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54

Interdependence of Biodiversity and Development Under Global Change

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Interdependence of Biodiversity and Development Under Global Change

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Cover photos (top to bottom): Agro-ecosystem used for thousands of years in the vicinities of the Mycenae palace (located about 90 km south-west of Athens, in the north-eastern Peloponnese, Greece). In the second millennium BC Mycenae was one of the major centres of Greek civilization (photo P. Ibisch).

Modern anthropogenic urban ecosystem dominated by concrete, glass and steel materials (London City Hall, Great Britain) (photo P. Ibisch).

Undernourished child in deforested and desertified inter-Andean dry valley ecosystem (between La Viña and Toro Toro, northern Potosí, Bolivia) (photo P. Ibisch).

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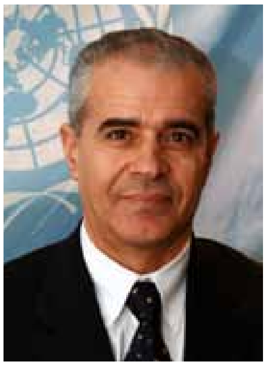

At its second meeting, held in Jakarta, November 1995, the Conference of the Parties of the Convention on Biological Diversity adopted the ecosystem approach as the primary framework for action under the Convention. The Ecosystem Approach recognizes that humans, with their cultural diversity, are an integral component of ecosystems. This has been known for a long time, but it has yet to be internalized by the whole society to assure present and future human survival.

Our modern civilization experiences—due to increased urbanisation and compartmentalised knowledge—an increasing alienation from nature obscuring common understanding of our real dependence on biodiversity and ecosystems. The complex global economy interwoven with a worldwide financial architecture has obscured the fact that all these human systems remain nested as sub-systems in the broader Earth eco-system. Humans and everything we create by using natural renewable or non renewable resources is subordinated to the general laws of nature that rule the functioning of this unique Earth system. Even though we are just a sub-system, human resource use driven by an ever accelerating growth and globalization of societies' activities has the power to catalyze irreversible degradation of the global ecosystem compromising human well-being and maybe even the existence of our civilization. As the Global Biodiversity Outlook 3 (GBO3) points out we are rapidly approaching critical tipping-points of life-supporting systems, if we don't break business as usual attitudes and habits.

Rediscovering the insights of these risks, the current technical series explores the manifold interrelations and interdependencies between biodiversity and human development. Applying system theory and through a transdisciplinary analysis of bio-cultural evolution, concrete up-to-date case studies and global statistical correlations this technical series goes deeply into the root-causes and drivers of environmental degradation and biodiversity loss. It shows that understanding the role and value of biodiversity and ecosystems for human well-being is more than ever a crucial pre-requisite and vital question for new and urgent needed development paradigms. In line with other initiatives like TEEB, IPBES or the Green Economy, among others, the technical series explores appropriate means and ways to translate proven knowledge and open questions into policy-relevant messages.

To find real solutions to both preserving biodiversity and securing sustainable development for the future in times of global socio-economic and environmental change, the authors of the technical series present and call for an in-depth understanding and comprehensive application of the CBD ecosystem approach. This requires to shift away from merely treating the symptoms of the biodiversity crisis. Following a precautionary approach, both knowledge and uncertainties should strategically be factored into decision-making to preserve the interests of current and future generations. New management systems for production, consumption for the global economy needs to be developed through a much more proactive management and by mimicking natural systems.

We are pleased to introduce this volume of the Technical Series of the Convention on Biological Diversity as a very useful contribution and enrichment of the debate on new paradigms for sustainable development in harmony with nature that actually move the agenda of committed scientists, policy-makers and practitioners worldwide.

Dr. Ahmed Djoghlaf
Executive Secretary
Convention on Biological Diversity

A. Technical section

A.1 INTERDEPENDENCE OF BIODIVERSITY AND DEVELOPMENT UNDER GLOBAL CHANGE: AN INTRODUCTION

Pierre L. Ibisch, Peter Hobson, Thora Martina Herrmann,
Martin Schluck & Alberto Vega E.

This new volume of the CBD Technical Series presents an analysis of the systemic character of global change, biodiversity and human development, and the relationships between them. The report describes and evaluates the complicated relationships and dynamics between human and biological systems. Theoretical concepts, such as complex systems models, are proposed as realistic and workable models for future strategies in sustainable development. So far there has been little attempt to move this science into practice partly because it lacks the unequivocal scientific evidence demanded by an increasingly scrutinising society. The radical view presented here argues the case for looking beyond known knowledge and evidence as an essential strategy for dealing with rapidly changing conditions and increasing uncertainty. The behaviour of complex systems defies attempts by contemporary scientists to provide answers to dynamic problems. Radical thinking and approaches are needed to meet the combined challenges of an exploding human population (with rapidly growing needs and wants), *and*the run-away problems of global environmental change. The new technical series also proposes the use of post-normal philosophy as a complementary, and in some cases, alternative framework to existing neo-classical economics and conventional policy mechanisms, thereby abandoning the idea that exact and 'modern' science is the only source of usable knowledge for policy-making and practice. In many instances *business as usual* is failing to meet long-term objectives for human sustainable development.

The consequences of poverty can contribute to loss of biodiversity, and conversely, biodiversity loss can increase poverty, or initiate poverty in some cases. At another level, the conservation of biodiversity can exacerbate poverty, whilst poverty alleviation can be achieved through prudent measures to protect biological diversity and natural resources. However, well-intended actions to reduce poverty can have negative consequences for biodiversity. There is a series of papers that support each of these statements (compare e.g. Hassan & Scholes 2005, Fisher *et al.* 2008, Naeem *et al.* 2009b, Roe & Elliott 2010; see also CBD Technical Series No. 55 which states that documented evidence for biodiversity conservation being a mechanism for poverty reduction still is somewhat deficient).

The so-called 2010 target linked significant reduction of biodiversity loss to human development: conservation was to alleviate poverty and benefit all life on Earth (SCBD—Secretariat of the Convention on Biological Diversity 2003, UN 2008). Failure to achieve this goal was a harsh lesson in setting targets that must be realistic and achievable rather than ambitious and naïve (Butchart *et al.* 2010). Despite overwhelming scientific evidence in support of arguments that human survival is inextricably tied to biodiversity, which includes the world's ecosystems, their products and services (Millennium Ecosystem Assessment, e.g. Hassan & Scholes 2005), the degradation of ecosystems, the extinction of species and the dynamic loss of populations and genetic diversity continue on an exponential trajectory.

Against all efforts to conjointly reduce poverty *and* biodiversity loss, and not withstanding examples of best practice and success stories, poverty remains one of the most serious social problems, coupled with the relentless decline in biodiversity. Furthermore, ongoing problems of poverty, among other drivers, are accelerating biodiversity loss. Human development depends on ecosystems and their services, and the state of poverty is influenced by strategies for both development and the distribution of nature's benefits. Poverty is not primarily a problem of biodiversity, but of systems that are established and steered by humans.

"*Biodiversity also incorporates human cultural diversity, which can be affected by the same drivers as biodiversity, and which has impacts on the diversity of genes, other species, and ecosystems*" (UNEP 2007). Thus, loss of biodiversity affects cultural diversity, as human societies worldwide are inherently connected with the natural world. The human impact on biodiversity, including its unparalleled loss during the last decades, is largely determined by the cultural value assigned to biodiversity. Similarly, biodiversity—its status, trends and the services it provides—influences the cultural expression of many peoples. Biological diversity and cultural diversity are mutually reinforcing and mutually dependent; in many parts of the world we find a clear correlation of both (Fig. 1).

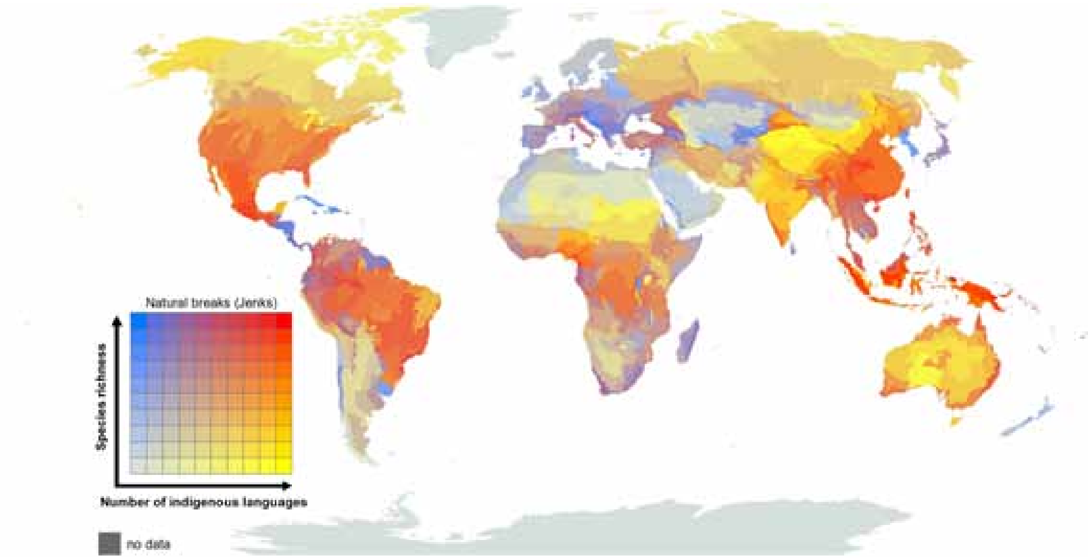

FIGURE 1: Correlation of biodiversity and cultural diversity. Here indicated as choropleth bivariate map of higher plant species richness (after Kier *et al.* 2005) and number of indigenous languages (after Lewis 2009) for the world's Ecopolitical Units (after Freudenberger *et al.*, B.1.1. in this document).

Numerous cultural practices, legends, songs, and rituals that encode and carry human relationships with the environment, depend upon elements of biodiversity for their continued existence. Furthermore, major ensembles of biological diversity are developed and managed by cultural groups with language and knowledge as tools for their management (Posey 1999). Indigenous peoples' cultures and local traditional societies clearly come under enormous pressure from both biodiversity loss and development processes that also threaten biodiversity. If the natural environment is changed or lost, the cultural knowledge based on it is lost, and the traditional practices vital to maintain livelihoods will disappear as well. The loss of each distinctive culture represents the collective loss for humankind of possible options and opportunities for innovation in responding to collective challenges. Languages are considered one of the major indicators to measure the relationship between the loss of cultural diversity and the loss of biological diversity. Among the estimated 5,000-7,000 languages spoken today, nearly 2,500 languages are in immediate danger of extinction (Mosely 2010). People who do not speak in their mother tongue often have no access to traditional knowledge and are thus excluded from vital information about subsistence, health and sustainable use of natural resources (Maffi & Woodley 2010).

In order to significantly improve the status of biodiversity, which underpins the well-being and development of humanity, it is crucial to recognise that most of the problems of loss of biological diversity, threats to human development and impoverishment of cultural diversity are closely connected and interrelated. They therefore require a holistic and more comprehensive approach for action at all levels. Nevertheless, there are numerous "barriers to integrating social science and conservation, both in the real world and in the minds of conservationists", and in conservation and development action we may need "inter-disciplinary people" rather than "interdisciplinary teams" (Adams 2010). An improvement on this idea might be the consolidation of *transdisciplinary* people and teams. Interdisciplinarity is the cooperation between autonomous disciplines, whilst *transdisciplinarity* infers action at all levels by scientists and practitioners unconstrained by traditional disciplinary boundaries (see Bora 2010). Ideally, this approach goes beyond a scientific eclecticism and establishes conceptual and theoretical linkages between issues that are normally analyzed and discussed separately by the various 'classical' disciplines. Transdisciplinary work achieves a new emergent disciplinary level by itself (Bora 2010). The emphasis is on applied scientific research, a *transscientific approach* (see Bora 2010). For a *transscientific approach* to succeed, a common language and overarching concept is required. This paper proposes an applied perspective of system science as an appropriate conceptual framework for translating and linking artificially separated sectors and topics that belong together. Acknowledging the challenges emerging out of problems inherent in complex systems and issues of non-knowledge, we advocate a more pluralistic approach to problem-solving and decision-making, which incorporates traditional and local knowledge.

The implementation of biodiversity policy and action at national and international levels is usually divided up between several sectors of society, and is reliant on effective communication and coordination. An example is environmental economics that requires the combined efforts of biodiversity specialists and economists to provide solutions to questions such as: *How much biodiversity do we need? What is the economic value of biodiversity? Who has to foot the bill?* At the international level the efforts of many experts have been coordinated under the umbrellas of the Millennium Ecosystem Assessment and the TEEB study (*The Economics of Ecosystems and Biodiversity;* TEEB—The Economics of Ecosystems & Biodiversity 2008, TEEB—The Economics of Ecosystems & Biodiversity 2009), to inform policy and action and provide answers to problematic questions. The organisation behind biodiversity action has developed into a sophisticated, multi-tasking machine with clear targets and goals. However, there is a collective trust and assumption by society that the scientists responsible for this task are asking the right questions. What if this is not the case? It is possible that the context, language or conceptual reference to the questioning is flawed. Often, the line of inquiry adopts a linear pathway rather than a pluralistic or transdisciplinary approa

The mainstream and normal approaches of linking biodiversity with development policy and action are shaped by the logics of the current system of (natural resource) economics, where values and prices drive decision-making, and where any action has to be efficient and repay its debts as quickly as possible. Conservation is part of a larger systemic game played according to a set of complex and dynamic rules. The tactics of the bigger game include a realistic and pragmatic approach to problem solving. The unpredictable nature of a game that periodically "ups" the level and indeterministically changes the rules leaves little to no time to reflect on whether we are playing the right game. Each step-up in the game represents a stage in socio-economic development towards greater complexity like increased globalisation. The game of development and biodiversity conservation has always been a difficult one; global socioeconomic as well as environmental change drive ordinary people, decision makers and even scientists to the edge of understanding of the complex situation of our planet and its rapid change.

The 21st century is a fitting moment in the history of mankind to mark the age of information. Considerable advances in both computer technology and knowledge-transfer platforms have saturated society with all possible forms of information, giving individual ownership of world-wide knowledge to all who desire it. Knowledge-surfing on the internet has created a generation of people with skills in accessing information, but also exposed societal inadequacies in evaluating complex relationships between multiple factors. As science progresses into unexpected depths of exploration it is losing ground because of dramatically increasing gaps of translation. Society appears to be in the suffocating grip of information overload.

The phenomenon of human-induced global change is a crisis of the complex Earth *System*. The interactions between humans and nature are just part of a much larger systemic process that includes biological and cultural evolution. Recently, science has developed theories and concepts that help to describe and analyze these phenomena systemically. Nevertheless, much of this work remains outside of the public domain. The Convention on Biological Diversity has adopted principles and practices of the *ecosystem* approach in an attempt to inter-collate the interests and activities of various disciplines. The successes of this approach are yet to be realised as there is little evidence of measurable outcomes at international or national levels.

Biodiversity conservation is an essential element in any strategy for sustainable development (Naeem *et al.* 2009a). This obvious statement trivialises attempts to integrate biodiversity needs into human development, and practical endeavours have not met scientific and political expectations. Part of this problem goes to the heart of the human condition—the freedom of choice. Science and ethics have provided the evidence and justification for sustainable development, but society prefers to ignore it for a variety of reasons that may include egoism and a lack of altruistic concerns for the well-being of future generations. A substantial quantity of academic literature on system thinking and sustainability exists in the public domain (e.g. Vester 1978, Vester 1988, Vester 2004, Clayton & Radcliffe 1997, Bossel 2007, Meadows & Wright 2008, Boardman & Sauser 2008, Norberg & Cumming 2008), and yet, the CBD, as well as broader development and conservation policies have not really embraced "*systemism*" (Mario Bunge 2000)[1]. This failing, coupled with the urgency to avert a global environmental and humanitarian crisis, demands a critical analysis of existing guidelines and policies and a *more radical approach to biodiversity conservation and sustainable development*.

The aim of this document is to provide some preliminary answers to the questions raised above. The approach taken is a cross- and trans-disciplinary one that attempts to build bridges between theory and practice across scales of operation. The ideas presented for discussion are based on existing literature as well as on first-hand experience in various developing and developed countries. A preliminary analysis and visualization of the correlation of environmental and socio-economic/cultural/developmental parameters are presented, as are case studies that illustrate the multiple facets of interdependence of biodiversity and development and the uneven distribution of different kinds of interdependence. The strategic element of the document is underpinned theories related to the functioning of the Earth super-ecosystem, including the embedded anthroposystem. Cultural aspects of biodiversity use and conservation are addressed, and the concept of sustainability according to the principles of system theory and thermodynamics provides the central tenant to the thesis. Through an analysis of various options, conclusions are derived for a better integration of biodiversity conservation and human development.

The contents of this Technical Series is both global and country specific, and the lessons learned are of universal significance. By broadening the scope of our analysis to consider poverty reduction and biodiversity conservation in the context of global sustainability and global change, we improve our understanding of the problem—and, perhaps more importantly, begin to focus on implementing real solutions based on a more radical ecosystem approach. This approach is the quintessence of our work that integrates and synthesizes all the theories, concepts, and findings highlighted in the various background papers (section B of this document) working towards a new sustainable development paradigm. Important components of this paradigm are complex system theory and approaches related to non-equilibrium thermodynamics as well as transdisciplinarity and post-normal philosophy, implying a more conscious and competent treatment of the various forms of knowledge and non-knowledge. The most important element is the intransigent recognition that humans are part of ecosystems. By consequence, all human-made systems are sub-systems of the broader ecosystem and are subordinate to nature's rules and laws.

1 Acknowledging the ubiquity of the concept of a system Mario Bunge (2000) suggests adopting a whole systemic worldview that is centered in the following postulates: "*1. Everything, whether concrete or abstract, is a system or an actual or potential component of a system; 2. systems have systemic (emergent) features that their components lack, whence 3. all problems should be approached in a systemic rather than in a sectoral fashion; 4. all ideas should be put together into systems (theories); and 5. the testing of anything, whether idea or artifact, assumes the validity of other items, which are taken as benchmarks, at least for the time being*". See also Hobson & Ibisch, B.2.1. in this document.

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REFERENCES

Adams, W. M. 2010. Thinking like a human: social science and the two cultures problem in D. Roe and J. Elliott, editors. The Earthscan reader in poverty and biodiversity conservation. Earthscan, London.

Boardman, J. and B. Sauser. 2008. Systems thinking. Coping with 21st century problems. CRC Press, Boca Raton, Fla.

Bora, A. 2010. Wissenschaftliche Politikberatung und die disziplinären Grundlagen der Wissenschaft. Pages 25–55 in A. Bogner, editor. Inter- und Transdisziplinarität im Wandel? Neue Perspektiven auf problemorientierte Forschung und Politikberatung. 1. Aufl. Nomos, Baden-Baden.

Bossel, H. 2007. Systems and models. Complexity, dynamics, evolution, sustainability, Nederstedt.

Bunge, B. 2000. Systemism: the alternative to individualism and holism. Journal of Socio-Economics **29**:147–157.

Butchart, S. H. M., et al. 2010. Global biodiversity: indicators of recent declines. Science **328**:1164–1168.

Clayton, A. M. H. and N. J. Radcliffe. 1997. Sustainability. A systems approach. 1. publ., reprint. Earthscan, London.

Fisher, R., S. Maginnis, W. Jackson, E. Barrow and S. Jeanrenaud. 2008. Linking conservation and poverty reduction: Landscapes, people and power. Earthscan, London.

Hassan, R. and R. Scholes, editors. 2005. Ecosystems and human well-being. Island Press, Washington, DC.

Kier, G., J. Mutke, E. Dinerstein, T. H. Ricketts, W. Küper, H. Kreft and W. Barthlott. 2005. Global patterns of plant diversity and floristic knowledge. Journal of Biogeography **32**:1107–1116.

Lewis, M. P., editor. 2009. Ethnologue: languages of the world: Sixteenth edition, Dallas.

Maffi, L. and E. Woodley. 2010. Biocultural diversity conservation. A global sourcebook. London: Earthscan.

Meadows, D. H. and D. Wright. 2008. Thinking in systems. A primer. Chelsea Green Pub, White River Junction, Vt.

Moseley, C., editor. 2010. Atlas of the World's Languages in Danger. 3rd revised, enlarged and updated edition. Paris: UNESCO.

Naeem, S., D. E. Bunker, A. Hector, M. Loreaeu and C. Perrings. 2009a. Can we predict the effects of global change on biodiversity loss and ecosystem functioning? Pages 290–298 in S. Naeem, D. E. Bunker, A. Hector, M. Loreaeu and C. Perrings, editors. Biodiversity, ecosystem functioning, and human wellbeing. An ecological and economic perspective. Oxford Univ. Press, Oxford.

Naeem, S., D. E. Bunker, A. Hector, M. Loreaeu and C. Perrings, editors. 2009b. Biodiversity, ecosystem functioning, and human wellbeing. An ecological and economic perspective. Oxford Univ. Press, Oxford.

Norberg, J. and G. S. Cumming. 2008. Complexity theory for a sustainable future. Columbia Univ. Press, New York, NY.

Posey, D.A. 1999. Cultural and spiritual values of biodiversity. [a complementary contribution to the Global Biodiversity Assessment]. London: Intermediate Technology Publ.

Roe, D. and J. Elliott, editors. 2010. The Earthscan reader in poverty and biodiversity conservation. Earthscan, London.

SCBD—Secretariat of the Convention on Biological Diversity. 2003. Handbook of the Convention on Biological Diversity, London.

TEEB—The Economics of Ecosystems and Biodiversity. 2008. The Economics of Ecosystems and Biodiversity: An interim report.

TEEB—The Economics of Ecosystems and Biodiversity. 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers: Summary: Responding to the Value of Nature.

UN. 2008. Millennium Development Goals Indicators.

UNEP (United Nations Environment Programme), editor. 2007. Global Environmental Outlook: *environment for development (GEO-4).*

Vester, F. 1978. Unsere Welt- ein vernetztes System. Klett-Cotta, Stuttgart.

Vester, F. 1988. The biocybernetic approach as a basis for planning our environment. Systemic Practice and Action Research **1**:399–413.

Vester, F. 2004. Sensitivity Model/Sensitivitätsmodell Prof. Vester, Munich.

A.2 MUTUAL MAINSTREAMING OF BIODIVERSITY CONSERVATION AND HUMAN DEVELOPMENT: TOWARDS A MORE RADICAL ECOSYSTEM APPROACH

Pierre L. Ibisch, Peter Hobson & Alberto Vega E.

A.2.1 CBD'S ECOSYSTEM APPROACH AND A CALL FOR A MORE RADICAL INTERPRETATION AND IMPLEMENTATION

Abstract

This paper recommends adopting a more intensive approach towards embedding principles and practice of ecosystem management in both the conservation sector and the wider development policy framework within and across state borders. In popularising the Ecosystem Approach, by for instance formulating the *Malawi principles* that target a broad audience, it has been expanded , almost to the point of diluting and losing some important underpinning fundamental scientific concepts rooted in ecosystem science. In an attempt to retrieve the fundamental messages of the Ecosystem Approach, this paper proposes an analysis of a *Radical Ecosystem Approach.* Radical, in this instance, refers back to the *roots* (Lat. *radices*) of the concept, specifically, inviting conservationists to focus strongly on the *root causes* of the problems that beleaguer the planet's ecosystems. In particular, recent evidence for human-induced climate change and the impacts it is already having on biodiversity has added to the sense of urgency, and the need for a much more *radical* reading and application of the Ecosystem Approach. Until now, there has been no acknowledgement that all problems arising from biodiversity loss, soil degradation/desertification and climate change are symptoms of the same root causes. This being the case, any workable solution would require a fully integrative strategy based on (eco)system science. Thus, a Radical Ecosystem Approach could also serve as a common basis for further integration of the different Rio conventions. The approach, outlined in 15 principles within four groups, is based on conclusions distilled from an extensive body of scientific literature as well as from empirical data related to the interlinkages of human development and biodiversity. It is of crucial importance to recognize that the "Earth super-ecosystem" is a complex system of higher order of nested and/or overlapping and interacting subsystems. Human systems are an integral and dependent part of the global ecosystem and all laws of nature that rule the functioning of this system should equally apply to the anthroposystem. Maintaining the function of the global ecosystem and avoiding significant state shifts of the Earth system must be the overarching goal of human development and biodiversity conservation. A competent and conscious dealing with non-knowledge is a fundamental part of ecosystem management (under global change). A post-normal science perspective recognizes the cognitive limitations of humans and provides important insights for management of pluralistic complex systems, which goes beyond the basis of 'hard' scientific evidence. We also discuss strategic objectives for biodiversity conservation that should be strongly focused on the root-causes of unsustainable development. Concrete elements for the implementation of a Radical Ecosystem Approach would include, amongst others, ecological economics and econics (a discipline that promotes the mimicking of ecological system dynamics and functioning for improved ecosystem management and functioning of socio-economic systems).

The Millennium Ecosystem Assessment (MA; e.g., Hassan & Scholes 2005) was a landmark study of the ecosystem services that support life on Earth. The findings revealed that about 60 percent of the ecosystem services such as fresh water, capture fisheries, air and water regulation, and the regulation of regional climate, natural hazards and pests were being managed unsustainably and in a state of degradation.

The prognosis for the future was that the situation would grow significantly worse in the next 50 years. Furthermore, the report stated that the ongoing degradation and loss of ecosystem services was an obstruction to the Millennium Development Goals (MDG) that had been agreed by the World leaders at the United Nations in 2000. The ongoing degradation of the ecosystem services examined in the study will have serious implications for human well-being.

The findings of the Millennium Ecosystem Assessment (MA) opened up a new moral imperative for today's society. The degradation to ecosystem services and loss of biodiversity are a direct result of human activity, and as such, the world has an ethical duty to restore the natural state of the planet. The MA exposes the paradox in the human-nature relationship. Human survival and development are dependent on ecosystem services—the very *stuff* of biodiversity. Throughout modern history, biodiversity has at best been marginalized or viewed as an inconvenience, and at times has been seen as a threat to social and economic progress, but never as essential to human well-being. More recently, this perception has been revised as a result of scientific evidence and better informed policy. Only now do we realise the extent and depth to which biodiversity supports and shapes human existence on this planet. There is no human life without biodiversity, the living planet is the life-support system of mankind, and from now on it must be central to all human endeavours and activities.

The **Ecosystem Approach** was not only designed as a primary framework for conservation action under the Convention on Biological Diversity, but it was equally expected to comprise strategies that were to adequately address the interlinkages between biodiversity and human development.

At its second meeting, held in Jakarta, November 1995, the Conference of the Parties (COP) of the Convention on Biological Diversity (CBD) adopted the Ecosystem Approach as the primary framework for action under the Convention, and subsequently has referred to the Ecosystem Approach in the elaboration and implementation of the various thematic and cross-cutting issue work programmes under the Convention (Decision II/8).

The Ecosystem Approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the Ecosystem Approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.

(Extracts from the website of the Convention on Biological Diversity; http://www.cbd.int/ecosystem/)

The Ecosystem Approach has become one of the most influential and most cited concepts to be promoted in the context of implementation of the CBD. Internet search engines such as Google currently record hundreds of thousands of web pages and articles that mention the approach. *Google Scholar* alone lists about 22,100 texts, more than 3,500 published in the last 2.5 years[2]. Efforts to describe the concept and its application as a more effective approach to the conservation of biodiversity have been exhaustive. The term "*ecosystem approach*" has come to represent the new genre in environmental science for aspiring scientists, a buzz-word or jargon often used to widen publication opportunities. Sometimes the term and concept have been used as a marketing ploy to win support from the public. More worryingly, where it should count most, and provide the framework for good practice, ecosystem approach remains "*stuck in the clouds*" (Fee *et al.* 2009). Consequently, the absence of any effective leadership from conservation has reduced awareness and stunted development in ecosystem management across the wider social spectrum. Although most countries have fully endorsed the Ecosystem Approach none have demonstrated a serious commitment to implement appropriate practice. This is not to diminish all efforts by either international or national sectors to develop an ecosystem approach culture, in fact, there have been noticeable advancements made at both levels to build collaborative dialogue and policy frameworks. For instance, large-scale and transboundary conservation projects are promoted in the name of the Ecosystem Approach, and modern ecoregional conventions, such as the Carpathian

2 Search results from June 21, 2010.

Convention explicitly refer to it[3]. Thus, despite shortcomings on the ground, the utility of the Ecosystem Approach for orienting and informing policy development has been proven.

Over the years the Ecosystem Approach, has been carefully rounded and softened to accommodate for a much wider audience, and to encourage broad political appeal. In popularising the Ecosystem Approach, by for instance formulation of the *Malawi principles* that target a broad audience (Box 1), it has been expanded, almost to the point of dilution with the subsequent loss of important underpinning fundamental scientific concepts (see Box 2). Arguably, generalisations about ecosystem management have led to misconceptions or even perceived arbitrariness, and lack of application in the field

For practical and historical reasons, it is understandable that the *principles* themselves and the corresponding concepts of the Ecosystem Approach were adapted to correspond to the goals of the Convention on Biological Diversity, rather than the other way round. For instance, principle 10 states, "*The ecosystem approach should seek the appropriate balance between, and integration of conservation and use of biological diversity*". This principle reflects the interlinkage of biodiversity and development, without necessarily being built on principles of ecosystem science (see below). Similarly, the CBD's Ecosystem Approach sourcebook[4] reflects the wide array of topics treated under the approach's umbrella, while also allowing for insights into apparent priorities (e.g., compare the sequence of listed topics starting with public participation, education and awareness), and gaps (e.g., complex systems, global change, understanding threats and their root causes are *not* addressed).

BOX 1: The 12 Principles of the Ecosystem Approach

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices.

Principle 2: Management should be decentralized to the lowest appropriate level.

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: a. Reduce those market distortions that adversely affect biological diversity; b. Align incentives to promote biodiversity conservation and sustainable use; c. Internalize costs and benefits in the given ecosystem to the extent feasible.

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Principle 6: Ecosystem must be managed within the limits of their functioning.

Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Principle 9: Management must recognize that change is inevitable.

Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of conservation and use of biological diversity.

Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

(Extract from the website of the Convention on Biological Diversity; http://www.cbd.int/ecosystem/)

3 Framework Convention on the Protection and Sustainable Development of the Carpathians (http://www.carpathianconvention.org/text.htm).

4 http://www.cbd.int/ecosystem/sourcebook/

In an attempt to retrieve the fundamental messages of the Ecosystem Approach (see Box 2), this paper proposes an analysis of a ***Radical Ecosystem Approach.*** Radical, in this instance, refers back to the ***roots*** (Lat. *radices*) of the concept, specifically, inviting conservationists to focus strongly on the ***root causes*** of the problems that beleaguer the planet's ecosystems. The concept of the Ecosystem Approach is fundamental to both preserving biodiversity and securing sustainable development for the future. Thus, we want to highlight the need for mutual mainstreaming of biodiversity conservation *and* human development. This paper recommends adopting a more intensive approach towards embedding principles and practice of ecosystem management in both the conservation sector and the wider policy framework within and across state borders.

BOX 2: The essence of the Ecosystem Approach as originally developed

The late Canadian J.J. Kay can be considered as one of the leading scientists who advanced thinking and scientific theories on the Ecosystem Approach. With his colleagues, Kay described the nature and function of complex systems using relatively recent concepts of non-equilibrium thermodynamics. Ecosystems were viewed as complex constructs of diverse interacting components, exhibiting emergent properties and the special characteristic of self-organization. The dynamics and numerous interactions between the large number of components within a complex system are often indeterministic and cannot be predicted. Consequently, outcomes and events are compounded by uncertainty that often frustrates the activities of managers. The laws of thermodynamics makes clear that changes within complex systems are inevitable; especially important are the abilities of nature to create order from chaos, to gather and form nested systems of higher order, and to evolve towards more complexity and higher thermodynamic efficiency. Out of the various laws of physics and concepts of ecology, a number of important conclusions can be drawn for the management of conservation projects, protected areas and sustainability. This is very well reflected in the works of Kay and colleagues, such as these cited below.

Kay, J.J. 1994a. The Ecosystem Approach applied to the Huron Natural Area. Document prepared for Environment Canada, State of the Environment Reporting, Ottawa, Canada.

Kay, J.J. 1994b. The Ecosystem Approach, ecosystems as complex systems and state of the environment reporting. Document prepared for North American Commission for Environmental Cooperation, State of the North American Ecosystem meeting, Montreal, Canada. 8-10 December.

Kay. J., Regier, H., Boyle, M. & Francis, G. 1999. An Ecosystem Approach for sustainability: Addressing the challenge of complexity. Futures **31**:721-742.

Waltner-Toews, D., Kay, J.J., & Lister, N. 2008. The Ecosystem Approach: Complexity, uncertainty, and managing for sustainability. Columbia University press series: Complexity in Ecological Systems. New York: Columbia University Press.

The impacts of human-induced climate change on biodiversity has added to the sense of urgency, and the need for a much more *radical* reading and application of the Ecosystem Approach. Inherent change in the character and behaviour of ecosystems is accepted as part of the natural evolutionary pathway, and is made explicit in the stated principles of the Ecosystem Approach (principle 9). However, very little reference to anthropogenic global (environmental) change is made in either the Convention or in the Ecosystem Approach. Even the Millennium Ecosystem Assessment can be criticized of oversimplification in its interpretation of the *biodiversity-ecosystem functioning* framework, which fails to adequately recognize the interdependency of biotic and abiotic components of the global super-ecosystem, as well as the critical importance of human globalization through trade and people's interactions (Naeem *et al.* 2009). Increasingly, climate change is seen as a major challenge to biodiversity conservation, and subsequent actions to mitigate against the effects of climate change are being viewed as a welcomed opportunity for the introduction of innovative conservation action (e.g. REDD—*Reducing Emissions from Deforestation and Degradation*). Climate change policy and related scientific work that is being promoted by the *Intergovernmental Panel on Climate Change* (IPCC), together with current mechanisms to evaluate the economic costs of climate change, have inspired conservationists to launch similar initiatives (see *Intergovernmental Platform on Biodiversity and Ecosystem Services*—IPBES, *The Economics of Ecosystems and Biodiversity*—TEEB).

Despite the various policies and strategies to combat the effects of climate change, there is little evidence of any real meaningful effort to tackle this problem in a fully integrated way with parallel concerns of biodiversity loss. Both concerns are commonly treated in isolation with their own set of causes and effects, rather than as interrelated facets of the same problem. There is much discussion about actual and potential synergies between policy and action in the fields of climate change mitigation and biodiversity conservation and increasingly joint activities between the three Rio conventions[5] are being sought. Whilst this is encouraging, there is still little movement in policy towards an acknowledgement that all problems arising from biodiversity loss, soil degradation/desertification and climate change are symptoms of the same root causes. This being the case, any workable solution would require a fully integrative strategy based on (eco)system science. Thus, a Radical Ecosystem Approach could also serve as a common basis for further integration of the different Rio conventions.

A.2.2 MESSAGES FROM SCIENCE: COMPLEX SYSTEMS, ECOSYSTEMS AND THE ANTHROPOSYSTEM

As a first step in the process of developing a Radical Ecosystem Approach this paper suggests a return to basics, including a more appropriate description of current knowledge and understanding of (eco) systems. A list of conclusions is distilled from an extensive body of scientific literature as well as from empirical data that have been processed in the background papers included in the second section of this document. The conclusions cover a range of issues including aspects of general system sciences and the overall Earth system, to specific dependent systems such as organisms, humankind and its social subsystems (Boxes 3-6).

BOX 3: Messages from system science, systemics

(For detailed analysis, discussion and references see Hobson & Ibisch, B.2.1. in this document)

Our world can be analysed and understood as a system consisting of interacting sub-systems. System theory is a key approach to inter- and trans-disciplinary understanding and work because it provides the necessary explanation and analysis of interactions of 'things', organisms, humans or institutions across disciplinary borders and scales. Systemics widens participation and acceptance amongst scientists and technicians across a broad spectrum through the use of familiar language and metaphors. System theory has had a significant impact on current thinking in both natural and social sciences. In a more applied context it has real potential for advancing practices in resources management. For instance, principles of complex systems management have been successfully transferred to business and institutional management.

Key messages:

- The components of this world tend to interact with each other exchanging energy, material and/or information. Ultimately, all interactions are the result and cause of energy conversion according to the laws of thermodynamics.
- Systems are created from interacting components that often produce combined effects that are larger and different from those expected from the individual components: emergent properties.
- Systems that have evolved tend to start interacting with other systems and thereby give rise to systems of higher order. Consequently, the world is composed of nested systems, in which components are simultaneously a self-organizing and functioning *whole* and a *part* of a bigger system (they are *holons*).
- A driving force of system conformation seems to be the tendency towards achieving thermodynamic efficiency, the ratio of possible order and work created by the use of a certain amount of energy. This appears to lead to a maximum closeness of the systems that in turn strengthens system definition and induces a 'boundary effect.' However, as systems are not completely closed but interact with other systems, these boundaries are not isolating, but rather perforated. The active maintenance of system boundaries is

5 Three international treaties have been adopted at the United Nations Conference on Environment and Development in 1992 in Rio de Janeiro, Brazil—a meeting popularly known as the 'Rio Earth Summit': The Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD).

especially characteristic of living organisms and is fundamental to maintaining thermodynamic efficiency and avoiding entropic collapse.

- The interaction of the components in systems tends to create system dynamics and change that are often characterized by feedback loops, (and thus) an auto-referential, auto-regulative and self-organizing performance, and non-linear and unpredictable behaviour.
- System characteristics or features such as occupied space, complexity, energy and material turnover adopt specific states or operating points. The non-linear performance of systems is related to the shifting of the system from one state to another.
- Over time, system shifts can correlate with an increase in structural and functional complexity as well as the degree of 'nestedness'. This is the process of evolution. A corresponding decrease is related to degradation or even dissolution and collapse.
- Systems that persist as a result of auto-regulative processes without significantly and abruptly changing structural and functional complexity, i.e. their characteristics (emergent properties), are described as *sustainable*.
- Unpredictability, uncertainty and the probability of surprising emergent properties increase with the complexity of the systems. Complexity is a measure that depends on the number of system components and their interactions.

