact of road networks on sensitive wildlife species. Paper presented at the Convention of the Society of American Foresters at Rochester, NY, October 16-19, 1988.

23) Brody, A.J., and Pelton, M.R. 1989. Effects of

roads on black bear movements in western North Carolina. Wildlife Society Bulletin 17: 5-10.

24) Buckingham, CA, Lefebvre, LW, Schaefer, JM, and Kochman, HI. 1999. Manatee response to boating activity in a thermal refuge. Wildlife Society Bulletin 27: 514-522.

25) Buckley, P.A., and Buckley, F.G. 1975. The significance of dredge spoil islands to colonially nesting waterbirds in certain national parks. In Proceedings of a Conference on Management of Dredge Islands in North Carolina Estuaries. J. Parnell and R. Soots, eds, p. 35. Raleigh, North Carolina: North Carolina State University Sea Grant Publications.

26) Buick, A.M., and Paton, D.C. 1989. Impact of off-road vehicles on the nesting success of hooded plovers Charadrius ruficollis in the Coorong Region of South Australia. Emu 89: 159-172.

27) Bundy, C. 1979. Breeding and feeding observations on the Black-throated diver. Bird Study 26: 33-36.

28) Burch, Jr. E. 1972. The Caribou/wild Reindeer as a Human Resource. American Antiquity Vol. 37, No. 3, 1927. 339-368.

29) Burch, Jr. E. 1998. The Inupiaq Eskimo Nations of Northwest Alaska, University of Alaska Press, Fairbanks

30) Burger, J. 1988. Effects of demolition and beach clean-up operations on birds on a coastal mudflat in New Jersey, USA. Estuarine, Coastal and Shelf Science 27: 95-108.

31) Burger, J. and Gochfeld, M. 1990. Nest site selection in least terns (*Sterna antillarum*) in New Jersey and New York. Colonial Waterbirds 13: 31-40.

32) Burger, J. and Shisler, J.K. 1979. The immediate effects of ditching a saltmarsh on nesting herring gulls Larus argentatus. Biological Conservation 15: 85-103.

33) Burton, N. H. K., Evans, P. R., and Robinson, M. A. 1996. Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artifical island at hartlepool, Cleveland. Biological Conservation 77: 193-201.

34) Cairns, D. 1980. Nesting density, habitat structure and human disturbance as factors in black guillemot reproduction. Wilson Bulletin 92: 352-361.

35) Cameron, R. D., Reed, D. J., Dau, J. R., and Smith, W. T. 1992. Redistribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. Arctic 45: 338-342.

36) Cameron, R. D., and Ver Hoef, J. M. 1996. Declining abundance of calving caribou in an arctic oil field complex. In Northwest Section Meeting, The Wildlife Society, 29-31 March 1996, Banff, Alberta (Abstract).

37) Cameron, R. D., Whitten, K. R., Smith, W. T., and Roby, D. D. 1979. Caribou distribution and group composition associated with construction of the Trans-Alaska Pipeline. Can. Field-Nat. 93(2): 155-162.

38) Caro, T.M., Pelkey, N., Borner, M., Campbell, K.L.I., Woodworth, B.L., Farm, B.P., Ole Kuwai, J., Huish, S.A., and Severre, E.L.M. 1998. Consequences of different forms of conservation for large mammals in Tanzania: preliminary analyses. African Journal of Ecology 36: 303-320.

39) Catterall, C. P., Kingston, M. B., Park, K., and Sewell, S. 1998. Deforestation, urbanisation and seasonability: Interacting effects on a regional bird assemblage. Biol. Conserv. 84: 65-81.

40) Chandler, S.K., Fraser, J.D., Buehler, D.A., and Seegar, J.K.D. 1995. Perch trees and shoreline development as predictors of bald eagle distribution on Chesapeake Bay. Journal of Wildlife Management 59: 325-332.

41) Chatuverdi, S. 1996. The Polar Regions: A Political Geography. Wiley; Chicester.

42) Cocklin, C., Parker, S., and Hay, J. 1992. Notes on cumulative environmental change I: Concepts and issues. J. Environm. Manage. 35: 31-49.

43) Cole, E.K., Pope, M.D., and Anthony, R.G. 1997. Effects of road management on movement and survival of Roosevelt elk. Journal of Wildlife Management 61: 1115-1126.

44) Coleman, J.S., and Fraser, J.D. 1989. Habitat use and home ranges of black and turkey vultures. Journal of Wildlife Management 53: 782-792.

45) Cowardin, L.M., Gilmer, D.S., and Shaiffer, C.W. 1985. Mallard recruitment in the agricultural environment of North Dakota. Wildlife Monographs 92: 1-37.

46) Cronin, M.A., Amstrup, S.C., Durner, G.M., Noel, L.E., McDonald, T.L., and Ballard, W.B. 1998a. Carbou distribution during the post-calving period in relation to infrastructure in the Prudhoe Bay Oil Field, Alaska. Arctic 51: 85-93.

47) Cronin, M. A., Ballard, W. B., Bryan, J. D., Pierson, B. J., and McKendrich, J. D. 1998b. Northern Alaskan oil fields and caribou: A commentary. Biological Conservation 83: 195-208.

48) Cryer, M., Linley, N.W., Ward, R.M., Stratford, J.O., and Anderson, P.F. 1987. Disturbance of overwintering wildfowl by anglers at two reservoir sites in south Wales. Bird Study 34: 191-199.

49) Dau, J. R., and Cameron, R. D. 1986. Effects of a road system on caribou distribution during calving. Rangifer Spec. Iss. No. 1., pp. 95-101.

50) de Roos, G.T. and Schaafsma, W. 1981. Is recreation affecdting the number of breeding bird's nests? Statistica Neerlandica 85: 69-90.

51) Dobrinsky, L.N. 1990. Ecological situation at the North in connection with off-road vehicles using in permafrost landscapes. In: Technic and economic questions of creation technique for the Far

52) North. Moskow, pp. 127-132.

53) Elzinga, A., and Bohlin, I. 1989. The politics of science in polar regions. Ambio 1: 71-76.

54) Fancy, S. G. 1983. Movement and activity budgets of caribou near oil drilling sites in the Saganavirktok River floodplain, Alaska. Arctic 36: 193-197.

55) Fetterholf, P.M. 1983. Effects of investigator activity on ring-billed gull *Larus delawarensis* behaviour and reproductive performance. Wilson Bulletin 95: 23-41.

56) Findlay, C.S., and Houlahan, J. 1997. Anthropogenic correlates of species richness in southeastern Ontario wetlands. Conservation Biology 11: 1000-1009.

57) Flemming, S.P., Chiasson, R.D., Smith, P.C., Austin-Smith, P., and Bancroft, R.P. 1988. Piping plover status in Nova Scotia related to its reproductive and behavioral responses to human disturbance. Journal of Field Ornothology 59: 321-330.

58) Forbes, B.C., 1992. Tundra disturbance studies. I. Long-term effects of vehicles on species richness and biomass. Environm. Conserv. 19:48-58.

59) Forbes, B. C. 1993. Aspects of natural recovery of soils, hydrology and vegetation at an abandoned high arctic settlement, Baffin Island, Canada. Pages 176-181 in Proceedings 6th International Conference on Permafrost, Vol. 1. South China Institute of Technology Press, Beijing.

60) Forbes, B. C. 1995a. Tundra disturbance studies. III. Short-term effects of aeolian sand and dust, Yamal Region, Northwest Siberia, Russia. Environmental Conservation 22:335-344.

61) Forbes, B.C. 1995b. Effects of surface disturbance on the movement of native and exotic plants under a changing climate. In: T.V. Callaghan (ed.) Global Change and Arctic Terrestrial Ecosystems. Ecosystems Research Report 10, European Commission, Brussels, pp. 209-219.

62) Forbes, B. C. 1997. Tundra disturbance studies. IV. Species establishment on anthropogenic primary surfaces, Yamal Peninsula, Northwest Siberia, Russia. Polar Geography 21:79-100.

63) Forbes, B. C. 1998. Cumulative impacts of vehicle traffic on high arctic tundra: soil temperature, plant biomass, species richness and mineral nutrition. Nordicana 57:269-274.

64) Forbes, B.C. 1999. Reindeer herding and petroleum development on Poluostrov Yamal: sustainable or mutually incompatible uses? Polar Record 35:317-322.

65) Forbes, B. C., and R. L. Jefferies. 1999. Revegetation in arctic landscapes: constraints and applications. Biological Conservation 88:15-24.

66) Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14: 31-35.

67) Forman, R. T. T. and Alexander, L. E. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

68) Forman, R.T.T., and Deblinger, R.D. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. Conservation Biology

14: 36-46.

69) Forman, R. T. T. and Hersperger, A. M. 1996. Road ecology and road density in different landscapes, with international planning and mitigation measures. Pages 1-22 in “Trends in adressing tranportation related widlife mortality”. Evink, G. L., Garrett, P., Zeigler, D. And berry, J., eds. Florida Dept. of Transportation, Tallahassee, Florida.