BOX 4: Messages from Earth system science and ecology

(For detailed analysis, discussion and references see Hobson & Ibisch, B.2.1., Ibisch & Hobson, B.2.2., Hobson & Ibisch, B.2.3. in this document)

Earth is a complex "super ecosystem" consisting of multiple nested and interacting subsystems with interacting biotic and abiotic components. Ecology is the science that studies the interaction of these components, which are characterised by permanent change. The human system (anthroposystem) is a dependent component of the global ecosystem, but has evolved the capacity of influencing the course of change of the super ecosystem.

Key messages:

- Interacting biotic and abiotic subsystems are semi-open to inter-system exchange of material, energy and information These relatively closed subsystems occur at all scales including continental, regional and local (e.g., terrestrial ecosystems on small oceanic islands are more identifiable as local 'systems' than parts of large sub-continental forest biomes).
- The smaller embedded systems are obligatory members of higher order systems and they depend on the dynamics and function of the latter. However, systems of lower order can create significant feedback changes to the systems of higher order (e.g., plants subtracting CO_2 from the atmosphere and producing oxygen).
- All systems on Earth are subject to the basic natural laws (especially laws of thermodynamics) and systemic rules (e.g., emergent properties, non-linearity). The global ecosystem is an open system with energy input primarily from the sun. The dissipation of incoming energy is a fundamental characteristic of living systems. Furthermore, nature is able to convert and store this energy as exergy (e.g., fossil and living carbon sources such as oil or wood), which is the potential of a system to cause a change as it achieves equilibrium with its environment. The photoautotrophic primary producers are the basis for providing exergy in living systems as they are able to convert solar energy into organic compounds.
- Conversion and storage of incoming energy and the work of living organisms has auto-regulative consequences, that is to say that life on Earth has a significant influence on the environmental conditions on Earth (e.g., influencing atmospheric composition and climate).
- Abiotic changes (e.g., related to solar influx or geological processes on Earth) as well as biogenic changes of the environment cause permanent local, regional and global change of the Earth system and/or the subsystems.
- Throughout the history of the planet, sporadic, abrupt, non-linear shifts in global ecosystems caused by feedback-loops (e.g. to different climate regimes) have driven systems to so-called tipping points, challenging the persistence of many subsystems.
- Throughout the history of the planet, global change has led to significant and dramatic impacts on subsystems. Notable events have included mass-extinction events that have changed the course of biological evolution. However, over time, the self-organizing forces of biological evolution have continued to drive

living systems towards increasing structural and functional diversity and complexity. This process is likely to continue until conditions for life on Earth become more unfavourable (e.g., by changes of solar energy influx).

- Ecosystems can be classified according to their ecological functions based on the contribution they make to regulating and stabilizing the planetary 'super-ecosystem'. For instance, large forest blocks interact with the climate system by absorbing and reflecting radiation, by sequestrating CO_2, and dissipating energy, emitting O_2, taking up and storing precipitation and evaporating it.
- Biodiversity, which is the variability of living systems and the ecosystems they live in, is fundamental in safeguarding ecological functions. The diversity of life contributes to multiple functions that locally and regionally can be affected by stochastic changes.
- As systems diversify and build in complexity they develop resilience, becoming less vulnerable to extreme changes. However, from a certain point onwards, hypercomplexity contributes to opening up systems, decreasing their thermodynamic efficiency and increasing their vulnerability to non-linear system shifts.
- The human species has created a dependent, ultra-complex system complete with its own nested sub-systems. Initially, these sub-systems functioned in isolation to each other (e.g., exchange of people, species, and material). Later development of social behaviour brought about changes including discovery of fossil fuels, and this resulted in the degradation and loss of diversity of ecosystems and their components together with a massive release of exergy stored in the Earth for millions of years (oil, gas, and coal). This development has led to changes that could have far-reaching effects including the potential to synergistically trigger non-linear state shifts of the Earth system and/or its subsystems. These shifts would occur at certain tipping points, e.g. related to the climate system.
- Many anthropic systems, including biomass-poor agricultural areas with biologically impoverished soils, are characterized by a very low thermodynamic efficiency in contrast to ecosystems not dominated by humans. As energy and exergy are the drivers to system evolution and persistence, this low efficiency seems to be a major factor contributing to unsustainability. Industrial ecology[6] has started to focus on issues such as material and energy flow studies, dematerialization and decarbonization and life-cycle-assessments. Clearly, the relevance of this discourse goes far beyond industry.). It is useful for the evaluation of the current development models and their impacts on ecosystems. Comparable approaches exist e.g. in agriculture (agroecology
- The development of complex anthropogenic systems coupled with human-induced global change dynamics has increased the risk of future unexpected and sudden changes in the global 'super-ecosystem'. Unfortunately, scientific evidence gathered from studies carried out at this scale and level of detail is limited. What is required is a more competent and conscious integration of non-knowledge-based analysis with clearly defined objectives such as investigating complex systems-related uncertainty; the management and interactions of ecological and social systems (proactive adaptive management). Even then, there will always be a frontier to the unknowable. From emergent systems come new opportunities for knowledge gain, but equally for unattainable knowledge.

BOX 5: Messages from anthropology, history and social sciences

(For detailed analysis, discussion and references see Ibisch & Hobson, B.2.2. in this document)

Early humans evolved in Africa as an integral species to the local ecosystems at the time. The distinctive evolutionary traits that gave rise to the 'human condition' were advanced social cooperation, intelligence and culture. The emergence of these characteristics can be explained by a systemic process of interaction with the environment. An understanding of human evolution, and the development of complex social behaviour, specifically the psychological relationship with nature, is imperative to the construction of practical frameworks for sustainable development, especially in the context of increasing alienation of people from ecosystems. Humanity must come to terms with its own cognitive limitations and recognize that there are systems and processes governing nature that are of such complexity that they operate well outside the human sphere of influence and understanding. The acceptance of cognitive limitations is a key concept of post-normal science.

Key messages:

- *Homo sapiens* represents a heterotrophic species that evolved the extraordinary ability to exploit ecosystems extensively, including a wide nutritional spectrum. It is the first species on Earth to significantly and permanently change and broaden its ecological niche. This was possible thanks to an auto-accelerating cultural evolution and expansion of the geographical range. Humans are also the first species to use ecosystems without inhabiting them (by transporting and trading ecosystem products).

6 "Systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems" (Allenby (2006)).

- The processes that have shaped biological evolution are the very same that are responsible for cultural development. Cultural evolution, as well as biological evolution, led to diversification, increased complexity, and expansion of subsystems, the social systems, and their subsequent condensing and formation of systems of higher order.
- Principles of system evolution, adaptation to changes, sustainability and collapse can also be applied to social systems and are backed by historical processes of developing and degrading or even collapsing societies.
- Cultural development and progress have enabled humans to consciously change and manage ecosystems according to arising and changing needs. Whenever humans directly use or depend on ecological functions provided by ecosystems or their components, these can be called ecosystem services.
- Cultural evolution and corresponding success related to ecosystem manipulation and management were accompanied by an accelerating alienation from ecosystems, culminating in the generation of urban landscapes.
- Science is the principal means of investigative study and evidence-gathering in the analysis of the human–nature relationship. However, conventional practices of applying reductionism and experimentation have led to an underestimation of the degree of dependence on ecosystem services provided by relatively intact, unmanaged ecosystems. The globalization (and apparent atopization) of ecosystem uses, and sharing of labour with ever fewer rural people involved in directly managing provisioning ecosystem services, has further obscured this relationship, and frustrated attempts to analyse it scientifically.
- Human-induced (global) changes to the environment with subsequent resource depletion and loss, challenge traditional notions human's ability to control and regulate planetary systems and processes. Human failings have created real risks of driving many of the planet's systems over the tipping point with unforeseeable consequences. Dangerous climate change alone could overburden many ecological, biological and social subsystems. Of particular concern are the responses of political systems to increasing multiple stresses. Global change-induced political crises and warfare will present threats to the stability of human civilization, long before direct natural impacts such as temperature rise reach critical impact levels.
- Modern civilization faces the challenge of understanding and resolving the difficult problems arising from global-change-related crises and their complex interaction. Solutions to these problems require a solid foundation of knowledge and applied skills. The combination of intellectual and technical advancements has created a global society overwhelmed by information and knowledge. Accelerated knowledge gain has created its own problems by generating rapidly widening gaps between information availability, information accession and knowledge application. In addition to the surplus banks of information, scientists also face the growing realisation that uncertainty, indeterminacy and ignorance, especially related to global (environmental) change, are exposing a systemic knowledge deficit in matters relating to the human–nature relationship.
- The "deficit model" proposes that scientific knowledge is increasingly decoupled from sector-related practices and policy. At another level, the rate of scientific progress is outstripping the ability of practitioners and policy makers to translate and implement much needed knowledge.
- Current observations and translations of environmental phenomena are presented as simple linear and mostly sectoral models to facilitate understanding and appeal across the social spectrum. However, these models fail to capture the natural complexity of ecosystems, and the interactions between humans and nature. Decision-making does not keep pace with scientific progress and explosion of both knowledge and non-knowledge.
- The post-normal science perspective recognizes that biological systems are so complex, in particular, the relationship they have with energy, that conventional lines of scientific inquiry (physics, chemistry and ecology) provide only part of the answer or solution to problems. It goes further in suggesting that uncertainty and indeterministic tendencies inherent in nature will always generate the unknowable.

BOX 6: Messages from economy and development under global change

(For detailed analysis, discussion and references see Ibisch & Hobson, B.2.2., Freudenberger et al., B.1.1., Kiefer et al. and Geyer et al., B.1.2., Herrmann et al., B.1.3. in this document)

The growth and expansion of modern civilisation has dramatically accelerated the demand for energy and raw materials. This progress of *growth*, normally called *development*, has exploited Earth's exergy and other natural resources as well as the occupation of space. The acquisition of land and resources has been possible by the repression of other living systems. The human appropriation of net primary production of plants has reached a historical maximum. As livelihoods, health and safety improve for more people, the incentive for continued '*growth-based development*' remains high. In particular, human economic systems depend on growth to persist and function. All aspects of the environment and society require innovative schemes for development policy as well as economic and financial flows. The global environmental problems create interlinks between social systems that have had no previous political or economical association. In the current economic climate it is impossible to analyze the complex relationships between human development and biodiversity at the local scale only.

Key messages:

- The conversion and exploitation of ecosystems, and the management of required ecosystem goods and services, has spawned principles and practices of neo-classical economics. Continued alienation of humans from nature has contributed to the sense of decoupling between biodiversity, ecosystem function, and human survival and well-being. More specifically, the neoclassical economic system has ignored the environmental and traditional values of land, and natural resources by externalizing environmental costs (to other countries, regions, continents), and also by overlooking hidden global environmental costs (such as the emission of greenhouse gases that slowly trigger global climate change). The costs of coping with global environmental problems also have impacts on both natural and social ecosystems.
- Developed countries partly compensate for the loss of ecosystem services or existing ecological deficits (less available bioproductive area than required for satisfying the needs of the population) by importing goods and using technological innovation. Conversely, poor countries generally export ecosystem products and services to richer neighbors and consequently increase the *footprint* and resource degradation in their territory.
- In developing and transforming countries multiple direct dependencies on biodiversity can be observed. Clearly, on the one hand, there are cases where biodiversity represents a safety net that mitigates against the consequences of economic and political crises. On the other hand, critical loss of ecosystem services in poor countries is likely to contribute to governance problems.
- Biodiversity loss, decreasing dependence on local ecosystem services, and the integration into the globalized market economy are accompanied by loss of cultural diversity and related biodiversity knowledge.
- Despite the homogenising tendencies of modern civilisation, cultural diversity continues to thrive in many regions, offering a diversity of perspectives and visions on biodiversity, its conservation and human development.
- Climate changes (as well as other environmental change processes) will have negative impacts on ecosystems and ecosystem services all over the world, but developing nations are more susceptible to these impacts. The high numbers of rural populations, their direct dependency on locally generated ecosystem services and agricultural products is increasing the exposure of these communities to the impacts of climate change.
- Environmental economics attempts to assess the values of ecosystems and ecosystem services according to conventional neoclassical rationales. Alternatively, ecological economics factors into the economy natural laws related to ecosystem properties and functioning as well as existing limits to spatial and material growth. Traditional monetary valuation of ecosystem services has limitations in cases where the intrinsic value of biodiversity is considered (as it has been done with the adoption of the CBD).
- Biodiversity valuation continues to be a problem for other reasons. For instance, it is difficult to account for the values placed on biodiversity by future generations. There are clear ethical considerations with this issue. The evaluation of ecosystem services such as regulating and supporting services has tangible elements with real practical implications for human well-being or even existence, and these measures of worth cannot be accounted for in monetary or commercial terms. Global environmental change and the threat of reaching dangerous tipping points of global systems show that global regulative services of ecosystems are of infinite value.

A.2.3 DEVELOPMENT OF THE ECOSYSTEM APPROACH TOWARDS A MORE UNIFYING FRAMEWORK FOR SUSTAINABILITY: A RADICAL ECOSYSTEM APPROACH

All relevant human actions, development and economic activities ultimately depend on ecosystem services. Supporting and provisioning services provide the necessary natural capital required for human physiological maintenance and economic activities, whilst regulating services prevent the Earth system from shifting to other operating points or system states that would be less or not favourable for our species or our civilization. The Ecosystem Approach has the desired potential for establishing a unifying framework for sustainability. To achieve this goal, it is suggested in this paper that certain amendments are made to the existing set of principles and strategic objectives outlined in the Ecosystem Approach.

The underpinning principle to an effective strategy is to accept that sequence and hierarchy matters. All aspects of the Ecosystem Approach are important, but some are of higher importance than others. For instance the integration of humans into ecosystems is fundamental to sustainable development. Furthermore, there is one 'super ecosystem' (Earth ecosystem) on which all sub-systems depend, and is conversely, dependent on the dynamics of these nested lower order systems. Another key feature of this revised strategy is that sustainability is discussed explicitly in the context of future generations. Finally, it is proposed that anthropogenic global change and the globalization of environmental problems is given special attention in the Ecosystem Approach. Some principles can be merged, and others deserve additional clarification (Box 7).

BOX 7: A Radical Ecosystem Approach

Ecosystems as complex, nested systems that change permanently and dynamically

Principle 1: The "Earth super-ecosystem" is a complex system of higher order of nested and/or overlapping and interacting subsystems.

Principle 2: Human systems (the *anthroposystem* comprising both their biological population and their social systems) are an integral and dependent part of the global ecosystem and all laws of nature that rule the functioning of this system should equally apply to the anthroposystem. Biodiversity, especially, will benefit from improving the thermodynamic efficiency of the anthroposystem.

Principle 3: Naturally complex ecosystems shall be managed with due consideration to emergent properties, non-linearity or feedback loops as well as the main drivers of self-organization and evolution. The laws of thermodynamics are of special importance for the understanding of systems' functioning and change.

Principle 4: The ecosystem approach shall be undertaken at the appropriate spatial and temporal scales *(Principle 7 of conventional Ecosystem Approach)*. In a socio-economically and politically globalizing world, with eminent threats related to global environmental change, ecosystem management must be implemented on the local, national and global scale.

Principle 5: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term (*Principle 8 of conventional Ecosystem Approach*).

Principle 6: Management must recognize that change is inevitable (*Principle 9 of conventional Ecosystem Approach*).

Maintaining the sustainable function of the global ecosystem as a key priority

Principle 7: Conservation of ecosystem structure and function, as a prerequisite to maintaining ecosystem services, should be a priority target of the ecosystem approach *(Principle 5 of conventional Ecosystem Approach)*. Maintaining the function of the global ecosystem and avoiding significant state shifts of the Earth system (that comprises all other ecosystems and species as well as all social systems) must be the overarching goal of human development and biodiversity conservation.

Principle 8: Ecosystems must be managed within the limits of their functional capacity *(also Principle 6 of conventional Ecosystem Approach)*, and ecosystem managers or users should consider the effects (actual or potential) of their activities on adjacent and other ecosystems *(Principle 3 of conventional Ecosystem Approach)*. Ecological deficits created by human use of ecosystem services shall not be compensated by externalization of environmental costs to other systems, but shall be reduced by seeking autosufficiency (comprising strategies of sustainable degrowth according to the carrying capacity of the ecosystems supporting a certain social system).

Principle 9: Due consideration must be given to the interlinkages between ecosystems particularly in the context of global environmental change and human globalization. No ecosystem should be treated in isolation; adaptive strategies to global change must be an integral part of ecosystem management, as well as a means to mitigate against the effects of global change.

Principle 10: The ecosystem approach should seek the appropriate balance between the conservation and exploitation of biological diversity *(Principle 10 of conventional Ecosystem Approach)*. Ecosystem use and its consequences must not compromise the functionality of the global ecosystem.

Responsible social participation, economic interests and future generations

Principle 11: Management objectives for land, water and living resources are a matter of societal choices *(Principle 1 of conventional Ecosystem Approach)*. Participatory decision-making shall take into account the interests of future generations irrespective of the constraints to development opportunities for current generations and stakeholders.

Principle 12: Holistic management principles that recognise the virtue and gains of economic evaluation of ecosystems should be practiced *(modified Principle 4 of conventional Ecosystem Approach)*. Equally, ethical and practical limits to the economic valuation of biodiversity shall also be respected.

Principle 13: Management should be decentralized to the lowest appropriate level *(Principle 2 of conventional Ecosystem Approach)*, keeping vertical coherence between higher intervention levels and horizontal coherence between development sectors and scientific disciplines. Ideally, the structure, behaviour and institutional arrangements of management systems should reflect the nested complex systems of nature.

Principle 14: The use of local, regional and global ecosystem services shall follow the principle of equitable benefit sharing. All aspects of human development should be regulated and measured using appropriate indicators of ecological sustainability and equitable benefit sharing. These indicators of sustainability should reflect ecosystem function, efficiency and resilience (principles and measures of thermodynamic efficiency apply here) as well as social justice among present and future generations.

Use of information, proactive adaptive management and post-normal science

Principle 15: The ecosystem approach shall consider all forms of relevant information, including scientific, indigenous and traditional local knowledge, innovations and practices *(Principle 11 of conventional Ecosystem Approach)*. In addition, all relevant sectors of society and scientific disciplines should be included in the process *(Principle 12 of conventional Ecosystem Approach)*. Limits to knowledge, knowledge gaps, uncertainty and blind spots must be factored into all aspects of practice and management. Whilst evidence-based management demonstrates good practice, equally, a competent and conscious dealing with non-knowledge is a fundamental part of complex ecosystem management. Adaptive management should be as proactive as possible, anticipating potential impacts of future changes. A post-normal science perspective recognizes the cognitive limitations of humans and provides important insights for complex systems management.

A.2.4 STRATEGIC OBJECTIVES FOR SUSTAINABLE DEVELOPMENT UNDER A RADICAL ECOSYSTEM APPROACH

Failure by the international community to meet 2010 biodiversity targets has prompted a degree of soul searching and a review of conservation policy (e.g., Mace *et al.* 2010). In the future, "*ambitious but realistic*" targets shall be pursued that also "*address the drivers of biodiversity loss*" (CBD—Convention on Biological Diversity 2009a). Ideally, a future strategic plan for the implementation of the CBD would adopt principles of a Radical Ecosystem Approach especially acknowledging that conserving the Earth's biodiversity is about the management of a spatially limited complex system. Biodiversity loss cannot be halted unless mankind recognizes its specific role as an integral and fundamental part of the global ecosystem. The root cause of all drivers of biodiversity loss is the prevailing human development paradigm that does not sufficiently respect the laws of nature and the need to integrate human economy into ecosystem functioning (and not vice versa).

The COP decision dealing with the post-2010 strategic plan (CBD—Convention on Biological Diversity 2009b) explicitly deals with interlinkages of development and biodiversity, but only to the extent that it is acknowledged that "*conservation and sustainable use of biodiversity should contribute to poverty eradication at the local level and not harm the livelihoods of the poor*". However, it is obvious that CBD's diagnoses are becoming more clear-cut and radical: "*Scientific consensus projects continuing loss of habitats and high rates of extinctions throughout this century, if current trends persist, with the risk of drastic consequences to human societies as several thresholds or "tipping points" are crossed. Unless urgent action is taken to reverse current trends, a wide range of services derived from ecosystems, underpinned by biodiversity, could rapidly be lost. While the harshest impacts will fall on the poor, undermining efforts to achieve the Millennium Development Goals, no-one will be immune from the impacts of the loss of biodiversity*" (Executive Secretary, CBD 2009).

It is more widely accepted that "*biodiversity will benefit people in many ways, including through better health, greater food security and less poverty*" (same document cited above). Now, the challenge is to "*address the underlying causes of biodiversity loss, including consumption patterns, through the main-streaming of biodiversity throughout government and society*" (same document). A number of recent concepts for CBD strategic targets state that 'ecological limits' have to be respected (Executive Secretary, CBD—Convention on Biological Diversity 2009b). Mace *et al.* (2010) propose a set of red, green and blue targets, based on urgency and priority. The highest priority is awarded to targets that address biodiversity change that is directly harmful to people such as collapse of marine fisheries or changes of intact functioning forests (red targets). Green targets would comprise the 'society-wishes-to-have' targets which would be less critical for survival and well-being of humans, and blue targets refer to knowledge gaps, "*enabling understanding and governing the system*". However, this proposal does not cover strategic objectives as it stops short of addressing the symptoms of biodiversity crisis (however motivated and guided by the principle of human well-being) and the call for more knowledge.

BIODIVERSITY AND DEVELOPMENT CRISIS: A POST-NORMAL APPROACH TO METASYSTEMIC MANAGEMENT

What if there is sufficient knowledge to understand the crisis, but an inability to use it? In modern conservation science, knowledge extends beyond simple inventories, the description of single elements of biodiversity or ecological studies. Conservation biology has produced abundant literature on problem analyses. Take the example of the study on Chimpanzees in Côte d'Ivoire (Campbell *et al.* 2008). The results indicate that the number of chimpanzee nests encountered has dropped by 90% from 1990 to today. In this case, a *strategic approach* would not call for increased efforts to monitor the obvious decline. Disease understood—patient dead. Rather, the relevant non-knowledge, not addressed by this kind of problem-focused research, refers to the solution of the problem. With all environmental and biodiversity problems, it is advantageous to know the dimensions and immediate mechanisms of a threat before formulating a strategy for recovery. In a number of cases the scientific 'diagnosis' fails to provide an answer to the problem. In the chimps' case, of course, the root causes of the problem are not related to their biology but instead, to human demographic and socio-economic changes; for instance, in the last 18 years the number of people in Côte d'Ivoire increased from 12 million to 18 million, amplifying poaching and deforestation. This example demonstrates the importance of patterns and factors outside the conventional sphere of biodiversity studies that have relevance to conservation practice. Relevant root causes to conservation problems are linked with the prevailing development issues. However, seldom is conservation research in a position to change the course of development and degradation. Consequently, it is often tarnished with the reputation of working in isolation, detached from reality, "*displacement behavior of academia*" (Whitten *et al.* 2001).

The perceived detachment between science and practice is also raised as a factor limiting the successes in effectively resolving conservation problems. Too often scientific knowledge is presented in an inappropriate style or format for use by practitioners. Equally, practitioners fail to keep abreast with scientific development, often because they are distracted by bureaucratic administration and work overload. Consequently, many conservation management plans and actions are carried out without the appropriate underpinning scientific evidence (e.g., Pullin *et al.* 2004). In recent years attempts to resolve this issue have been forthcoming, in particular, the initiation of evidence-based conservation (e.g. Sutherland 2000, Pullin & Knight 2001). This initiative has made much better use of existing knowledge, and as a result it has greatly improved the credibility of the conservation sector. However, questions remain about measurable improvements in conservation practice as a result of these changes (Grantham *et al.* 2009). For instance, does evidence-based conservation integrate or hamper the use of non-knowledge in concept-building, planning and action for the maintenance of biodiversity? Is there a danger that the focus on generating more knowledge and compiling all the evidence leads to counterproductive results—because the increasing relevance of non-knowledge is ignored or underestimated? Finally, in times of rapid global change with many complexly related and dynamically acting factors, should the emphasis not shift towards a non-knowledge-based approach rather than a knowledge- or evidence-based one? Or are these approaches complementary and of equal importance?

The realized knowledge deficit between the unknown or unknowable and the capacity to gain knowledge sets strong constraints on any strategy that relies on evidence-based practice. Vitek & Jackson (2008) call for an *ignorance-based worldview.* They are aware of the traditional negative connotation of *ignorance* that is generally seen as a deficient human condition that can and should be corrected. We propose a more moderated perspective—*non-knowledge*—a neutral term widely used in sociology and philosophy. It encompasses ignorance, uncertainty and the other facets of the unknown and the unknowable (e.g. Weinstein & Weinstein 1978, Böschen et al. 2006). Furthermore, we propose to adopt *non-knowledge-based conservation* as a kind of post-normal approach to the efforts of saving Earth's biodiversity (Ibisch *et al.* 2009).

This implies that pragmatic and mistake-friendly adaptive management, sited in the Ecosystem Approach, is an important part of this concept. Problems relating to the unknown and the unknowable, knowledge deficiency or overload are no longer treated as constraints or hindrances to effective management and decision-making. In an ideal world, absolute knowledge would help resolve all problems, but in times of rapid and uncertain change the relentless pursuit of knowledge to find the solution fails to "beat the clock".

A *non-knowledge-based conservation approach* would draw on an understanding of complexity of biological/ecological and social systems, and would also adopt lessons learned from applied principles of complex systems, such as those developed in business administration. Observation and steering of the system should not be implemented on a detailed object-systemic level, but rather on a metasystemic level. According to Malik (2008), metasystemic management implies that the direct contents of the problem solving process is less important than the general characteristics of this process. Metasystemic variables include the relative importance of a specific problem in a systemic context; the quality of the solution; the available resources for problem solving; the acceptable or required stress for the problem solving system; and ethical principles and rules (Malik 2008). It is also worthwhile to explore traditional (non-)knowledge systems and approaches to risk management, which are not founded upon detailed information about the natural science of agricultural production, but in many cases achieved to adapt to harsh environmental conditions and changes.

Malik (2008) compares the management of complex systems with a game that operates with changing rules, for instance, alteration in the number of players (some of which are carrying names such as *chance* or *accident*). To be a successful player, it is important to empathise with the other players and guess how they might (re)act; what kind of new players will join the table; and what you then need to do in order to stay in the game. Clearly, this game was easier to play in early times of biodiversity conservation, when the number of players was limited, velocity of change of rules was slower, and the players themselves were less complex.

More recently, international biodiversity conservation has developed conceptually towards more holistic and systemic approaches. The CBD's Ecosystem Approach currently is pretty much in line with post-normal science (Kay 2008). In particular, the approach integrates uncertainty into descriptive models and decision-making practices. Furthermore, it adopts a pluralistic strategy to dealing with problems (Ravetz 1986, Funtowicz & Ravetz 2008). Rather than dealing with elements of a system in isolation, the conservation of ecosystem structure and functioning are made priority targets (principle 5). The consideration of appropriate spatial and temporal scales (principle 7) and the acknowledgement of the need for long-term efforts (principle 8) as well as the principle that change is inevitable (principle 9) implicitly relate to non-knowledge philosophy. Thus, the Ecosystem Approach—if interpreted and developed adequately—is an appropriate framework for managing environmental and social sustainability

(Waltner-Toews 2008). The systematic exploration of principles and methods of post-normal science is of strategic importance for the development of the Ecosystem Approach and CBD's strategic plan.

The integration of the perspectives of the 'post-normal scientists' will also have to be consolidated under the umbrella of the new IPBES (*Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*). As it has been acknowledged that this "*intergovernmental science policy platform for biodiversity and ecosystem services should be established to strengthen the science policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long term human well-being and sustainable development*" (*Busan outcome*; UNEP 2010) The *Busan outcome* sends an encouraging message to the conservation sector: "*Use clear, transparent and scientifically credible processes for the exchange, sharing and use of data, information and technologies from all relevant sources, including non peer-reviewed literature, as appropriate.* (…) *Recognize and respect the contribution of indigenous and local knowledge to the conservation and sustainable use of biodiversity and ecosystems.* (…) *Recognize the unique biodiversity and scientific knowledge thereof within and among different regions, and also recognize the need for full and effective participation of developing countries as well as balanced regional representation and participation in its structure and work* (…). *Take an inter- and multi-disciplinary approach that incorporates all relevant disciplines including social and natural sciences*".

STRATEGIC OBJECTIVES—OUTCOME AND ROOT-CAUSE ORIENTATION

Strategic objectives for the implementation of a Radical Ecosystem Approach should be a prerequisite to any major strategy in biodiversity conservation. As well as clearly stated outcome objectives and prioritized action that help to reduce *dangerous biodiversity change*, it is also necessary to include complementary statements detailing the means of achieving these outcomes. These types of objectives would be an important tool for mainstreaming conservation and development. Ultimately, strategic objectives for the conservation of biodiversity are not '*conservation objectives*' but rather '*development objectives*'. For instance, in many cases, national biodiversity strategies are criticized for the apparent lack of a logical strategic framework (and consequently ineffective) because they simply represent wish lists of outcomes related to the state of biodiversity without going into the mechanisms of biodiversity loss. Strategic and effective conservation is more than a simple justification for the relevance and (economic) value of biodiversity or describing desirable states of species and ecosystems and naming the threats. Rather, it should include the development of constructive alternatives, such as *industrial ecology* or *ecological economics*. Furthermore, it should operate within parameters of nature that include inevitable change, indeterministic dynamics and uncertainty, and scale-related patterns, and feedback processes. The concerns linked to human development and economics is justifiably as much an issue for conservation as is the conventional protection of biodiversity. Both paradigms identify two ends of a continuum.

The **overall goal** or **vision** of a strategic plan in line with a Radical Ecosystem Approach should be written in the context of the Earth super-ecosystem, and should emphasise the importance of creating bridges with the directives for sustainable development as well as the other Rio conventions. The goal statement could be the following:

> ***"To secure a functional and sustainable global ecosystem that provides the necessary services for the well-being of current and future generations without diminishing ecosystem quality or driving systems beyond tipping-points towards alternative unstable states"***.

A corresponding **biodiversity-outcome-objective** would state the following:

> ***"Biodiversity as a prerequisite to human existence is maintained and restored so that it may be fit for purpose for all future generations".***

The formulation of clearly defined and principled objectives presented as a set of holarchic priorities that cut across spatial and temporal scales are fundamental to the process. For instance, where it is accepted that anthropogenic climate change represents one of the major threats to biodiversity and global ecosystem functionality, and thus sustainable development, mitigation of climate change must be of highest priority. Furthermore, those ecosystems that play a major role in gaseous and water transference with the atmosphere, such as forests or mires, must be prioritized for conservation. For instance, uninhabited boreal forests can contribute to global alleviation of (current and especially future) poverty as much as tropical rain forests, and thus deserve equal protection status. All ecosystem services that help to reduce vulnerability against global change should be prioritized. Of course, areas of the world that have high rates of poverty and social vulnerability should be especially targeted. The current draft of the CBD strategic plan proposes that "*ecosystems that provide essential services and contribute to health, livelihoods and well-being, are safeguarded and/or restored and equitable access to ecosystem services is ensured for all*".

Various indicators can be used to describe nature's status and its benefits for people (see e.g., Layke 2009). However, in monitoring, especially on a global level, it is important to reduce the number of indicators to an absolute minimum. The evaluation and monitoring of global ecosystem functionality and quality ideally should be based on a few proxy indicators of system function and dynamics. The following measures could be adequate candidates (see Hobson & Ibisch, B.2.3. in this document):

- Biomass production/carbon storage
- Diversity of native primary producers (species richness)
- Diversity of plant growth forms (functional groups/ strategic types)
- "Trophic tree index" (the number of functional groups of fauna and flora).

Objectives relating to the root-causes of biodiversity loss will have to address the problems of the prevailing development models. One issue is how socio-economic progress is achieved and what development means in terms of material and energy flows. In response, a strategic objective could include the following statement:

> ***"Future technological, scientific and socio-economic developments should be designed to operate towards thermodynamically-efficient systems".***

- To protect biodiversity, the soils, the climate and the whole Earth system, efforts should focus on decoupling human well-being from the following:
- Ever-accelerating energy and material flows;
- depletion of the Earth's stored exergy (e.g., fossil and living carbon sources, such as oil or wood);
- globalization of environmental problems, among others, by externalizing and exporting environmental costs (e.g., through inter-continental trade of timber or agricultural commodities including biofuels).

The goal is eco-innovation towards eco-efficiency (Huppes & Ishikawa 2009)[7]. This includes the mainstreaming of principles of industrial ecology beyond simply decarbonization of energy-provision. It relates to socio-economic development and especially natural resource management towards improved feedback processes, closed cycles and systemic management. Much can be learned from natural systems, and a corresponding key-concept could be called ***econics*** (Box 8).

7 Eco-innovation is a change in economic activities that improves both the economic and the environmental performance of a society (Huppes & Ishikawa 2009).

BOX 8: Econics

The authors propose this term and concept as a logical complement or homologue concept to bionics. Just as *bionics* (or *biomimimcry*) is the application of biological methods and structures found in nature to the study and design of engineering systems and technology (e.g., enzymes, surfaces, materials), then so too might *econics* be the discipline that promotes the mimicking of ecological system dynamics and functioning for an improved ecosystem management and functioning of socio-economic systems. This concept, whilst new, had already been proposed by Dirk Althaus („*Ökonik*"; in German, Althaus 2007), who suggested, that more research into a system science and ecosystem management approach to economic activities in a 'post-fossil society'[8] was needed to inform human activities and socio-economic development.

Econics could be subdivided into approaches that would look at 1. systemic processes and interactions of components in complex systems, 2. thermodynamic and material efficiency of ecological systems, and 3. the role of diversity in the minimization of risks and building adaptive capacity. Energy-dissipating processes that regulate the ecological dynamics within the Earth's biosphere are of special importance (e.g., Ripl 2003). Industrial ecology (Allenby 2006) that aims at achieving thermodynamically efficient material and energy flows as observable in efficient mature ecosystems would be a subdiscipline of econics. It would embrace the concepts of permaculture (e.g. Holmgren 2003) and agro-ecology (e.g., agriculture based on small-scale, biodiverse farms, especially in the context of climate change, Altieri 2002, 2008, Altieri & Koohafkan 2008), as well as a well-implemented and 'close to nature forestry' that mimicks natural dynamics of undisturbed forests, structural diversity and complexity and other characteristics found in undisturbed forests. The development of econical strategies would have particular relevance and value in various strategies devised to meet the challenges of climate change. Specifically, it would promote a better understanding of the thermodynamic efficiency and resilience of natural ecosystems, and how this information could then best be translated into practice that mimics these patterns. In biodiversity conservation and ecosystem utilization, metasystemic management (see above) that mimicks self-regulative processes of complex (eco)systems, would be another example of an econic approach.

A significant improvement in the human footprint could be achieved by reducing the complex and globe-wide use of provisioning and supporting ecosystem services. A successful initiative to promote effective self-sufficiency in sovereign states or even smaller political units would significantly reduce the pressure on ecosystems, especially in biodiverse areas in developing countries. In many cases, it would also contribute to the reduction in vulnerability of (poor) people and regions against sudden changes in the global commodity markets or energy/fuel prices. A reorganising of regional agricultural production cannot be implemented without significant paradigm-shifts in trade, economy and development.

Proxy measures for ecosystem efficiency could take the following form (see Hobson & Ibisch, B.2.3. in this document):

- Quantity of energy input and utilization
- Exergy capacity (stored, usable energy in the system + carbon storage—resource banking)
- Positive feedback measures (quantity of non-recyclable energy and material—waste material and heat loss/capacitance)
- Connectivity/connectedness (biodiversity).

Mainstreaming thermodynamic efficiency would be complemented by the strategic objective of exploring development models beyond economic growth:

EXPLORE POLITICALLY AND SOCIALLY ACCEPTABLE WAYS OF IMPLEMENTING A STEADY-STATE AND RESILIENT GLOBAL ECONOMY.

The entire discipline of ecological economics (see Ibisch & Hobson, B.2.2. in this document) is in line with the Radical Ecosystem Approach as outlined above. To maintain a course towards full ecosystem recovery and long-term sustainability, a serious commitment to the radical principles of the Ecosystem

8 Althaus (2007) claims that the German Johann Heinrich von Thünen was a first protagonist of econics. In his *The Isolated State* (1826), von Thünen developed an analytical concept of spatial economics where the use of a specific plot of land is understood as a function of the costs of transport to markets and the land rent a farmer can afford to pay. Here, energetic efficiency is a key issue that informs the land use. The result was a proposal of an ideal spatial design with four concentric circles around urban centres with, for example, dairying and intensive farming in the inner one, and ranching in the outer one.

Approach would be required. Current trends in global environmental change warn of the planetary boundaries approaching or possibly exceeding tipping points (Meadows *et al.* 2004, Rockström et al. 2009). If one of the targets in sustainable development is to ensure that societies in developing countries reach certain measures of equitability to those in developed states, then compensatory action must be taken by richer societies that involves forms of socially sustainable de-growth (e.g., Fournier 2008). All forms of growth have to be addressed, from population growth to consumption and mobility growth. Parameters such as national biocapacity and ecological footprint or ecological deficit/reserve (Ewing *et al.* 2009), as well as the Human Development Index, would be relevant criteria for negotiating 'growth allowances'. This type of global environmental governance, with its new rules, would require new global governance structures or institutional arrangements. Clearly, the minimization of the externalization of environmental costs is rather incompatible with the current globalization paradigm in trade and economy. The 2009 Copenhagen climate change negotiations have given us an idea of a potentially dangerous future with an economically and environmentally globalized society without global (environmental) governance, nor effective organizations that can moderate political processes at the intersection of national short-term interests and global needs. Naturally, the "*intergovernmental processes that constitute*" *environmental "regimes are too closely allied with the forces that give rise to the problems in the first place to produce real change*" (Speth & Has 2006). Thus, possibly, it is not realistic to expect substantial changes to occur as a top-down process. Paradoxically, global environmental governance will (also) have to start in the form of multiple bottom-up processes. Some authors call even for new forms of civil disobedience in order to catalyze cultural change required for a "great transformation" (Leggewie & Welzer 2009).

Even alternative approaches to trade and production such as 'fair trade' or biological farming would have to further develop in order to embrace sustainability principles such as national self-sufficiency or thermodynamic efficiency of socio-economic systems. "Fair trade" is not necessarily ecologically sustainable, and "biologically produced" is not automatically thermodynamically efficient (e.g. when products are transported over long distances). Without any doubt, the hurdles for restructuring trade and global economy are immense. Additionally, initiatives seeking economic de-growth and agricultural self-sufficiency of developed countries could negatively affect developing countries whose economic structures are largely based on facilitating the externalization of environmental costs of developed countries (e.g., earning their money with the export of agricultural commodities or by the import of industrial waste).

While there is a clear consensus that extreme poverty, hunger and other lacks of human well-being in developing countries must be eliminated, it will be more difficult to achieve a general understanding in developed countries for the need of a reduction of the current consumption standard[9]. Proposing de-growth in developed countries is likely to meet with resistance, because, amongst other factors, it would mean a re-distribution of wealth and work. People would have to work for fewer hours but over an extended period of time, while earning and spending less (and being less free to move wherever they want). Clearly, this requires fundamental changes to socio-economic structures promoting a sustainable population while maintaining the social fabric. A 'down-sizing' in individual economic status of the rich few, brought on by a realisation that prudent accounting and use of the world's natural capital and exergy is the only means of securing long-term sustainability of the planet's biodiversity and peoples, will force modern society to re-assess values of human well-being.

In a limited way, the process has started with the development and implementation of the ecosystem services assessment (TEEB 2008, 2009). However, if this initiative is to move beyond the status of a political gesture and glorified paper exercise, certain traditional dogmas and increasingly dated and inappropriate structures and practices will have to re-invent themselves or go. A single reliance on monetary and materialistic wealth as an expression of well-being has stifled and suppressed much of the other individual and societal values. Recent resurgence in political and religious radicalism warns us of the perils ahead if this singular pursuit continues unchecked. Positive political signals from 'poor' countries

9 Not the *living standard* has to be reduced, but the *consumption standard*. According to a new development paradigm in 'beyond-GDP' societies consumption would not be equal to living standard (e.g., compare EU-Initiative: http://www.beyond-gdp.eu/).

such as the inclusion of mother Earth's rights in the constitution of Ecuador, or the Bhutan concept of Gross National Happiness (e.g., see Braun 2009), may give some hope.

Social and socio-economic indicators of a strategy for biodiversity conservation and sustainable development would have to address more complex and sustainable parameters than the conventional GDP. For instance, energy efficiency and happiness could be combined. Additionally, basic issues such as food security and social justice also have to be addressed.

- National Happiness per energy input and utilization
- Food security for all through sufficient access to vital ecosystem services
- Mechanisms towards a better social justice among present and future generations are established at various administrative and political levels (e.g., percentage of ombudsmen for young and future generations in parliaments).

Human endeavour and prosperity should be evaluated using criteria that define capacity building in communities; meaningful work, and participation in society or creative endeavour (Jackson 2009). This requires a paradigm shift in social logic away from a commodity-driven world to one that is based much more on human-centric values—participation, education and social cohesion (which itself requires the elimination of extreme poverty). Under this system, the economic domain is recognised as part of the biosphere and as such is based on natural capital rather than infrastructural capital. Ecological economics rejects the proposition that natural capital can be substituted for anthropocentric capital derived through the relentless pursuit of resource-hungry technology. Furthermore, the concept factors in irreversibility of environmental change, uncertainty and intergenerational equity. It is rather more adaptive to indiscriminate changes, relying on agent-based modelling techniques that recognise the value of 'self-organising systems.' This micro-system approach is complemented by macro-scale systems thinking that operates a holistic approach to deal with socio-economic interests.

The validation of the ecological economics model is underscored by the primary objective, which is to ground economic thinking and practice in the laws of nature. Success, goals and outcomes are no longer exclusively measured in monetary worth but also by using relative valuation and environmental accounting—biological and physical indicators of worth—a form of 'biodiversity financing'.

A change of this magnitude amounts to a profound paradigm shift in social behaviour and cultural values, nothing less than an induced evolutionary turn in the history of mankind. The alternatives to this chosen pathway are severely limited in the current scenario of global ecosystem degradation and growing population demands. The laws of thermodynamics dictate the circumstances as they are—there is a finite capacity to the planet's exergy capital, surplus energy cannot be created, demands on energy cannot continue relentlessly (for more details see Hobson & Ibisch, B.2.1. in this document)—there is no such thing as continued growth. If survival of current and future societies and a healthy planet are the single most important human objective, then the decision is simple. However, the realisation of this objective is far more problematic, and will require a Radical Ecosystem Approach that guides our policies.

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REFERENCES

Allenby, B. 2006. The ontologies of industrial ecology? Progress in Industrial Ecology **3**:28–40.

Althaus, D. 2007. Zeitenwende. Die postfossile Epoche; weiterleben auf dem Blauen Planeten. 1. Aufl. Mankau, Murnau a. Staffelsee.

Altieri, M.A, 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agriculture, Ecosystems and Environment **93**:1-24.

Altieri, M.A 2008. Small farms as a planetary ecological asset: five key reasons why we should support the revitalisation of small farms in the global South. Third World Network. Penang, Malaysia.

Altieri, M.A and P. Koohafkan. 2008. Enduring farms: climate change, smallholders and traditional farming communities. Third World Network. Penang, Malaysia.

Böschen, S., K. Kastenhofer, P. Wehling, L. Marschall, I. Rust and J. Soentgen. 2006. Scientific cultures of non-knowledge in the controversy over genetically modified organisms (GMO): the cases of molecular biology and ecology. GAIA—Ecological Perspectives for Science and Society **15**:294–301.

Braun, A.A. 2009. Gross National Happiness in Bhutan: a living example of an alternative approach to progress. Wharton International Research Experience. Wharton University of Pennsylvania (http://www.schoolforwellbeing.org/studiesz.php?id=19).

Campbell, G., H. Kuehl, P. N. Kouamé and C. Boesch. 2008. Alarming decline of West African chimpanzees in Côte d'Ivoire. Current Biology **18**:R903-R904.

CBD—Convention on Biological Diversity. 2009a. COP 9, Bonn.

CBD—Convention on Biological Diversity. 2009b. Revision and updating of the strategic plan: possible outline and elements of the new strategic plan.

Ewing, B., S. Goldfinger, A. Oursler, A. Reed, D. Moore and M. Wackernagel. 2009. The Ecological Footprint Atlas 2009, Oakland.

Fee, E., K. Gerber, J. Rust, Haggenmueller, H. Korn and P. L. Ibisch. 2009. Stuck in the clouds: bringing the CBD's Ecosystem Approach for conservation management down to earth in Canada and Germany. Journal for Nature Conservation **17**:212–227.

Fournier, V. 2008. Escaping from the economy: the politics of degrowth. International Journal of Sociology and Social Policy **28**:528–545

Funtowicz, S. and Ravetz, JR. 2008. Post-normal sciences in C. J. Cleveland, editor. Encyclopedia of Earth, Washington, D.C.

Grantham, H. S., K. A. Wilson, A. Moilanen, T. Rebelo and H. P. Possingham. 2009. Delaying conservation actions for improved knowledge: how long should we wait? Ecology Letters **12**:293–301.

Hassan, R. and R. Scholes, editors. 2005. Ecosystems and human well-being. Island Press, Washington, DC.

Holmgren, D. 2003. Permaculture: principles & pathways beyond sustainability. Nimbus Publishing.

Huppes, G. and M. Ishikawa. 2009. Eco-efficiency guiding micro-level actions towards sustainability: Ten basic steps for analysis* Ecological Economics **68**:1687–1700.

Ibisch, P.L., B. Kunze & S. Kreft 2009. Biodiversitätserhaltung in Zeiten des (Klima-) Wandels: Risikomanagement als Grundlage eines systemischen nichtwissenbasierten Naturschutzes. Pages 44-62 in: Ministerium für Infrastruktur und Landwirtschaft (MIL) des Landes Brandenburg, Landeskompetenzzentrum Forst Eberswalde (LFE), editors. Wald im Klimawandel—Risiken und Anpassungsstrategien. Eberswalder Forstliche Schriftenreihe Band 42, Eberswalde, Germany.

Jackson, T. 2009. Prosperity without growth: Economics for a finite planet. Repr. Earthscan, London.

Kay, J. J. 1994a. The Ecosystem Approach applied to the Huron Natural Area. Document prepared for Environment Canada, State of the Environment Reporting, Ottawa, Canada.

Kay, J. J. 1994b. The Ecosystem Approach, ecosystems as complex systems and state of the environment reporting. Document prepared for North American Commission for Environmental Cooperation, Montreal, Canada.

Kay, J. J. 2008. An introduction to systems thinking. Pages 4–13 in D. Waltner-Toews, editor. The ecosystem approach. Columbia Univ. Press, New York.

Kay, J. J., H. Regier, M. Boyle and G. Francis. 1999. An Ecosystem Approach for sustainability: addressing the challenge of complexity. Futures **31**:721–742.

Layke, Christian. 2009. "Measuring Nature's Benefits: A Preliminary Roadmap for Improving Ecosystem Service Indicators." WRI Working Paper. World Resources Institute, Washington DC. Available online at http://www.wri.org/project/ecosystem-service-indicators.

Leggewie, C. and H. Welzer. 2009. Das Ende der Welt, wie wir sie kannten. Klima, Zukunft und die Chancen der Demokratie. S. Fischer Verlag, Frankfurt am Main.

Mace, G. M., et al. 2010. Biodiversity targets after 2010. Current Opinion in Environmental Sustainability **2**:3–8.

Malik, F. 2008. Strategie des Managements komplexer Systeme: Ein Beitrag zur Management-Kybernetik evolutionärer Systeme. Haupt Verlag, Bern.

Meadows, D. H., J. Randers and D. L. Meadows. 2004. Limits to growth: The 30-year update. 1. printing. Chelsea Green Publ. Company, White River Junction, Vt.

Naeem, S., D. E. Bunker, A. Hector, M. Loreaeu and C. Perrings. 2009. Can we predict the effects of global change on biodiversity loss and ecosystem functioning? Pages 290–298 in S. Naeem, D. E. Bunker, A. Hector, M. Loreaeu and C. Perrings, editors. Biodiversity, ecosystem functioning, and human wellbeing. An ecological and economic perspective. Oxford Univ. Press, Oxford.

Pullin, A. S. and T. M. Knight. 2001. Effectiveness in conservation practice: pointers from mdecine and public health. Conservation Biology **15**:50–54.

Pullin, A. S., T. M. Knight, D. A. Stone and K. Charman. 2004. Do conservation managers use scientific evidence to support their decision-making? Biological Conservation **119**:245–252.

Ravetz, J. R. 1986. Usable knowledge, usable ignorance: incomplete science with policy implications. Pages 415–432 in W. C. Clark and R. E. Munn, editors. Sustainable development of the biosphere. Cambridge Univ. Pr., Cambridge.

Ripl, W. 2003. Water: the bloodstream of the biosphere. Phil. Trans. R. Soc. Lond. **358**:1921-934.

Rockström, J., et al. 2009. A safe operating space for humanity. Nature **461**:472–475.

Speth, J.G. and P.M. Haas. 2006. Global environmental governance. Washington, DC:Island Press.

Sutherland, W. J. 2000. The conservation handbook. Research, management and policy. Blackwell Science, Oxford.

TEEB—The Economics of Ecosystems and Biodiversity. 2008. The Economics of Ecosystems and Biodiversity: An interim report.

TEEB—The Economics of Ecosystems and Biodiversity. 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers: Summary: Responding to the Value of Nature.

Thünen, J.H. von. 1826. Der isoli[e]rte Staat in Beziehung auf Landwirtschaft und Nationalökonomie, oder Untersuchungen über den Einfluß, den die Getreidepreise, der Reichthum des Bodens und die Abgaben auf den Ackerbau ausüben. Hamburg : Perthes.

UNEP (United Nations Environment Programme). 2010. Busan outcome. Third ad hoc intergovernmental and multi-stakeholder meeting on an intergovernmental science-policy plattform on biodiversity and ecosystem services.

Vitek, W. and W. Jackson. 2008. The virtues of ignorance. Complexity, sustainability, and the limits of knowledge. University Press of Kentucky, Lexington Ky.

Waltner-Toews, D., editor. 2008. The ecosystem approach: Complexity, uncertainty, and managing for sustainability. Columbia Univ. Press, New York.

Weinstein, D. and M. Weinstein. 1978. The sociology of non-knowledge: a paradigm. Research in the Sociology of Knowledge, Sciences and Art **1**:151–166.

Whitten, T., Holmes, D. and K. MacKinnon. 2001. Conservation biology: a displacement behavior for academia? Conservation Biology **15**:1–3.

B. Background papers

B.1 EMPIRICAL BACKGROUND PAPERS

B.1.1 A VIEW ON GLOBAL PATTERNS AND INTERLINKAGES OF BIODIVERSITY AND HUMAN DEVELOPMENT

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ABSTRACT

This paper proposes the use of the more than 9000 Ecopolitical Units (EPU 9000), a combination of all national state and ecoregional borders, as means of carrying out a detailed statistical assessment of the interdependencies and linkages between biodiversity, human development and global change. To determine general linkages between the social and ecological systems a broad statistical analysis using 66 parameters related to biodiversity, environment, socioeconomics and politics was carried out. Both the statistical treatment and the mapping of selected relationships between different factors (choropleth bivariate maps) shed light on the spatial pattering of coinciding parameters. Major findings, for instance, have revealed a lack of evidence for a relationship between the distribution of carbon storage and vascular plant species richness although species richness appeared to correlate negatively with the degree of threat to biodiversity. However, highest carbon storage was found in those regions of the world that were identified as "most intact" and, and also corresponded with lowest records for vascular plant species richness. Further analysis of the data suggested there were associations to be found between various measures of social parameters such as international trade, demographic factors and human development, and that these also correlated against the index for biodiversity. Furthermore human development and increasing wealth were associated with higher resource consumption and therefore with higher environmental costs and degradation. The findings of this study highlight a complexity of multiple factors underlying the status of global biodiversity that requires a pluralistic approach to integrative planning for biodiversity conservation and sustainable humanwellbeing. In its pretext this paper recognizes that current practices in social and environmental affairs operate in isolation and this is already having a severe impact on human-wellbeing and biodiversity. High export rates coupled with increasing overexploitation of nature are driving down the provisioning of ecosystem services, and this in turn is most affecting local and poor communities in developing countries. The environmental costs for the high standards of living of more developed countries are in many cases externalized and shifted towards poorer countries with high biocapacity.The more developed countries are saving their own resources due to international trade. Especially areas in the northern boreal hemisphere like Russia, Japan and northern Europe are importing agricultural products while they maintain high quantities of forest coverage. Since biodiversity and human development are constantly interacting and are mutually dependent, conservation has to be incorporated in human development policy much more consciously and actively. Equally, biodiversity conservation has to operate within the realistic expectations of social needs including growing demands on resources. The extreme effects of globalization on both ecology and social wellbeing demands a radical approach to future strategies of managing human and environmental sustainability.

INTRODUCTION

Societies and nature cannot be seen as two separate systems (e.g. Silver 2008; Ibisch& Hobson, B.2.2. in this document). Almost all ecosystems on the planet are shaped either directly or indirectly by human activity. Attempts to segregate culture from nature and to work in isolation from the natural environment

10 L.F. implemented the research and analyzed the data; P.L.I. guided and supervised the research; M.S. compiled the data and maps; P.H. and H.S contributed statistical support; L.F., P.L.I., M.S., and P.H. wrote the paper. W.B. and W.C. contributed data and ideas.

have created untold problems including failure to take account of essential feedbacks of complex adaptive (so-called) social-ecological systems (Folke 2007).

All systems are dynamic and subject to change as a result of unpredictable events. Global environmental change coupled with ongoing globalization and associated economic, demographic and social development has led to the extensive transformation of our environment. Human population is projected to increase to 9 billion by 2050 (United Nations Department of Economic and Social Affairs 2009) and this will greatly increase the demand for energy (Dias *et al.* 2006). Over the last one hundred years social development has been responsible for the degradation and transformation of many ecosystems, and for much of the planet's largest systems—the oceans, freshwater ecosystems and forests, the threshold that signifies the "tipping point" for a system has been reached. This will have profound implications for the wellbeing of future generations as the long-term survival and sustainability of human civilization depends on the health and resilience of ecosystems providing services that are integral to human survival (Monticino*et al.* 2007). Any shift in regime of the world's major ecosystems will result in cascade effects across many other ecological and social systems (Rockström*et al.* 2009). However, safeguarding global biodiversity and social sustainability will require a complex interdependent operational framework that accounts for the dynamics and feedback loops between various social constructs and nature at all scales (Silver 2008; Ibisch& Hobson, B.2.2. in this document). Such a framework would acknowledge the uncertainties and emergent properties of complex systems including the open exchange of energy and materials, for instance, the global use of ecosystem services (Ibisch& Hobson, this document).

But in the globalized social and ecological system we live in, human development and biodiversity is not only taking place sheltered from external influences. We have to consider that the use of ecosystem services is not localized anymore (Ibisch& Hobson, B.2.2. in this document).

Most human population across the planet profits to varying degrees from natural resources and other ecosystem services sourced elsewhere. The use of some of these services, such as timber products, minerals, fossil fuels and oceanic fish stocks is internationally regulated but much of the planet's natural capital and ecosystem services including clean air, pollination, biological pest control, decomposition and hydrological regimes are not. Furthermore, regulatory measures depend on import and export rates that do not necessarily relate to the resource needs of the local population. To effectively account for current and future pressures on biodiversity, human development, and potential future resource conflicts under global change, it is necessary to consider global trade flows and how they may change under a plausible future scenario of diminishing ecosystem services.

Current global strategies in conservation are exercised through legal regulations enforced through social and political frameworks. Increased globalization over the last 70 years has moved conservation more towards international conventions and agreements that are designed to overcome the hurdle of administrative boundaries. Nevertheless, international directives for conservation are ultimately administered through national policy and legislation. There are scale-related problems with this strategy such as insufficient understanding of the interactions, interdependencies and feedbacks of human and natural patterns that define many aspects of globalization (compare Silver 2008).

Numerous studies have analyzed the relationship between different environmental variables and climate. For example, greatest species richness can be found in warm and humid regions (Kreft&Jetz 2007; Sommer*et al.* 2010). Other studies focused on patterns, such as carbon storage and biodiversity (Strassburg*et al.* 2010). More recently researchers have explored possible links between human development and biodiversity. But with increasing global challenges such as climate change, population growth and overexploitation of natural resources, a much more integrative approach for biodiversity conservation and sustainable human development is needed (Redman *et al.* 2004; Folke 2006; Sachs *et al.* 2009). Learning from past experiences, an analysis of the interactions between biodiversity and development is crucial to a better understanding of the mechanisms of avoiding problematic pathways in the future (Cornell et al. 2010, in press).

Specific research on human population growth and its effects have revealed some evidence for a congruent distribution between human population density and biodiversity (Brashares*et al.* 2001; Araujo 2003; Turner *et al.* 2004; Evans & Gaston 2005; Gaston 2005; Vazquez &Gaston 2006; Luck 2007), and for a strong positive correlation between population density and threats (McKinney 2001) including species extinctions (Brashares*et al.* 2001; Ceballos& Ehrlich 2002; Gaston 2005). For example, human population density and growth were found to be significantly higher in biodiversity hotspots, which are those parts of the world considered to inhabit most species and to be most under threat from human activity (Cincotta*et al.* 2000). Areas with high levels of endemism also overlapped with human impact and projected land-cover change (Kier *et al.* 2009). The congruence between human population density and species richness has primarily been explained by higher primary productivity and energy availability (e.g. Chown*et al.* 2003; Evans & Gaston 2005; Luck 2007). These studies indicate that human needs and species diversity are dependent on the same climatic and ecological conditions. This pattern is most noticeable in Africaunlike the rest of the world where a different set of factors appear to play a much more important role (Bawa&Dayanandan 1997).

Historical and anthropological factors appear to have some bearing on human relationships with nature. For instance elements of both culture and biodiversity show similar relationships to area, latitude, forest extent and climate (Collard & Foley 2002; Moore *et al.* 2002; Sutherland 2003). Furthermore human population growth and development correspond to rates of deforestation (compare Carr 2004; Jha&Bawa 2006) and energy consumption (Dias *et al.* 2006). Agricultural trade is also correlated with deforestation (DeFries*et al.* 2010) and likewise the extent of agricultural development corresponds with habitat loss (Bawa&Dayanandan 1997; DinizFilho*et al.* 2009); species endangerment (Czech *et al.* 2000; Lenzen*et al.* 2009); and species population extinction (Ceballos& Ehrlich 2002). Other socio-environmental factors such as rates of deforestation and ranching, and outdoor recreation, or the harvesting of wild species also appeared to correlate positively with species loss and extinction rates(Czech *et al.* 2000).

In their work DeFries*et al.* (2010) suggested that the relationship between population growth and deforestation was particularly strong for urban population growth, indicating that urbanization was increasing forest clearance and that this would continue in the future as globalization, population growth and urbanization continued to increase. What is more, urbanization was impacting on remote areas also known to be rich in biodiversity as these regions were opening up to global markets and this in turn was bringing about change in household economics, social networks, infrastructure, information and communication technologies (McDonald *et al.* 2008; Kramer *et al.* 2009; McDonald *et al.* 2009). These findings were also confirmed in the studies carried out by Araujo*et al.* (2008), where it was suggested that there was an even higher probability of increased urbanization and associated threats in areas with comparably high species richness due to the effects of human activity on species diversity.

The pressures on natural resources, ecosystems and species are not only related to demographic and economic issues but also to social and political factors. Examination of the interaction between development and deforestation demonstrated that initial stages of deforestation human development appeared to benefit,but as the process advanced there was a steady down-turn for human wellbeing and development (Ewers 2006; Rodrigues *et al.* 2009). Additionally there appeared to be a correlation between armed conflicts and biodiversity hotspots, the areas with highest biodiversity were also commonly recorded as regions experiencing highest threat rates (Hanson *et al.* 2009). Similarly, regions with relatively high numbers of threatened species coincided with high levels of economic inequality (Holland *et al.* 2009). In keeping with this pattern, those areas of the World noted for relatively high numbers of threatened species were also identified as hot spots of economic prosperity (Naidoo&Adamowicz 2001). The findings of this study also revealed apparent associations between measures of corruption and extent of forest cover, although this result was likely to be influenced by the stronger relationship between per capita gross domestic product and deforestation (Smith *et al.* 2003). Furthermore, Morse (2006) found a relationship between sustainability as defined by the Environmental Sustainability Index, per capita income, and corruption. Sustainability appeared to decline with decreasing income while corruption worsened.

Empirical evidences for the effects of corruption on conservation efforts are scarce, and scientists were unable to determine whether the relationship between the two was positive or negative. On one hand corruption is destabilizing governmental structures which are important for maintaining law and order, and conservation effectiveness and efficiency, whilst on the other hand corruption also destabilizes the economy and in doing so could have indirect positive effects as a result of reduced resource extraction (Katzner 2005; Smith & Walpole 2005). In contrast, a positive association between democracy and environmental conservation is apparent (Li &Reuveny 2006) as well as a positive effect of institutions on conservation outcomes (Oldekop*et al.* 2010). Although there are also arguments that the effects of institutional and technological changes are negligible if we consider the impacts of consumption behavior and resource needs (York *et al.* 2003).

The cited studies provide a detailed and focused analysis of specified components of nature-culture relationships but do not attempt to build these into a complex or integrative framework. This section of the series adopts a whole systems approach by examining the interdependency between multiple human-induced factors and the collective affects they exert on natural systems.

Extensive metadata on many aspects of social and ecological systems exist in a variety of formats (e.g. United Nations Environmental Programme (UNEP); Socioeconomic Data and Applications Center (SEDAC); Hoekstra & Molnar 2010). This range of socio-ecological data is suitable for detailed analyses using a combination of spatial and statistical techniques.

IN THIS PAPER THE FOLLOWING QUESTION IS ADDRESSED:

How do biodiversity, ecosystem services and societal parameters spatially coincide at a global scale?

Drawing on theresults of the analysis the authors discuss the influence of globalization and global change on human development and biodiversity. In the concluding section of the paper the application of these findings in developing a more sustainable pathway towards development are outlined.

Generally, it was not possible to include all the perceived number of parameters reflecting all levels of biodiversity and ecosystem services due to time constraints and the limited amount of data available. Furthermore, this study only presents a snapshot in time. Therefore, lag-time effects between variables are not explicitly considered. Notwithstanding these constraints, this paper attempts to show how human development is influencing the provision of ecosystem services, as well as identify the particular conditions that favour human development.

The concept of spatial and temporal scale is important in social and ecological science (Sayre 2005). Ecologists more often work with spatial dimensions and less with temporal patterns and changes. Nevertheless, spatio-temporal patterns and processes are inherent to the Earth's natural system but more recently have undergone profound changes as a result of human activity. Geological and biological patterns determine ecological units and although modified by human impact, these structures are still apparent today and can be referred to as the ecological spatial view of the world. In their research Olson (2001) structured the terrestrial biosphere into ecoregions which are large units of land containing a distinct assemblage of natural communities sharing a large majority of species, dynamics and environmental conditions (Olson *et al.* 2001).

In addition, social and political structures also exhibit scale-dependent phenomena including individuals to organizational and social institutions determining rules, laws, policies, and formal and informal cultural norms that govern the extent of resource access rights and management responsibilities (Cumming *et al*. 2006). Administrative borders and societal differences have been shaped through history since human genesis. War and migration have led to a constant reformation of the political structures of the world for administrative purposes and to satisfy the need of social affiliation. National states represent similar social, political and economic conditions and can be seen as the most predominant and well-defined socio-political units of the world.

Administrative borders are in some instances analogues to ecoregional stratification (e.g. in cases of rivers or mountains) but in many cases they are not. The ecoregion No. 223 "MediterraneanForests, Woodlands and Scrub", for example, is composed of territories belonging to 29 different countries (Olson *et al.* 2001; WWF). This mismatch between the human and the ecosystem dimension has been called the "problem of fit" which hypothesizes that the fit between the different institutions, and also with the biophysical and social domains in which they operate, account for the effectiveness and the robustness of social institutions (Cash *et al.* 2006; Folke*et al.* 2007). This may result in mismanagement of ecosystems, degradation of social and ecological systems and the loss of important ecosystem services (Cumming *et al.* 2006). Furthermore, ecosystem services are not always derived from the same socio-political unit that society belongs to, and the impacts emanating from one society may affect ecosystems and ecosystem services somewhere else (Cumming *et al.* 2006).

In this study the Earth's systems are spatially analyzed according to both ecological and political boundaries, and then integrated under a new proposed classification, the Ecopolitical Units (EPU9000). Based on this new spatial resolution comprising 9042 EPUs a global assessment is provided, complemented by an analytical perspective of the state of the world. Specifically, relationships between a spectrum of indicators for biodiversity, ecosystem function and conservation status, social and political realities are explored.

Currently, there are only a few studies including a broad set of indicators of environment and development interactions for a global social-ecological inventory (e.g. Geist &Lambin 2002; York *et al.* 2003). This research is the first of its kind that combines both environmental and developmental attributes onto one scale—the Ecopolitical Units (EPU 9000). This way it is possible to evaluate more effectively the interdependencies between human development and ecological conditions.

To determine general linkages between the social and ecological systems a broad statistical analysis using 66 parameters was carried out. In figure 1 they are displayed within a Driver-Pressure-State-Response framework (DPSIR). The DPSIR framework provides a system-analysis sight into the relationships between the ecological, social, economic and political system and facilitates a systematic selection of indicators. The original DPSIR framework was developed by the European Environment Agency (EEA 1999) and modified for the purpose of this study. The driving forces describe the influences and human activities that underpin the resulting pressures. The state describes the current status of the systems and impacts are effects of pressures on the state. Responses refer to the efforts and actions undertaken to mitigate or to adapt to impacts.

A detailed methodology, and an in-depth presentation and discussion of the results as well as a description of the analyzed parameters can be found in the appendix (A to D).

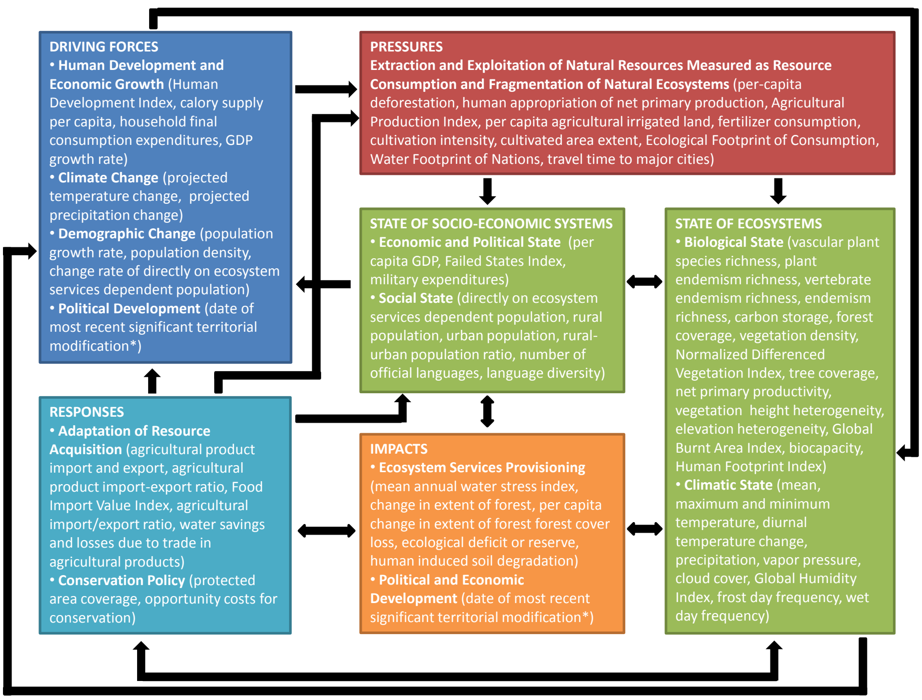

FIGURE 1: Modified Driver-Pressure-State-Impact-Response model with indicators used in this study. Indicators are displayed within brackets. Indicators labeled with * are assigned to more than one box. Arrows indicate causal relationships and direction of influence.

SELECTED INTERLINKAGES BETWEEN THE ECOLOGICAL AND SOCIAL SYSTEMS

The statistical analysis (see appendix) revealed the following major findings:

- Species richness and carbon storage are not congruent in their distribution. Vascular plant species richness is lower in sites with higher carbon storage and vice versa. A trade-off between carbon sequestration and areas with high species richness might exist and this would have implications for conservation practitioners and planners.
- Those areas of the world considered to be most threatened from human activity are also recorded as having the highest species richness but lowest carbon storage, while areas with low species richness and high carbon storage are the most intact ecosystems with the lowest degree of threat.
- Although countries that are less developed are characterized by relatively low resource consumption rates they appear most degraded, and also suffer from high levels of resource exploitation. More developed countries, on the other hand, with high resource consumption rates are characterized by lower Human Footprint Index values.

These results indicate that resource overexploitation and environmental degradation do not necessarily promote human development. The anomaly that exists in countries with high consumption and resource demand but low ecosystem degradation is examined further using GIS–constructed atlas maps.

HUMAN DEVELOPMENT AND RESOURCE DEGRADATION

Notwithstanding the relatively low values recorded for both Human Footprint Index and Human Development Index in some areas of the world, these regions are also recorded as having a higher ecological deficit due to higher consumption rates. Generally, it is the more developed nations that fall into this category (see statistical analysis in Appendix B.). This is especially the case in North America (except Canada), Europe, Saudi-Arabia, Iran, Turkey, China, South Korea, Japan and Thailand (Figure 2). Other developed countries that buck this trend by supporting significant ecological reserves and wildlife capital include Canada, Finland, Sweden, Australia, New Zealand and also most parts of South America, and to an extent Russia. Many African states are relatively rich in wildlife capital and ecological reserve but are poor performers in measures of human development.

The map picturing the Human Development Index together with the Water Footprint Index shows a similar pattern (Figure 3). The Water Footprint Index is extremely high in the more developed countries of North America, many parts of Europe, Brazil and Argentina, Russia, China, Southeast Asia and Japan. Low Water Footprint Index values combined with relatively high human development appear in very few countries such as Norway and Finland. Many of the countries with a low Water Footprint Index also have corresponding low rates for human development. This category includes many of the African countries. However there are a number of countries including India, Nigeria, Indonesia and the Philippines that have high Water Footprint Index values but a low Human Development Index.

HUMAN DEVELOPMENT, INTERNATIONAL TRADE AND ENVIRONMENT

Today, global markets represent rather open systems (see Ibisch& Hobson, B.2.2. in this document), and this phenomenon of globalization has led to dramatic increases in both import and export trading. Both economic demands and manufacturing needs in many of the developed countries have altered the way trading is carried out and now extends beyond political boundaries to include other countries where production costs are lower or biocapacity is higher. This exchange of goods has led to a complex system of mutual dependency. This aspect of economic dependency is depicted in figure 4 using data for agricultural import-export ratios, and also for ecological deficits and reserves. For instance, North America, South America, Australia and Southeast Asia (shown in green and yellow) are exporting agricultural commodities (and thus, indirectly, natural resources such as water or soils) to some European, Asian and African regions (shown in blue and purple). The spatial data for agricultural import and export ratio, and human development indicates that countries fall into one or other categories of export or import (Figure 5). Additionally, resource demand is high in those countries with corresponding high values for human development status. South America, for example, is a major exporting region for agricultural products satisfying the needs of other countries such as the USA, most European and some Asian countries. Although some African countries are importing much more agricultural goods than they export, their resource use is relatively small since their Human Development Index is very low. Other countries in Africa appear to have high export rates, but a low Human Development Index.

Agricultural production and high export rates of developing countries are often justified with the argument that open trade will lead to human development. The Kuznets curve typifies the relationship between export-oriented development and economic growth, followed by a reduced pressure on natural resources and assumes the inverted "U"-shaped relationship between wealth and environmental damage. But evidence for this relationship is weak (compare Muradian& Martinez-Alier 2001; Kessler *et al.* 2007; Bradshaw *et al.* 2010). We argue that at the tipping point, where human development leads to decreasing environmental damage, the environmental costs are often externalized. Because of the leakage effect, environmental costs can only be determined on a global scale considering trade flows and true average resource demand per capita (compare Ghertner&Fripp 2007, Ibisch& Hobson, B.2.2. in this document). This paper supports the findings of Muradian&Martinez-Alier (2001) in refuting the Kuznets Curve for the unsubstantiated assumption it makes about the time lag between the period of development and the point at which the effects of development reach levels that prompt action to mitigate against environmental problems, and restore damaged systems. Furthermore, the model also assumes the immobility of production factors. In fact, economic and resource capital flows almost without restriction around the world, and it is often foreign companies and people that profit rather than the local communities.

Furthermore, developing countries are producing increasing quantities of unprocessed agricultural commodities which has had the effect of lowering global prices. Increase in commercial crop production has substantially raised the levels of pressure and threats to natural resources and ecosystems. More recently, some regions have responded to this down turn in environmental conditions by switching production towards increased specialization. This has its own problems including raised levels of vulnerability to price fluctuations and the impacts of climate and environmental change (Muradian& Martinez-Alier 2001; Ericksen 2008). This paper proposes that primary production is not necessarily promoting technological innovation or skill development. The status of developing nations is likely to remain unchanged if they continue to concentrate on resource exploitation and export of agricultural commodities (compare Muradian& Martinez-Alier 2001). Current trends would suggest that sustainable management of resources can only be achieved by a world-wide reduction in use of energy and materials (compare York *et al.* 2003; Ehrlich & Pringle 2008; Caviglia-Harris *et al.* 2009). In this study it is predicted that high export rates coupled with increasing overexploitation of nature will have negative effects on ecosystem services provisioning within regions of high agricultural production and exportation. The most vulnerable sectors of society will be the local and poor populations but ultimately the whole humanity will feel the impact. The environmental costs for the high standards of living of more developed countries are in many cases externalized and shifted towards poorer countries with high biocapacity.

THE EXTERNALIZATION OF ENVIRONMENTAL COSTS

Our data indicate that the externalization of environmental costs is having negative effects on ecosystem services especially in less developed areas with a high proportion of poor and rural populations. The importing countries, on the other hand, are saving their own resources due to this international trade. In many areas high export rates are leading to intensive deforestation (Figure 6), while forests in agricultural import-oriented countries can be maintained (Figure 7). In particular, areas in the northern boreal hemisphere like Russia, Japan and northern Europe are importing agricultural products while they maintain high quantities of forest coverage. Simultaneously many Southeast-Asian countries and some South American regions are covering their resource demands (indicated by the yellow coloring) through a combination of high export and high deforestation rates. Some regions in Africa (e.g. Namibia, Angola, D.R. Congo, R. Congo, Gabon and Equatorial Guinea), also have a high import and low deforestation rate, but here the lower demand forall resources should be factored into the analysis. Most areas in northern Africa are characterized by sparse vegetation and hence low deforestation rates. Therefore their low deforestation rates cannot be considered as a true contribution to the conservation of global forests.

The externalization of environmental costs refer not only to extraction of wood or minerals but also factor in the global trade of water-intensive products such as coffee or cotton resulting in an international trade of water (Figure 8). In some areas water is not naturally available but they are still inhabited by people. Water has to be imported to these areas either because of high population densities or because of high resource consumption rates (Figure 9).

There are a number of countries that export ecosystem products to other parts of the world and in doing so are degrading their own natural environment as well as diminishing and degrading the exported natural resource. Within developing sovereign states decisions concerning resource exploitation and exportation reside with those countries. However, often the combination of poverty and crippling debts creates an import-export dependency on more economically wealthy trading states, a form of economic colonialism.An analysis of the dependency between the date of acquisition of sovereignty and the agricultural import-export trade patterns (Figure 10)reveals a number of discernable patterns relating to the post-independent age of some countries. Certain former colonies have extremely high export rates (especially in Southeast Asia, and Oceania) while other former colonies are importing as much as they export (e.g. mostly in Africa). One possible explaination for this difference is the insufficient provision of logistical structures or generally low biocapacity (especially in northern African countries).