70) Fox, A. D., and Madsen J. 1997. Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: Implications for refuge design. J. Appl. Ecol. 34: 1-13.

71) Fraser, J.D., Frenzel, L.D., and Mathisen, J.E. 1985. The impact of human activities on breeding bald eagles in north-central Minnesota. Journal of Wildlife Management 49: 585-592.

72) Fuller, T.K., Berg, W.E., Radde, G.L., Lenarz, M.S., Joselyn, G.B. 1992. A history and current estimate of wolf distribution and numbers in Minnesota. Wildlife Society Bulletin 20: 42-55.

73) Glue, D.E. 1971. Saltmarsh reclamation stages and their associated bird life. Bird Study 18: 187-198.

74) Golovatin, M.G., Dobrinsky, N.L., Korytin, N.S., Paskhalny, S.P., Sosin, V.F., Shtro, V.G. 1997. Land vertebrates. Pp.153-177 in: Dobrinsky, L.N. (ed.) Monitoring of the biota of the Yamal peninsula in relation to the development of facilities for gas extraction and transportation. Ekaterinburg: The URC "AeroCosmoEcology" Press, 191 p. (in Russian).

75) Green, RE, Tyler, GA, and Bowden, CGR. 2000. Habitat selection, ranging behaviour and diet of the stone curlew (Burhinus oedicnemus) in southern England. Journal of Zoology 250, 161-183.

76) Gotmark, F. 1989. Effekter av friluftsliv på fågelfaunan: en kunskapsöversikt. Rapport 3682. Statens naturvardverk, Solna, Sweden.

77) Griffiths, F., and Young, O. R. 1990. Protecting the Arctic’s environment. Working group on Arctic international relations, Third session, Moscow and Murmansk, USSR, Jan. 22-27, 1990, 34 pp.

78) Griffiths, M., and Van Schaik, C.P. 1993. The impact of human traffic on the abundance and activity periods of Sumatran rain forest wildlife. Conservation Biology 7: 623-626.

79) Hall, C. M. & Johnston, M. E. (eds.) 1995. Polar Tourism: Tourism in the Arctic and Antarctic Regions. Wiley; Chicester.

80) Halme, E., and Niemela, J. 1993. Carabid beetles in fragments of coniferous forest. Annales Zoologici Fennici 30: 17-30.

81) Hannah, L., Lohse, D., Hutchinson, C., Carr, J. L., and Lankerani, A. 1994. A preliminary inventory of human disturbance of world ecosystems. Ambio 23: 246-250.

82) Hanski, I., Kuussaari, M., and Nieminen, M. 1994. Metapopulation structure and migration in the butterfly Meliataea cinxia. Ecology 75: 747-762.

83) Hanski, I., Pakkala, T., Kuussaari, M. and Lei, G. 1995. Metapopulation persistence of an endangered butterfly in a fragmented landscape. Oikos 72: 21-28.

84) Hanson, W. C. 1981. Caribou (Rangifer tarandus) encounters with pipelines in Northern Alaska. Can. Field-Nat. 95: 57-62.

85) Harrington, F. H., and Veitch, A. M. 1991. Short-term impacts of low-level jet fighter training on caribou in Labrador. Arctic 44(4): 318-327.

86) Haworth, P.F. and Thompson, D.B.A. 1990. Factors associated with the breeding distribution of upland birds in the South Pennines, England. Journal of Applied Ecology 27: 562-577.

87) Heimberger, M., Euler, D., and Barr, J. 1983. The impact of cottage development on common loon Gavia immer reproductive success in central Ontario, Canada. Wilson Bulletin 95: 431-439.

88) Helle, T., and Särkelä, M. 1993. The effects of outdoor recreation on range use by semi-domesticated reindeer. Scan. J. For. Res. 8: 123-133.

89) Henderson, M. T., merriam, G., and Wegner, J. 1985. Patchy environments and species survival: Chipmunks in an agricultural landscape. Biological Conservation 31: 95-105.

90) Henry D. J. and E. Husby E. 1995. Wilderness Quality Mapping in the Euro-Arctic Barents Region: A Potential Management Tool. ESRI Users Conference Proceedings, Redlands.

91) Hill, D., Hockin, D., Price, D., Tucker, G., Morris, R., and Treweek, J. 1997. Bird disturbance:

improving the quality and utility of disturbance research. Journal of Applied Ecology 34: 275-288.

92) Hill, G. and Rosier, J. 1989. Wedgtailed shearwaters, white capped noddies and tourist development on Heron Island, Great Barrier Reef Marine Park. Journal of Environmental Management 29: 107-114.

93) Hobson, K.A., Knapton, R.W., and Lysack, W. 1989. Population, diet and reproductive success of double-crested cormorants breeding on Lake Winnipeg, Manitoba, Canada, in 1987. Colonial Waterbirds 12: 191-197.

94) Hockin, D., Ounsted, M., Gorman, M., Keller, V., and Barker, M. A. 1992. Examination of the effects of disturbance of birds with reference to its importance in ecological assessments. J. Environm. Manage. 36: 253-286.

95) Horejsi, B. L. 1981. Behavioral response of barren ground caribou to a moving vehicle. Arctic 34(2): 180-185.

96) Hubner, T. and Putzer, D. 1985. Störungsökologische Untersuchungen rastender Kormorane an niederrheinischen Kiesseen bei Storungen durch Kiestransport, Segel-Surf- und Angelsport. Seevogel, Vol. 6, pp. 122-126. Sonderband: Festschrift Vauk.

97) Husby E., and Henry D. J. 1995. Wilderness Mapping in the Euro-Arctic Barents Region, in Northern Wilderness Areas: Ecology, Sustainability, Values, Anna-Liisa Sippola et al. (eds.). Arctic Centre Publications 7. Arctic Centre, University of Lapland, Rovaniemi. ISBN: 951-634-456-9

98) Ims, R. A., Rolstad, J., and Wegge, P. 1993. Predicting space use responses to habitat fragmentation: Can voles *Microtus oeconomus* serve as an experimental model system (EMS) for capercaille grouse *Tetrao urogallus* in boreal forest. Biological Conservation 63: 261-268.

99) Ivanov, I. 1999. The Northern Sea Route tariff system – present practice and future requirements – the ARCDEV experience. P. 77 in The Northern Sea Route User Conference Oslo 18-20 November 1999 – Executive Summaries. The Fridtjof Nansen Insititute, P.O.Box 326, 1326 Lysaker, Norway. 136 pp.

100) Jackson, L. J. and Thacker, P.T. (Eds). 1997. Caribou and Reindeer Hunters of the Northern Hemisphere. Aldershoot, Avebury.

101) Jeffery, R.G. 1987. Influence of human disturbance on the nesting success of African black oystercatchers. South African Journal of Wildlife Research 17: 71-72.

102) Jensen, W. F., Fuller, T. K., and Robinson, W. L. 1986. Wolf (*Canis lupus*) distribution on the Ontario-Michigan border near Sault Ste. Marie. Canadian Field-Naturalist 100: 363-366.

103) Joensen, A.H. 1973. The breeding of the eider (*Somateria mollissima*) in Denmark. Danske Viltundersøgelser 20: 5-36.

104) Joensen, A.H. and Madsen, J. 1985. Waterfowl and raptors wintering in wetland of western Greece. Natur Jutlandica 21: 169-200.

105) Käkönen, J. (ed.) 1993. Politics and Sustainable Growth in the Arctic, Aldershot; Darthmouth.

106) Kaltenborn, B. P. 1999. Setting preferences of Arctic tourists: a study of some assumptions in the recreation opportunity spectrum framework from the Svalbard Archipelago. Norsk geografisk Tidsskrift, Vol. 53, 45-55

107) Kaltenborn, B. P. & Hindrum R. 1996 Opportunities and problems associated with the development of Arctic tourism. A report prepared for the Arctic Environmental Protection Strategy (AEPS). Task Force on Sustainable Development and Utilization. DN-notat 1996-1.

108) Keller, V. 1989. Variations in the response of great crested grebes *Podiceps cristatus* to human disturbance – a sign of adaption? Biological Conservation 49: 31-45.

109) Keller, V.E. 1990. The effect of disturbance from roads on the distribution of feeding sites of geese (*Anser brachyrhynchus, A. anser*) wintering in north-east Scotland. Ardea 79: 228-231.

110) Khitun, O., 1997. Self-recovery after technogenic and natural disturbances in the central part of the Yamal Peninsula (Western Siberian Arctic). Pages 531-562 in R. M. M. Crawford (ed.) Disturbance and Recovery in Arctic Lands: an ecological perspective. Kluwer Academic, Dordrecht.