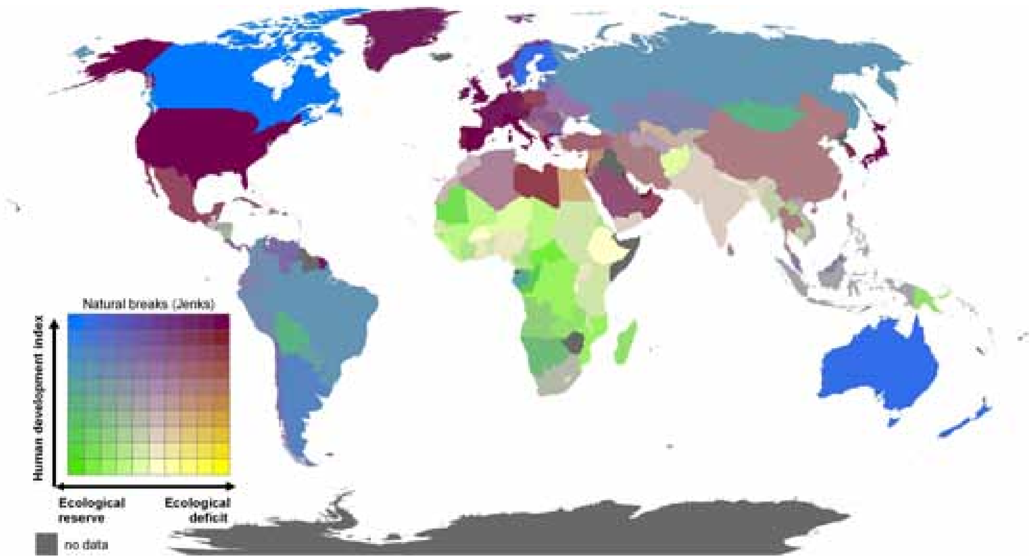

FIGURE 2: Choropleth bivariate map of the Human Development Index and the ecological deficit respectively reserve for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

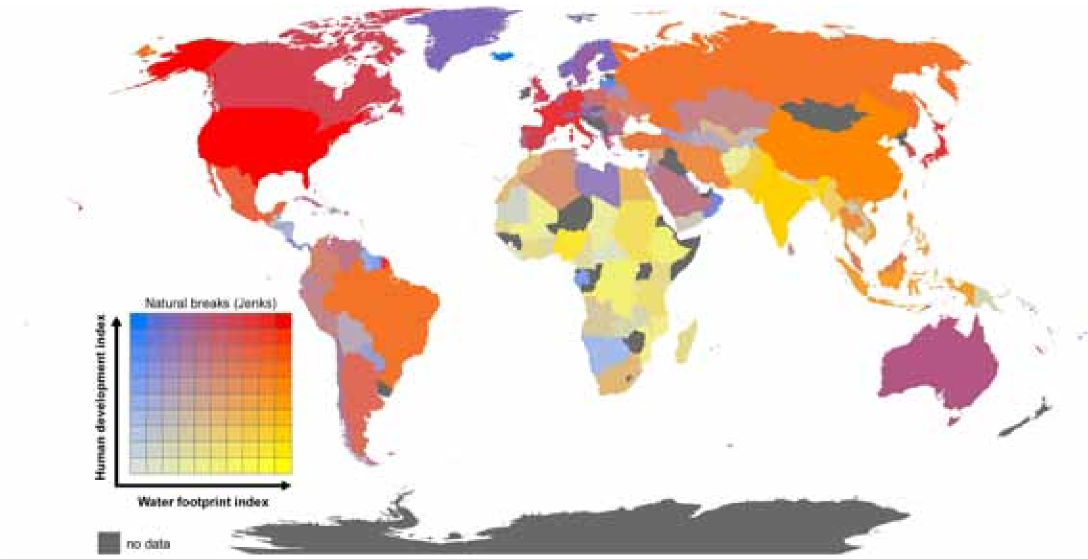

FIGURE 3: Choropleth bivariate map of the Human Development Index and the Water Footprint Index for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

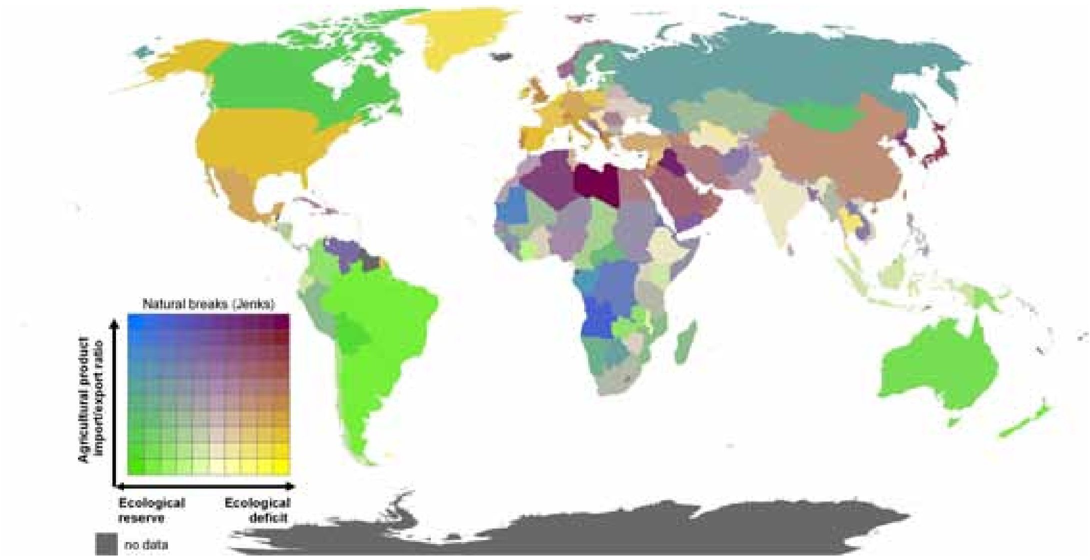

FIGURE 4: Choropleth bivariate map of the ecological reserve or deficit and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

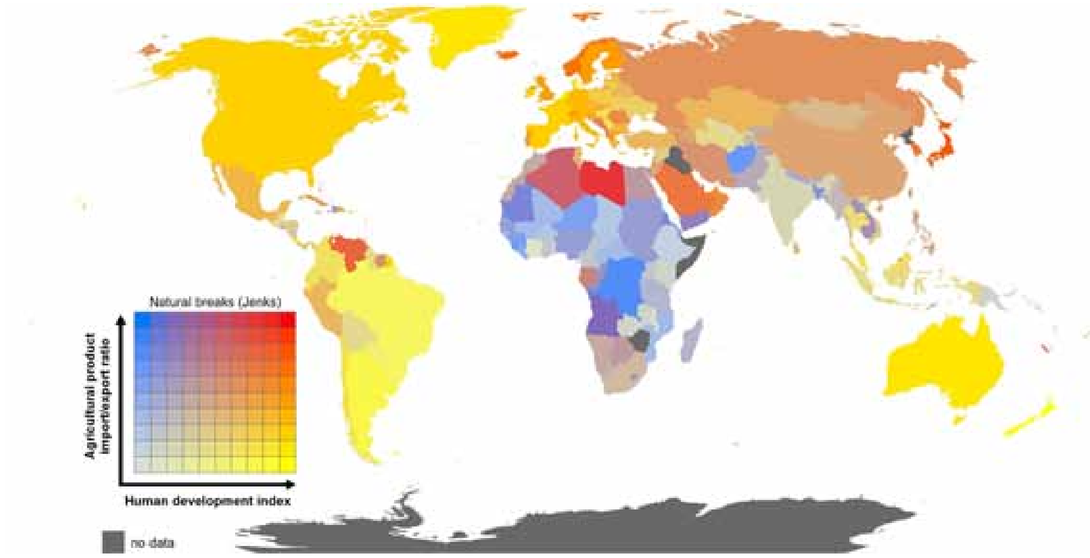

FIGURE 5: Choropleth bivariate map of the Human Development Index and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

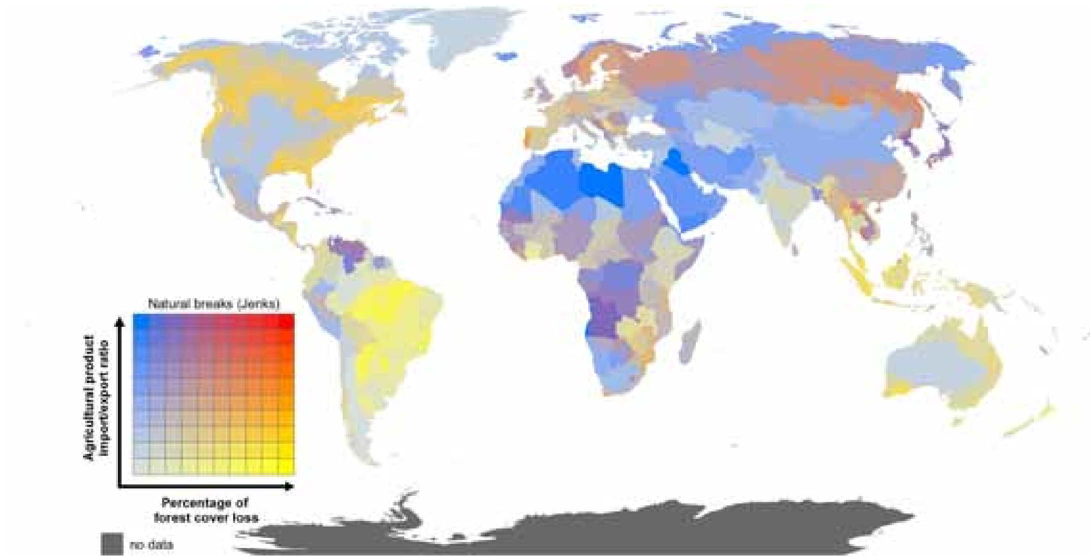

FIGURE 6: Choropleth bivariate map of the percentage of forest cover loss and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

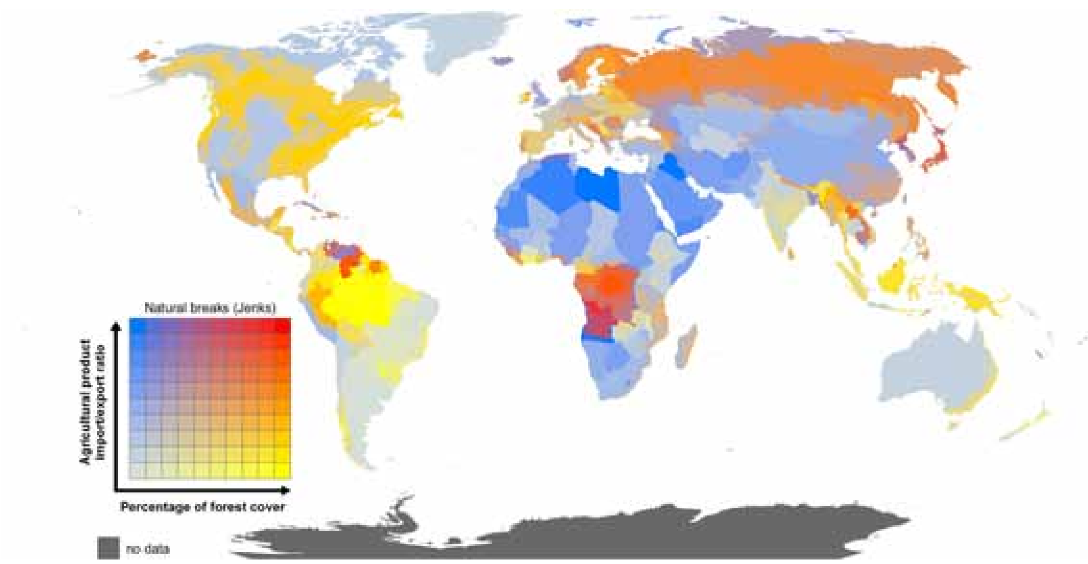

FIGURE 7: Choropleth bivariate map of the percentage of forest cover and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

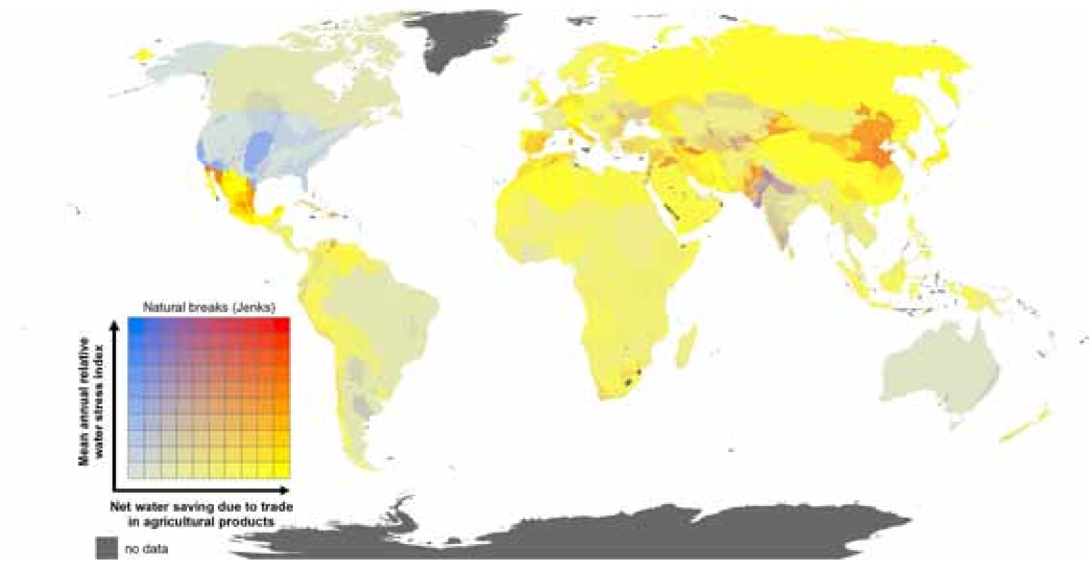

FIGURE 8: Choropleth bivariate map of the relative water stress index vs. water savings due to international trade for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

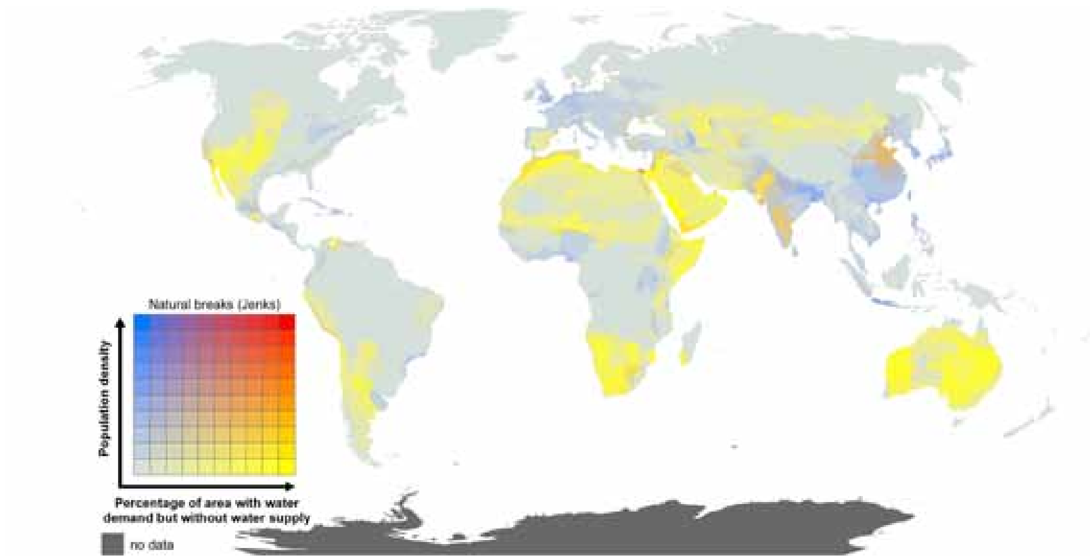

FIGURE 9: Choropleth bivariate map of population density vs. water demand but without water supply for Ecopolitical Units. Grey areas represent missing data; classification by natural breaks (Jenks).

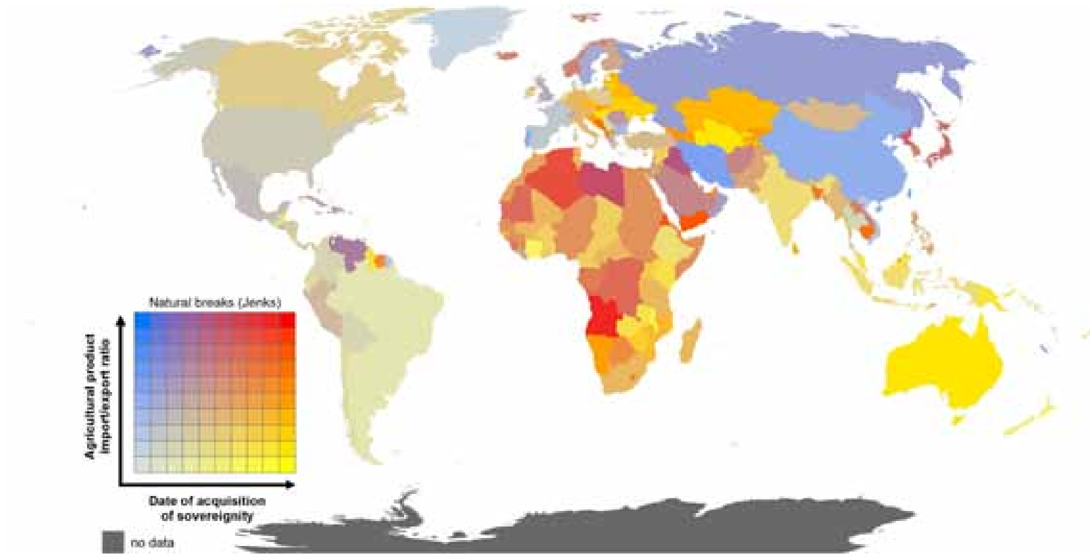

FIGURE 10: Choropleth bivariate map of the date of acquisition of sovereignty and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

PROSPECTS ON HUMAN DEVELOPMENT AND BIODIVERSITY CONSERVATION UNDER ENVIRONMENTAL GLOBAL CHANGE

The impacts of global change, especially climate change, appear to be accelerating and also causing more pronounced effects on both ecological and socio-political systems. However, the effects of this change are unevenly distributed across the planet. Temperature rise is expected to be higher in the upper and lower latitudes but only moderate around the equator. Nonetheless, direct economic and social impactsare projected to be much higher in areas with lower human development and lower adaptive capacity. The maintenance of the world's biggest carbon storages and sinks is one of the most effective and immediate ways to slow down anthropogenic climate change.

Figures 11 to 13 show where forest cover, carbon storage, projected temperature and precipitation change (according to the selected model and emission scenario)is likely to overlap, and this scenario suggests that temperature increase will be most significant in northern areas with high carbon storage and greatest cover of vegetation. The greatest changes in precipitation and carbon storage are projected for Southeast Asia, Middle Western Africa and South America. Apart from expected temperature increase and precipitation decrease there are indications that changes in the number and severity of extreme events, droughts, floods and other climate related events will have an extreme impact on ecosystems and their functioning. Ecosystem integrity can be seen as a prerequisite for a correspondingly required resilience to cope with or adapt to these changes. Yet some of the possibly more strongly impacted areas are still profiting from their comparably low Human Footprint. However, overexploitation of natural resources, indicated here as deforestation (Figure 14), cultivation (Figure 15 and 16) and human induced soil degradation (Figure 17), already has had severe impacts on the integrity of natural ecosystems and their capability to adapt to global climate change. This is especially the case for parts of North America, Europe and Russia. Those parts of the world considered less degraded continue to provide low opportunity costs for conservation as pressures on land, for the time being, remain low. These areas could be targeted for global conservation action to preserve vital regulatory ecosystem services for the wider region (Figure 18).

Specifically in these low-impact/high-ecosystem-services areas not only is the resilience of ecosystems playing an important role in mitigating against the impacts of climate change but it is also contributing to the collective resilience of societies and their capability to adapt to new climatic conditions. This adaptive capacity is lower in areas with a high proportion of rural and poor populations. Typically, these communitiesrely heavily on the ecosystem services from the local area,this is particularly evident in forested landscapes (seeSunderlin et al. 2008). This is especially noticeable in China, India and Southeast Asia (Figures 19 and 20). People in more developed regions with a lower proportion of agricultural population are also heavily reliant on ecosystem services. However, for those societies which are already importing many of the ecosystem services, they will have the opportunity to rearrange their economic import export relationship in order to maintain their supply, unless their economies degrade or collapse as a result of global, political or economical changes. At the same time resource demand is likely to increase in areas with high population growth rates, as is projected for most of the African countries (Figure 21). Any significant increase in population across the African states will inevitably raise the demands for agricultural products. However, meeting these needs will be problematic for those countries suffering severe poverty and economic crisis. In some cases the combination of poor environmental and economic conditions will drive these states into political instability.The continuing effects of climate change and human exploitation will dramatically reduce and degrade the planet's natural resources and thus drive down ecosystem functionality.The resulting scarcity of ecosystem services will drive up prices and contribute to socio-political instability in the most vulnerable regions.

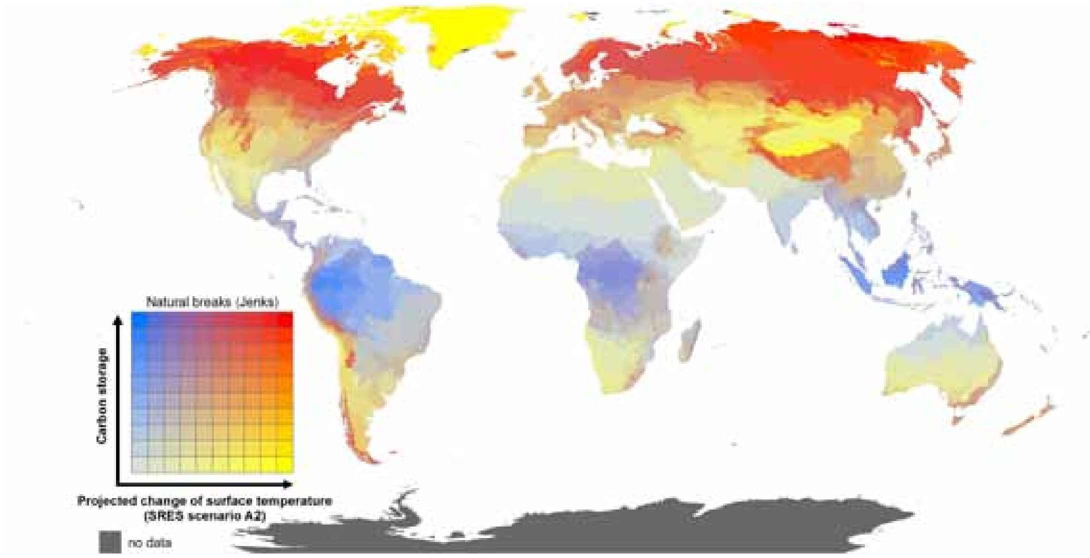

FIGURE 11: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and carbon storage in vegetation, litter and soil (maximum depth of 1.5 m) for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

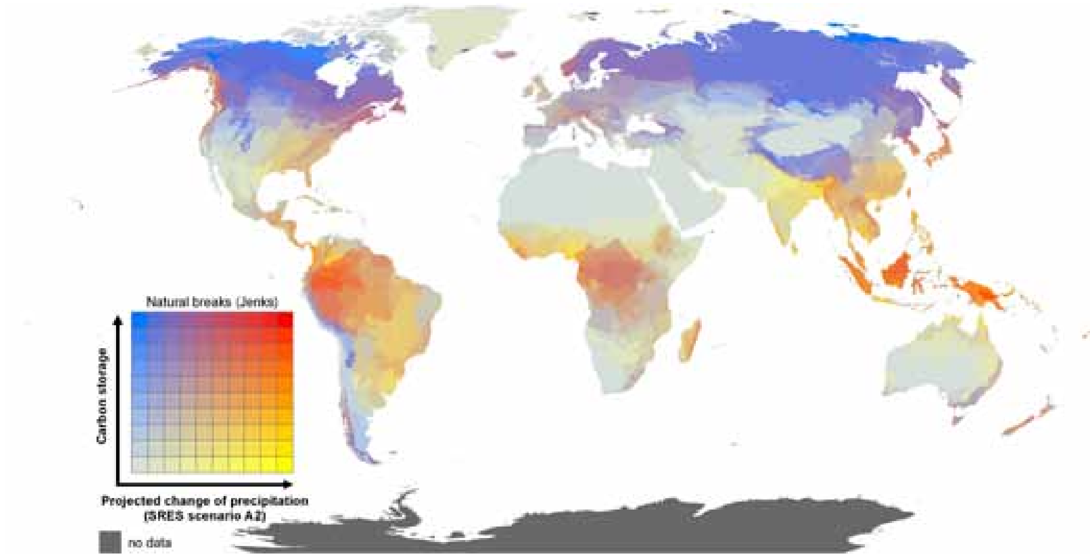

FIGURE 12: Choropleth bivariate map of the projected change of precipitation till 2050 according to SRES A2 and carbon storage in vegetation, litter and soil (maximum depth of 1.5 m) for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

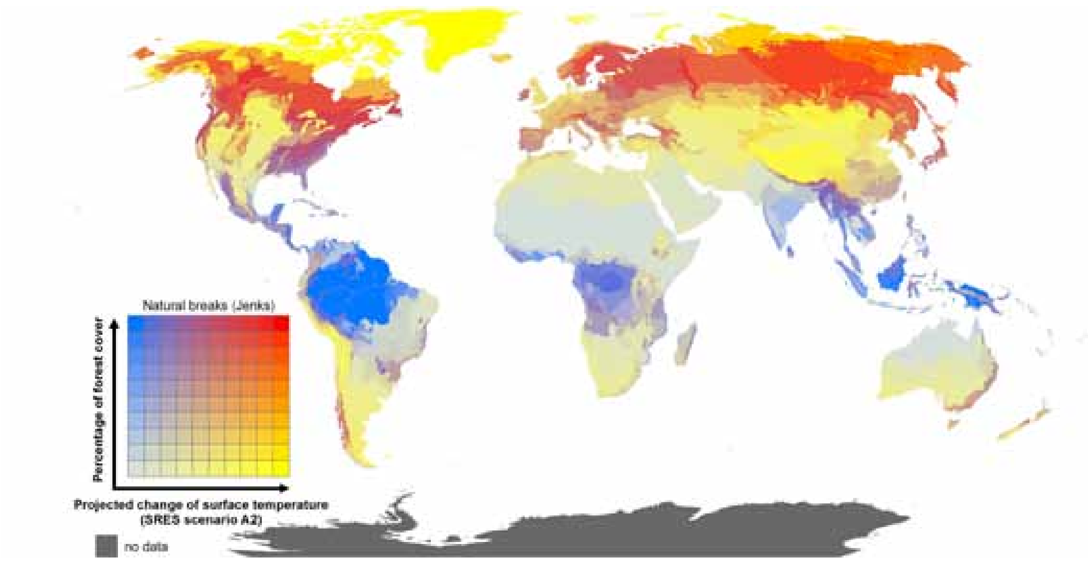

FIGURE 13: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and forest coverage for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

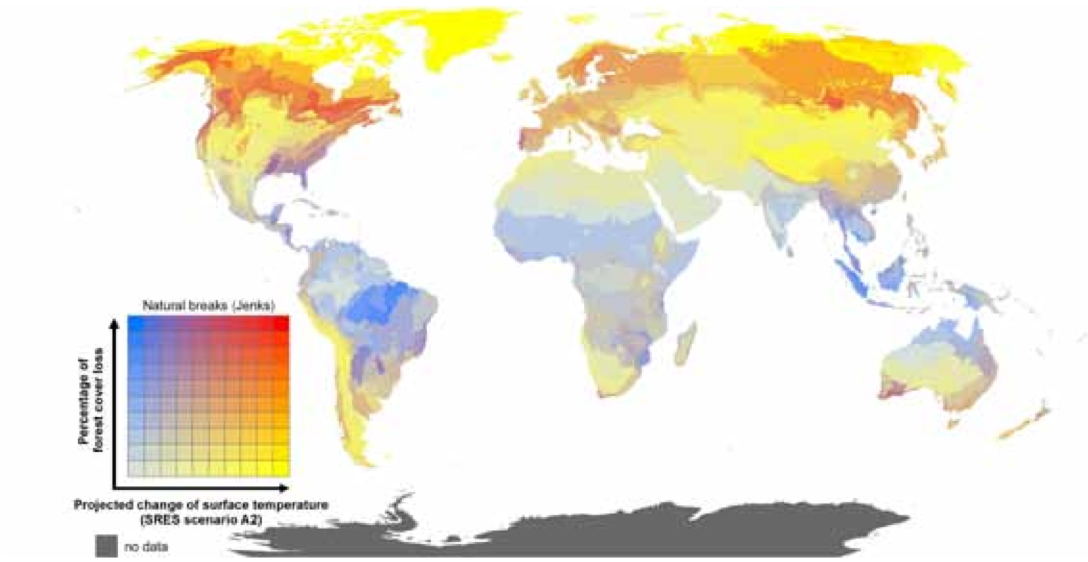

FIGURE 14: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and deforestation for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

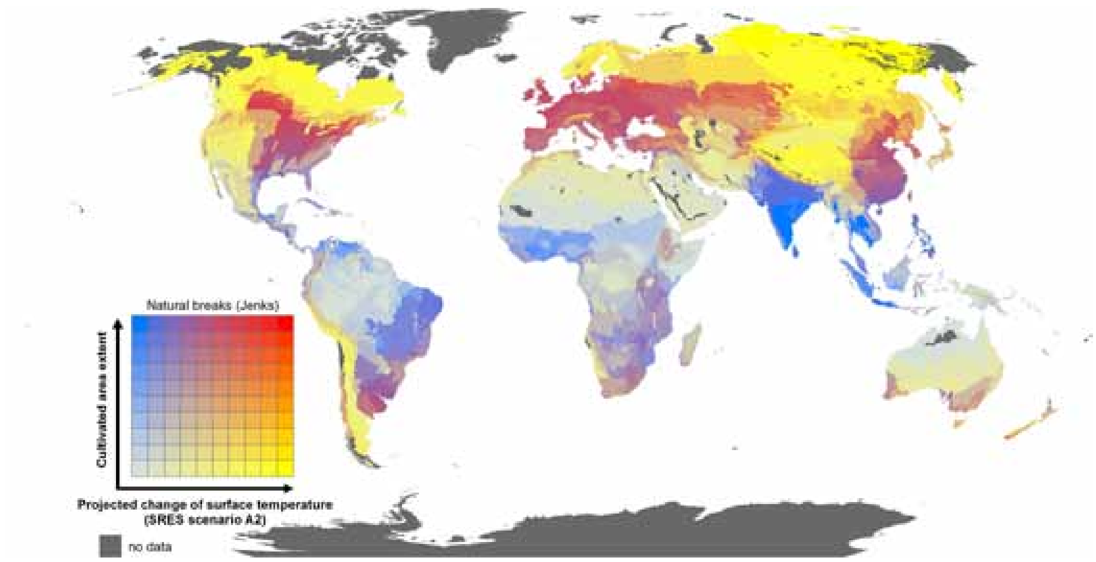

FIGURE 15: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and cultivation cover for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

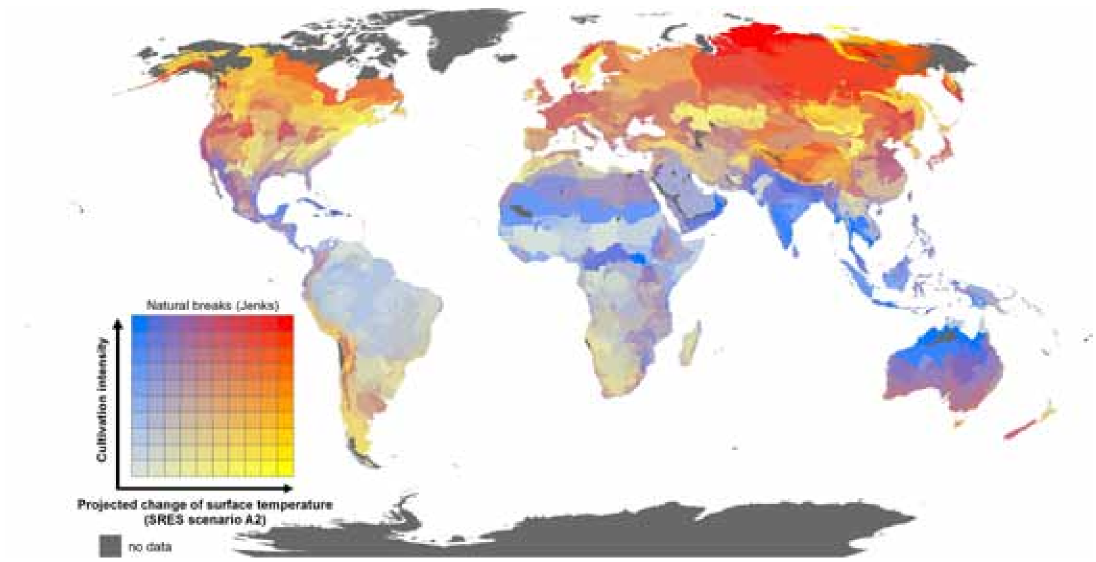

FIGURE 16: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and cultivation intensity for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

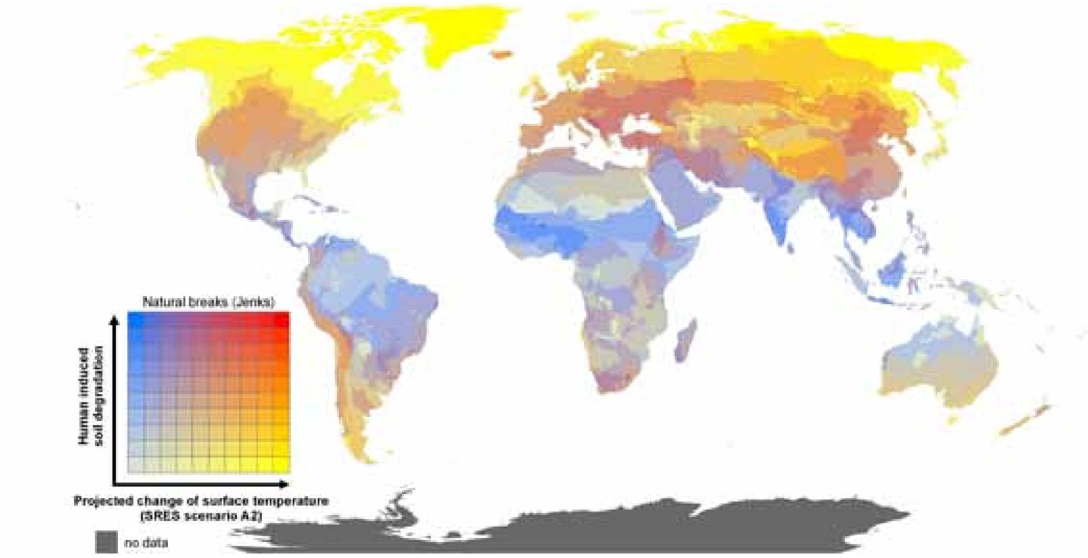

FIGURE 17: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and human induced soil degradation for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

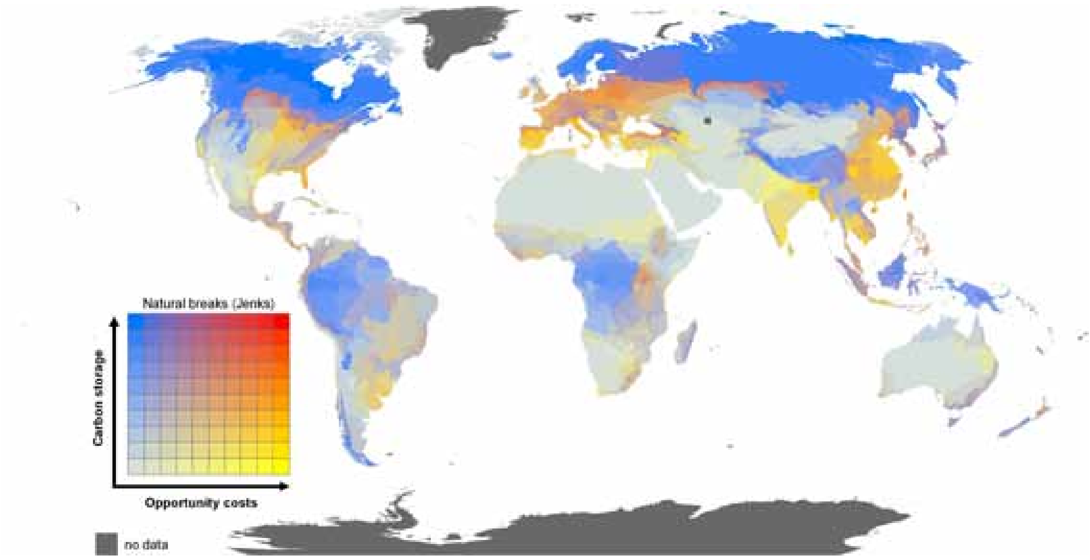

FIGURE 18: Choropleth bivariate map of opportunity costs of conservation and carbon storage for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

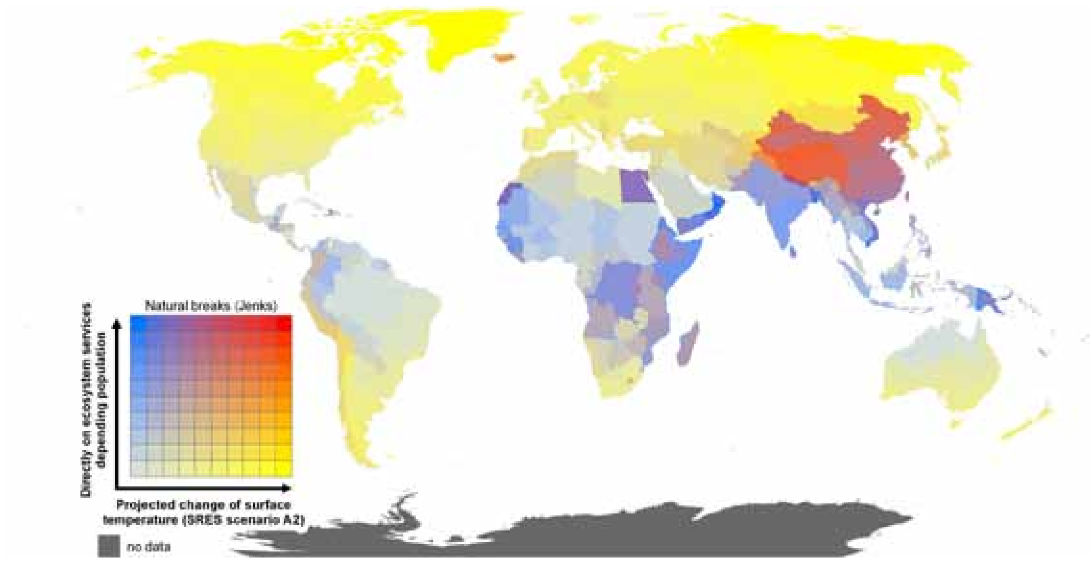

FIGURE 19: Choropleth bivariate map of the projected change of surface temperature till 2050 according to SRES A2 and the number of directly on ecosystem services depending population (agricultural population) for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

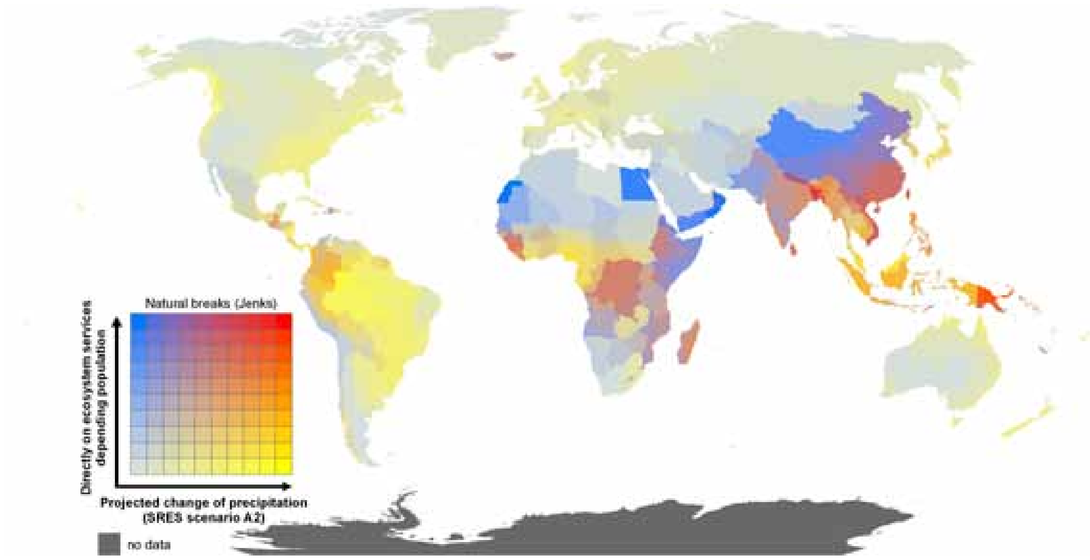

FIGURE 20: Choropleth bivariate map of the projected change of precipitation till 2050 according to SRES A2 and the number of directly on ecosystem services depending population (agricultural population) for Ecopolitical Units. Grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

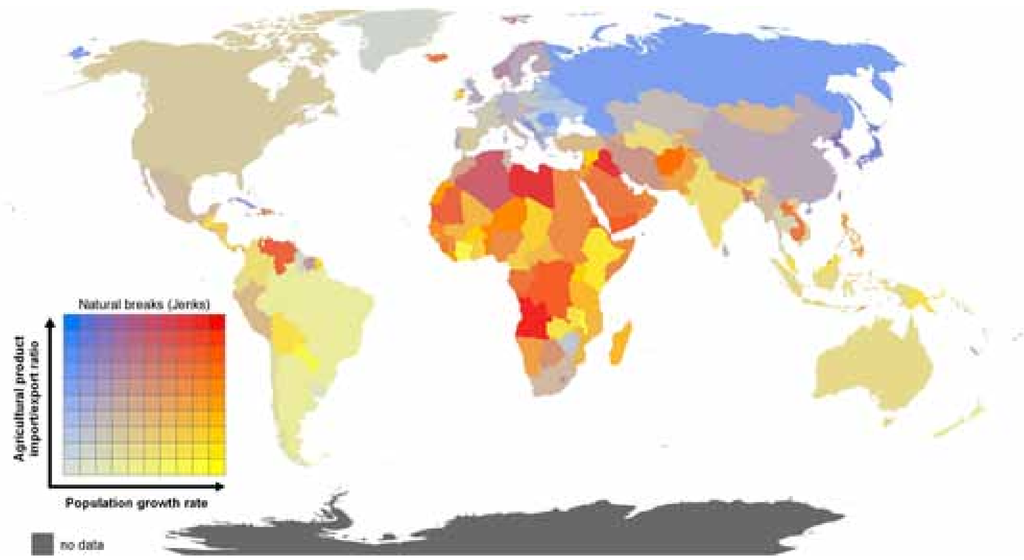

FIGURE 21: Choropleth bivariate map of average annual population growth rate and the agricultural import-export ratio for Ecopolitical Units. Consistency with national state borders since data are only available per country; grey areas represent missing data; color code matrix classification by natural breaks (Jenks).