111) Klein, D. R. 1989: Subsistence hunting. In: Hudson, R.J., K. R. Drew, L. M. Baskin (eds.): Wildlife production systems: economic utilisation of wild ungulates. Pp. 96-111. Cambridge: Cambridge University Press.

112) Klein, D. R. 1991. Caribou in the changing North. Appl. Anim. Behav. Sci., 29: 279-291.

113) Kofinas, G. 1998. The Cost of Power Sharing, University of British Columbia, unpublished Ph.D. Dissertation, Vancouver, B.C.

114) Kofinas. G, Osherenko, G., Klein, D.R., and Forbes, B.C. 2000. Research Planning in the Face of Change, The Human Role in Reindeer Caribou Systems. Polar Research 19(1): 3-21.

115) Korobeynikova, V.P. 1991. Off-road vehicles impact at vegetation of the Far North. In: Rational using and protection of plant cover of the Urals. Sverdlovsk, pp. 79-85.

116) Kotliar, N.B. and Burger, J. 1986. Colony site selection and abandonment by least terns Sterna antillarum in New Jersey, USA. Biological Conservation 37: 1-22.

117) Kruess, A., and Tscharntke, T. 1994. Habitat fragmentation, species loss, and biological-control. Science 264: 1581-1584.

118) Kuck, L., Hompland, G. L., and Merrill, E. H. 1985. Elk calf response to simulated mine disturbance in southeast Idaho. J. Wildl. Manage. 49(3): 751-757.

119) Kury, C.R. and Gochfeld, M. 1975. Human interference and gull predation in cormorant colonies. Biological Conservation 8: 23-34.

120) Lamprecht, R. and Graber, W. 1996. Modeling dry deposition of dust along the Dalton Highway. In: J.F. Reynolds and J.D. Tenhunen (eds.) Landscape function and disturbance in arctic tundra. Springer-Verlag, N.Y., pp. 325-345.

121) Laurila, T. 1989. Nest site selection in the common eider *Somateria mollissima*: Differences between the archipelago zones. Ornis Fennica 66: 100-111.

122) Lawton, J.H., Bignell, D.E., Bolton, B., Bloemers, G.F., Eggleton, P., Hammond, P.M., Hodda, M., Holt, R.D., Larsen, T.B., Mawdsley, N.A., and Stork, N.E. 1998. Biodiversity inventories, indicator taxa and effects orf habitat modification in tropical forest. Nature 391(6662): 72-76

123) Leadley, P.W., Li, H., Ostendorf, B. and Reynolds, J.F. 1996. Road-related disturbances in an arctic watershed: analyses by a spatially explicit model of vegetation and ecosystem processes. In: J.F. Reynolds and J.D. Tenhunen (eds.) Landscape function and disturbance in arctic tundra. Springer-Verlag, N.Y., pp. 387-415.

124) Lehtonen, L. 1970. Zur Biologie des Prachttauchers, Gavia a. arctica. Annales Zoologica Fennici 7: 25-60.

125) Levenson, H. and Koplin, J.R. 1984. Effects of human activity on productivity of nesting ospreys. Journal of Wildlife Management 48: 1374-1377.

126) Levin, M.G. and Potapov, L.P. 1964: The Peoples of Siberia. Chicago, USA.

127) Linnell, JCD, Swenson, JE, Andersen, R, and Barnes, B. 2000. How vulnerable are denning bears to disturbance? Wildlife Soc. Bull. 28: 400-413.

128) Lok, C.M. and Bakker, L. 1988. Seasonal use of feeding grounds by cormorants *Phalacrocorax carbo* at Voorne, Netherlands. Limosa 61: 7-12.

129) Lovallo, M.J., and Anderson, E.M. 1996. Bobcat movements and home ranges relative to rads in Wisconsin. Wildlife Society Bulletin 24: 71-76.

130) Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81: 592-595.

131) Lord, A., Waas, J. R., and Innes, J. 1997. Effects of human activity on the behaviour of Northern New Zealand dotterel *Charadrius obscurus aquilonius* chicks. Biol. Conserv. 82: 15-20.

132) MacArthur, R. A., Geist, V., and Johnston, R. H. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. J. Wildl. Manage. 46(2): 351-358.

133) MacArthur, R. A., Johnston, R. H., and Geist, V. 1979. Factors influencing heart rate in free-ranging bighorn sheep: a physiological approach to the study of wildlife harassment. Can. J. Zool. 57: 2010-2021.

134) Mace, R.D., Waller, J.S., Manley, T.L., Lyon, L.J., and Zuuring, H. 1996. Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33: 1395-1404.

135) MacInnes, C.D. and Misra, R.K. 1972.

Predation on canada goose nests at McConnell river, Northwest Territories. Journal of Wildlife Management 36: 414-422.

136) Madsen, J. 1985. Impact of disturbance on field utilisation of pink-footed geese in west Jutland, Denmark. Biological Conservation 33: 53-63.

137) Magomedova, M.A., Bolshakov, V.N, Bogdanov, V.D., Dobrinsky, L.N., Zhigalsky, O.A., Korytin, N.C., Kryazhimsky, F.V., and Morozova, L.M. 1998. Control of biological resources state in connection with industrial development in the Arctic. In: Andreeva, E.N., Getzen, M.V., Getzen, V.V., and Tyupenko, T.I. (eds.) The Arctic Town and Environment. Works of II International Conference, Syktyvkar, pp. 244-257.

138) Magomedova,M.A. and Morozova, L.M. 1997. Vegetation. Pp. 11-99. in: Dobrinsky, L.N. (ed.) Monitoring of the biota of the Yamal peninsula in relation to the development of facilities for gas extraction and transportation. Ekaterinburg: The URC "AeroCosmoEcology" Press, 191 p. (in Russian).

139) Maki, A. 1992. Of measured risks: the environmental impacts of the Prudhoe Bay, Alaska, oilfield. Environ. Toxicol. Chem. 11: 1691-1707.

140) Matushenko, N.I. 1999. What can we offer? Russia is optimistic about the future of the Northern Sea Route. P. 33 in The Northern Sea Route User Conference Oslo 18-20 November 1999 – Executive Summaries. The Fridtjof Nansen Insititute, P.O.Box 326, 1326 Lysaker, Norway. 136 pp.

141) McLellan, B.N., and Shackleton, D.M. 1988. Grizzly bears and resource-extraction industries: Effects of roads on behaviour, habitat use and demography. Journal of Applied Ecology 25: 451-460.

142) Mech, L. D. 1989. Wolf population survival in an area of high road density. American Midland Naturalist 121: 387-389.

143) Miquet, A. 1988. Effets du derangement hivernal sur les depacements et al reproduction du Tetras lyre (*Tetrao tetrix*). Gibier Faunce Sauvage 5: 321-330.

144) Mlandenoff, D.J., Sickley, T.A., and Wydeven, A.P. 1999. Predicting gray wolf landscape recolonization: Logistic regression models vs. new field data. Ecological Applications 9: 37-44.

145) Moij, J.H. 1982. Die Auswirkungen von Strassen auf die Avifauna einer offenen Landschaft am Unteren Niederrhein (Nordrhein-Wastfalen), untersucht am Verhalten von Wildgänsen. Charadrius 18: 73-92.

146) Morozova, L.M., Magomedova, M.A. and Stepanova, A.V. 1995. Techogenic transformation of Arctic tundra at the Yamal peninsula. In: State of plant cover and animals of the Yamal peninsula. Ekaterinburg: UIF"Nauka" Publishers, pp. 3-17.

147) Murphy, S. M., and Curatolo, J. A. 1987. Activity budgets and movement rates of caribou encountering pipelines, roads, and traffic in northern Alaska. Can. J. Zool. 65: 2483-2490.

148) Nellemann, C., and Cameron, R. D. 1996. Effects of petroleum development on terrain preferences of calving caribou. Arctic 49: 23-28.

149) Nellemann, C., and Cameron, R. D. 1998. Cumulative impacts of an evolving oilfield complex on the distribution of calving caribou. Can. J. Zool. 76: 1425-1430.

150) Nellemann, C., Vistnes, I. Jordhøy, P. and Strand, O. 2001. Winter distribution of wild reindeer in relation to powerlines, roads and resorts. Biological Conservation (in press).

151) Nellemann, C., Jordhøy, P., Støen, O.-G., and Strand, O. 2000. Cumulative impacts of tourist resorts on wild reindeer (*Rangifer tarandus tarandus*) during winter. Arctic 53: 9-17.

152) Newmark, W.D., Boshe, J.I., Sariko, H.I., and Makumbule, G.K. 1996. Effects of a highway on large mammals in Mikumi National Park, Tanzania. African Journal of Ecology 34: 15-31.

153) North, R.N. 1999. Financing of the Northern Sea Route infrastructure: Russian resolve and possible international constributions. P. 119 in The Northern Sea Route User Conference Oslo 18-20 November 1999 – Executive Summaries. The Fridtjof Nansen Insititute, P.O.Box 326, 1326 Lysaker, Norway. 136 pp.

154) Okotetto, M. and Forbes, B. 1999. Conflicts between Yamal-Nenets reindeer husbandry and petroleum development in the forest tundra and tundra region of North-west Siberia. Pp 95-99 in “Proceedings of the timberline workshop”, May 10-11, 1998, Whitehorse, Canada.

155) Ollason, J.C. and Dunnet, G.M. 1980. Nest failures in the fulmar: the effect of observers. Journal of Field Ornithology 51: 39-54.

156) Owen, M., Atkinson-Willes, G.L., and Salmon, D. 1986. Wildfowl in Great Britain. Cambridge: Cambrigde University Press.

157) Owens, N.W. 1977. Responses of wintering brent geese to human disturbance. Wildfowl 28: 5-14.

158) Paine, Robert, 1994, Herds of the Tundra: A Portrait of Saami Reindeer Pastorisim. Smithsonian Institution Press. Washington.

159) Parnell, J. and Soots, R. (eds.) 1975. Proceedings of a conference on management of dredge islands in North Carolina Estuaries. North Carolina State University Sea Grant Publications, Raleigh, USA.

160) Paruk, J.D. 1987. Habitat utilization by bald eagles wintering along the Mississippi River (USA). Transactions of the Illinois State Academy of Science 80: 333-342.

161) Pienkowski, M.W. 1984. Breeding biology and population dynamics of ringed plovers Charadrius hiaticula in Britain and Greenland nest predation as a possible factor limiting distribution and timing of breeding. Journal of Zoology 202: 83-114.

162) Phillips, GE, and Alldredge, AW. 2000. Reproductive success of elk following disturbance by humans during calving season. Journal of Wildlife Management 64: 521-530.

163) Posch, M. de Smet, P. A. M. Hettelingh, J-P. and Downing, R. J. (Eds.): 1995, Calculation and mapping of critical thresholds in Europe. Status report 1995. RIVM-report 259101004.

164) Putzer, D. 1989. Wirkung und Wichtung menschlicher Anwesenheit und Störung am Beispiel bestandsbedrohter, an Feuchtgebiete gebundener Vogelarten. Schriftenreihe für Landschaftspflege und Naturschurz 29: 169-194.

165) Racine, C.H. and Ahlstrand, G.M. 1991. Thaw response of tussock-shrub tundra to experimental all-terrain vehicle disturbances in south-central Alaska. Arctic 44: 31-37.

166) Racine, C.H. and Johnson, L.A. 1988. Effects of all-terrain traffic on tundra vegetation near Anuktuvuk Pass, Alaska. CRREL Special Report 88-17, Hanover, NH, 12 pp.

167) Reicholf, J. 1970. Der Einfluss von Störungen durch Angler auf den Entenbrutbestand auf den Altwassern am Unteren Inn. Vogelwelt 91: 68-72.

168) Reicholf, J. 1975. Der Einfluss von Erholungbetrieb, Angelsport und Jagd auf das Wasservogel-Schutzgebiet am untern Inn und die Möglichkeiten und Chancen zur Steuerung der Entwicklung. Schriftenreihe für Landschaftspflege und Naturschutz 12: 109-116.

169) Reijnen, R. and Foppen, R. 1994. The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. J. Of Applied Ecology 31: 85-94.

170) Reijnen, R. Foppen, R., Braak, C. T., and Thissen, J. 1995. The effects of car traffic on breeding bird populations in woodland III. Reduction of density in relation to the proximity of main roads. J. Of Applied Ecology 32: 187-202.

171) Reijnen, R. Foppen, R., and Meeuwsen, H. 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. Biological Conservation 75: 255-260.

172) Reijnen, R. Foppen, R., and Veenbaas, G. 1997. Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. Biodiversity and Conservation 6: 567-581.

173) Richardson, J.R. 1992. Hunting for a balance. National Parks 63 (3-4): 33-39.

174) Richardson, W. J., Finley, K. J., Miller, G. W., Davis, R. A., and Koski, W. R. 1995. Feeding, social and migration behavior of Bowhead whales, *Balaena mysticetus*, in Baffin bay vs the beaufort Sea – regions with different amounts of human activity. Marine Mammal Science 11: 1-45.

175) Robertson, R.J. and Flood, N.J. 1980. Effects of recreational use of shorelines on breeding bird populations. Canadian Field Naturalist 94: 131-138.

176) Robinson, S. K., Thompson, F. R., Donovan, T. M., Whitehead, D. R., and Faaborg, J. R. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267: 1987-1990.

177) Rodgers, J.A., and Smith, H.T. 1997. Buffer zone distances to protect foraging and leafing

waterbirds from human disturbance in Florida. Wildlife Society Bulletin 25: 139-145.

178) Rolstad, J., and Wegge, P. 1989. *Capercaille Tetrao urogallus* populations and modern forestry – a case for landscape ecological studies. Finnish Game Res. 46: 43-52.

179) Ross, C., and Srivastava, A. 1994. Factors influencing the population-density of the Hanuman langur (*Presbytis-entellus*) in Sariska Tiger Reserve. Primates 35: 361-367.

180) Rost, G.R. and Bailey, J. A. 1979. Distribution of mule deer and elk in relation to roads. Jorunal of Wildlife Management 43: 634-641.

181) Russell, Don, Gary Kofinas, Brad Griffith, 2000. Need and Opportunity for a North American Caribou Knowledge Cooperative. Forthcoming in Polar Research 19(1).

182) Rottenborn, S.C. 1999. Predicting the impacts of urbanization on riparian bird communities. Biological Conservation 88: 289-299.

183) Safina, C. and Burger, J. 1983. Effects of human disturbance on reproductive success in the black skimmer. Condor 85: 164-171.

184) Saville, N. M., Dramstad, W. E., Fry, G. L. A., and Corbet, S. A. 1997. Bumblebee movement in a fragmented agricultural landscape. Agriculture, ecosystems and Environment: 61: 145-154.

185) Scott, D.K. 1980. The behaviour of Bewick's swans at the Welney Wildfowl Refuge, Norfolk, and on the surrounding fens: a comparison. Wildfowl 31: 5-18.

186) Sorley, C.S., and Andersen, D.E. 1994. Raptor abundance in south-central Kenya in relation to land-use patterns. African Journal of Ecology 32: 30-38.

187) Spiess, A.E. 1979. Reindeer and Caribou Hunters. An archaeological Study. New York.

188) Stalmaster, M.V. and Newman, J.R. 1978. Behavioural responses of wintering bald eagles to human activity. Journal of Wildlife Management 42: 506-513.

189) Storey, A.E. 1987. Adaptions for marsh nesting in common and Forster's terns. Canadian Journal of Zoology 65: 1417-1420.

190) Strauss, E. and Dane, B. 1989. Differential reproductive success in a stressed population of piping plovers in areas of high and low human disturbance. American Zoologist 29: 42A

191) ten Brink, B. 2000. Biodiversity indicators for the OECD Environmental Outlook and Strategy – A feasibility study. RIVM-report 402001014, Bilthoven, The Netherlands.

192) Thiel, R. P. 1985. Relationship between road densities and wolf habitat suitability in Wisconsin. The American Midland Naturalist 113: 404-407.

193) Tremblay, J. and Ellison, L.N. 1979. Effects of human disturbance on breeding of black-crowned night herons. Auk 96: 364-369.

194) Trombulak, S.C., and Frissell, C.A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14: 18-30.

195) Tuite, C.H. 1981. The impact of water-based recreation on the waterfowl of enclosed inland waters in Britain. A report to the Sports Council and the Nature Conservancy Council. Slimbridge, U.K.: The Wildfowl Trust, Nature Conservancy Council and Sports Council.

196) Tuite, C.H., Hanson, P.R., and Owen, M. 1984. Some ecological factors affecting winter wildfowl distribution on inland waters in England and Wales, and the influence of water-based recreation. Journal of Applied Ecology 21: 41-62.

197) Tuite, C.H., Owen, M., and Paynter, D. 1983. Interaction between wildfowl and recreation at Liangorse Lake and Talybont Reservoir, South Wales. Wildfowl 34: 48-63.

198) Tyler, N. J. C. 1991. Short-term behavioural responses of Svalbard reindeer *Rangifer tarandus platyrhynchus* to direct provocation by a snowmobile. Biol. Conserv. 56: 179-194.

199) van Daele and van Daele, H.A. 1982. Factors affecting the productivity of ospreys *Pandion haliaetus* nesting in west central Idaho, USA. Condor 84: 292-299.

200) van der Zande, A.N., Berkhuizen, J.C., van Latesteijn, H.C., Ter Keurs, W.J., and Poppelaars, A.J. 1984. Impact of outdoor recreation on the density of a number of breeding bird species in woods adjacent to urban residential areas. Bio-

logical Conservation 30: 1-39.