CONCLUSIONS

The findings of this study reveal a complex interdependency between socio-political and environmental factors that provides convincing evidence to support a more pluralistic approach to dealing with global issues. Human dependency on natural resources and the ecosystem services they provide is inescapable. Current levels of resource demand, especially inthe more developed world, is driving down biodiversity and consequently degrading ecosystems and thus reducing the resilience and functionality of these systems to cope with environmental change. At another level, change in societal wellbeing within local communities and across regions is alteringsocial norms and values including concerns about conservation action. However, differences in cultural attitudes and economic circumstances, partly accounted for by patterns and dynamics in globalization, is complicating if not distorting these social norms.

All the evidence points to a clear linear relationship between human development, increased resource demand/exploitationand a rise in ecological costs.However, the effects of globalizationare introducing complex scenarios including the ecological debt suffered by a number of states (primarily developing countries), brought on by the externalization of ecosystem services to other nations. Poorer nations attempt to reduce their economic problems by exporting agricultural and forest products, as well as other ecosystem goods, to richer countries, thus increasing the Human Footprint in their own country. Theargument that open trade will lead to human development is often used to justify these actions. However, a combination of open markets, global trade and large corporate organizations often drives down both socioeconomic and environmental conditions in the regions of origin whilst benefiting the few socioeconomic elite in the trading nations. In accordance with the current thinking proposed by the Radical Ecosystem Approach, this paper concludes that ecological deficits should not be compensated by externalization of environmental costs (Ibisch& Hobson, A.2.1. in this document, *Principle 8 of the Radical Ecosystem Approach*).

Human population density is likely to increase mainly in developing countries which will put greater demands on natural resources and ecosystem services in these areas.Furthermore, the impacts of climate change will hit these countries hardest. The high proportion of population, their direct dependency on locally generated ecosystem services and agricultural products, and their predominant primary sector are the main contributing factors to their vulnerability.In contrast, rich countries may have the opportunity to rearrange their national trade relations and pay higher prices to maintain or even increase their resource supply. This could lead not only to higher food prices and hunger in developing countries, but also to riots and political instabilities. Protectionism, economic and military reactions of rich nations may increase if the developed world takes action to protect or increase its wealth. Biodiversity conservation has the possibility to slow down this development by maintaining the functional ecosystems of the world. In line with Lee & Jetz (2008) this paper emphasizes the importance of including future global change into both development and nature conservation planning, and argues for a Radical Ecosystem Approach focusing on ecosystem resilience, and taking future changes into account (Ibisch& Hobson, A.2.1. in this document, *Principles 6 and 7 of the Radical Ecosystem Approach*). This process has to be based not only on ecological data, but also on social and economic data (e.g. Polasky 2008) to minimize future conservation development conflicts and to make use of synergies. This strategy would not only make a contribution to climate change mitigation, but also to climate change adaptation and ecosystem services conservation. To increase efficiency, conservation planners have to consider social and economic factors and minimize opportunity costs. However, it is unlikely that this action alone will resolve the long-term problems facing humanity.

Biodiversity and human development are constantly interacting and mutually dependent. Therefore, biodiversity conservation has to be incorporated into human development plans more consciously and actively. Equally, biodiversity conservation has to consider future resource demands and social impacts in a more integrative and holistic way. At the moment, this practice has been exercised in just a few areas and only then at a very local level. The effects of globalization are causing dramatic changes to both the ecology and social fabric of all inhabited regions of the world. As a result it is imperative that a globe-wide strategy of mainstreaming the incorporation of interdisciplinary action in planning and decision-making is rolled out across all nations.

REFERENCES

Cited references and used sources are given in the appendix D.

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B.1.2. INTERLINKAGES BETWEEN HUMAN DEVELOPMENT AND BIODIVERSITY: CASE STUDIES

The following two case studies shall provide some background to the conception of the Radical Ecosystem Approach from a practical perspective. It was our hypothesis that so-called undeveloped or developing regions like Madagascar or the Ukrainian Carpathians can still be described as more or less closed socio-ecological systems with mainly local utilisation and circulation of ecosystem goods and services and rather insignificant exchange with external systems. It was also intended to better understand concrete interlinkages between human development and biodiversity in regions where a more intensive interdependence was assumed.

We based our analysis on the following eight guiding questions, which were later translated into chapters (humans & biodiversity, vulnerability against global change, conservation approaches, future developments).

1. In what way is biodiversity reflected by cultural and land use diversity?
2. How and how much do the various 'socioeconomic strata' depend on biodiversity, especially referring to ecosystem goods and services?
3. To which extent does economic growth and human wellbeing depend upon the trade of ecosystem services, especially the import of ecosystem goods and services or the export of environmental costs?
4. In what way is the status of biodiversity and ecosystem services impacting the socio-economic/socio-political stability?
5. How is the status of biodiversity influencing the vulnerability against global change?
6. How significant and effective are current biodiversity conservation efforts for human development (and vice versa)?
7. Which current approaches and instruments attempt the conciliation of development and biodiversity conservation?
8. What could the interdependence of biodiversity and development look like in future, taking environmental and socio-economic changes into account?

Answers for each of those guiding questions were elaborated from a combination of sources. Most input came from local experts and those having worked and conducted research in the focal regions for a long time. Further information was derived from the analysis of research results of completed and ongoing projects including numerous interviews with the local population, local and regional authorities, protected area management staff and other experts. Additionally, literature was searched to support and complement the findings. Especially grey literature and reports of NGOs, ministries and other relevant institutions and projects proved most informative.

B.1.2.a DEVELOPMENT, BIODIVERSITY CONSERVATION AND GLOBAL CHANGE IN MADAGASCAR

Iris Kiefer, Pascal Lopez, Claudine Ramiarison, Wilhelm Barthlott & Pierre L. Ibisch[11]

ABSTRACT

Madagascar's outstanding biodiversity, with exceptionally high species richness and a remarkable rate of endemism, is largely threatened by anthropogenic pressure driven by population growth and non-sustainable use of its natural resources. Its mainly rural and poor population shows a high dependence on natural resources and a strong relation to nature and environment, which is reflected in the Malagasy culture and traditions. Urban populations and (semi-)external stakeholders also depend on Madagascar's ecosystem goods and services, but generally have more choices and access to alternatives. As a tropical island state, Madagascar's economy depends to a great extent on exported ecosystem goods such as seafood and spices, and increasingly on minerals derived by extractive industries. Human wellbeing could be enhanced by generating income from the sustainable use of its biodiversity and related ecosystem services. The condition and availability of biodiversity and ecosystem services seems to be interlinked with political stability. Unsustainable use of its biodiversity, probably coupled with foreign investments related to land and natural resource use imply the risk of social inequality and unrest. Global environmental and socio-economic changes, such as climate change or high population growth rates, increasingly have an influence on human wellbeing, which makes the access to, and availability of, ecosystem services a major concern. The integrity of biodiversity, hence, contributes to the extent of vulnerability of Madagascar's population and the reduction of dependences and poverty. Various approaches are undertaken to conserve Madagascar's unique biodiversity, but they still need to be amplified and to be conciliated with development (aid and cooperation). In three scenarios we suggest possible futures for Madagascar, depending on internal and external factors such as political and economic performance, demographic changes and global warming. The worst-case scenario of failing governance and collapsing ecosystem services has to be avoided by all means.

INTRODUCTION

Madagascar is one of the most critically threatened global centers of biodiversity. Its remarkable flora and fauna, exceptional species richness and high percentages in endemism are highly endangered by the ongoing destruction of natural habitats (Myers *et al.* 2000, Ganzhorn et al. 2001).

With a length of 1,600 km and a surface of 587,000 km^2 Madagascar is the Earth's fourth largest island and stretches from the Tropics to the southern Subtropics (Figure 1). Separated by the Mozambique Channel it is located 400 km off the southeastern coast of the African continent from which it is disconnected some 160 million years ago. The central high plateau divides the island into a dry western part and a moist eastern part. The trade winds in the austral winter (from May to September) and the tropical storms, driven by monsoon in the southern summer (from December to April), can bring more than 3,000 mm annual rainfall to the eastern humid rainforests, but only little arrives in the western dry and southern spiny forests, in some areas less than 400 mm per year.

Biodiversity: The high geodiversity of the island contributed to the evolution of diverse ecosystems. They are home to Madagascar's outstanding biodiversity (Lourenço & Goodman 2000, Barthlott *et al.* 2005). The Masoala Peninsula in the Northeast harbors the highest proportion of undisturbed lowland humid evergreen forest while the eastern and southeastern rainforest patches are smaller, more degraded and often disconnected. Since the 1970s, 33.4% of Madagascar's humid forest has been lost (Moat & Smith 2007). The last remaining patches of littoral forest are restricted to the southeastern parts of the island. The natural vegetation of the central highlands is evergreen sclerophyllous *tapia* (*Uapaca bojeri*, Phyllanthaceae) woodland and montane scrubland, but these formations are severely reduced and replaced by vast areas

11 I.K. and P.L. implemented the study and collected data; P.L.I. guided and supervised the research; C.R. and W.B. contributed data and ideas; I.K., P.L., C.R. and P.L.I. wrote the paper.

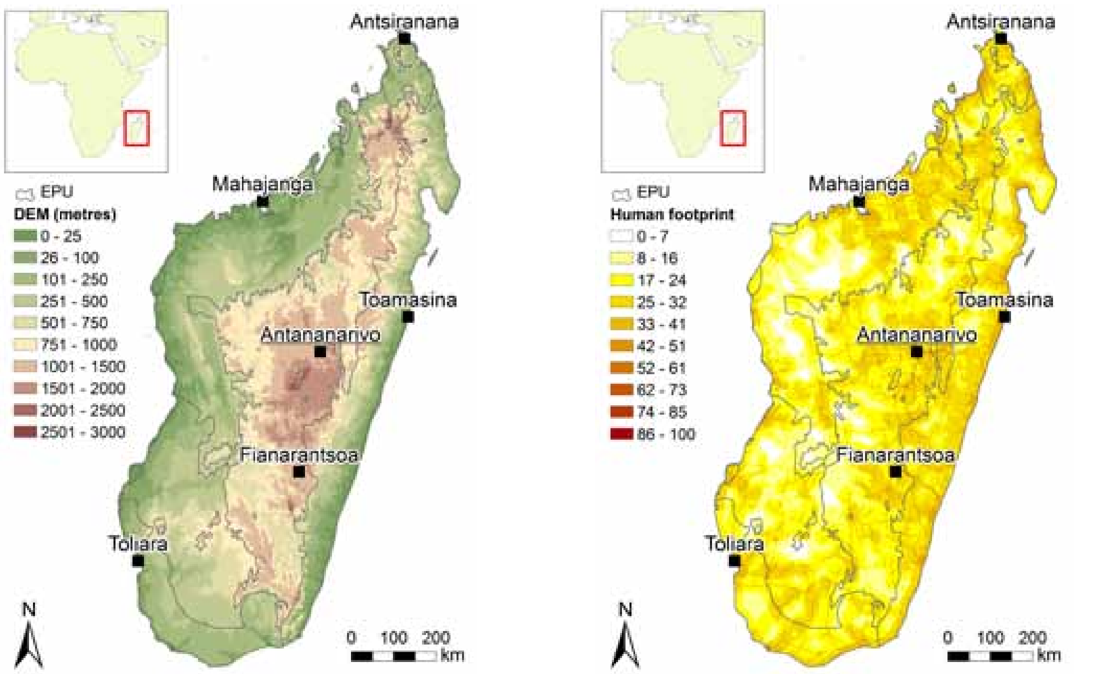

FIGURE 1: Maps of Madagascar showing topography (based on a Digital Elevation Model (DEM), left) and the "Human Footprint" (after WCS & CIESIN 2005, right). Ecopolitical Units (EPU) indicate the major terrestrial ecoregions of Madagascar. Lighter shades in the map on the right side indicate lower direct human impact on the land's surface from e.g., human land uses, human access from roads, railways, major rivers, or electrical infrastructure. Protected areas and remaining forest patches, but also hardly accessible or mountainous regions in the lowlands show low human footprint, while urban agglomerations appear in darker colors. Generally, human footprint, as defined by WCS & CIESIN 2005, is rather low in Madagascar.

of species-poor grass savannahs and partly by pine and eucalyptus plantations. In the dry western regions of the island deciduous formations are naturally dominating such as the seasonally dry western forest and the coastal forests. The natural vegetation of the semi-arid Southwest is a dense and low spiny forest-thicket and coastal bushland, today mainly replaced by grass savannahs and patches of prickly pear (*Opuntia* spp., Cactaceae). The bushland was already reduced by 38% since the 1970s (Du Puy & Moat 1996, Moat & Smith 2007). Small patches of mangroves remain on the western coastline. Four major terrestrial ecoregions**,** one marine and one freshwater ecoregion are listed as priority for conservation in the "Global 200" reaching from tropical moist broadleaf forest in the East to the spiny forests in the Southwest. Five of these six ecoregions are classified as critically endangered (Olson & Dinerstein 2002).

More than 13,000 vascular plants, over 360 reptile species and more than 370 species of amphibians, almost 290 bird species and 155 mammal species, including nearly 70 species of lemurs, are part of Madagascar's extraordinary biodiversity (Phillipson *et al.* 2006, Glaw & Vences 2007, Vieites *et al.* 2009). The uniqueness of Madagascar's biodiversity has been caused by its early split-off from the ancient super-continent Gondwana and its long isolated history. It has some exceptional features related to its endemism richness, especially in vascular plants, reptiles and mammals (Kier *et al.* 2009). Estimates reveal that 92% of the vascular plant species are endemic (excluding ferns), and 99-100% endemism exists in native amphibians, non-volant mammals and some plant families (Goodman & Benstead 2005). Six of the world's eight species of Baobab only exist in Madagascar, world's unique lemurs are restricted to this island and the neighboring Comoro islands and the giant elephant bird *Aepyornis*, pygmy hippos and some of the larger lemur species became extinct only a millennium upon the arrival of humans (Burney *et al.* 2004). Additionally, Madagascar shares some biogeographical features with South America like the boas and iguanas, which are absent in Africa. Furthermore, the absence of large native herbivores like zebras, giraffes, elephants, or larger carnivores, which developed in continental Africa, is remarkable (Glaw & Vences 2007). The largest predator is the cat-like *fosa* (*Cryptoprocta ferox*).

People: Madagascar has a rather young history of human colonization. The first settlers arrived in Madagascar some 2,000 years ago and were of Indo-Malaysian and East-African origin, making

Madagascar the last great landmass to be colonized (Dewar & Wright 1993). Madagascar became a melting pot of south-east Asian and African traditions and languages and had also some Arabian influence. The Malagasy language evolved from the different influences and is today spoken in dialects by the 18 main ethnic groups. It is an Austronesian language and shows a very high similarity with a native language spoken in southern Borneo and also contains vocabulary from Bantu languages of East Africa (Hurles *et al.* 2005).

The ethnical diversity follows geographical patterns of its early settlers. Their descendants still occupy biogeographic zones of the island that are similar to their places of origin and practice similar land use techniques as their ancestors, such as extensive cattle breeding, slash-and-burn agriculture or rice cultivation. Cattle play a very important role in the Malagasy culture (Hurles *et al*. 2005), especially in the western and southern parts of the country. Rice cultivation in terraces was brought from the Asian regions and is mainly found in the central high plateau. At the coastal areas (total coastline of Madagascar: > 4,800 km) the local population depends mainly on fishing and, additionally, on the cultivation of, e.g., manioc, corn, and millet. Since the first colonization of Madagascar, the settlers transformed the ecosystems, mainly forests, into arable land, and almost all larger animals were driven to extinction.

Today, Madagascar is home to 21.3 million people[12] with an estimated total population growth rate of 2.7% for 2005-2010. In cities the growth is significantly higher. About 71% of the population is living in rural areas, and less than one third is living in urban areas (UN 2006). Madagascar is classified as a country with a medium human development level. It has a Human Development Index value of 0.543, which ranks it at the 145th place out of 182 countries (HDR 2009). According to the World Bank (2007), 61% of the population lives on less than 1 US$ per day, 85% on less than 2 US$/day; most of them are highly dependant directly on natural resources for their livelihood. The access to "modern" media is rather restricted for the rural population, since electricity supply in rural areas is very limited; the TV and telephone grid are not well developed and many regions remain difficult to access (Figure 1).

Political history: Madagascar had a partly turbulent history since its first colonization 2,000 years ago. Several parallel kingdoms were widely united from the end of the 18th century onwards. In 1896 Madagascar was conquered by the French and became a colony. Since it achieved independence from France in 1960 Madagascar adopted several forms of governance and—similar to the French system—"republics". Its first republic, which was still characterized by a post-colonial era, was replaced in 1972 by a socialist regime. Nationalization and centralization marked the era of this 2nd republic. It was destabilized several times by lack of a firm foundation within the Malagasy society and a difficult economic development. Political fragility (recently in 1991, 2001/2002 and since 2009) has repeatedly destabilized the country, negatively affecting its population and its natural resources, including biodiversity (USAID 2010).

The present ongoing political crisis started late 2008 and had a peak, when Marc Ravalomanana stepped down in March 2009 after months of protests and Andry Rajoelina became president of a transitory government. However, the takeover of power by Andry Rajoelina was widely considered as unconstitutional and thus many bi- and multilateral partners suspended their cooperation with Madagascar or its membership from international bodies, such as the African Union and the South African Development Community (SADC) (Ploch 2009).

Threats to biodiversity and conservation: Madagascar's outstanding native biodiversity evolved without human impact until the first settlers arrived. As its terrestrial biodiversity is mainly harbored in forest ecosystems, which was the prevailing vegetation type, any decrease of forest area can be considered as a vital threat to its biodiversity. The conversion of natural sites into arable land by the first settlers led to extensive habitat destruction. Particularly, the burning of grassland and savannahs for the provision of grazing areas, the conversion of forests into agricultural sites and the overexploitation of forests for timber and fuel wood have led to a decrease of forest cover to less than one fifth of its original size. Almost 40% of the forest cover was lostbetween 1950 and 2000 (Harper *et al.* 2007). Today, most of Madagascar's territory is covered with species-poor

12 1950: 4.2 million, 1980: 9.1 million, estimated for 2050: 44.4 million people (UN 2006)

grass savannahs, which have little water retention capacity, resulting in large-scale erosion phenomena (local name for the deep clefts caused by erosion: *lavaka*). Ongoing deforestation is exacerbating soil erosion and sediment run-off (UNEP 2004). The intensive soil erosion gave Madagascar the name "red island" since it looks like it would be bleeding, when the washing-out of red lateritic soils colors the rivers. Additionally, introduced invasive plants threaten the native vegetation, e.g., prickly pear (*Opuntia* spp., Cactaceae) or sisal (*Agave sisalana*, Asparagaceae) in the dry regions of Madagscar (Binggeli 2003). The prickly pear was introduced to Madagascar by the French to defend their forts and is still used as a "living fence" for cattle or crop fields by the Malagasy. The green leaf-like cladodes are used as fodder and the fruits are often the basic food resource for the local population in times of food scarcity. The French also introduced sisal and established a prosperous sisal business in southern Madagascar. Today, sisal plants are also used as "living fence". Both are widespread along roads and even in protected areas.

The unchecked growth of the population and their growing demand for agricultural land and ecosystem services in combination with unsustainable land use management practices is severely threatening Madagascar's biodiversity as more and more forest areas are exploited or converted. Plans for the implementation of industrial agriculture investments for the production of palm oil, bio-fuels or animal fodder have been made (Üllenberg 2009). Expanding industrial agriculture is considered to be a main threat driving deforestation, habitat loss and general degradation of the environment. Large-sized mining projects are also going up in numbers, due to new exploration and extraction technologies as well as increasing global prices for minerals. More than half of Madagascar's territory is covered with exploration concessions; in many protected areas minerals, such as ore and sapphire, oil, and uranium are confirmed or expected. The conciliation of mining and biodiversity conservation is becoming a challenge (Cardiff & Andriamanalina 2007). Another threat to Madagascar's biodiversity, which is still difficult to assess since reliable data is scarce, is climate change. It is especially related to extreme weather events such as droughts, floods, and cyclones with potentially devastating direct and indirect impacts on ecosystems and their flora and fauna.

Currently, Madagascar's biodiversity conservation is severely weakened by the ongoing political crisis. National parks and other valuable forest areas are plundered for precious wood and poaching and the illegal export of its unique fauna and flora are said to have risen dramatically (USAID 2010). Consequently, CITES has imposed a six month moratorium for export of crocodile products (CITES 2010) and UNESCO has included Madagascar's World Heritage Site, the Eastern rainforest (Rainforest of the Atsinanana), on its *List of World Heritage in Danger* due to extensive logging activities (UNESCO 2010).

The aim of this paper is to provide an overview of the interdependencies of biodiversity and human development in Madagascar, regarding economic development, social and cultural aspects, and the integrity of biodiversity and its conservation status, by pointing out and analyzing the influencing factors. The three scenarios apply the various drivers and show possible future trends for biodiversity and development with special focus on global change impacts.

MATERIAL AND METHODS

The represented findings and analyses are based on many years of research and experience[13] living in Madagascar and working in the Malagasy environmental sector, derived from numerous interviews with

13 *Iris Kiefer* started research in biodiversity conservation in Madagascar in 2005 with a major focus on anthropogenic impacts on biodiversity. In several visits, at least every two years, she spent in total more than 12 months in the country. During this time she was living in urban agglomerations as well as rural communities and worked with local and national authorities, the national parks administration (Madagascar National Parks, MNP), NGOs and research institutions. *Dr. Pascal Lopez* conducted research in Madagascar from 1998 to 2000 and was then frequently working as a consultant in the environmental sector. Since early 2008 he has worked permanently in the country and is today head of the German-Malagasy Environmental Program (PGM-E) implemented by the German technical cooperation (GTZ). Both have been working in the context of community-based management of natural resources and conservation, with a main focus on developing solutions for integrative conservation approaches and sustainable natural resource management. *Dr. Claudine Ramiarison* is an expert on biodiversity issues and held the position as the Malagasy CBD focal point from 2002 to 2008. From 2005 to 2007 she was a member of the SBSTTA bureau. As executive secretary of SAGE, a para-statal agency for environmental management, she worked intensively in the field of Access and Benefit-sharing (ABS) but also local natural resources management. Currently, she is a temporary member of the advisory board of the Ministry for Environment and Forests and works as a consultant on protected areas, governance, and ABS.

experts and local stakeholders. Apart from personal assessments and consultations of experts in biodiversity and sustainable development, an intensive literature review was made to support the findings, including grey literature and reports of NGOs, ministries and other relevant institutions.

HUMANS & BIODIVERSITY

Cultural diversity, biodiversity and natural resource use

Madagascar's cultural diversity, contemporarily expressed by its 18 main ethnic groups, is still linked to the origins of its early settlers and is also the result of its ecosystem diversity and the corresponding variety of natural resources. The late colonization of Madagascar brought people from the Indonesian archipelago, East Africa and the Arabic region. The common cultural base is expressed particularly by the Malagasies relation to nature and their environment. The Antandroy ("*people of the thorns*") and the Mahafaly ("*those who make taboos*"), in the southern and western lowlands are predominantly cattle breeders with ancestors probably mainly coming from East Africa, while the highland Merina ("*people of the highlands*") and Betsileo ("*the many invincible ones*") are traditionally rice cultivators and primarily of Asian origin. The Vezo population living mainly at the southwestern coastal zone traditionally depends mainly on marine resources, particularly derived from traditional fishing. Cattle-rice cultivators are found amongst the Antankarana, Bara, Bezanozano, Sakalava, Sihanaka, and Tsimihety. Tanala and Betsimisaraka are called the forest peoples (Minten & Barrett 2008).

Culture plays an important role in perceiving, preserving, and using nature and biodiversity for the Malagasy population. The meaning of "*land*" can be translated into "*land of the ancestors*" or "*tanindranzana*" which is related with the respect of traditions. Land is a sacred place and a kind of mediator between the living people and their ancestors. That is also true for many continental African countries. Religion is important for rural as well as for urban populations and Christianity and ancestral worship are harmoniously co-existing. The land and its resources provide food, but also ecosystem services and, hence, it is necessary to preserve its capacities and cultural values by applying spatial organization and social regulations, which are decreed by traditional and local laws, called "*dina*". *Dina* govern the use of water resources, plants, animals and the use of land, e.g., in the form of local use rights for yield and hunting transferred to people living close to forests. Those traditional laws are based on rights, obligation, and taboos, locally called "*fady*". The *fady* may concern a plant or an animal, a forest site or even a certain behavior and may be specific for a family, a village or in a certain territory (Lingard *et al.* 2003, Jones *et al.* 2008). The applications of those regulations are supervised by the elder or "*tangalamena*". The *dina* are even recognized by the modern Malagasy law and are still applied in rural areas. Sacred places are an important part of the culture and local traditional rights. For example, in Ranomafana national park in southeast Madagascar or in the Sakoantovo forest on the Mahafaly plateau, certain sacred places exist which are used as graveyards by the local populations. Those sites are often the best preserved forest areas outside protected areas (Tengö *et al.* 2007).

Moreover, single biodiversity or landscape features such as trees or lakes can be sacred. Their access and use is regulated by local laws and can be a place of worship, which is respected by (local) peoples. In some parts of Madagascar, certain trees, e.g., *mendoravy* (various species, often *Mendoravia dumaziana*, *Albizia greveana* or *Albizia tulearensis*, all Fabaceae) or *ramiavona* (various species, often genus *Xylopia*, Annonanceae) are even exclusively used either for coffins or as totem and may not be felled except for these purposes. Another biocultural aspect is traditional knowledge of the use of medicinal plants by healers, by rural populations and also by inhabitants of urban areas. There is a set of rites for their collection and use, which are in relation with the origin of the land they are found on and certainly vary depending on the species and local culture.

Biocultural considerations continue to have influence on the local management of biodiversity in the rural areas. With the development of modern sustainable management concepts, like protected areas, and the arrival of new migrants with different cultural values and concepts, these local traditions are altered; also due to the trade of ecosystem services, the development of bioprospecting and other processes that bring in new concepts, ideas and values to rural areas and its populations.

Traditional land use techniques like slash-and-burn agriculture (locally called *tavy*) may increase soil fertility in a short-term view. Agricultural fields are usually abandoned after two to four years (Erdmann 2003). Applied in a small scale and with time intervals of 10 to 15 years, soil fertility may be restored and the natural vegetation has often the potential to regenerate. Thus, under certain conditions slash-and-burn agriculture is not necessarily unsustainable. However, in Madagascar population growth and the increasing demand for land and food made the agricultural systems often ecological instable and un-sustainable. Additionally, agricultural production might be only slowly developing in some areas since cultural constraints demand to keep traditional but low productive land use techniques.

In the southern regions of Madagascar, cattle are bred as a status symbol and money storage with numerous heads per herd. However, with the purpose to keep open extensive grazing land, it is a major cause for deforestation and spacious anthropogenic bush fires (Kull 2002). Ongoing population growth may continuously favor the increase of cattle herds in these regions. Especially, in the Antandroy and Mahafaly regions cattle herds can reach up to 300 heads and more. However, they do not produce regular economic income since they are usually only sold in "emergency" situations.

In general, all forest areas outside protected areas are already affected by *tavy*, artificial fires, and forest clearings for the purpose of opening of new arable and pasture land. The high demand for ecosystem services by urban agglomerations, especially provisioning services like food, timber and fuel wood, are satisfied by the vast exploitation of the natural resources in rural areas. Frequently, the corresponding logging and hunting activities are conducted by non-residents or migrants causing social conflicts and overexploitation of local resources. Thus, the degradation of natural resources may lead to migration and to further social conflicts if local *fady* are not respected in the recipient region, which may then experience "cultural homelessness" and a loss of traditions. Conversely, the loss of biodiversity may exacerbate the loss of culture, e.g., in the case of medicinal plants and related indigenous knowledge. In urban agglomerations the connection to traditions might be rather decoupled, since sacred places might be far away. However, ancestors and taboos still play an important role in the daily life of urban population.

Dependency of socioeconomic strata on biodiversity

Being an island state the size of a micro continent, Madagascar has experienced a dependency on its own biodiversity and ecosystem services. Corresponding to its size and its location, Madagascar has good capacity for cultivation of a great variety of fruits and crops. Furthermore, being a country where more than 70% of the population lives in rural areas (UN 2006), where poverty is prevailing, leading to an overall low purchasing power and little access to imported industrial or natural goods, the majority of the population depends directly on local ecosystem services for their livelihoods. Traditional agricultural and pastoralist systems as well as traditional fishery are prevailing in rural areas.

Different socio-economic strata have varying dependencies on local or national biodiversity and ecosystem services due to their respective possibilities of choice. In this study, the following main socio-economic strata were identified for Madagascar: rural populations, urban populations, and (semi-)external stakeholder, i.e., people related to inter- and transnational institutions, or to global commerce including also tourists. Table 1 categorizes the dependency on biodiversity and ecosystems services among these strata.

Local and rural populations: Madagascar's rural population lives largely under subsistence conditions. For these people, ecosystems and ecosystem services play a vital role in their livelihood strategies as sources for food, freshwater, timber and remedy and by providing services such as erosion control and agricultural land resources. The (relative) dependence on ecosystem services is determined by several economic, ecological, and cultural factors: purchasing power is so low that the substitution of services from ecosystems is out of the reach. Ecosystem services are rarely traded, and (urban) markets are hardly accessible due to distances.

Since access to major markets is limited, the rural population highly depends on subsistence farming for the supply of basic agricultural products. Small scale fields are located in the surroundings of the villages, mainly used for the cultivation of manioc, corn, rice or potatoes, depending on soil and climate conditions. Fruits are only seasonably available. The most important fruits are plantains, mangos, litchis, bananas, pineapple, and apples. Dairy products play a minor role in rural areas since cattle are mainly bred for status purposes or for trade. Zebu cattle are most dominant, while dairy cows are rather rare and mainly to be found in the highlands. The farming of goats and sheep is widespread only in Southern and Western parts. They are often herded together for different families by young children. Most families have poultry, and some chicken, ducks, and turkeys. Small mammals, including lemurs, birds and even Nile crocodiles and caimans may complement the diet, depending on the region.

Rural people, in particular, depend on a considerable diversity of medicinal plants, which are used for self-treatment. The access to modern medicine is difficult since pharmacies or shops selling pharmaceutical products generally only exist in larger villages. Dependency is also accentuated by limited access to forest areas, which provide a variety of important services, particularly when forests are designated as (potential) protected areas with limited access rights.

TABLE 1: Dependency on ecosystem services among socio-economic strata (ecosystem services according to the Millennium Ecosystem Assessment; red = high, green = low)*.

		Rural Population	Urban Population	(Semi-)External Stakeholders
Provisioning S.	Food	red	yellow	green
	Fresh water	red	yellow	green
	Fuel wood	red	yellow	green
	Fiber	red	yellow	yellow
	Biochemicals	yellow	yellow	green
	Genetic resources	yellow	yellow	yellow
Regulating S.	Climate regulation	red	red	yellow
	Disease regulation	red	yellow	green
	Water regulation	red	red	green
	Water purification	red	yellow	green
	Pollination	red	yellow	green
Cultural Services	Spiritual & religious	red	yellow	green
	Recreation & ecotourism	green	yellow	red
	Aesthetic	red	yellow	green
	Inspirational	red	yellow	green
	Educational	red	yellow	green
	Sense of place	red	yellow	green
	Cultural heritage	red	yellow	green

* The dependency on supporting services like soil formation, nutrient cycling, and primary production is rather indirect and therefore not listed in this table, however, it is of high importance for each stratum.

Urban populations: Accordingly, almost 30% of the Malagasy population lives in urban agglomerations (UN 2006). For them, ecosystem services play an important role as a source of food (cereals, fruits, meat) and for the provision of drinking water. However, this stratum is less dependant on direct and local ecosystem services, as access to traded goods is better since shops and markets provide a big variety of international goods. Forest products play an important role as energy sources and as construction wood for housing and artisanal furniture building for the urban population. Both modes of utilization account for a wood consumption of approximately 9.7 million m^3 per year in urban areas (GISC 2009). While more than 90% of the households use charcoal as the primary energy source, construction wood is used in practically every house building. According to the ecoregion, the dependency on wood products differs considerably. In the central highlands and towards the eastern slopes of Madagascar climatic conditions with a minimum of 1,500 mm of annual precipitation have encouraged people from colonial times onwards to establish timber plantations. Nowadays, the major cities in the central highlands like Antananarivo, Antsirabe, or Fianarantsoa, obtain their fuel wood in form of charcoal exclusively from introduced species of the genera *Eucalyptus* (Myrtaceae) and *Pinus* (Pinaceae) (Bertrand *et al.* 2010). A considerable part of the consumed construction wood in these cities comes also from pine and *Eucalyptus* plantations. In contrast to this situation, the regional capitals in the dry western and southern parts of the island depend to a large part on charcoal that has been produced from natural forests; only small amounts originate from manmade plantations. Investments in plantations are limited due to major climate constraints[14] that put economic and silvicultural sustainability at at risk. In default of sustainable alternatives, natural forest formations harboring the lion's share of Madagascar's biodiversity are the main sources for charcoal. Consumers indeed prefer this charcoal because of the mix of many hardwood species including even precious wood species, such as ebony (*Diospyros* spp., Ebenaceae) rosewood or *palissandre* (both *Dalbergia* spp., Fabaceae).