201) van der Zande, A.N., TerKeurs, W.J., and van der Weijden, W.J. 1980. The impact of roads on the densities of four bird species in an open field habitat – evidence of a long-distance effect. Biological Conservation 18: 299-321.

202) van der Zande, A.N. and Verstrael, T.J. 1985. Impacts of outdoor recreation upon nest-site choice and breeding success of the kestrel *Falco tinnunculus*. Ardea 73: 90-98.

203) Van Dyke, F. B., Brocke, R. H., Shaw, H. G. 1986a. Use of road track counts as indicies of mountain lion presence. Journal of Wildlife Management 50: 102-109.

204) Van Dyke, F. B., Brocke, R. H., Shaw, H. G., Ackerman, B. B., Hemker, T. P., and Lindzey, F. G. 1986b. Reactions to mountain lions to logging and human activity. Journal of Wildlife Management 50: 95-102.

205) Vance, G. & Tyler, N (eds.) 1995. Arctic Wilderness. The 5th Wordl Wilderness Congress, 342 pp. North American Press, Golden Colorado.

206) Verbeek, N.A.M. 1982. Egg predation by north western crows: its association with human and bald eagle activity. Auk 99: 347-352.

207) Verlinden, A. 1997. Human settlements and wildlife distribution in the southern Kalahari of Botswana. Biol. Conserv. 82: 129-136.

208) Vermeer, K. 1973. Some aspects of the nesting requirements of the common loons in Alberta. Wilson Bulletin 85: 429-435.

209) Vilchek, G. E. and Bykova, O. Y., 1992: The origin of regional ecological problems within the northern Tyumen Oblast, Russia. Arctic and Alpine Research, 24: 99-107.

210) Vistnes, I. and Nellemann, C. 2001. Avoidance of cabins and power transmission lines by semi-domesticated reindeer during calving. Journal of Wildlife Management.

211) Voigt, D. R., and Broadfoot, J. D. 1995. Effects of cottage development on white-tailed deer, *Odocoileus virginianus*, winter habitat on Lake Muskoka, Ontario. Can. Field-Nat. 109(2): 201-204.

212) Vos, C.C., and Chardon, J.P. 1998. Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. Journal of Applied Ecology 35: 44-56.

213) Walker, D. A., Webber, P. J., Binnian, E. F., Everett, K. R., Lederer, N. D., Nordstrand, E. A., and Walker, M. D. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. Science 23: 757-761.

214) Ward, D.H., Stehn, R.A., Ericksson, W.P., and Derksen, D.V. 1999. Response of fall-staging brant and Canada geese to aircraft overflights in southwestern Alaska. Journal of Wildlife Management 63: 373-381.

215) Watson, A. 1988. Decline of shore waders at loch Morlich, U.K. Scottish Birds 15: 91-92.

216) Weisenberger, M. E., Krausman, P. R., Wallace, M. C., De Young, D. W., and Maughan, O. E. 1996. Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. J. Wildl. Manage. 60: 52-61.

217) Whitten, K. R., and Cameron, R. D. 1983a. Distribution of caribou calving in relation to the Prudhoe Bay Oil Field. In Caribou and human activity. Proceedings of the 1st North American Caribou Workshop, Whitehorse, Yukon, 28-29 Sept. 1983. Edited by A. M. Martell and D. E. Russell. Canadian Wildlife Service, pp. 35-39.

218) Whitten, K. R., and Cameron, R. D. 1983b. Movements of collared caribou, *Rangifer tarandus*, in relation to petroleum development on the Arctic Slope of Alaska. Can. Field-Nat. 97(2): 143-146.

219) Winkelman, J.E. 1989. Birds and the wind park near Urk: collisions, victims and disturbance of ducks, geese and swans. Report of Research Insititute of Nature Management 89/15. Netherlands.

220) Witt, H.H. 1984. Dichte, Diversität und Aequitat von Seevogelgemeinschaften im Mittelmeeraum und die sie beeinflussenden Faktoren. Oekologia Vogel 6: 131-139.

221) Yefimenko, A.A. 1999. The Arctic environment and the indigenous peoples. P. 121 in The Northern Sea Route User Conference Oslo 18-20 November 1999 – Executive Summaries. The Fridtjof Nansen Institute, P.O.Box 326, 1326 Lysaker, Norway. 136 pp.

10.0 Appendix 1 Examples of impacts from infrastructure

This appendix does not provide a complete review of disturbance studies on wildlife from infrastructure, harbors etc., but gives a range of studies and impact zones to show the variety of impacts. *Avoidance* includes significantly lower species densities in areas close to disturbance than in areas not disturbed, and long-term shifts in distribution after development compared to before development. Zone affected (meters away from source of disturbance) is given if this was measured.

Marine mammals

Species	Type of disturbance	Estimated effect	References
Manatee *(Trichechus manatus latirostris)*	Recreational boating	Distribution patterns changed/avoidance	Buckingham et al. 1999
Bowhead whale *(Balaena mysticetus)*	Human activity on sea	Changes in behavior in disturbed sea	Richardson et al. 1995

Primates

Species	Type of disturbance	Estimated effect	References
Squirrel monkey *(Saimiri oerstedi)*	Tourism, deforestation, developments	Near extinction outside of national parks	Boinski and Sirot 1997
Cercopithecus mitis	Logging	Decline in population, also decades after logging	Chapman et al. 2000
Cercopithecus ascanius	Logging	Decline in population, also decades after logging	Chapman et al. 2000
Procolobus tephrosceles	Logging	Decline in population, slow recovery after logging	Chapman et al. 2000
Hanuman langur *(Presbytis entellus)*	Grazing of livestock, human activity	Avoidance	Ross and Srivastava 1994

Amphibians and reptiles

Species	Type of disturbance	Estimated effect	References
Moor frog *(Rana arvalis)*	Roads	Decrease in occupied ponds with increase in road density	Vos and Chardon 1998

Insects (only examples, numerous studies available)

Species	**Type of disturbance**	**Estimated effect**	**References**
Carabus glabratus	Deforestation, fragmentation	Confined to contiguous forest	Halme and Niemelä 1993
Carbus violaceus	Deforestation, fragmentation	Confined to contiguous forest	Halme and Niemelä 1993
Cychrus caraboides	Deforestation, fragmentation	Confined to contiguous forest	Halme and Niemelä 1993
Pterostichus nigrita	Deforestation, fragmentation	Confined to contiguous forest	Halme and Niemelä 1993
Meliataea cinxia	Habitat fragmentation	Reduced survival, risk of local extinction	Hanski et al. 1994, 1995
Apion seniculus	Habitat fragmentation	75% reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Apion virens	Habitat fragmentation	75% reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Apion apricans	Habitat fragmentation	Sign. reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Apion assimile	Habitat fragmentation	Sign. reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Apion trifolii	Habitat fragmentation	Sign. reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Lasioptera sp.	Habitat fragmentation	75% reduction in population density in fragmented habitat	Kruess and Tscharntke 1994
Hymenoptera parasitoid species	Habitat fragmentation	Number of parasitoid species reduced from 8-12 to 2-4 in fragmented habitat, releasing pest insects from parasitism	Kruess and Tscharntke 1994

Mammals

Species	Type of disturbance	Estimated effect	References
African elephant *(Loxodonta africana)*	Roads and other development	Local extinction, avoidance of roads 7000 m, avoidance of roads 600 m	Barnes et al. 1991, Newmark et al. 1996, Barnes 1999
Buffalo *(Syncerus caffer)*	Settlements, poaching	Avoidance	Caro et al. 1998
Eland *(Taurotragus oryx)*	Settlements, poaching	Avoidance of settled areas, avoidance 600m of roads	Newmark et al. 1996, Caro et al. 1998
Giraffe *(Giraffa camelopardalis)*	Settlements, poaching	Avoidance	Caro et al. 1998
Hartebeest *(Alcelaphus spp.)*	Settlements, poaching	Avoidance	Caro et al. 1998
Roan antelope *(Hippotragus equinus)*	Settlements, poaching	Avoidance	Caro et al. 1998
Waterbuck *(Kobus ellipsiprymnus)*	Settlements, poaching	Avoidance	Caro et al. 1998
Zebra *(Equus burchelli)*	Settlements, poaching	Avoidance of settled areas, avoidance of roads 200 m	Newmark et al. 1996, Caro et al. 1998
Bushbuck *(Tragelaphus scriptus)*	Settlements, poaching	Avoidance	Caro et al. 1998
Hippopotamus *(Hippopotamus amphibius)*	Settlements, poaching	Avoidance	Caro et al. 1998
Wildebeest *(Connochaetes taurinus)*	Roads	Avoidance 600 m	Newmark et al. 1996
Binturong *(Arctictis binturong)*	Human activity	Avoidance	Griffiths and van Schaik 1993
Barking deer *(Muntiacus muntjak)*	Human activity	Avoidance	Griffiths and van Schaik 1993
Malayan sun bear *(Helarctos malayanus)*	Human activity	Has become nocturnal	Griffiths and van Schaik 1993
Caribou *(Rangifer tarandus)*	Roads and industry	Avoidance, increased predation in remaining habitat	James and StuartSmith 2000
Caribou and reindeer *(Rangifer tarandus)*	Roads, industry and/or tourism	Avoidance 4-10 km from disturbance, followed by a zone of 4-25 km from disturbance with increased/ changed use	Dau and Cameron 1986, Cameron et al. 1992, Helle and Särkelä 1993, Nellemann and Cameron 1996, 1998, Nellemann et al. 2001, Vistnes 2001
Elk *(Cervus elaphus)*	Roads, poaching	Survival negatively correlated with increased accessibility to area	Cole et al. 1997
Elk *(Cervus elaphus)*	Mining	Avoidance	Kuck et al. 1985
Elk *(Cervus canadensis)*	Roads	Avoidance 200 m	Rost and Bailey 1979
Elk *(Cervus elaphus)*	Human traffic on foot	Decreased production	Phillips et al. 2000
Mule deer *(Odocoileus hemionus)*	Roads	Avoidance 200 m	Rost and Bailey 1979
Black bear *(Ursus americanus)*	Roads	Avoidance	Brocke et al. 1988
Brown bear *(Ursus arctos)*, black bear *(Ursus americanus)*, and polar bear *(Ursus maritimus)*	Disturbance of dens by roads, industrial activity	Abandonment of dens, reduced survival	Linnell et al. 2000
Grizzly bear *(Ursus arctos)*	Roads	Avoidance 100 m	McLellan and Shackleton 1988

Mammals (continued)

Species	Type of disturbance	Estimated effect	References
Wolf *(Canis lupus)*	Roads and settlement	Avoidance of areas with road densities exceeding 0.5-0.6 km/km^2	Thiel 1985, Mech et al. 1988, Fuller et al. 1992, Mladenoff et al. 1999
Bobcat *(Lynx rufus)*	Roads		
Mountain lion *(Felis concolor)*	Logging, human activity	Avoidance 100 m	Lovallo and Anderson 1996
		Avoidance of areas <1000 m from logging and with >0.6 km/km2 roads	Van Dyke et al. 1986b

Birds

Species	Type of disturbance	Estimated effect	References
Gaviidae			
Black-throated diver/ Arctic loon *(Gavia arctica)*	Buildings/infrastructure, boating	Lower reproductive success, avoidance	Lehtonen 1970, Bundy 1979, Anderson et al 1980, Gotmark 1989
Great northern diver/ Common loon *(Gavia immer)*	Cottages and other development, boating	Avoidance 150 m, lower hatching and reproductive success	Vermeer 1973, Robertson and Flood 1980, Alvo 1981, Heimberger et al 1983
Podicipedidae			
Great crested grebe *(Podiceps cristatus)*	Boating, angling, walking	Lower hatching success, increased predation of eggs	Keller 1989
Little grebe *(Tachybaptys ruficollis)*	Recreation	Avoidance	Tuite 1981
Procellariiformes			
Northern fulmar *(Fulmarus glacialis)*	Shore-line activities	Lower reproductive success	Ollason and Dunnet 1980.
Pacific shearwater *(Puffinus pacificus)*	Buildings/infrastructure	Avoidance	Hill and Rosier 1989
Pelicanidae			
Brown pelican *(Pelecanus occidentalis californicus)*	Shore-line activities	Increase in nest abandonments, lower reproductive success	Anderson and Keith 1980, Anderson 1988.
White pelican *(Pelecanus erythrorhynchos)*	Shore-line activities	Lower hatching success	Boellstorf et al 1988.
Phalacrocoracidae			
Double-crested cormorant *(Phalacrocorax auritus)*	Human activity	Leave nest, increased predation of eggs and egg losses, lower reproductive success	Kury and Gochfeld 1975, Verbeek 1982, Hobson et al 1989
Great cormorant *(Phalacrocorax carbo)*	Water-based activities	Avoidance	Hubner and Putzer 1985, Lok and Bakker 1988
Ciconiiformes			
Black-crowned night heron *(Nycticorax nycticorax)*	Shore-line activities	Increased predation of eggs and nestling mortality	Tremblay and Ellison 1979
Cygnus			
Bewick's swan *(Cygnus columbianus)*	Shooting	Avoidance, aggregation in undisturbed areas	Scott 1980

Birds (continued)

Species	Type of disturbance	Estimated effect	References
Anser, Branta			
Geese *(Anseriformes)*	Hunting, shore-/water-based activities, wind park	Avoidance	Tuite et al 1983, 1984, Joensen and Madsen 1985, Owen et al 1986, Putzer 1989, Winkelman 1989
White-fronted goose *(Anser albifrons)*	Roads	Avoidance, aggregation in undisturbed areas	Mooij 1982
Pink-footed goose *(Anser brachyrhynchus)*	Roads	Avoidance 100m	Keller 1990
Pink-footed goose *(Anser brachyrhynchus)*	Roads	Avoidance 500m	Madsen 1985
Brent goose *(Branta bernicla)*	Shore-based activities, aircraft	Avoidance	Owens 1977
Canada goose *(Branta canadensis)*	Shore-line activities	Increased predation of eggs	MacInnes and Misra 1972
Anatini, Aythya, Somateria etc.			
Anatidae	Angling	Decline in population	Reicholf 1970, 1975
Common teal *(Anas crecca)*	Recreation	Avoidance	Tuite 1981, Bell and Austin 1985
Northern shoveler *(Anas clypeata)*	Roads	Avoidance 65-320 m, depending on traffic volume	Reijnen et al. 1996
Common pochard *(Aythya ferina)*	Angling	Avoidance	Cryer et al 1987
Wigeon *(Anas penelope)*	Angling	Avoidance	Bell and Austin 1985, Cryer et al 1987
Mallard *(Anas platyrhynchos)*	Angling	Avoidance	Bell and Austin 1985, Cryer et al 1987
Common goldeneye *(Bucephala clangula)*	Recreation	Avoidance	Tuite 1981
Common eider *(Somateria mollissima)*	Shore-line activities	Lower hatching success, increased predation of eggs and young. Avoidance	Joensen 1973, Ahlund and Gotmark 1989, Laurila 1989
Accipitriformes, Falconiformes			
Golden eagle *(Aquila chrysaetos)*	Roads, human activity	Avoidance	Fernandez 1993
Turkey vulture *(Cathartes aura)*	Buildings/infrastructure	Successful nests further from buildings	Coleman and Fraser 1989
Black vulture *(Coragyps atratus)*	Buildings/infrastructure	Successful nests further from buildings	Coleman and Fraser 1989
Common kestrel *(Falco trinnunculus)*	Human activity	Avoidance, lower reproductive success	Van der Zande and Verstrael 1985
Bald eagle *(Haliaeetus leucocephalus)*	Roads, hiking trails, Logging, human activity	Avoidance 1600 m	Anthony and Isaacs 1989
Bald eagle *(Haliaeetus leucocephalus)*	Buildings/infrastructure, human activity	Avoidance	Stalmaster and Newman 1978, Fraser et al 1985, Paruk 1987
Osprey *(Pandion haliaetus)*	Buildings/infrastructure , walking	Lower reproductive success	Van Daele and Van Daele 1982, Levenson and Koplin 1984
Tetraonidae			
Black grouse *(Tetrao tetrix)*	Skiing	Avoidance	Miquet 1988

Birds (continued)