(Semi-)External stakeholders or people related to inter- and transnational institutions and globally connected companies perceive biodiversity and ecosystem services from Madagascar's forests mainly in two ways:

1. Forest landscapes as natural heritage often managed as protected areas and visited by international tourists for recreational purposes. According to Madagascar National Parks, the state protected area authority, about 130,000 persons visited sites within their protected area network in 2008. Although relatively low in figures, the tourism sector is one of Madagascar's major foreign exchange earners. According to Ballet & Rahaga (2009) the monetary value of this subsector amounted to an added value of more than 165 million US$ in 2008. Madagascar is classified as a biodiversity hotspot (Myers *et al.* 2000) and up to now several hundreds of millions US$ have been invested in the Environmental Program (1990-2010), with the purpose of preserving its unique biodiversity.

2. Timber derived from species-rich forests that is commercialized and transformed outside the country. Madagascar's precious timber species are highly coveted for high quality furniture, marquetry, and music instruments (guitars, woodwinds). The specific features and rarity of the precious hardwood, mainly ebony, rosewood, and *palissandre*, is reflected by their commercial value: high quality rosewood is traded at 5 US$ per kg (GW & EIA 2009). The illegal exploitation and exportation of those timber species has increased significantly during the 2009/2010 political crisis and severely impacted several national parks and protected areas (Schuurman & Lowry 2009, Wilmé *et al*. 2009).

Importance of trade of ecosystem services for economy and human wellbeing

Self-sufficiency

Madagascar, in terms of ecosystem services, is a rather self-sufficient country. Favored by its low economic performance and, hence, little international trade, its insular setting, and a high percentage of rural people that live largely under subsistence conditions, the import of ecosystem services from other countries is limited. In terms of ecosystem services, one of the main goods being imported is rice at a value of 74 million US$, which is less than two percent of total national imports in 2008 (ITC 2010). The amount being imported depends highly on yearly national yields, but has dramatically changed within

14 Annual rainfall varies between < 400 and 1,500 mm per year, depending on region.

the last decades: "*Madagascar has gone from being one of the world's top rice producers in the 1960s to being a net importer of rice today*" (BS 2010). However, the diverse natural environment of Madagascar provides a wide range of ecosystem services that both still serve national and international markets. In terms of electricity consumption, Madagascar's situation is quite remarkable: more than two thirds of its national electric consumption of nearly 486,000 MWh is provided by hydropower (ADER 2008), which is highly depending on ecosystem functioning, such as water regulation by forests.

Economic development

In the context of the economics of ecosystems and biodiversity, Madagascar faces two major obstacles that are common to many countries: there is a "*systematic under-valuation of ecosystem services*" and many ecosystem services are not captured in national accounting systems (TEEB 2009). For Madagascar this is particularly true because of the informal character of most markets. In Madagascar, ecosystem services derived from forests, such as timber, fuel wood, ornamental plants and animals are in general under the authority of the state forest administration. A body of (forest and environmental) law, governing all steps from management and exploitation to trade exists. However, the governance within the forest sector is weak due to the lack of manpower, infrastructure, communication, and transportation facilities at all levels. Law enforcement has also to be seen in the context of poverty: any attempt to formalize access and markets for natural resources would limit the access and lead to higher retail prices through taxing and reduction of offer. These are impacts that would hit the poorest both at the production and consumption side severely. Corresponding measures by the Atsimo-Andrefana regional administration in 2007 to formalize charcoal production led to local riots and the measures were immediately withdrawn (Bertrand *et al.* 2010). Hence, "*access to forest and biodiversity resources is in essence open*" (World Bank 2003). This favors informal markets that are not accounted in national statistics. The case of charcoal shows that for some cities like Toliara or Morandava in the Southwest 100% of the charcoal is from natural forests (Bertrand *et al.* 2010), thus illegally harvested and informally traded, as no harvesting permits are issued. As for construction wood, estimations from 2004 indicate that only 5% of the consumed wood is legally produced, i.e., on the base of harvesting/exploitation permits (GISC 2009). For other products, like orchids (as ornamental plants) no information on harvested or traded quantities at national level is available at all. To sum up, the contribution of the forest sector, despite its potential, remains rather limited. The most important exported ecosystem goods, in terms of monetary value, are sea food (crustaceans) and spices (particularly vanilla and cloves); these three products had a share of 12% of total exports and a monetary value of nearly 200 million US$ in 2008 (ITC 2010). Wood products, as defined by WTO, amount to only about 16 million US$ in 2008 or 0.95% of the total national export value in 2008 (ITC 2010). The economic potential derived from activities such as wood production, bio-prospecting (Acces and Benefit-Sharing, ABS), controlled trade with CITES species and from environmental fiscal reform, are still to be developed or at their beginning.

Human wellbeing

Particularly in rural areas, ecosystem services are almost entirely derived from or provided by locally available natural resources, whether it is goods (agricultural products, fodder, fuel wood, construction wood, food, medicinal plants, and water) or services (such as water purification or soil protection). Beyond direct use, several ecosystem services play an important role in some areas in enhancing human wellbeing through the generation of income. That is the case when markets for ecosystem services exist, which is particularly true for wood energy. Fuel wood and charcoal represent more than 90% of domestic energy sources in Madagascar (Bertrand *et al.* 2010). The entire offer is provided by forests (natural and artificial) located in rural areas. Charcoal makers, transporters, and lumbers all receive their monetary share in the value chain at the local level. Other direct sources of income from ecosystem services are related to protected area management. Madagascar maintains a network of more than 70 protected areas that currently totals 4.8 million hectare (MEFT & UNDP 2009). The engagement of riparian local populations in their management is often foreseen and is part of the governance scheme, e.g., as local guides, rangers, temporary workers or others. Moreover, the concept of sharing visitors' entry fees with local communities and the commitment of many conservation agencies to enhance local social development contribute to human wellbeing through nature conservation. Christie & Crompton (2003) state that 55% of the international tourist arrivals (ITA) visit Madagascar for ecotourism, which can be linked to "visiting" Madagascar's biodiversity, and actually 68% of the international tourists visited at least one protected area (ATW Consultants 2009). Nevertheless, benefitting local populations with the earnings from tourism remains a challenge for national politics, development agencies, and certain tourism operators.

The role of biodiversity for socio-economic and -political stability

Since gaining its independence in 1960, Madagascar has been shaken by recurrent political crises (Maunganidze 2009). Madagascar's political stability, as highlighted during the 2009/2010 political crisis, can be described as rather fragile. Independent rating agencies consider the current situation of Madagascar between "critical" and "warning" (The Fund for Peace 2010). Among others, this becomes manifest in the form of security problems, "absence of adequate legal guarantees, weak political institutions, and capricious policymaking" (Control-Risks 2009).

Madagascar's political crisis that started early 2009 has revealed that political stability can also be linked with increasing scarcity of ecosystem services and the availability of land they are produced on. According to Üllenberg (2009), the issue of foreign direct investment in land (for agricultural purposes) can be seen as one of the underlying causes for the former head of state Marc Ravalomanana to resign and the subsequent mounting political crisis. A case which caused international attention was the so called *DAEWOO deal*. A foreign investor from South Korea was about to sign a 1.3 million ha land lease deal with the Malagasy government. It was the intention to produce, among other products, corn and palm oil for the South Korean domestic markets. The size of the project and its non-transparent handling was perceived skeptically by the Malagasy and was used as an argument for the opposition to question the former president (Maunganidze 2009). In the follow-up of the crisis, when many bi- and multilateral partners of the environmental and forest sector suspended their aid and cooperation with the government, the state sector was close to paralyzed as activities could not be further executed as necessary and planned.

The dependency of the Malagasy Ministry of Environment and Forests on international collaboration is illustrated by its annual budget: 81% of the projected income of the fiscal year 2008[15] was planned to be provided as external contributions (by donors, technical partners, and non-governmental organizations, both international and national) (Andrianorosoa 2010). Thus, the suspension of (financial and technical) cooperation had direct and harsh impacts on the implementation of the ministry's programs, its activities on the ground and the fulfillment of sovereign tasks such as planning and controlling. The destabilization of the environmental sector, best expressed by the alarming increase of illegal logging of precious woods particularly from national parks in 2009 and 2010, was evident (Schuurmann & Lowry 2009, GW & EIA 2009).

Negative effects on socio-economic stability through the loss of biodiversity and ecosystem services are generalized in Madagascar. The main drivers of biodiversity loss are deforestation and degradation of forests, the loss of fertile soils, large scale erosion, in combination with an ever growing population and its growing demand for natural resources, which leads to less access to ecosystem services in terms of quality and quantity. Further degradation of resources and internal migration movements are part of this vicious circle (WWF 1999). Large parts of Madagascar have become rather uninhabitable, as they are providing less and less ecosystem services due to repetitive clearings and burnings, leaving unproductive grasslands and degraded soils behind. The fact that urban centers of Madagascar have a significantly higher population growth (approx. 5 vs. 3%) reflects this rural exodus and the socio-economic

15 The last "regular" year before the crisis started was 2008 and is therefore chosen as a reference.

fragility in parts of the rural zones. With unorganized city development and considerable numbers of people living under precarious conditions, the rapid growth of urban centers also has the potential of contributing to political destabilization. Migration also happens towards still relatively resource-rich areas, which then in turn are exploited by migrants (WWF 2002).

BIODIVERSITY INTEGRITY AND VULNERABILITY AGAINST GLOBAL CHANGE

Compared to the world's average per-capita CO_2 emissions of 3.22 (1960) and 4.27 (2005), respectively, Madagascar's emissions are very low: 0.07 (1960) and 0.15 (2005) (WRI 2009). Irrespective of its low contribution to climate change, the country is among the territories that may be significantly hit by its impacts, especially related to extreme weather events such as abnormal precipitation, floods, storms, droughts and heatwaves. As shown above, the tropical island state of Madagascar is strongly dependant on national ecosystem services. Therefore, losses of biodiversity and ecosystem services may weaken the island's autarky and may increase the vulnerability of its population against global change. This is particularly true for provisioning and regulative services in terms of global environmental change and the loss of food and timber resources.

The high deforestation rate and ongoing degradation of forest areas lead to desertification and critical changes of local climates and microclimates and may, additionally, drive the change of local precipitation regimes. Severe droughts are frequently reported in the southern parts of the island causing famines and migration. The majority of the larger rivers running southwestwards carries water only a few days or weeks per year. Decreasing precipitation and water regulating services (due to loss of forest cover) might consequently diminish the amount of water reaching the riparian fertile soils in the lowland, thus making flood irrigation agriculture increasingly unfeasible. High sedimentation due to erosion may, additionally, threaten the reefs and the fragile equilibrium of the mangrove forests.

Access to water might be of even larger concern in the future if droughts become even more severe and, hence, migration may become more common and intense. This might increasingly cause social conflicts in population-receiving areas. So far, only minor migration events may be ascribed to climate change driven events, such as the emigration of coastal inhabitants towards the central regions in search of more fertile soils.

In the southern and southwestern regions of the island, food sources are already dramatically scarce during the winter months (May-September) and famines affecting thousands of people are frequent (WFP 2010). Cattle die and animal husbandry becomes unfeasible. Adapted crops are rare and the local population mainly depends on manioc (*Manihot esculenta*, Euphorbiaceae), yams (*Dioscorea* spp., Dioscoreaceae), and introduced invasive plants like the prickly pear (*Opuntia* spp., Cactaceae) that is widely spread in the dry regions often covering vast areas. Former crops such as millet, which are better adapted to the dry weather conditions, were replaced by corn in some regions when foreign investors promised higher revenues. However, corn was not well adapted to the dry conditions and some investors cut back their local business.

Since water sources are often very limited (and in the southern and western dry regions only seasonally available), the applicability of sustainable utilization techniques is already limited. If temporary water basins appear they are extensively used for drinking and washing purposes and to gain water for cooking, watering cattle and bathing of humans and animals, but not usually for watering the cultivable acreage. In some regions temporary water is stored in Baobab trees (*Adansonia* spp., Malvaceae) for drinking purposes (WWF 2009). Alternative and more efficient water storages to cleanly collect and store rain water are in great need in the semi-arid regions.

Tropical cyclones hit Madagascar regularly in the austral summer; they are most numerous and severe from January to May. In 2007, Madagascar was impacted by six cyclones killing at least 150 people and affecting hundreds of thousands of people which lost their houses and goods. In February 2008, cyclone Ivan was one of the most severe cyclones recorded in Madagascar and destroyed 90% of the infrastructure of Sainte Marie Island a few kilometers off the east coast of Madagascar (DPA 2008, JDLNA 2008, Reuters 2008). Furthermore, such extreme events harm the agricultural sector through direct losses of crops and cattle and, indirectly, through the loss of supporting services like the erosion-driven loss of arable land and fertile soil cover. There is evidence that the frequency and intensity of these extreme events is increasing due to climate change and, particularly, the warming of the Indian Ocean's water temperature (Emanuel 2005).

Global socio-economic changes like the investment of foreign enterprises in agricultural resources, or the development of the telecommunication sector by foreign investors, may lead to complex international dependencies. The loss of medicinal plants and traditional knowledge by overexploitation and the replacement by "modern" medicine may weaken rural populations in terms of self-supply. The dissolution of social structures and the destruction of traditional biodiversity-based livelihoods are likely to cause the loss of safety-nets that do not have an alternative.

CURRENT APPROACHES AND INSTRUMENTS FOR THE CONCILIATION OF BIODIVERSITY AND HUMAN DEVELOPMENT

Policies and legal aspects

As early as 1989, the Malagasy government's commitment to environmental protection already resulted in the elaboration of a *National Environmental Action Plan* (NEAP). At that time it was the first of its kind in Africa. Its overall objective was to protect and improve the environment while working for sustainable development and economic growth. The NEAP received legal status in 1990 by the adoption of the *National Environmental Charter* and the *National Environment Policy* (law 90-033) The NEAP was put into operation in 1991; it was established as a 15-year plan, divided into three 5-year phases, which was subsequently extended until 2009. The engagement of the government was also reflected by its readiness to work with the international conservation and development aid community, and its ratification of all the major regional and international conventions related to the environment and sustainable development (CBD, UNFCC, UNCCD, etc.).

Another major orientation for biodiversity conservation and local development was set in 1996/97, when the government adopted its new forestry policy (law 97-017) allowing the management of renewable natural resources to be handed over to local communities (known as the GELOSE law; *Gestion Locale Sécurisée*: secured local management) either for conservation and/or sustainable utilization. Later, the GCF decree was adopted (*Gestion Contractualisée des Forêts*: contractualised forest management), which partly responded to the complexity of GELOSE by providing a more adapted and simplified mechanism for the unique transfer of forest resources.

A new dynamic was created in 2003, when Madagascar's Head of State Marc Ravalomanana announced at the World Parks Congress in Durban, South-Africa, the so-called "*Durban Vision*": An undertaking to extend the size of Madagascar's protected areas by 2012 from 1.7 million to 6 million hectares, meeting the IUCN objective to protect at least 10% of the national territory, while aiming mutually at conserving biological diversity and promoting sustainable development (Norris 2006).

The second generation of Madagascar's *Poverty Reduction Strategy Paper* (PRSP), called *Madagascar Action Plan* (MAP) was released in 2007. One of the eight top priorities for development was the seventh engagement, called "*Cherish the Environment*". By this step, the government acknowledged the importance of Madagascar's natural resources for economic development and, thus, poverty reduction. It formed the basis for the Ministry's program of work from 2008 onwards. Up to now, the MAP has not been replaced by another PRSP. Early in 2010, the transitional government adopted a new *National*

Environmental Policy, which follows the previous policy. It recognizes the challenges that biodiversity conservation and poverty reduction are facing, including climate change. Furthermore, it points out the importance of the environment for human and economic development in Madagascar.

Widely supported by bi- and multilateral cooperation, Madagascar has adopted a wide range of legal instruments for managing and conserving its biodiversity. Among others are: a law that decrees environmental impact assessments for different forms of investments that may harm the environment (mining, infrastructure, but also protected areas); a protected areas code that governs all type of protected area categories (including the formal participation of "new" stakeholders like private sector actors or the recognition of local communities as managers of protected areas); and several regulation for CITES species (e.g., crocodiles, lemurs, chameleons, and orchids). The use of traditional medicine is recognized by modern law (decree 62-072 from 1962) and at present, Madagascar actively participates in the actions for establishment of a protocol on *Access and Benefit-Sharing of genetic resources* (ABS) within the *Convention on Biological Diversity*.

Traditional rights and culture are considered in modern Malagasy law:

- The legalization of usufruct rights in the new forestry law (1997), along with the maintenance of rights to practice the collection and hunting of (unprotected) plant and animal species for local use on their territory.
- The obligation not to resettle local populations in new protected areas, as is the case for the Mikea forest in the Southwest, where some groups of indigenous populations are living who are very much tied to their land.

The *Malagasy Protected Area Code* (Code des Aires Protégées, COAP) foresees that the national protected area authority redistributes 50% of the entrance fees to concerned municipalities for social investments; new categories of protected areas have been legally adopted by the government and allow for management of protected areas by local communities, private operators and foresee sustainable valorization activities of the natural resources. The *GELOSE* law on management transfers of natural resources to local communities recognizes explicitly the local *dina* and gives them legal status as part of the transfer contract between the administration and the local population.

In addition, Madagascar has developed new strategies for the integration of environmental aspects into other sectors as well as promoted an intersectoral approach that aims at better coordination of programs and actions (for instance in the context of oil exploration and exploitation, mining, and fishery). Intersectoral synergies are also pursued within the ratified international environmental conventions and their national action plans, for example the *National Action Plan for Adaptation* (to climate change) and the undertaking to fight desertification, derived from the *United Nations Convention to Combat Desertification*.

Institutional aspects

The institutional landscape of the environmental sector was developed significantly during the first phase of the NEAP (1990-1995). Besides the existing sector ministry, currently in charge of the environment and forests, several institutions in charge of managing, financing, and monitoring environmental aspects were created and still exist in order to implement the national policy. Some of the most important institutions include: *Madagascar National Parks* (MNP), formerly known as *Association Nationale pour la Gestion des Aires Protégées* (ANGAP), in charge of managing a network of almost fifty major protected areas; l'*Office National pour l'Environnement* (ONE), which is mainly responsible for environmental protection and coordination of those activities; the *Observatoire National du Secteur de l'Environnement et des Forêts* (ONESF); as well as SAGE (*Service d'Appui à la Gestion de l'Environnement*), which in particular supports management transfers of natural resources to local communities and also hosts the ABS focal point. At the operational level, the ministry has two general directorates (environment and forests) and several directorates that are in charge of the overall strategy and current programs: protected areas, the valorization of natural resources, planning and monitoring, control and integrity, environmental awareness and communication. Regional directorates are located in all of Madagascar's 22 regions.

Conscious of the challenge of sustainably financing biodiversity conservation and sustainable natural resources management, Madagascar set up two foundations: *Tany Meva* for financial assistance to local initiatives and activities as well as the *Madagascar Foundation for Protected Areas and Biodiversity* (FAPBM), which finances protected area management and is mainly fueled by official development aid and private funding.

It has to be pointed out that the state forest sector never received the same attention and support as the conservation sector. Management transfers of forests were indeed supported by donor agencies and non-governmental organizations, but usually for the purpose of creating community-based types of "protected areas" and rarely with the intention of producing any products for markets in order to improve livelihoods. However, any form of institutional support was—compared to biodiversity engagements—rather limited. The forest administration is lacking capacities and institutional reform has been on the agenda for many years.

As mentioned above, a large part of conservation activities is financed and also implemented through international development cooperation, but also through a multitude of international and national environmental non-governmental organizations, and local consultancy companies. Substantial aid comes from the World Bank and the United Nations and their institutions, the European Union, France, Germany, USA, Japan, and Switzerland as well as from environmental organizations such as WWF, Conservation International, the Wildlife Conservation Society, and the Durrell Wildlife Conservation Trust. An evolving actor is a recently created platform of civil society organizations, called "*Alliance Voahary Gasy*" assembling national and regional environmental non-governmental organizations and lobbying particularly at the national level for environmental consciousness and action.

Local populations and associations play an important role in formal or contracted natural resource management; they are one of the key actors in biodiversity conservation. The government (by its policy and legal framework) as well as international and national organizations from science to development aid, have acknowledged this fact. They support local populations to be formalized and recognized as a legal entity by the state, and they develop their capacities and assist technically and financially in the implementation of activities related to natural resources. However, a major challenge is to render community-based associations effective and sustainable. Within the given context of limited market access, a high illiteracy rate, and the remoteness of their territories, new approaches need to be developed.

A new concept for coordinating the numerous partners and aid (technical and financial) of the environmental sector was about to be established in 2008, which involved the government, with the support of the major international and national stakeholders. However, this effort was suspended at the beginning of the 2009 political crisis when many donors halted their official aid to the government.

Practical/technical aspects

The above described rural exodus and the intra-national migration show the importance of stable ecosystems for stable human systems, particularly, at the local level: ecosystem services are directly used for livelihoods by more than 70% of the Malagasy population and are stabilizing or improving their socio-economic situation. Wherever income is generated from ecosystem services, the contribution to stability can be considered even more important. Monetary income can be used for investments in agricultural productivity, education, and health and is thus stabilizing. For this reason the promotion of local economic development is pursued by developing agencies and the government (e.g., PSDR: *Programme de Soutien pour le Développement Rural*), and increasingly technical cooperation agencies involved in natural resource management are supporting local initiatives to set up sustainable value chains and get market access at the local, national, or international level. The diversity of promoted ecosystem services, not exclusively concerning native species, is considerable and ranges from the production of certified Bourbon vanilla (*Vanilla planifolia*, Orchidaceae), essential oils (*Ravensara aromatica,* Lauraceae), charcoal (*Eucalyptus camaldulensis*, Myrtaceae) to ecotourism. Stabilizing effects from formal valorization of natural resources also take place at the municipal level, as the municipality receives local taxes that contribute to their communal budget. However, stabilization effects for the state are rather a potential than a reality and are highly underdeveloped. Not only is value-added processing of natural resource into higher value products generally low, but the state receives little taxes and fees, due to the dominance of informal markets and the current fiscal legislation for natural resources (which was under revision as of 2009). Important financial resources required for a stable sector development are thus missing. The above mentioned dependency on external resources for financing sector activities, such as protected area management mirrors the weak internal resource mobilization. Indeed, a particular case is that of protected areas in Madagascar. While they are set up for conservation aspects they can, however, have negative affects on the socio-economic stability of the "affected" population. This is the case, if access to ecosystem services, such as timber, fruits, and watering places is limited or even cut due to the management regime put in place. The World Bank, which supported the establishment and management of protected areas within the Environmental Program, requires for each new creation or extension of a protected area, an environment and social safeguard plan following its safeguard policies for project implementation, in order to prevent unfavorable impacts on affected populations inside and outside of a protected area.

The first efforts to protect Madagascar's outstanding biodiversity date back to 1927, when the first protected areas were established as *nature reserves* representing the main ecosystems. Since that day, a comprehensive network of protected areas was established progressively in order to cover the main ecosystems and their biodiversity. Following Madagascar's independence (1960), new categories were introduced in order to have adapted forms of governance and objectives: national parks, special reserves, classified forests, hunting reserves, and reforestation and restoration zones. The conservation strategies have evolved ever since. In the 1980s the concept of *Integrated Conservation and Development Projects* (ICDP) was introduced to Madagascar, applying a zoning concept with a central protected core zone and adjacent peripheral zones with regulated access and sustainable use by local populations. The promotion of sustainable land and resource management techniques as well as income generating activities were the key supports to local populations that were deprived from part of their traditional rights. It was not before 2000 that the governance and management of protected areas became more open and more adapted to the prevailing socio-economic conditions. They favored the sustainable management and use of ecosystems and integrated new stakeholders such as private operators for tourism development and local communities.

In the beginning of 2010, Madagascar was holding 76 protected areas within the network, including additional ecosystems such as marine protected areas, and using the six IUCN categories. Currently, almost five million hectares are under protection, some of them still temporary. As a result of these biodiversity conservation efforts the annual loss of forest (cover) has been reduced (MEFT *et al*. 2009a).

Another major pillar of biodiversity conservation is the management transfers of natural resources to local communities or associations. Stipulated in the new forestry law of 1997, this tool recognizes the importance of the local population in managing and preserving ecosystems. The main features of this concept are the elaboration of a management plan for the resources or ecosystem, the creation of a local association to whom the management of the resources is transferred, and the contract between the administration and the association. While in the first years many transfers were concluded, several obstacles were realized: the social, institutional, and technical weakness of local associations, the reduced capacity of the administration to monitor and support the transfers, the elevated costs for technical support (e.g., inventories, elaboration of management plans), the reduced possibilities to serve markets with local products, and gaps in the legislation. Today, the support for management transfers is aiming at rendering the local population capable of managing their sites and setting up economic incentives through the commercialization of ecosystem services by sustainable use and the valorization of forest products.

A major potential threat to all biodiversity conservation efforts are resource or area consuming economic activities, such as infrastructure projects and, in particular, mining activities (Cardiff & Andriamanalina 2007). For the majority of Madagascar's terrestrial territory, mining exploration concessions have been issued, including within protected areas and sites where management transfers exist. In order to solve those potential conflicts a commission composed of the ministry in charge of environment and forests and the ministry in charge of mining has been created. Furthermore, the handling of the permits is rather transparent, as a land registry exists that facilitates access to information. In addition, the two ministries have issued a guide to address the problem (*Manuel de procédures de traitement des problématiques de superposition des Nouvelles Aires Protégées avec les carrés miniers*) (MEFT *et al.* 2009b), and the subject is treated in several legal texts. However, large mining projects develop a certain dynamic due to their size and economic volume and it is, finally, a political decision if and how area and biodiversity consuming investments are prioritized and implemented.

FUTURE DEVELOPMENTS

It is not time to sing the requiem for Madagascar's biodiversity; there remain options for a more sustainable development that embraces an effective conservation of biodiversity. Many forests and presumably large parts of unknown biodiversity have been lost in the past; however, the island still harbors a unique treasure of ecosystems and biodiversity that can be preserved for the wellbeing of future generations. In the previous sections of this study, the drivers of biodiversity loss in Madagascar have been identified and stakeholder-influencing conditions have been described.

In Madagascar's history, political changes were often followed by times of uncertainty. Biodiversity conservation was a major issue for most of the former governments, regardless of their political direction. However, biodiversity governance is not becoming easier as it is facing strong and increasing challenges. Some of them, such as demographic change or poverty, are not new but gain ever more importance. Additionally, the development of Madagascar is more than ever under the influence of international relations, dependencies of global markets, and other often unpredictable drivers of global change, such as global climate change. Rising sea-level, extreme weather events, and subsequent food scarcity may harm Madagascar's efforts towards better biodiversity conservation and hamper its endeavors for sustainable development and poverty reduction.

In the following paragraphs three possible future developments, simply called 'scenarios', are succinctly outlined, taking into account past developments, current settings, and possible future directions. They are influenced by various internal and external (international) interacting drivers and are equally conceivable depending on the commitment, performance and power of various stakeholders as well as the impacts of global change. In the first possible future, major obstacles and challenges, as described above, are overcome and lead Madagascar into a sustainable, 'green' future. In contrast to that, the second scenario leaves Madagascar with the same or even growing obstacles and biodiversity loss worsens. The third scenario presents an intermediary future development, and takes up elements from both the first and second scenario.

Alternative future 1: **"Madagascar's green future"—conciliating biodiversity conservation and development**

For achieving biodiversity conservation and sustainable development simultaneously, both internal and external factors of the environmental sector have to be favorable. If biodiversity conservation, sustainable management of natural resources and the contribution of both to socio-economic development shall be achieved, important sector external processes and drivers have to be adjusted towards this "green future". A sustainable "green" development of the Malagasy environmental sector depends particularly on the achievement of the following goals:

- Population growth is curbed, particularly in urban areas where ecosystem services are intensively consumed;
- Poverty reduction strategies are successfully implemented;
- Global environmental and socio-economic change are considered in all sectors;
- Good governance at all levels and intersectorial coordination are efficient;
- Economic development contributes ecologically and sustainably to Malagasy people's wellbeing—without a strong integration into global markets;
- Mining and other large scale infrastructure projects are implemented following socially and ecologically sound standards;
- The agricultural sector enhances its performance sustainably and provides enough food for the population, from local to national level, without major further extension of areas under cultivation;
- National policies favor sustainable development, with a major component being environmental fiscal reform.

Concerning the environmental sector, major goals to be achieved are:

- Stakeholders negotiate climate change issues at the international level and develop and implement (adaptation) strategies and solutions at the national level;
- Biodiversity conservation and climate change management are harmonized;
- Competences and capacities of relevant stakeholders, particularly the ministerial authorities, civil society, private sector, and local populations in charge of environmental management are strengthened;
- Decentralization and support by local actors is favored;
- Sustainable financing of relevant institutions and activities;
- Development and implementation of a policy that ensures sustainable provisioning of ecosystem services;
- Development and formalization of markets for ecosystem services and value-adding for natural resources;
- Development aid within the sector is harmonized, coordinated, and follows national policies and priorities.

Effects on biodiversity and development

If above mentioned conditions are realized, Madagascar's biodiversity has a great chance of being conserved in the long term. This would mean that the country would be developed on the basis of its natural richness, without selling it cheaply to industrialized economies. The remaining extent of natural habitats (particularly forests and protected areas that harbor forests) will be preserved and its biodiversity maintained as conversion of forests into agricultural land will be halted. This will require the improvement of traditional land use techniques, and the effective adaptation of the agricultural sector to climate change. Limited population growth will lead to less (growing) demand for food and other ecosystem services. The network of protected areas will grow in size and number, both improving connectivity and taking into account local community needs. Revenues from entry fees are fairly distributed within the communities and are also reinvested in the protected areas. Ecosystems that provide marketable services (water purification, energy and construction wood, medicinal plants, etc.) will contribute to local and national development by providing jobs, income, and taxes for the state, which will be in turn further invested into the sector. Alternative income activities will be generated, especially for the rural population, by protection and sustainable use of forest products and services. This will reduce the pressure on natural resources from charcoal production, timber and firewood exploitation; therefore, wood is also grown in sustainable timber plantations to cover national and international demand. Mining and oil industrial projects will minimize environmental harm to an acceptable extent; benefits derived from these operations shall contribute to the compensation and mitigation of negative impacts. Authorities are competent and have good presence at the local level to adapt policies to new developments and challenges, and to implement existing policies and supervise action on the ground. The vulnerability of both biodiversity and local populations to global change and, particularly, climate change is diminished by implementation of strategies and solutions that include consideration of global and climate change in land use and urban planning and are supported by competent authorities, NGOs, and other stakeholders. Alternative and sustainable sources of funding of forests and protected areas are functional with large participation at local level (REDD, Payment for Ecosystem Services, etc.) and support conservation efforts. Resilience will be increased and biodiversity becomes a main source of sustainable development.

Alternative future 2: ***Driving beyond tipping points***

Efforts to enhance biodiversity conservation may be undermined by various factors including low and unsustainable development. The framework conditions which anticipate the development towards a sustainable future are:

- Population continues to grow at rates between three (rural) and five (urban areas) percent each year and will double by 2025 in major cities;
- Poverty reduction strategies are weak and social inequalities increase;
- Global change is not considered in national policies and, therefore, the development and implementation of adaptation strategies is low;
- Harmonization and profiting from synergies is not achieved between different but adjacent sectors, particularly with regard to land use planning;
- The performance of the national economy is too weak to have favorable impacts on the development;
- Important foreign exchange earners, such as mining projects or bioenergetic enterprises extract and export natural resources, harm the environment, neglect environmental and social requirements and negatively affect local populations; profits received are not invested in development;
- Subsistence farming dominates and barely feeds the rural population, major imports of rice and other agricultural products are necessary to satisfy the growing national demand;
- Sustainable development is not promoted as a guiding principle for national policies.

Concerning the environmental sector, driving factors are:

- Ministerial authorities are weakened and—together with other relevant stakeholders—neither able to manage the natural resources sustainably nor to implement international mechanisms such as REDD or ABS on a broad scale;
- The efforts to strengthen competences and capacities are weak and interventions by state authorities, development aid agencies, and non-governmental organizations achieve only localized and temporary effects, since coordination is not enhanced;
- Biodiversity conservation and climate change adaptation management are not harmonized but rather inconsistent;
- Many decisions are taken on a central level without comprehensive participation of different stakeholders on other relevant levels;
- The concepts and principles of sustainable development and biodiversity conservation are not integrated into national policies;

- Modes of sustainable financing of the environmental sector are not implemented, leading to a constant lack of money to support institutions and activities, even though several structures or institutions have been set up formally;
- Most markets for environmental services remain informal and the state authorities and communities hardly benefit.

Effects on biodiversity and development

Forest and biodiversity loss will continue because the principle drivers are not adequately addressed (e.g., growing population, subsistence farming with little output, demand for ecosystem services such as wood for energy and construction). The access to natural resources remains mainly unregulated; biodiversity and ecosystems services are undervalued and prone to be overexploited. Vulnerability to climate change is high, and the adaptive capacities of both human populations and biodiversity are low. Ecosystem services are lost in some regions since the resilience of ecosystems is weakened. Mitigation projects are few in number and weak. Adaptation strategies exist, but are only slowly implemented. The agricultural sector shows insufficient adaptation to climate change and rural populations lack the skills and resources to implement more productive techniques. Unsustainable land-use techniques dominate and the amount of arable land decreases while food scarcity is amplified by growing demand and stagnating (or even decreasing) productivity. Climate change reduces the quantity and increases the variability of agricultural production. The purchase of land remains difficult and land property is increasingly in the hands of few. The (rural) populations' self-sufficiency is endangered and internal migration becomes a major problem. Sustainable management of forests, including plantation forestry, is not sufficiently implemented leading to degradation and deforestation. As natural resources are disappearing, the pressure on biodiversity-rich areas is growing, impacting especially vulnerable and unique areas. Local efforts of sustainable management of resources continue, but fail to achieve a critical mass required for effectiveness. Large-scale investments harm the environment and even protected areas are threatened both by mining activities and exploitation of resources. Protected areas do not benefit the neighboring population and become less relevant destinations for visitors because access and lodging infrastructure are insufficient. Community-based organizations are weakened by a lack of enforcement, and a lack of income generating alternatives may lead to a violation of traditional and modern rights due to ongoing exploitation of their managed natural resources. Illegal trade of biodiversity (faunal and floral species, precious wood) and habitat destruction increasingly threaten already endangered species. In the energy sector, sustainable alternatives and renewable energies are still lacking, and charcoal as well as firewood from natural forests remains the main source for energy supply in many regions. The existing sustainable plantations for timber and fuel wood are insufficient to satisfy the increasing demand and are depleted.

Alternative future 3: ***Avoiding the worst and maintaining the hope***

This "scenario" is marked by two antagonist developments, where the sector performance is enhanced while the parameters outside the environmental sector are rather unfavorable. The improved performance of the environmental sector is not embedded in a similar national and cross-sectoral policy and is, thus, lacking effectiveness.

The main parameters outside the environmental sector hampering sustainability are:

- Constant population growth between three and five percent per year;
- Poverty reduction strategies that are successfully developed, but whose implementation remains difficult;
- The inconsistent consideration of global change issues without adequate mainstreaming;
- Large-scale projects increasingly follow environmental and social requirements but control mechanisms stay weak;
- Stagnation of the agricultural sector performance, which continues to be based on subsistence farm-

ing, increasing conversion of forests into agricultural land and increasing dependency on imports;

- Environmental sustainability is seen only sectorally, without being acknowledged as a cross-sectoral issue of strategic and systemic importance;
- A (weak) economic performance that does not set off significant development.

Concerning the environmental sector, this development would be somewhat (but in the mid-term insufficiently) counter-balanced by the following tendencies:

- Significant strengthening of competencies and capacities of all stakeholders taking part in environmentally relevant decisions;
- Encouragement and harmonization of environmental institutions; the administration of their programs leads to an efficient use of natural resources;
- Enhancement of decentralization and development of local structures;
- The environmental sector generates income that allows sustainable financing;
- Continued implementation of an emerging forestry reform and good governance;
- Development and strengthening of environmental policies.

Effects on biodiversity and development

The high population growth rate in both rural and urban areas will lead to a continuously growing demand for natural resources and an overexploitation of agricultural land and forest areas. The implementation of poverty reduction strategies hardly makes progress, and the direct dependence on diminishing natural resources is high, especially amongst the rural population. The agricultural sector has a low performance; in some regions techniques will be unsustainably improved, but in most regions subsistence farming and traditional land use techniques are predominant and are not adapted to cover the rising demand for food. More arable land is needed leading to advancing degradation of valuable ecosystems. The environmental sector faces many challenges that may reduce effectiveness of conservation, but develops sustainably, including various stakeholders. Biodiversity governance and conservation are enhanced by good management inside and in the vicinities of protected areas. Sustainable forest management, including the establishment of additional sustainable timber and fuel wood plantations, mitigates the pressure on natural resources. The illegal traffic of flora and fauna diminishes slowly, but progressively. Communities are increasingly involved in biodiversity conservation and generate corresponding basic income. However, the intellectual and financial external input required for these achievements stays high since framework conditions (derived from other sectors) are not favorable. Since the good approaches of the environmental sector are difficult to be harmonized with other sectors such as mining, fishery, agriculture, or energy, conflicts may rise and long-term conservation of biodiversity remains a major challenge. Global change and, particularly, climate change are considered in decisions concerning the environmental sector, but vulnerability of the local population is still high, especially in poor regions with multiple stressors. Adaptation strategies and approaches are not mainstreamed and are mainly applied in priority ecosystem and conservation zones. Priority setting, taking into account existing human and financial circumstances, and sustainable approaches, enhance both sustainable development and biodiversity conservation.