Species	Type of disturbance	Estimated effect	References
Rallidae			
Common coot *(Fulica atra)*	Roads	Avoidance 20-75 m, depending on traffic volume	Reijnen et al. 1996
Common moorhen *(Gallinula chloropus)*	Recreation	Avoidance	Tuite 1981
Charadriidae, Scolopacidae			
Little plover *(Charadrius dubius)*	Angling	Nest failures	Putzer 1989
Ringed plover *(Charadrius hiaticula)*	Shore-line activities	Lower reproductive success	Pienkowski 1984
Piping plover *(Charadrius melodus)*	Shore-line activities, off-road vehicles	Lower hatching and fledging success, higher territory abandonment	Flemming et al 1988, Strauss and Dane 1989
Hooded plover *(Charadrius ruficollis)*	Off-road vehicles	Lower hatching success, nests run over	Buick and Paton 1989
Black oystercatcher *(Haematopus moguini)*	Shore-line activities	Lower reproductive success	Jeffery 1987
Oystercatcher *(Haematopus ostralegus)*	Roads	Avoidance 1700-3530 m, depending on traffic volume	Reijnen et al. 1996
Oystercatcher *(Haematopus ostralegus)*	Human activity	Increase in no. of nests after stopping traffic	De Roos and Schaafsma 1981
Black-tailed godwit *(Limosa limosa)*	Roads	Avoidance 230-930 m, depending on traffic volume	Reijnen et al. 1996
Black-tailed godwit *(Limosa limosa)*	Roads	Avoidance 625-2000m, depending on traffic volume	Van der Zande et al. 1980
Tringa hypoleucus	Unspecified	Avoidance; population decline with increased disturbance, but not at other lakes with no increase in disturbance	Watson 1988a
Redshank *(Tringa totanus)*	Roads	Avoidance, lower nest densities	Van der Zande et al. 1980
Northern lapwing *(Vanellus vanellus)*	Roads	Avoidance 120-560 m, depending on traffic volume	Reijnen et al. 1996
Northern lapwing *(Vanellus vanellus)*	Roads	Avoidance 500-2000m, depending on traffic volume	Van der Zande et al. 1980
Laridae			
Black noddy *(Anous minutus)*	Buildings/infrastructure	Avoidance	Hill and Rosier 1989
Herring gull *(Larus argentatus)*	Buildings/infrastructure	Avoidance	Burger and Shisler 1979
Ring-billed gull *(Larus delawarensis)*	Human activity	Lower hatching and fledging success, increased predation	Fetterholf 1983
Heermanns's gull *(Larus heermanni)*	Walking	Increased predation of eggs and young	Anderson and Keith 1980
Black skimmer *(Rynchops niger)*	Human activity	Lower hatching and fledging success, avoidance	Safina and Burger 1983

Birds (continued)

Species	Type of disturbance	Estimated effect	References
Sternidae			
Least tern *(Sterna antillarum)*	Off-road vehicles, buildings/infrastructure	Lower hatching success, avoidance	Kotliar and Burger 1986, Burger and Gochfeld 1990
Common tern *(Sterna hirundo)*	Buildings/infrastructure	Avoidance	Storey 1987
Alcidae			
Black guillemot *(Cepphus grylle)*	Human activity	Lower hatching and reproductive success	Cairns 1980
Alaudidae			
Sky lark *(Alauda arvensis)*	Roads	Avoidance 100-490 m, depending on traffic volume	Reijnen et al. 1996
Motacillidae			
Meadow pipit *(Anthus pratensis)*	Roads	Avoidance 25-90 m, depending on traffic volume	Reijnen et al. 1996
Sylviidae			
Willow warbler *(Phylloscopus trochilus)*	Roads	Avoidance 200m	Reijnen and Foppen 1994 (part I)
Passeridae			
Sparrows *(Passeriformes)*	Recreation	Significant negative correlation between species density and recreational intensity for 8 of 13 species	Van der Zande et al 1984
Tyrannidae			
Eastern king bird *(Tyrannus tyrannus)*	Shore-/water-based activities	Lower fledging success	Robertson and Flood 1980
Studies of several species			
Geese, cranes, falcons, plovers, sparrows *(Anseriformes, Gruiformes, Falconiformes, Charadriiformes, Passeriformes)*	Reclamation of saltmarshes	Short-term increase followed by long-term decrease, mainly in wildfowl	Glue 1971
Charadriiformes	Unspecified	Avoidance	Haworth and Thompson 1990
Gulls, terns, waders	Buildings/infrastructure	Avoidance	Parnell and Soots 1975, Burger 1988
Seabirds	Buildings/infrastructure	Avoidance	Witt 1984
Terns, waders	Buildings/infrastructure	Avoidance	Buckley and Buckley 1975

11.0 Appendix 2 Acknowledgements

A number of people have contributed to help develop this report, including reviews, technical contributions and other types of assistance.

UNEP is particular grateful to the Reindeer Administration in Norway who helped finance some of our work in the Barents Sea region, and especially Roger Pedersen, Johan Mattis Turi, Mona Røkke and Jarle Jonassen for their courage and support.

UNEP would especially like to thank Dr. Antonio Machado, Spain, Dr. Brian N. K. Davis, UK, Dr. J. P. Hettelingh, The Netherlands, Dr. H. Croze, Kenya; Dr. Walt Reid, and not the least Dr. Walter Vergara in the World Bank for their contributions and corrections.

Thanks is given to Dr. Gary Fry, Norway; Dr. Wenche Dramstad, Norway; Maren Aschoug, Norway; David Henry, Canada, Dr. Jostein Skurdal and Margrethe Tingstad at NINA, Norway for assisting technically or scientifically with comments. Petter Sevaldsen at GRID-Arendal put in long hours in preparing and improving the layout of the report.

Finally UNEP would like to thank all the institutions and researchers who contributed to the report. Many other people contributed, too many to be mentioned, but not forgotten.

12.0 Appendix 3 Reviews

12.1 Review No. 1

”This is to comment and endorse the many merits that the GLOBIO initiative has. GLOBIO, in my personal view has provided essential tools for the assessment of sustainability of human interventions and has done deploying the best and most modern techniques available.

As we encroach into the last frontiers (High Amazon, Central Africa, Northern and Southern seas), GLOBIO is capable of providing a framework to analyze the anthropogenic impacts and will assist in ascertaining the cost and benefits of these activities. In fact, I personally strongly believe that the methods provided by GLOBIO in combination with modern economic valuation techniques for natural capital may constitute one of the best chances we have to communicate to decision makers a vision of alternative development paths for these regions.

I hope the work done through GLOBIO will continue and expand, not only through the analysis of large ecosystems under encroachment but also through the analysis of past sins. This will provide information on how natural capital was lost and the value of associated long term economic losses.

We are so far losing the battle, my hope is that systems like GLOBIO will help us turn the tide”.

Walter Vergara
Lead Engineer, Coordinator Quality Assurance Group,
The World Bank, 31st May 2001

12.2 Review No. 2

“No one can doubt that indirect human impacts now affect every corner of the globe to some degree, whether one thinks of the finding of DDT residues in Antarctica during the 1970s or the increasing hole in the ozone layer over the northern hemisphere in the past decade. Elsewhere in the world, native wildlife is everywhere in retreat before the expansion of human populations and ancillary infrastructures such as roads and industrial developments. This has occurred throughout human history but, today, scientists are able to measure changes, to use accumulated knowledge of wildlife reactions and to explore possible scenarios if current trends continue. This will allow policy-makers to make choices between alternative actions. Would we have decided that we were willing to experience Rachel Carson's "Silent Spring" if we had been able to predict all the side effects of pesticides in 1950?

GLOBIO is a novel approach for studying human impacts on the biosphere. Infrastructures can be readily mapped by satellites and this initial application to the Arctic allows us to start with a nearly clean slate. Apart from current proposals to explore and exploit oil, gas and mineral resources, it is possible that global warming in the next fifty years will allow the expansion of settlements further north. The "impact zones" are necessarily based on a broad summation of existing research studies on individual species and communities of plants and animals, and the list of 221 papers examined in this report is an impressive one. Specialists might argue that more weight could have been given to the known effects of roads on amphibians and reptiles, and numerous studies have been made on the effects of power lines on birds. However, such data would probably not significantly affect the input to the GLOBIO model insofar as it is applied to this initial pilot study.

I am less sure about how it would be applied to other parts of the world where there are few remaining large pristine areas. Here, it seems to me, one is looking at further fragmentation of habitats: by roads that allow access to tourism if nothing else. While some species may adapt to low level disturbance others will not and will simply disappear. A choice between infrastructures "for the good of the community" and the longer term needs to preserve intact samples of natural habitats can only be made by an educated society. In Kerala, for example, a unanimous government policy to dam a river in Silent Valley, a pristine area of rainforest, was overturned by public opposition and finally declared a National Park and Biosphere Reserve . Today this has minimal public access in order to conserve a wide range of rare fauna and flora. Environmental education is a global commodity and GLOBIO offers the opportunity to share ideas world-wide”.

Dr. Brian N. K. Davis
Editor-in-Chief for the Scientific journal *Biological Conservation*

12.3 Review No. 3

”Having read the draft report entitled "GLOBIO - Global methodology for mapping human impacts on the biosphere", it is my general opinion that the report is tackling a very challenging issue in a novel way. The inclusion of infrastructure coverage as an indicator for pressure on ecosystems makes to my mind much sense for a number of reasons:

1) Infrastructure as pressure indicator:

Infrastructure is one of the first major anthropogenic pressures affecting the natural environment - such as the Arctic or other natural areas which seem to be still less at risk (i.e. in comparison to the environment in already more developed regions in the world).

2) Infrastructure "critical levels":

Infrastructure is a simple indicator which can be comprehensively used both by scientists and policy makers to reflect the response surface of human interaction, while contributing to the identification of critical thresholds of such interaction.