CONCLUSION

The three scenarios drafted above show three possible futures for Madagascar. The influencing drivers show that political will and good governance are of major concern for Madagascar's future development. Global change processes enhance the existing problems and new ones; they will require ever improving environmental governance. A strong focus on the conciliation of biodiversity conservation and development could probably avoid the worst-case scenario of failing governance and collapsing ecosystem services. There is still a potential for achieving higher social equality, fair access to ecosystem services, higher benefits from the economic potential, and more effective conservation of biodiversity.

Today's environmental management is still dominated by a rather centralized and sectoral approach, and the development towards an integrative and participatory management involving all actors has to be reinforced and mainstreamed. On the international level, Madagascar's participation in treaties and conventions is an important component of successful biodiversity conservation, including the negotiation and development of adaptation strategies. The bi- and multilateral development cooperation activities should support Madagascar in pursuing the objectives established by signing and ratifying international conventions such as the CBD. Approaches must especially contribute to a national climate change management strategy which comprises all feasible adaptation and mitigation options.

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REFERENCES

ADER (Agence de Développement de L'Electrification Rurale). 2008. Statistique officiel 2008. Unreleased, internal report.

Andrianorosoa, O. 2010. Analyse du budget du ministère de l'environnement et forêt (MEF). Internal Report for GTZ—Public Finances.

ATW Consultants. 2009. Enquête visiteurs pour la filière tourisme à Madagascar. Rapport final. Unpublished report of the World Bank project "Pôles Integrés de Croissance PIC"

Ballet, J. and N. Rahaga. 2009. Impact Économique des Arrêtés autorisant les Exportations de Bois Précieux à Madagascar. Unpublished report to PGM-E/GTZ.

Barthlott, W., J. Mutke, M. D. Rafiqpoor, G. Kier and H. Kreft. 2005. Global centres of vascular plant diversity. Nova Acta Leopoldina **92**:61–83.

Bertrand, A., B. Ramamonjisoa and P. Montagne. 2010. Les filières péri-urbaines d'approvisionnement en bois énergie des grandes villes de Madagascar. Pages 23-36 in P. Montagne, S. Razafimahatratra, A. Rasamindisa and R. Crehay, editors. ARINA, le charbon de bois à Madagascar: entre demande urbaine et gestion durable. CITE, Antananarivo.

Binggeli, P. 2003. Introduced and invasive plants. Pages 257-268 in S. M. Goodman and J. P. Benstead, editors. The Natural History of Madagascar. The University of Chicago Press, Chicago, London.

Burney, D. A., L. Pigott Burney, L. R. Godfrey, W. L. Jungers, S. M. Goodman, H. T. Wright and A. J. T. Jull. 2004. A chronology for late prehistoric Madagascar. Journal of Human Evolution **47**:25–63.

BS (Bertelsmann Stiftung). 2009. BTI 2010—Madagascar Country Report. Bertelsmann Stiftung, Gütersloh.

Cardiff, S. G. and A. Andriamanalina. 2007. Contested Spatial Coincidence of Conservation and Mining Efforts in Madagascar. Madagascar Conservation & Development **2**:28-34.

Christie, I. T. and E. D. Crompton. 2003. Republic of Madagascar: Tourism Sector Study. Africa Region Working Paper Series No. 63. Worldbank.

CITES (Convention on the International Trade with Endangered Species). 2010. Madagascar. Recommendation to suspend trade. Notification to the parties, no. 2010/015. http://www.cites.org/eng/notif/2010/E015.pdf

Control-Risks. 2009. A world of seismic change. Press release. Available from http://www.control-risks.com/pdf/riskmap_2009_press_release.pdf.

Dewar, R. E. and H. T. Wright. 1993. The Culture History of Madagascar. Journal of World Prehistory **7**:417–466.

DPA (Deutsche Presse-Agentur). 2008. Cyclone Ivan kills 11 in Madagascar, headed for Mozambique. Available from http://www.reliefweb.int.Du Puy, D. J. and J. Moat. 1996. A refined classification of the primary vegetation of Madagascar based on the underlying geology: using GIS to map its distribution and to assess its conservation status. Pages 205–218 in W. R. Lourenço, editor. Biogéographie de Madagascar. Proceedings of the International Symposium on the Biogeography of Madagascar, Paris.

Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature **436**:686-688.

Erdmann, T. K. 2003. The dilemma of reducing shifting cultivation. Pages 134-139 in S. M. Goodman and J. P. Benstead, editors. The Natural History of Madagascar. The University of Chicago Press, Chicago, London.

Ganzhorn, J. U., P. P. Lowry II, G. E. Schatz and S. Sommer. 2001. The biodiversity of Madagascar: one of the world's hottest hotspots on its way out. Oryx **35**:346–348.

GISC (Global Innovation and Strategy Center). 2009. Etude sur la production et la consommation en produits forestier ligneux à Madagascar. Report submitted to IRG/USAID.

Glaw, F. and M. Vences. 2007. A fieldguide to the amphibians and reptiles of Madagascar. 3rd edition. Vences & Glaw, Köln.

Goodman, S. M. and J. P. Benstead. 2005. Updated estimates of biotic diversity and endemism for Madagascar. Oryx **39**:73–77.

GW and EIA (Global Witness and Environmental Investigation Agency). 2009. Investigation into the illegal felling, transport and export of precious wood in SAVA Region Madagascar. Unpublished report to the Government of Madagascar. Available from http://www.illegal-logging.info/uploads/madagascarreportrevisedfinalen.pdf.

Harper, G. J., M. C. Steininger, C. J. Tucker, D. Juhn and F. Hawkins. 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation **34**:325-333.

HDR (Human Development Report). 2009. Overcoming barriers: Human mobility and development. Report published for the United Nations Development Program (UNDP). Palgrave Macmillan, New Hampshire, New York.

Hurles, M. E., B. C. Sykes, M. A. Jobling and P. Forster. 2005. The dual origin of the Malagasy in Island Southeast Asia and East Africa: evidence from maternal and paternal lineages. American Journal of Human Genetics **76**:894–901.

ITC (International Trade Center). 2010. Trade performance HS: imports of Madagascar. Available from http://www.intracen.org.

JDLNA (Joint Damage, Losses and Needs Assessment). 2008. Damage, Loss, and Needs Assessment for Disaster Recovery and Reconstruction after the 2008 Cyclone Season in Madagascar. Cyclone Fame, Ivan and Jokwe in Madagascar. A Report prepared by the Government of Madagascar with the support of the United Nations and The World Bank. Available from http://www.pdf.ph/downloads/PDNA/Library/Madagascar_JDLNA_Report_Final.pdf.

Jones, J. P. G., M. M. Andriamarovololona and N. Hockley. 2008. The importance of taboos and social norms to conservation in Madagascar. Conservation Biology **22**:976-986.

Kier, G., H. Kreft, T. M. Leeb, W. Jetz, P. I. Ibisch, C. Nowicki, J. Mutke and W. Barthlott. 2009. A global assessment of endemism and species richness across island and mainland regions. Proceedings of the National Academy of Science of the United States of America **106**:9322–9327.

Kull, C. A. 2002. Madagascar aflame: landscape burning as peasant protest, resistance, or a resource management tool? Political Geography **21**:927-953.

Lingard, M., N. Raharison, E. Rabakonandrianina, J.-A. Rakotoarisoa and T. Elmqvist. 2003. The role of local taboos in conservation and management of species: the radiated tortoise in Southern Madagascar. Conservation and Society **1**:223-246.

Lourenço, W. R., and S. M. Goodman, editors. 2000. Diversité et Endemisme à Madagascar. Mémoires de la Société de Biogéographie, Paris.

Maunganizde, O. 2009. Madagascar: anatomy of a recurrent crisis. Institute for Security Studies. Pretoria, South Africa.

MEFT (Ministère de l'Environnement, des Forêts et du Tourisme) and United Nations Development Programme. 2009. Quatrième rapport national de la convention de la biodiversité biologique.

MEFT (Ministère de l'Environnement, des Forêts et du Tourisme), United States Agency for International Development and Conservation International. 2009a. Evolution de la couverture de forêts naturelles à Madagascar, 1990-2000-2005.

MEFT (Ministère de l'Environnement, des Forêts et du Tourisme), Ministère de l'Energie et des mines and United States Agency for International Development. 2009b. Manuel de procédures de traitement des problématiques de superposition des Nouvelles Aires Protégées avec les carrés miniers. Minten, B. and C. B. Barrett. 2008. Agricultural technology, productivity, and poverty in Madagascar. World Development **36**:797-822.

Moat, J. and P. Smith, editors. 2007. Atlas of the vegetation of Madagascar. Kew Publishing, Royal Botanic Gardens, Kew, Richmond.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca and J. Kent. 2000. Biodiversity Hotspots for Conservation Priorities. Nature **403**:853-858.

Norris, S. 2006. Madagascar Defiant. BioScience 56 (12): 960-965.

Olson, D. M. and E. Dinerstein. 2002. The Global 200: priority ecoregions for global conservation. Annals of the Missouri Botanical Garden **89**:199-224.

Phillipson, P. B., G. E. Schatz, P. P. Lowry II and J.-N Labat. 2006. A catalogue of the vascular plants of Madagascar. Pages 613-627 in S. A. Ghazanfar and H. J. Beentje, editors. Taxonomy and Ecology of African Plants: Their Conservation and Sustainable Use. Proceedings XVIIth AETFAT Congress. Royal Botanic Gardens, Kew.

Ploch, L. 2009. Madagascar's 2009 Political Crisis. CRS Report for Congress, R40448. Available from http://www.opencrs.com/document/R40448/2009-10-07/download/1005/.

Reuters. 2008. Cyclone hits Madagascar, threatens Mozambique. Available from http://www.alertnet.org/thenews/newsdesk/L1829902.htm.Schuurman, D. and P. P. Lowry II. 2009. The Madagascar rosewood massacre. Madagascar Conservation & Development **4**:98-102.

TEEB. 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers. Summary: Responding to the Value of Nature. Available from http://www.teebweb.org.

Tengö, M., K. Johansson, F. Rakotondrasoa, J. Lundberg, J.-A. Andriamaherilala, J.-A. Rakotoarisoa and T. Elmqvist. 2007. Taboos and Forest Governance: Informal Protection of Hot Spot Dry Forest in Southern Madagascar. Ambio **36**:683-691.

The Fund for Peace 2010. 2010. Failed State Index. Available from http://www.fundforpeace.org.

Üllenberg, A. 2009. Foreign Direct Investment (FDI) in Land in Madagascar. GTZ, Eschborn.

UN (United Nations). 2006. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2007 Revision. Available from http://esa.un.org/unup.

UNEP (United Nations Environment Programme). 2004. Payet, R. A., N. Soogun, E. Ranaivoson, R. J. Payet and F. Ali Abdallah. Indian Ocean Islands. Global International Waters Assessment, Regional Assessment 45b. University of Kalmar, Kalmar, Sweden. Available from http://www.unep.org/pdf/sids/giwa_regional_assessment_45b.pdf.

UNESCO (United Nations Educational, Scientific and Cultural Organization) 2010. World Heritage Committee inscribes Rainforests of Atsinanana (Madagascar) on List of World Heritage in Danger. Available from http://whc.unesco.org/en/news/639.

USAID (United States Agency for International Development). 2010. Paradise Lost? Lessons from 25 years of USAID environment programs in Madagascar. Final report. Available from http://www.rmportal.net/library/paradise-lost-madagascar/view.

Vieites, D. R., K. C. Wollenberg, F. Andreone, J. Kohler, F. Glaw and M. Vences. 2009. Vast underestimation of Madagascar's biodiversity evidenced by an integrative amphibian inventory. Proceedings of the National Academy of Sciences of the United States of America **106:**8267-8272.

WCS and CIESIN (Wildlife Conservation and Center for International Earth Science Information Network). 2005. Last of the Wild Data Version 2: Global Human Footprint data set (HF). Available from http://sedac.ciesin.columbia.edu/wildareas/.

WFP (World Food Programme). 2010. Countries: Madagascar. Available from http://www.wfp.org/countries/madagascar

Wilmé, L., D. Schuurman, P. P. Lowry II and P. H. Raven. 2009. Precious trees pay off—but who pays? Poster for the World Forestry Congress in Buenos Aires, Argentina, October 18-23, 2009.

World Bank. 2003. Madagascar Rural and Environment Sector Review; Report No. 26106-MG; Volume I: Main Report.

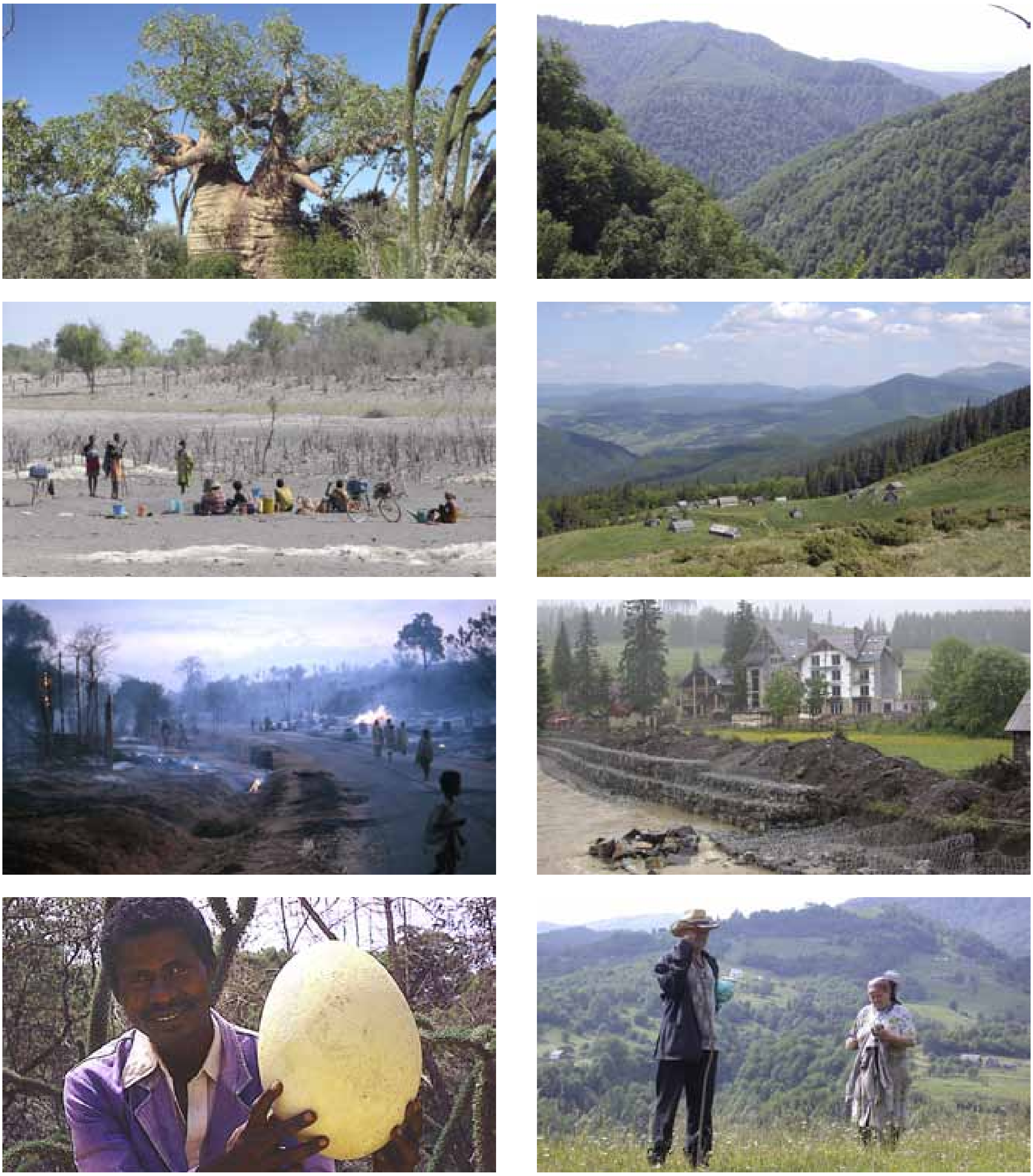
World Bank, Development Data Group. 2007. 2007 World Development Indicators Online. The World Bank, Washington, DC. Available from http://data.worldbank.org/data-catalog/world-development-indicators/wdi-2007.

WRI (World Resource Institute). 2009. Climate Analysis Indicators Tool (CAIT). Version 6.0. Washington, DC. Available from http://cait.wri.org.

WWF (World Wide Fund for Nature). 1999. Les tendances actuelles de la migration des peoples et son impact dans la région écologique des forets épineuses à Madagascar.

WWF (World Wide Fund for Nature), Conservation Strategies Unit. 2002. Mapping the Connections: Population-Environment Lessons from Madagascar. WWF, Washington, DC.

WWF (World Wide Fund for Nature). 2009. Nos baobabs lancent un sos. WWF Madagascar & Western Indian Ocean Programme Office, Antananarivo.



The case study regions Madagascar (left column) and the Ukrainian Carpathians (right column).
LEFT COLUMN FROM TOP TO BOTTOM: Adansonia rubrostipa (Malvaceae), one of 6 native baobab species; rural population waiting for a well to refill in South Madagascar (photos by I. Kiefer); burning dry forest close to Sakaraha (photo by W. Barthlott), Southwest-Madagascar; egg shell of the extinct elephant bird Aepyornis (photo by W. Barthlott).
RIGHT COLUMN FROM TOP TO BOTTOM: managed deciduous mountain forest in East Transcarpathia; traditional high alpine cattle farm (polonyna); accelerating (tourism) development and resulting erosion problems near Bukovel, Hutsul couple tending cattle on a mountain meadow (photos by P.L. Ibisch).

B.1.2.b DEVELOPMENT, BIODIVERSITY CONSERVATION AND GLOBAL CHANGE IN THE UKRAINIAN CARPATHIANS

Juliane Geyer, Lars Schmidt, Ivan Kruglov, Viktoria Gubko, Pier Carlo Sandei & Pierre L. Ibisch[16]

ABSTRACT

The Ukrainian Carpathians hold both high biological diversity and cultural diversity for similar reasons. They are influencing each other in their decline caused by rapid regional changes. Most of the population lives in rural areas and depends directly on ecosystem services. Subsistence farming and non-timber forest products provide direct supplies for most people's livelihoods. Forestry and tourism are the main branches of economic activity and source of income. However, regional and global changes are starting to cause a disconnection between people and direct ecosystem services. The export of ecosystem services, especially in the wood-processing and tourism sectors plays a greater role for the economy and human well-being than their import and there is a high degree of self-sufficiency. Biodiversity and ecosystem services play a major role in socio-economic and socio-political stability, providing a kind of safety net in times of crisis. Their integrity also lowers vulnerability to global change; impacts can primarily be observed where biodiversity integrity is already interrupted. In the Carpathians the legal and institutional framework for a conciliation of development and conservation is exceptionally sophisticated and bears high potential, but practical implementation in the Ukrainian Carpathians is still rather uncerain. In particular, proactive biosphere reserve management is a very promising instrument integrating developments in forestry and tourism. The lively history of the area indicates that major and sudden changes can be expected in future. The future development of biodiversity and conservation might very much depend on economic and political developments at various scales (national and regional) and could go in quite different directions.

INTRODUCTION

Biodiversity: The Carpathian Mountains represent a certain bridge between the temperate and boreal forests of Northern Europe and the Mediterranean ecosystems. The Carpathians have the richest community of large carnivores in Europe, including all of the large European predators, and their populations are still numerous and viable. In addition to many red-listed and endemic species, this mountain range also harbors large areas of near-natural ecosystems and the greatest remaining reserve of old growth forests outside of Russia. The largest remaining old-growth beech forest in Europe is situated on the Southern slopes of the Ukrainian Carpathians in the Eastern Transcarpathian Region (Fig. 1). The old-growth beech forest in the massif Uholka-Shyrokiy Luh with 8800 ha is the largest coherent piece of its kind in Europe (Commarmot *et al.* 2007). Together with relicts of virgin beech forests in Slovakia and Romania it represents European natural heritage of highest rank and has been included in the UNESCO World Heritage Site *Primeval Beech Forests of the Carpathians* since 2007 (UNESCO 2010). The World Wildlife Fund (WWF) recognized the Carpathians as a natural treasure of global importance and included it in its "Global 200" list of the most significant ecosystems. A characteristic feature of the Carpathians' landscape is the typically small scale of land use patches. Except for large tracts of forest, areas of other land use types such as grasslands, pastures, agriculture and urban settlement are small.

The Eastern parts of the Carpathians traverse through the south-westernmost part of Ukraine covering only four percent of the country's territory. Because two-thirds of Ukraine's territory lies within the steppe and forest-steppe zones, characterized by lowland landscapes and steppe flora and fauna, the Carpathian Mountains have a particular significance for Ukraine and are considered part of the national heritage. The highest peaks of Ukraine (Hoverla 2061 m, Petros 2020 m) are found here. The area is

16 J.G. conducted the research and wrote the paper. L.S. contributed ideas and data, especially on scenarios, I.K., V.G. and P.C.S. contributed ideas and data based on local expertise. P.L.I. guided and supervised the research and the elaboration of the manuscript.

characterized by a temperate-continental climate with Atlantic influences, the mountain range protecting the leeward side from dry-cold northeast winds. Precipitation ranges from 650 mm in the lowland up to 1600 mm in the mountains and usually there is snow between November and April. According to geographic and climatic conditions, there are different vegetation belts. About 90% of the area is forested. In the lowlands and on the foothills agricultural land and mixed oak forests prevail. Between 350 and 1450 m high precipitation favors the growth of rich montane beech forests. In higher altitudes, fir and spruce mix into the beech forest, finally forming mixed and pure spruce forests at 1200-1650 m altitude. The timber line is characterized by *krummholz* vegetation of green alder, juniper and mountain pine. The mountain tops are mostly vegetated by anthropogenically influenced alpine grasslands with a rich alpine flora (*polonynas*) (Herenchuk 1968; Holubets *et al.* 1988). While protected areas occupy about four percent of Ukraine's entire territory, in the Ukrainian Carpathians they occupy eight percent, and in Transcarpathia oblast over 13 percent. Transcarpathia (*Zakarpatska Oblast*) is situated on the southwestern slopes of the Ukrainian Carpathians in the country' far west "behind the Carpathians" bordering Poland, Slovakia, Hungary, Romania and the other two Ukrainian Oblasts in the Carpathians, Ivano-Frankivsk Oblast and Lviv Oblast.

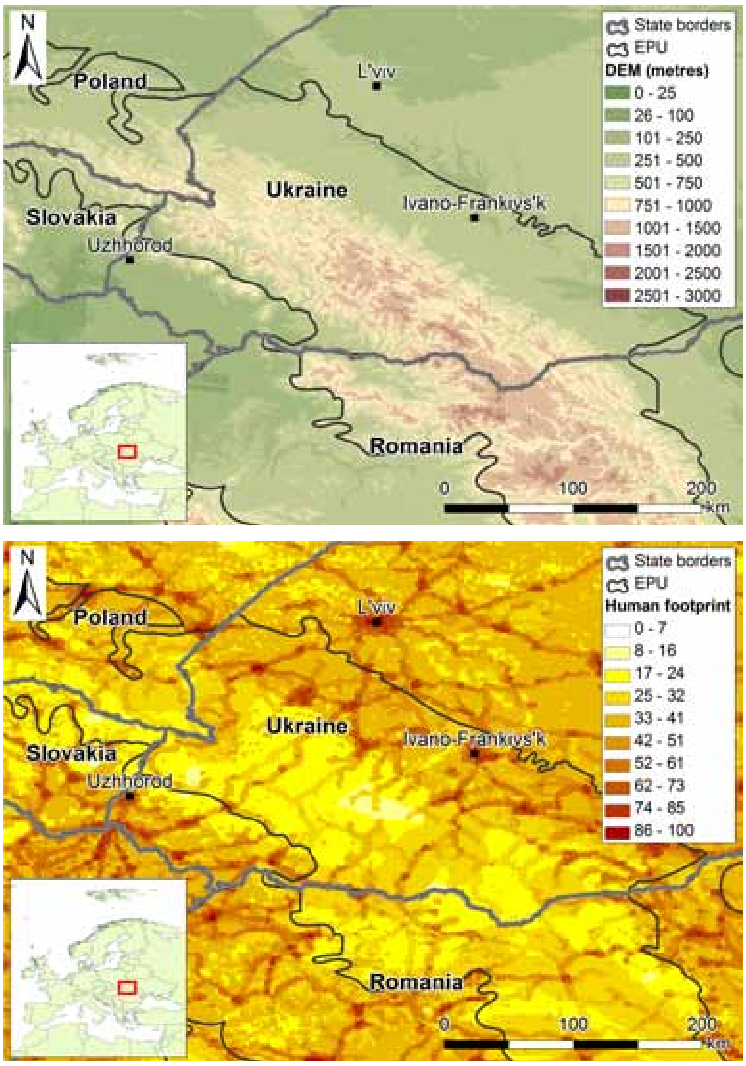


FIG. 1: Maps of the study area showing topography (top) and the "Human Footprint" (after WCS & CIESIN 2005, bottom). The study area basically covers the Ecopolitical Unit (EPU) "Ukraine-Carpathian Montane Conifer Forests" shown in the centre of the map (for EPU compare Freudenberger et al., B.1.1 in this document). Lighter shades in the bottom map indicate lower direct human impact on the land's surface from e.g. human land uses, human access from roads, railways or major rivers or electrical infrastructure. The mountainous and other rural areas with low human footprint are mostly characterized by a continuous coverage of (near-)natural forest.

People: In the turbulent history of Transcarpathia the region has been a pawn for the mighty and undergone a very special political and ethnic development. Transcarpathia has formed peculiar associations among the South and North, East and West of Europe, symbolized the crossing of several nations and a meeting point of political conceptions of European history, but mainly those of the Eastern Slavs. Political leadership changed many times, especially in the time between the last two turns of the centuries. For a long time, from the period of the early medieval kingdoms onwards (11th century), the territory belonged to the Hungarian kingdom or to oligarchic states related to Hungary. After short intermezzos in the Ottoman Empire (in the 16th and 17th century, as part of Transylvania), from 1718 until 1918 it was part of Austria and the Hungary-Austrian Dual Monarchy (as part of Galicia), very briefly in 1919 belonged to the Hungarian Republic of councils, and was under Czechoslovakia between 1919 and 1939 (Magocsi & Magocsi 2002). After very short independence of the Eastern Transcarpathian territory "Carpatho-Ukraine" in 1939, it was occupied by Hungary once more until the end of the Second World War. Despite all these dramatic political changes, the region had never lost its essential Slavic bonds and its economic and cultural relations with nations on the other side of the Carpathians. In 1944 Czechoslovakia dropped its claims for Transcarpathia in favor of the Soviet Union. With the liberation of Transcarpathia in autumn 1944 (many people regarded it as such), and its incorporation into the Ukrainian Soviet Republic, a new history of this region was started. The new administration pursued a definite cultural policy of Sovietization and Ukrainization, which ultimately integrated the Transcarpathian region into the mainstream of Ukrainian civic life. This integration was reflected in the December 1991 Referendum on Ukrainian Independence, in which the residents of the oblast, notwithstanding their unique history, voted 92.5% in favor of the independence of Ukraine from the Soviet Union.

Nowadays, Transcarpathia is characterized by a diverse population of people with different origins, cultures, languages and religions. About three quarters of the population are Ukrainian. The others are Russian (4%), Romanian (3%), Slovakian (1%) or of Austrian, German, Czech, Polish, Italian, Georgian or Armenian origin (Magocsi & Magocsi 2002; Brändli & Dowhanytsch 2003). With an area of 12,800 km^2 and 1.29 million inhabitants it is one of the most densely settled areas of Ukraine (Cabinet of Ministers of Ukraine 2010). The population of Transcarpathia is distributed according to the topography and is therefore uneven. The most densely settled areas are the Tysa lowlands and the foothills of the Volcanic Ukrainian Carpathians. In the mountains, population densities are around 40 persons per km^2 and are concentrated in the bands of lower elevation and in the perpendicular valleys. The high mountainous areas are almost devoid of permanent settlement, although over the summer there are still many livestock herders on the alpine meadows tending their flocks. This Eastern and mountainous part of Transcarpathia belongs to the Hutsul ethnographic zone and many people still call themselves Hutsuls.

Threats to biodiversity and conservation: The region is facing rapid socio-economic development and has been undergoing many changes and transformations since 1991. Factors impacting the region include the decollectivization of agriculture, high unemployment rates and work migration, land privatization, inflation and global developments such as climate change. Rural depopulation is decreasing tremendously, which on one hand is lowering the pressure on biodiversity, but on the other is limiting an active conservation of cultural landscapes. Kuemmerle *et al.* (2009) found that unsustainable forest use and illegal logging are persisting, resulting in continued loss of older forests and their services as well as in the ongoing fragmentation of some of Europe's last large mountain forests. Another threat for the biodiversity of the region is uncontrolled tourism development. Unfortunately there is a lack of understanding of what sustainable and ecological tourism means. There are numerous regional and district tourism development programs (the current one will be over in 2011, and a new one is about it be launched in Transcarpathia). The most harmful results of these chaotic developments are erosion processes on highland ski resorts (like Dragobrat and Bukovel) and mountain roads, pollution and a great visitor pressure on vulnerable ecosystems.

MATERIAL AND METHODS

This case study is primarily based on ongoing research and project work on adaptive conservation management in the area as well as on experiences of local experts and several at least yearly visits since 2006. Information was mainly gained from interviews and workshops with the local population, local and regional authorities, protected area management staff and other experts. Further, literature consultation, especially the Carpathians Environment Outlook KEO 2007 (UNEP 2007) and the report "VASICA—Visions and strategies in the Carpathian area" of the Carpathian Project (Borsa *et al.* 2009), but also of several other sources complemented this study.

HUMANS AND BIODIVERSITY

Cultural diversity and biodiversity

Biodiversity as well as cultural and land use diversity are very high in the Ukrainian Carpathians for very similar reasons. The Carpathian Mountains have been and still are an area of meeting and transit of Eastern, Western, Northern and Southern biodiversity, cultures, religions and traditions (Borsa *et al.* 2009). They were and are a corridor, exchange point and melting pot, barrier and refuge for many species and people who equally met, fought, colonized and assimilated each other. The Carpathian Mountains belong to the areas with highest biodiversity in Europe and large tracts of European old-growth ("primeval") forests have been preserved here. The Carpathians are characterized by many unique landscapes and natural and cultural sites which express both geographical diversity and distinctive patterns of regional evolution of man-environment relation over time (Borsa *et al.* 2009). Over the last centuries the Carpathian region of Ukraine has been part of several states and empires and the remains are widely preserved. Monuments of European folk art are best preserved in the Carpathians. Like biological diversity, the variety of traditional cultures also developed due to different environmental conditions and the difficult accessibility of mountain ranges. The traditions of Carpathian tribes like the Hutsuls, Boikos and Lemkos, for example, developed according to their spatial distribution and the specific geographical and ecological characteristics of their environment. Generally, people in the lowlands are more active in crop and fruit cultivation and the people in mountainous areas practice traditional livestock (especially sheep) farming on high alpine pastures (*polonynas*) in more or less stationary farms (e.g. Hutsul and Boikian farming styles respectively; Stetsiuk 2008).

The loss of culture and knowledge certainly plays an important role in the loss of biodiversity and vice versa. The loss of biodiversity influences the loss of culture and knowledge, but is not the main reason for this decline in the Ukrainian Carpathians. On the one hand, traditional knowledge of resource use such as hunting, fishing, the use of non-timber forest products, especially medicinal plants and mushrooms, might be affected by biodiversity loss and ecosystem degradation brought on by, for example, deforestation and overexploitation of forests. Similarly, a loss of traditional knowledge about the variety of special Carpathian breeds of domestic animals parallels the decline in bred animal stocks. When certain landscape elements (e.g. *polonynas* or specific forests) or species vanish, so will the folk stories and songs about them. For example the *edelweiss* (*Leontopodium alpinum*) used to be very abundant in the high mountains and has many stories, fairytales and songs attached to it. Nowadays *edelweiss* numbers are very low and the stories around that flower are almost forgotten.

On the other hand, open cultural landscapes regarded as typical for the region only exist because of local land use traditions and cultivation. The abandonment of traditional farming is leading to mountain meadows and ridgetop pastures, with their rich highland flora, to overgrow in the course of natural succession. Decreasing grazing and mowing activities caused by the decline in livestock numbers therefore causes a decline in landscape diversity.

The loss of traditional culture and knowledge is not yet very advanced and this area is still characterized by comparatively well-preserved folk traditions. However there are signs of its acceleration, partly enhanced by biodiversity loss, but truly caused by the high speed of modernization and globalization trends threatening sensitive historical structures and traditional behavioral patterns (UNEP 2007). New media such as television and internet, new foreign goods, tourists and better border permeability influence the people, diverting them from their traditions and changing societal values. In many areas human life does not depend so much on local resources anymore and transport is much more facilitated. The decline in livestock numbers and alpine *polonyna* pasture use, for example, is mainly caused by the low economic competitiveness of this activity, increasing disinterest among the younger generation and time constraints of the working population (Bitter & Bomba 2008). The future of traditional cultures is unclear; it depends on the attitude of local communities and can only persist if the communities continue to value it as part of their lives.

Dependency of different socioeconomic strata on biodiversity

There is a socioeconomic inequality between rural and urban areas in the Ukrainian Carpathians (UNEP 2007). The socioeconomic situation of mountain areas and valleys/lowlands is slightly different. In the Ukrainian Carpathians 59%-91% of the population lives in rural areas (Bosch *et al.* 2008). The rural population depends very much on ecosystem services, especially those people not directly living near the main roads. After independence in 1991, the few industrial structures established in Soviet times closed down and since then poverty and unemployment have prevailed in the area (UNEP 2007). The living standard is lower than in cities.

Subsistence farming is the most important response to unemployment and poverty. Traditional agriculture and livestock remain the basic sources of food for local rural communities. Most families have a garden and domestic animals like cows, goats, pigs and chicken. The fodder is grown in the garden and hay is mown on meadows adjacent to the house or higher up in the mountains. Agricultural activities are comparatively basic without the use of high-tech equipment, fertilizers or pesticides. People are therefore very much dependent upon supporting ecosystem services like soil formation and nutrient cycling or regulating services like pollination and water regulation. A wide variety of animals and plants, specially adapted to the harsh mountain climate, is bred for agricultural purposes (amongst them the Hutsul horse, the Carpathian sheep and the Hutsul bee (UNEP 2007)), but are losing importance. Additionally, most families also have 3-7 livestock (sheep or cows), which are herded collectively on the alpine pastures (*polonyna*) over the summer. This represents an interesting form of land use diversification and vertical control of various altitudinal production belts.

Sheep and cattle products such as milk, cheese, meat and wool are used for self-supply or are sold locally. Also non-timber forest products like mushrooms, berries and game, as well as medicinal herbs collected in the surroundings, are additional vital resources for self-supply and additional income when sold. Most houses have electricity supply but water is taken from nearby wells and rivers (Geyer *et al.* 2009). The consumption of natural mineral water from the over 800 sources is an old tradition (Kolodiychuk 2008). Most villages have no sewage system (Bosch *et al.* 2008). Village dwellers have dry toilets and wastewater is disposed off via drainages and water courses. Wood is the major fuel for heating and cooking. Firewood is provided by local forestry and wood processing enterprises or collected illegally. Wood is also used as construction timber and for traditional handicrafts, which are also sold for additional income. Forestry and wood processing enterprises are the main local sources of income and employment (Geyer *et al.* 2009), and in some areas small sawmills and wood processing industries have a more social than economic character in preventing local unemployment (UNEP 2007). Forests are the basic and emergency source of resources and income, especially for the very poor or during hard times. A growing source of additional income is the provision of tourism and recreational services like guest rooms, transport services to remote areas for skiing and hiking or horse riding (Geyer *et al.* 2009). The Ukrainian Carpathians offer rich natural and cultural heritage that is the foundation of tourism development in the area. The cultural heritage is closely tied to the natural environment—to certain landscapes, species or natural processes, for example.

A great part of the rural population seeks seasonal and even permanent work abroad (Bosch *et al.* 2008; Geyer *et al.* 2009). The additional money earned in foreign currencies increases their spending power. A further phenomenon gaining significance is that numerous landowners near developing ski and mineral water resorts like Drahobrat, Bukovel and Skhidnytsia sell their land to recreation and tourism entrepreneurs for extremely high prices making them very affluent for local standards. Those new-rich people invest in building large houses along the main roads and big cars or start tourism enterprises themselves. This detaches families from direct dependence of biodiversity and ecosystem services. For instance, families abandon subsistence farming as they can afford to buy their supplies and have no time for farming because of their work.

The urban population and those living in larger villages in the lowlands depend less on direct ecosystem services. They have easier access to imported or indirect services such as drinking water and food. However, compared to other Carpathian countries (EU countries) the direct dependence on ecosystem services is relatively high, even if slightly spatially displaced. The urban shops offer a more or less rich assortment of domestic and foreign goods (Bosch *et al.* 2008). Water supply is steady, but water is drawn mainly from regional groundwater sources and water bodies. Sources of energy supply are gas and electricity. Similar to more rural areas, also in towns, forestry and tourism play a relatively great role as part of the local economy and source of employment depending very much on forest resources and accessibility as well as cultural ecosystem services of the region such as aesthetic, recreational or educational services.

Importance of trade of ecosystem services for economy and human well-being

Eastern Transcarpathia is comparatively self-sufficient in terms of ecosystem services. The import of services is rather low. Food products, especially staples like cereal products and some fruits, are imported from nearby lowland areas in neighboring Ukrainian *oblasts*, Hungary, Romania or Poland. A very high share of vegetables, meat and milk products are home-produced by the people themselves and preferred over imported goods.