3) Merits for policy development:

It is important to further explore the potential of a rather simple indicator such as the coverage of infrastructure as a comprehensive early warning mechanism. As such, a valuable contribution to policy developments and scenario assessments with respect to habitats and biodiversity could be made. Indeed, as the GLOBIO report points out, critical threshold approaches and scenario analysis in combination with geographical mapping (of areas at risk) have been successfully used to support negotiations of air pollution reduction protocols in the framework of the UN/ECE Convention on Long Range Transboundary Air Pollution. Critical loads and levels have proven to simplify the communication between science and policy in a common effort to provide early identifications of areas at risk. The use of infrastructure could cover similar mileage for the potential scientific support of policy negotiations,

Thus, the potential benefits of a systematic approach to assess natural resource exploitation and anthropogenic changes to habitats and biodiversity - including a simple indicator such as infrastructure - deserve the attention initiated by the GLOBIO report. Of course, it is important to also consider interactions with other pressures (e.g. air-, water- and soil pollutants affecting changing bio-geochemical cycles). Infrastructure is not the only driving mechanism. In general, the propagation of environmental degradation (as well as recovery) or fragmentation also has origins in both global as well as local environmental cause-effect mechanisms. The exploration of ideas presented in the GlOBIO report in conjunction with the integrated assessment of other impacts (including those associated to infrastructure) is a valid issue for future work.

In conclusion, I believe that the methodology tentatively outlined in the GLOBIO report has an important potential to contribute further to the scientific and technical support of policy and protocol developments regarding the mitigation of anthropogenic pressure on habitats and biodiversity”.

Prof.dr.Jean-Paul Hettelingh
University of Leiden, Centre of Environmental Science

12.4 Review No. 4

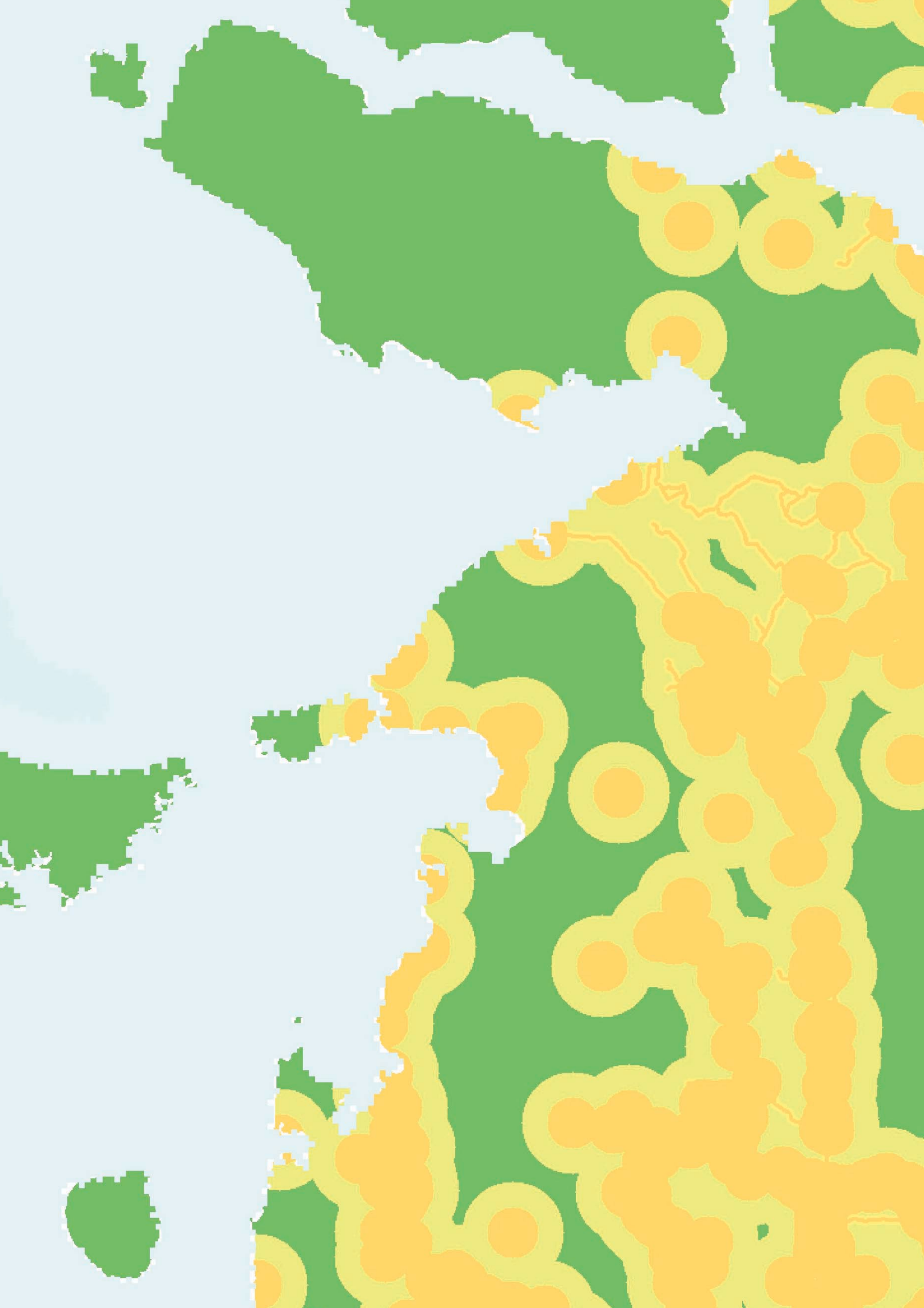
“During the last decades, human activity has reached a biosphere scale with unprecedented impact on the world's natural resources. The "Living Planet Report 2000", in which the UNEP also participated, illustrates how the world capacity for sustaining life was passed over already in 1975. The natural capital of our planet is being consumed: man is not living anymore from the rent.

A sustainable approach to development on all scales is therefore an urgent need, and a formidable political and technical challenge. We are aware of the problem, but we do not have enough knowledge or political consensus to solve such a complex problem. Trial and error has been our approach at the local level, and we still search for methods that can be applied on a large scale with sufficient pragmatism for decision makers, but without losing a minimum of rigor.

The present GLOBIO study fits into this category of new tools, analysing the potential consequences of different scenarios of infrastructure development during the coming decades in the Arctic region. It is wise to select infrastructures as the key element that best links territorial direct, indirect and cumulative antropogenic impacts with ecosystems functioning and maintenance of biodiversity. The case-study of the Arctic is crystal clear and promising. The question now is if this innovative method can equally be applied to large and more complex regions that are already more heavily intervened, and where available studies regarding impact on species are not so accurate or are just simply biased. Contradictory demands of the local population may also complicate the scenarios, but this should not become an insurmountable drawback.

The GLOBIO methodology will not deliver exact results, but it surely deems to be useful in the policy-making arena. At this stage, man cannot anymore afford rigorous time-consuming scientific studies. Thus, GLOBIO is quick and worth trying.

Dr Antonio Machado
President of the European Centre for Nature Conservation
Editor-in-Chief for the scientific journal Journal for Nature Conservation



QUOTES ON GLOBIO

"GLOBIO is a pioneering attempt to meet the needs of decision-makers and the public for scientifically-based information about the consequences of their choices today for the future of biodiversity, sustainable development, and local cultures. (...) GLOBIO gives us all a chance to explore where the road we are following will lead us."

Dr. Walter Reid, Director, Millenium Ecosystem Assessment

"It's extremely thorough and can stand as a useful reference document itself. As with all good ideas, GLOBIO appears to be elegant in its simplicity and leads one to exclaim, "Of course, infrastructure is the inevitable early footprint of development, and you can even see it from space! Why didn't I think of that? ...cut a road into the forest for whatever purposes and the chainsaws will soon follow"."

Dr. Harvey Croze, Former Division Director UNEP

"I personally strongly believe that the methods provided by GLOBIO in combination with modern economic valuation techniques for natural capital may constitute one of the best chances we have to communicate to decision makers a vision of alternative development paths for these regions. (...) We are so far losing the battle, my hope is that systems like GLOBIO will help us turn the tide."

Dr. Walter Vergara, Head of the Quality Assurance Group, The World Bank

"GLOBIO is a novel approach for studying human impacts on the biosphere. (…) Environmental education is a global commodity and GLOBIO offers the opportunity to share ideas world-wide."

Dr. Brian N. K. Davis, Editor-in-Chief for the Scientific journal Biological Conservation

"In conclusion, I believe that the methodology tentatively outlined in the GLOBIO report has an important potential to contribute further to the scientific and technical support of policy and protocol developments regarding the mitigation of anthropogenic pressure on habitats and biodiversity."

Prof. Dr.Jean-Paul Hettelingh, University of Leiden, Centre of Environmental Science

"(…) crystal clear and promising. (...) it surely deems to be useful in the policy-making arena. At this stage, man cannot anymore afford rigorous time-consuming scientific studies. Thus, GLOBIO is quick and worth trying."

Dr. Antonio Machado, President of the European Centre for Nature Conservation
Editor-in-Chief for the scientific journal Journal for Nature Conservation