The main branches of economy in the region are forestry and tourism/recreation (Geyer *et al.* 2009). The Ukrainian Carpathians are both rich in forest resources and recreational resources like mountains, skiing areas, mineral water sources, lakes and forests. Water resources as a key factor for development and human well-being—for agriculture, fishery, industry, power generation, tourism and human consumption—are plentiful due to the region's favorable climatic and hydro-geological conditions (UNEP 2007). Over 80% of human water consumption in Carpathians is supplied by groundwater (Borsa *et al.* 2009). Agricultural activities are mainly for self-supply and almost entirely self-sufficient.

The share of exported ecosystem services is higher than the import. The export of timber and wood products like pulp and paper plays an important role in the regional economy and socio-economic welfare (UNEP 2007). Also non-timber forest products are exported at low rates. The large tracts of forests play a great role in carbon sequestration and in the hydrological system. Those ecosystem services are globally relevant and exported, although not marketed. The import of environmental costs plays a greater role than their export. Tourism and recreation development including marketed recreational services is a growing economic branch.

The role of biodiversity for socio-economic and political stability

Since many people are directly dependent upon biodiversity and ecosystem services, at least in rural areas, and their lives are determined by them, their status certainly affects socio-economic stability. In the

Carpathians, the integrity of biodiversity and ecosystem services is widely intact. This condition and the traditional connection to biodiversity and ecosystem services by local people is the most important insurance of socio-economic and socio-political stability in the area. It serves as a kind of socio-economic safety net. Since independence, the economic situation in the Ukrainian Carpathians has been mostly precarious, and poverty and unemployment have been serious problems. In the 1990s, the country was suffering from a major crisis including hyperinflation and drastic falls in economic output. However, due to traditional subsistence farming and livestock herding as well as easy access to and rich supply of wood, non-timber forest resources, fish and game, people are relatively well-provided for also in hard times. Functioning community structures have evolved according to those traditional resource uses and facilitate additional socio-economic stability. Livestock, especially sheep, are herded collectively by village herdsmen on the nutritious alpine pastures and the village dwellers take turns in providing the herders with food and collecting the milk products like sheep cheese. People help each other with hay making over the summer. The young men of the village take care of firewood for older village dwellers, even if cut illegally. Due to the relative independence of the supply of goods and services, of wages and prices, people have been able to avoid economic crises and social unrest has not emerged. In times of crisis resources are exploited to their limits, but due to low population density of the region the opportunity for ecosystem regeneration was given. Forestry and tourism as the major and developing economic branches and main sources of employment and additional income are directly based upon ecosystem services such as wood or recreational resources. The status of those resources has a great impact on the development of those economic sectors and therefore on socio-economic stability. Often small local sawmills and wood processing industries have a more social than economic character, preventing local unemployment, providing people with firewood for very low prices or as gifts and supporting village festivals (UNEP 2007).

If the status of biodiversity and ecosystems degrades, the accessibility to ecosystem services is restricted or people get too detached from their traditional land uses and values—as is already the case in many regions along the main roads—socio-economic stability will not be as easily kept as is currently the case, especially in times of crisis. The preservation and continuation of traditional resource and land use and the accordingly low dependence on imported goods and services from regional and global markets may therefore play a crucial role for the overall socio-economic stability of the region.

BIODIVERSITY INTEGRITY AND VULNERABILITY AGAINST GLOBAL CHANGE

In the last decade the frequency and severity of heavy rains and floods in the Ukrainian Carpathians has increased. The increased risk of floods and erosion in connection with global climate change poses challenges to human lives and livelihoods and many economic activities (UNEP 2007). In the Ukrainian Carpathians extensive clear-cutting often results in accelerated run-off during heavy rainfalls (UNEP 2007), which are occurring more often and more severely (Björnsen Gurung *et al.* 2009). Vegetation also has been and is severely damaged with the establishment of ski resorts. Forests have a special protective function in soil conservation, reducing water run-off and erosion. Soil water retention decreases as soil cover is degraded through timber extraction, forest thinning and chemical changes in pasture glades (UNEP 2007). Maintaining continuous forest cover and sustainable forestry practices without extensive clearcuts is therefore relevant for flood mitigation. Further, forests have a balancing function, reducing or buffering the effects of other weather extremes like droughts, heat waves or storms. Large tracts of continuous and functional forests might prove more resilient against the effects of global climate change. However, after the Second World War deforested areas were reforested with spruce monocultures, which are now very vulnerable to extreme events, diseases and calamities. Further, mean temperature rise and changes in precipitation weaken spruce monocultures even more, especially those planted in the beech belt, making them more vulnerable (UNEP 2007). Since valuable timber resources are affected, the vulnerability of forestry increases, too. Drought may also influence the supply of non-timber forest products like mushrooms, which local communities depend on. Mixed and broadleaved forests seem to be less vulnerable, i.e. more resilient, to climatic changes and extreme events. They are also less susceptible to bark beetle calamities.

Extreme events also directly have an effect on crops and livestock. There are special Carpathian breeds of different domestic animals like the Carpathian sheep that are more robust and can cope with extremes much better, but they are rarely bred anymore. Their reintroduction appears essential for successful agriculture and there are already corresponding aid programs running.

If temperatures continue to rise, evapotranspiration will increase, snow cover will be reduced and the winter season will inevitably get shorter (UNEP 2007). This will lead to changes in the water balance of the area. Water availability might decrease affecting communities and industry as well as ecosystems (Björnsen Gurung *et al.* 2009). Functional forest ecosystems will be much more able to buffer those effects and provide hydrological services like water retention, purification and ground water regeneration. Functional water systems will also be essential in balancing hydrological changes. Less snow and shorter winters will also negatively influence winter and ski tourism—the main tourism branch in the area. However, well-preserved landscapes with rich biodiversity might provide an alternative attraction for summer tourism as well as scientific and educational tourism, thereby decreasing the dependence on long winter seasons.

In addition to climate change, other global change processes and their indirect consequences are influencing local communities and resources in the Ukrainian Carpathians. The demand for wood as fuel and timber, especially in Western Europe, is continuously rising. With forestry being the main economic branch in the Ukrainian Carpathians and (still) plenty of forest resources standing, logging might increase dramatically. This might lead to further deforestation and a reduction of local supply of wood and non-timber forest products. Selective logging techniques, natural regeneration and the protection of large tracts of forests might reduce resource exploitation and buffer the effect on local communities.

Well-preserved biodiversity and functional ecosystems have proven and will continue to provide a sort of insurance for local communities. Rich and easily accessible forest resources, traditional subsistence farming, hunting, fishing and the use of non-timber forest products as well as productive mountain meadows, make local communities more resilient against economic and political changes, even crises, because they are relatively independent from global markets and foreign supplies. Ukraine has been facing many economic and political changes over the last decades and local communities were able to endure all of them in their own traditional way and without major social unrest.

APPROACHES OF CONCILIATION OF DEVELOPMENT AND BIODIVERSITY CONSERVATION

Political, legal and institutional approaches

Conservation in the Ukrainian Carpathians is solidly founded on Ukrainian national environmental legislation and policies, but due to the area's international importance conservation is also shaped by regional conservation efforts and initiatives. Protected areas as institutions play a very important role in biodiversity conservation and sustainable development in the Ukrainian Carpathians. The Law "On Nature Conservation Fund [protected territories and objects] of Ukraine" from 1992 includes the following protected area categories: strict nature reserve (*zapovidnyk*), biosphere reserve, national nature park, regional landscape park, and nature (botanical, wildlife) reserve. In the Ukrainian Carpathians there are eight National Nature Parks (NNP), eight Regional Landscape Parks, two Strict Nature Reserves and two UNESCO Biosphere Reserves (CNPA (Carpathian Network of Protected Areas) 2008). The Biosphere Reserves, in particular, seek conciliation of development with biodiversity conservation by promoting sustainable development as recognized under UNESCO's Man and the Biosphere Program. They can function as model sites for, and have the capacity to act as engines for regional sustainable development in the whole Ukrainian Carpathians. The Carpathian Biosphere Reserve as the main protected area in

Eastern Transcarpathia is bordering Synevir NNP in the West, the Carpathian NNP in Ivano-Frankivsk Oblast in the East, Maramures Nature Park in Romania in the South. Gorgany Nature Reserve is situated in close vicinity in Ivano-Frankivsk Oblast. The already mentioned Carpathian Network of Protected Areas (CNPA) is a very important tool for the cooperation among protected area managers.

Ukraine has also ratified the Convention on Biological Diversity in 1995 and the United Nations Framework Convention on Climate Change in 1997. In addition, following the example of the Alpine Convention, the Carpathian countries adopted the Framework Convention on the Protection and Sustainable Development of the Carpathians (the "Carpathian Convention"), which was born in the Ukrainian Carpathians at a conference in the Carpathian Biosphere Reserve in 2002 and signed and ratified by all seven Carpathian countries in 2003. The Carpathian Convention provides the strategic framework for cooperation and multi-sectoral policy coordination, a platform for joint strategies for protection and sustainable development of the Carpathians, and a forum for dialogue between all stakeholders involved. It supports the Carpathian countries in a common vision and in integrating development and environmental goals (UNEP 2007; Borsa *et al.* 2009; The Carpathian Convention 2010). The Carpathian Convention has a special function for Ukraine, not being an EU member, as it facilitates close economic, social and environmental interactions with the Carpathian EU member states (UNEP 2007). The Carpathian Convention's strongest instrument for forwarding the conservation of biodiversity is the biodiversity protocol (Protocol on Conservation of Biological and Landscape Diversity) adopted at the last Meeting of the Ministers and already ratified by five countries (Ukraine ratified in 2009). Although this convention is a rather sophisticated and exemplary approach, it does not however, address the topic of global change.

According to Article 4 of the Carpathian Convention (*Conservation and sustainable use of biological and landscape diversity*) the Carpathian Network of Protected Areas (CNPA) was established. It is directly involved in guaranteeing conservation and sustainable use of the Carpathians' natural and cultural resources by implementing the decisions and recommendations of different Carpathian Convention bodies and other relevant programs or directives, first and foremost the EU Habitats Directive, Birds Directive, Water Framework Directive and the NATURA 2000 network, and by working to promote sustainable livelihoods (CNPA 2008; Borsa *et al.* 2009).

Of further importance and interest is the Carpathian Ecoregion Initiative (CERI), which was initiated by the WWF's Danube-Carpathian-Program 1999, after WWF International had identified the Carpathian Mountains as one of the globally 200 most important ecoregions (Global 200) in need of biodiversity conservation, in order to apply the WWF approach to ecoregional conservation planning. CERI is an international partnership of more than 45 partners (governmental, non-governmental, funding, scientific and academic organizations) from seven countries of the Carpathian region who signed up to the common "CEI Vision", aiming "to achieve the long term conservation of the unique nature of the globally important Carpathian Mountains, while supporting its economy and culture for the lasting benefit of people through international partnership" (CERI 2010). CERI aims at (1) strengthening institutional development of both, governmental and non-governmental conservation agents in order to increase their "capacity to act", (2) establishing a Carpathian ecological network, and (3) generating sustainable economic benefits for the people in the region through for example eco-tourism, integrated natural resource management and local production chains (CERI 2010).

Practical approaches

Currently, practical approaches to the conciliation of biodiversity conservation and development are rather uncertain diffident although the potential is comparatively high. The conventional protected area management approach is characterized by a very strict and isolated focus on inventory and research of biological and ecological systems often neglecting a systemic integration of the human dimension and the identification of resulting conservation threats and opportunities.

The administration of the *Carpathian Biosphere Reserve* (CBR) has recently started to develop a proactive adaptive management concept, acknowledging the importance of integrating conservation and sustainable development, and therefore extending management strategies beyond the CBR's legal borders and current threats. Conservation strategies will include the continued support of local communities and traditional land uses such as *polonyna* farming, the promotion of sustainable forestry, as well as sustainable tourism development, but also the strict protection of the remaining large tracts of old-growth ('primeval') forests (Geyer *et al.* 2009).

The continuation of traditional cattle herding does not only conserve typical biodiversity and habitat variety but also diminishes the loss of productive land, of open landscapes also suitable for other purposes like tourism, recreation and sporting, and of cultural landscapes. Traditional cattle herding also diminishes the loss of local, typical products and traditional farming practices. It supports cultural and social heritage and identity as well as connected traditional lifestyles. At the same time, as a local economic activity it produces traditional, organic products that help secure the food supply of local villages and can be sold on local, national or international markets. Also the conservation of other parts of biodiversity and the support of traditional uses of natural resources like hay meadows, small subsistence farms or wild fruits and berries can be beneficial for human development, making people rather independent from external disturbances and crises such as supply and price volatility of global markets.

By protecting local resources from overexploitation and conserving the functionality of local ecosystems, conservation efforts can lay the foundation of sustainable development since they are the basis for local livelihoods and economic activities like tourism (Borsa *et al.* 2009). Conservation efforts might reverse depopulation and support local (traditional) income sources and land uses. A general concern for the natural environment improves quality of spaces, creating better conditions for life and businesses (Borsa *et al.* 2009). At the same time, conservation efforts can also help halt accelerated infrastructure development, impede uncontrolled tourism development, and reduce the exploitation of forests—developments that might threaten the character and integrity of the region and outdistance some parts of the population (especially poor and traditional families) due to a desire for rapid economic growth. Local people remaining in their villages and keeping their traditions as guardians of the landscape and traditional knowledge, combined with increased environmental education and awareness raising, communication and public participation, could form the basis for a sustainable environment in the Ukrainian Carpathians (Borsa *et al.* 2009).

The development of the administration and methods of forestry is very important for conservation of forests. The large tracts of unmanaged old-growth forests and the ecological integrity of managed forests can only be maintained if forestry changes and its monopoly status as the most important economic sector and source of employment can be overcome. Besides the Carpathian Biosphere Reserve, FORZA (Swiss-Ukrainian Forest Development Project in Zakarpattya) was until recently cooperating with two local State Forestry Enterprises as model regions for multifunctional community forestry. Although the project itself has finished, FORZA is currently establishing itself as an NGO and planning to further pursue their mission. The WWF-DCP project "Protection and sustainable use of natural resources in the Ukrainian Carpathians" is trying to establish sustainable forest management in the region in cooperation with the State Forestry Enterprises.

Also tourism is on its way to becoming an important economic branch in the region. Assuming controlled and adequate development, tourism could favor conservation efforts since the cultural heritage, the characteristic landscapes, wildlife and rich biodiversity are the basis for tourism and the reasons for tourists to visit the area. Conservation should be a major concern of the tourism sector. In particular, wellness/health and scientific tourism seem to be very promising for the region (UNEP 2007), and can only operate successfully along with sound nature conservation.

Through protecting forests, conservation certainly aids in climate change mitigation and reduces extreme climate change impacts like increasing floods and erosion on the region. Furthermore, maintaining forest functions like water retention and ground water regeneration will make the region more resilient towards droughts and potential water deficiency. Beyond specific protection categories, some forest managers already make efforts to preserve forest functions and protective services (UNEP 2007), although the State Forestry Enterprises are not compensated for the momentary economic loss. The ecological conditions of the environment and its ability to regenerate natural resources like soil, water, or air depend very much on the share of forested areas (Kolodiychuk 2008).

FUTURE DEVELOPMENTS

In projecting plausible future developments it is often useful to have a look back into the past—not only to identify trends but rather to get a measure of how fast and sudden things may actually change. It is not too daring to assume that 20-25 years ago, no one could have imagined the sudden and rapid changes that Ukraine experienced as a result of the disintegration of the Soviet Union. The opinion that the post-Soviet era would be one of geo-political and global economic stability was quickly belied. As a result of both internal and external factors Ukraine today remains, both politically and economically, a rather vulnerable country in transformation. In economic terms, neither its industrial and agricultural output, nor level of employment and per-capita purchasing-power has reached Soviet levels. From a political perspective, Ukraine today is a politically divided and thus unstable country, walking a fine line between the EU and NATO on the one side, and the revitalized Russian Federation on the other. In addition, while its state structures and public administration have largely survived, they often fail to meet their responsibilities and new challenges, also as a result of their sometimes outdated structures and lack of financial resources. Even though the Ukrainian Carpathians were not an industrial or agricultural production centre of great importance, its main economic sectors were still affected. The little industry which had been developed subsequently collapsed. The same applied to large-scale agriculture in the Pannonian lowlands, forestry and timber processing and dairy production on the alpine meadows. Today, only forestry has recovered to some extent; however it is exploiting forest resources at an unsustainable pace.

Taking this as a point of departure, three scenarios for what are considered equally plausible alternative futures are described.

Alternative future 1: ***Into the maelstrom***

Political and economic instability and isolation lead to the emergence of regional political governance, but largely reduced public administrative services, control and law enforcement. Organized/commercial economic actors will decline. Timber and mineral resources will be exploited through individuals and exported to the EU and Asia. The region will face an urban exodus, a migration to rural areas, and an expansion of subsistence agriculture. Traditional livelihoods and lifestyles such as *polonyna* farming, the full reliance on wood as fuel and a construction resource, the collection and consumption of non-timber forest products and wildlife hunting will re-emerge and gain in importance.

Effects on biodiversity: Logging will intensify in the most accessible areas, and even in protected areas. Inaccessible areas will remain untouched and grow in size due to a lack of road maintenance. The collection of firewood by the local population will intensify in areas around settlements. The collection of non-timber forest products and grazing livestock in the forest will equally be intensified thereby affecting forest succession. There might be further clearing of forest at the upper forest line for and by an expansion and intensification of *polonyna* farming. This will cause a barrier for forest ecosystems expanding uphill due to climatic changes. Climate change also causes increased drought stress to forest ecosystems such as spruce stands, resulting in possible mass die-offs facilitated by bark beetle infestation. The overall impact on forests, in comparison to their present situation, is rather difficult to judge.

Habitat conditions for wildlife will improve. There will be less habitat fragmentation, connectivity might even increase, and inaccessible areas remain refugees for wildlife. However, the overall pressure on wildlife populations, especially ungulates and birds, might increase due to increased hunting for subsistence meat. The alpine grassland ecosystems will be revitalized and possibly even grow due to an expansion of *polonyna* farming. The succession and re-vegetation of anthropogenic alpine grasslands will be minimized, thereby conserving natural and cultural grassland communities. However, climate change and overgrazing might constitute major threats to those communities. Water quality will improve over time as urban and industrial discharge and waste are drastically reduced. The pressure on fish populations due to increased fishing for subsistence will intensify.

Alternative future 2: ***Breaking the waves***

This future is characterized by a stronger economic and political integration either towards the EU or the Russian Federation, a political recovery resulting in strengthening of institutions, reforms and a reduction in corruption. This will go along with a development push including infrastructure development, agricultural intensification and partial re-industrialization. In the Ukrainian Carpathians public services such as waste and sewage management, water quality in major streams as well as alternative heating and energy supply will improve. This area will be largely spared from industrial development, but will be affected by infrastructure development. The rural population will increasingly migrate to the cities. The rising demand for timber, woody biomass and mineral resources is largely resisted and resources are primarily used locally. Instead, the protected area network will expand and more sustainable harvesting rates and practices will be applied. Improved law enforcement reduces the exploitation of protected areas. The Ukrainian Carpathians will develop into a prime nature recreation and tourism site in an organized manner. Traditional *polonyna* farming practices will be supported with subsidization schemes, although with little success.

Effects on biodiversity: The loss of old-growth forests is halted and natural forest areas develop further due to an expansion of the protected area network and more effective law enforcement. Forest ecosystems are able to expand uphill and to (re-) colonize former *polonynas.* The overall pressure on forests is reduced as forest grazing and the use of fuel wood decline. Commercial timber harvesting remains an important economic pillar of the regional economy but harvesting quotas are strictly controlled. Even-aged spruce stands are converted into uneven-aged multi-structural mixed forests stands, increasing forest resilience to climatic change. Institutional changes, investments in harvesting and processing technology and practices result in biodiverse managed forest stands and larger returns. Ungulate and predator populations recover as a result of stricter law enforcement, less dependency on bushmeat by the local population and better habitat connectivity and quality due to larger protected areas and rural exodus. The overall impact on forest biodiversity is positive. Traditional land-use and farming continue to lose importance but are kept alive for tourists. Despite subsidization schemes, *polonyna* farming is widely abandoned. Upward moving forest ecosystems start to replace alpine grasslands and their typical biodiversity except in places where *polonynas* are kept open in protected areas and tourism operations. The distribution of many species is strongly reduced and often restricted to the mountain tops causing their isolation. In the long term there will be significant losses in the typical *polonyna* biodiversity. The water quality in rivers and streams increases as a result of improved wastewater management and treatment. Fish populations recover as the local population becomes less and less dependent on local fish resources and fishing quotas are introduced. Gallery forests and natural riverbanks become victims of technical flood control measures.

Alternative future 3: ***Handing over the keys***

A stronger economic and political integration either towards the EU or the Russian Federation supports a development push, including infrastructure development, re-industrialization of some parts of Ukraine and the intensification of industrial agriculture. Political institutions will remain weak and overstrained. Continued privatization and high corruption allow no real steering of development, especially with regard to reducing environmental impacts. The political system is overrun or absorbed by corporate business. For the Ukrainian Carpathians this will mean increased investments and development of further infrastructure such as roads and ski tourism resorts. Rapid urban development exacerbates the existing waste and sewage problems. Rural exodus in some areas is countered by expanding towns and weekend houses. Traditional farming will largely be abandoned and natural as well as mineral resources will be heavily exploited. Protected area regulations are weakened and protected area financing plummets.

Effects on biodiversity: This development will increase the pace of forest exploitation including old growth forests and forests in protected areas as a result of better access, weak law enforcement and a lack of funds for conservation and forestry management. Plantation forestry (spruce) replaces most deciduous/mixed forest stands. The survival of viable populations of large carnivores will be unlikely as trophy hunting, mainly for predators, increases while hunting for meat (deer) decreases and habitat fragmentation accelerates. Traditional land-use and farming, especially dairy farming on *polonynas* continues to lose importance and is largely abandoned. Upward moving forest ecosystems start to replace *polonynas* and their typical biodiversity except in places where *polonynas* are kept open in protected areas and by tourism operators. The distribution of many species is strongly reduced and often restricted to mountain tops causing isolation. Water quality and aquatic ecosystems continue to deteriorate as a result of urbanization and related sewage and waste problems, re-industrialization and leaching of chemicals caused by mineral extraction.

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REFERENCES

Bitter, O. and M. Bomba. 2008. Recommendation for the usage of the high mountain area (polonyna) pasture in Volosianka. Pages 403–408 in M. Roth, R. Nobis, V. Stetsiuk and I. Kruhlov, editors. Transformation processes in the Western Ukraine. Concepts for a sustainable land use. Weißensee Verlag, Berlin.

Björnsen Gurung, A., et al. 2009. Global change research in the Carpathian mountain region. Mountain Research and Development **29**:282-288.

Borsa, M., et al. 2009. VASICA—Visions and strategies in the Carpathian area. Protection and sustainable spatial development of the Carpathians in a transnational framework. UNEP Vienna—Interim Secretariat of the Carpathian Convention (ISCC), Carpathian Project. UNEP Vienna—Interim Secretariat of the Carpathian Convention (ISCC), Vienna.

Bosch, B., V. Kravtsiv and W. Endlicher. 2008. Social and demographical aspects in rural areas of Carpathians and Precarpathians. Pages 329–339 in M. Roth, R. Nobis, V. Stetsiuk and I. Kruhlov, editors. Transformation processes in the Western Ukraine. Concepts for a sustainable land use. Weißensee Verlag, Berlin.

Brändli, U.-B. and J. Dowhanytsch. 2003. Urwälder im Zentrum Europas. Ein Naturführer zum Karpaten-Biosphärenreservat in der Ukraine. Haupt, Bern.

Cabinet of Ministers of Ukraine. 2010. Zakarpattya region. Available from http://www.kmu.gov.ua/control/en/publish/article?art_id=117393&cat_id=32596.

CERI. 2010. Carpathian Ecoregion Initiative. Available from http://www.carpates.org/

CNPA (Carpathian Network of Protected Areas). 2008. A network of protected areas for the Carpathians. Available from http://www.carpathianparks.org/.

Commarmot, B., V. Chumak, P. Duelli, N. Küffer, P. Lovas and Y. Shparyk. 2007. Buchenurwälder als Referenz für Naturschutz: Forschungsergebnisse aus den ukrainischen Karpaten. Natur und Landschaft **82**:398–400.

Geyer, J., F. D. Hamor and P. L. Ibisch. 2009. Carpathian Biosphere Reserve (Ukraine): towards participatory management. eco.mont—Journal on Protected Mountain Areas Research **1**:5–12.

Herenchuk, K.I. (Ed.) 1968. Pryroda Ukrainskykh Karpat [Nature of the Ukrainian Carpathians]. Vydavnytstvo Lvivskoho Universytetu, Lviv (in Ukrainian).

Holubets, M. A., M. T. Honchar, V. I. Komendar, V. A. Kucheryavyi, and Y. Odynak, P. (Eds.) 1988. Ukrainskiye Karpaty. Priroda [The Ukrainian Carpathians. Nature] Naukova Dumka, Kyiv (in Russian).

Kolodiychuk, I. 2008. The natural potential and problems of sustainable development of the Carpathian region. Pages 341–344 in M. Roth, R. Nobis, V. Stetsiuk and I. Kruhlov, editors. Transformation processes in the Western Ukraine. Concepts for a sustainable land use. Weißensee Verlag, Berlin.

Kuemmerle, T., O. Chaskovsky, J. Knorn, V. C. Radeloff, I. Kruhlov, W. S. Keeton and P. Hostert. 2009. Forest cover change and illegal logging in the Ukrainian Carpathians in the transition period from 1988 to 2007. Remote Sensing of Environment **113**:1194–1207.

Magocsi, P. R. and P. R. Magocsi. 2002. Historical atlas of Central Europe. Rev. and expanded ed. University of Washington Press, Seattle.

Stetsiuk, V. 2008. Ukrainian tribes in the Ukrainian Carpathians and their traditions. Pages 321–327 in M. Roth, R. Nobis, V. Stetsiuk and I. Kruhlov, editors. Transformation processes in the Western Ukraine. Concepts for a sustainable land use. Weißensee Verlag, Berlin.

The Carpathian Convention. 2010. The Convention on the Protection and Sustainable Development of the Carpathians. Available from http://www.carpathianconvention.org.

UNEP. 2007. Carpathians environment outlook 2007. UNEP/DEWA Europe, Geneva.

UNESCO. 2010. Primeval beech forests of the Carpathians. Available from http://whc.unesco.org/en/list/1133/.

WCS and CIESIN (Wildlife Conservation Society and Center for International Earth Science Information Network). 2005. Last of the Wild Data Version 2: Global Human Footprint data set (HF). Available from http://sedac.ciesin.columbia.edu/wildareas/.

B.1.3 BIOCULTURAL DIVERSITY AND DEVELOPMENT UNDER LOCAL AND GLOBAL CHANGE

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ABSTRACT

Biological diversity and cultural diversity are mutually reinforcing and mutually dependent and in many parts of the world we find a clear correlation of both. Numerous cultural expressions of peoples are influenced by biodiversity, its status, trends and the services it provides. Major ensembles of biological diversity are developed and managed by cultural groups, using language and knowledge as tools. The preservation of this biocultural diversity depends on social, historical relationships and cultural practices which have "co-evolved" between human societies and nature. However, this mutual dependence is now under threat. As highlighted by the Third Global Biodiversity Outlook (GBO3) the "extinction crisis" of global bio-cultural diversity—which includes human beings, species, ecosystems, languages,

cultures and traditional knowledge—is advancing at an alarming and unparalleled pace, and is exacerbated by climate change. If the natural environment is changed or lost, the cultural knowledge based on it is also lost, along with the traditional practices vital for maintaining local indigenous livelihoods in agricultural, pastoral, coastal and marine settings. In order to significantly improve the status of biodiversity, which underpins the well-being and development of humanity, it is crucial to recognise that most of the problems of loss of biological diversity, threats to human development and impoverishment of cultural diversity are closely connected and interrelated. The Chapter is divided into five sections. The first section gives an overview on biocultural diversity, local ecological knowledge and why these notions/approaches are relevant for sustaining livelihoods and for understanding the interlinkages between nature and culture. It presents the various development/research approaches available to assist in strengthening local and indigenous institutions and ownership, while putting an emphasis on endogenous development. The second and third sections will discuss the human rights based approach to development, local knowledge and biocultural diversity, by looking at the linkages between conservation and use of biodiversity, benefit sharing from the commercial use of biodiversity (biopiracy), traditional knowledge and intellectual property rights, and international negotiations. The fourth section will elaborate on how changes in local and global contexts have forced local communities to find new adaptation strategies. The fifth section will explore the scope, diversity and challenges of Indigenous and Community Conserved Areas (ICCAs), and the usefulness of the ICCA concept for securing community governance of natural resources, and preserving biocultural diversity in the face of global and local changes. A number of case studies included in this Chapter clearly illustrate the issues adressed. Each section of this Chapter draws lessons learned, develops recommendations, and provides options for actions for policy at the local, national and international level. This Chapter shows that by incorporating biocultural diversity into development planning and implementation—for example through the legal empowerment or appropriate recognition of Indigenous and Community Conserved Areas—not only contributes to the safeguarding of ecosystem services in times of global and local changes, but also enhances human development and well-being.

B.1.3.a LOCAL ECOLOGICAL KNOWLEDGE, BIOCULTURAL DIVERSITY AND ENDOGENOUS DEVELOPMENT

A summary of local ecological knowledge and biocultural diversity instantly confronts problems of terminology and definition. Specific terms, meanings and connotations have varied over time and place, with more contestation by colleagues of diverse disciplines than consensus among them.

Although there is widespread use of the characterization accepted by the parties to the Convention on Biological Diversity in Article 8j and elsewhere—“knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles”—it is instructive to delve more deeply into these concepts. A short overview of historical and contemporary perspectives situates the debate, suggests the futility of providing standard definitions and predicts a constant reconceptualization depending on context.

Many authors (for example Agrawal 1995) recognize that terms used to describe knowledge systems and ways of thought—such as indigenous, local and traditional (and contrasted with global, modern, scientific and western)—are problematic. Although not equivalent they are often used interchangeably and personal preference or objection play a role in which terms are adopted in particular disciplines, institutions and social groups (Heckler 2009). This chapter does not attempt to differentiate or define these terms, preferring to use them in the generally accepted sense implied in the CBD.

Until about thirty years ago, the knowledge, innovations and practices of small-scale societies were generally denied, considered an obstacle to development, or coveted as an extractive resource. These societies and their attributes were marginal in the prevailing view of modernity, which gave credence to science as a way of understanding the world, development as the pathway to progress, and nation-states as holders of legitimate political authority (Posey & Dutfield 1996, Alexiades 2009). The legitimacy of traditional beliefs, knowledge and beliefs was questioned and they 'became something to be overcome, to be subverted rather than encouraged' (Ellen and Harris 2000). As Alexiades (2009) summarizes, the modernist discourse denied 'the value, and at times even the existence, of indigenous knowledge'.

In contrast to this dominant view, a small cadre of academics, the founders of late 19th century interrelated disciplines variously referred to as economic botany, ethnobotany or ethnobiology, began to reveal the value of local knowledge and genetic resources for the development of agriculture, industry, medicine and other matters of economic and livelihood concern for developed countries (Clément 1998). Responding to colonial commercial interests as well as a modernist quest for scientific documentation of nature and culture, these scientists began extensive surveys of the knowledge of local experts, including elders, medicine men, sages and shamans. While gaining a growing awareness of the complexity of cultural knowledge and subsistence systems, field researchers extracted a wealth of information about specific plants and animals.

In the 1950s and 1960s, there was a turn towards ethnoscience, an anthropological, linguistic and eventually ecological reassessment of local knowledge and practice that revealed sophisticated ethnobiological classification systems, cognitive maps of landscapes and resource management strategies. Researchers focused on emic approaches, that is, the study of knowledge systems and resource use from a local perspective, with a reduced emphasis on the potential commodification and commercial value of plant and animals.

The 1970s saw a growing awareness of the political and social context of research in local and indigenous communities, which led to the development of an advocacy ethnoecology that privileged action and participatory research. This trend, particularly strong in Mexico and other parts of Latin America, gradually spread to Europe, the United States and many other parts of the world.

The intermingling of ethnoscience and advocacy ethnoecology laid the ground for recognition and validation of the potential contribution of local knowledge systems to agricultural innovation, biodiversity conservation, economic development and the scientific research that substantiate these and other applied endeavors. Academic discourse found fertile ground in policy circles increasingly concerned with achieving longterm economic, environmental and social wellbeing, encapsulated in the term 'sustainable development'.

The fifteen years from the UN Conference on the Human Environment in 1972 to the World Commission on Environment and Development in 1987 provided the context for influential works that rehabilitated indigenous and local knowledge systems and linked them firmly to the emerging sustainable development agenda (Brokensha et al., 1980; Warren et al. 1991).

Once academia and development agencies embraced indigenous knowledge, a next logical step was to more clearly define the increasingly popular term and compare it with science as part of a process towards an eventual integration in science-based development. The typologies produced, if flawed from today's perspective, raised awareness about local knowledge systems and provoked intense debate. Indigenous knowledge was differentiated from science because of differences in subject matter, methodological approaches and level of integration with local cultural and environmental contexts.

Agrawal (1995), in questioning the logic of this approach, provided a perceptive critique of these contextual, epistemological and methodological grounds for making a distinction between science and indigenous knowledge. He argued that the collection, ex situ archiving and dissemination of traditional knowledge was an extractive enterprise, which takes knowledge out of its context and history. Disembodying ecological knowledge from its cultural context also raised concerns about abuse of traditional resources rights, including those related to intellectual property and genetic resources (Shiva 1993, 1997).

Agrawal admitted the existence of differences, rooted in cultural context and history, between indigenous and western knowledge and suggested that distinctive—if overlapping—characteristics could be identified. This encouraged in part a return to assessing and valuing local knowledge systems in situ, instead of seeking ways to integrate them unilaterally into science-based development.

In this trend, Berkes (1999) differentiated four levels of an ecological knowledge system: (1) the names of living components (such as plants and animals) and physical elements (soils, water and weather for example) of ecosystems; (2) the functions and uses of these components and elements; (3) the land and resource management systems, and the social institutions that govern them; and (4) the worldviews and cosmologies that guide the ethics of people in the system. Based on this typology, Berkes et al. (2000) later characterized traditional ecological knowledge (TEK) as a 'knowledge-practice-belief complex'.

Furthermore, they proposed specific characteristics of TEK, noting that it is adaptive by nature, accumulates incrementally by trial-and-error and is transmitted to future generations orally or by shared practical experiences. In addition, they situated TEK as an attribute of small-scale often indigenous societies that are primarily nonindustrial or less technologically advanced and have historical continuity in resource use and practice in a particular place. Although useful as rules of thumb, the scientific literature is rich with exceptions to these observations (Alexiades 2009).

Pilgrim et al. (2008) note that, 'accumulated knowledge about nature, whether termed TEK, local ecological knowledge (LEK), indigenous knowledge (IK), ecoliteracy, or more generally ecological knowledge, is an important part of people's capacity to manage and conserve both wild and agricultural systems over extended periods'. This point of general consensus, further supported by insights from historical ecology that demonstrate how anthropogenic landscapes have evolved over time, created fertile ground for an emergent consciousness of the interactions of biological and cultural diversity in the late 1980s and early 1990s.

The Declaration of Belem, issued after the first International Congress of Ethnobiology in 1988, called attention to the 'inextricable link between cultural and biological diversity'. The late geographer Bernard Nietschmann (1992) subsequently proposed a 'biocultural axiom', which states that biological and cultural diversity are mutually dependent and geographically overlapping. Recognition of this symbiosis has come to constitute a key principle for applied and theoretical conservation theory, stimulate integrative, interdisciplinary scientific research and contribute to sustainable development paradigms.

A contemporary definition, proposed by Maffi and Woodley (2010), states that "biocultural diversity comprises the diversity of life in all of its manifestations—biological, cultural and linguistic—which are interrelated (and likely co-evolved) within a complex socio-ecological adaptive system". As with other terms and definitions, this perspective will be debated and reformulated in various contexts. For example, UNESCO and the CBD Secretariat tend to prefer to use 'biological and cultural diversity' instead of the conjugated term, at least until the putative co-evolution and intrinsic linkages between distinct manifestations of diversity are better elucidated. Attempts to associate diversity with social goals such as equality, justice, pluralism and sustainability is leading theorists to consider epistemological, identity and political diversity as essential elements in any consideration of biocultural diversity.

This expansion of the conceptual playing field is motivated by awareness that the richest centres of biocultural diversity are beset by poverty, marginalisation and political struggles, often leading to rapid demographic and social change (de Soysa and Gleditsch 1999). Natural disasters, land use changes and shifting climatic conditions accelerate this process. Displacement leaves in its wake fractured knowledge societies, disrupted systems of ethnobiological knowledge and abandoned landscapes. It also creates interacting networks of indigenous peoples who recreate elements of their traditional lifestyles in peri-urban and urban areas of their country or abroad, a process that includes redefining their identity and knowledge systems. They often seek to maintain a connection with their homeland, and their eventual return is enriched by new knowledge and identities that stimulate cultural hybridization. Because of these trends, they have evolved into multilocal and transnational communities that play a key role in determining the future of centres of biological, cultural and linguistic diversity around the world.

The concept of knowledge society, originally coined to describe the global exchange and valuation of information through contemporary technologies such as the internet, embraces the history and current reality of these small-scale societies. The terms 'indigenous peoples' and 'local communities', as used by the CBD, UNDRIP and other multilateral environmental agreements, refer to diverse ethnolinguistic groups characterized by unique languages, ethnobiological classification systems, resource management techniques and relationships to the natural environment. These distinctive social groups create, share and use knowledge for the prosperity and well-being of their members, and thus qualify as a knowledge society as defined in contemporary discourse.

Non-written languages and oral transmission are basic elements of local knowledge systems, which are an important productive resource alongside land labour and capital in small-scale, mixed subsistence economies. The emergence of multi-locality and transnational societies from a mobile group of rural dwellers ensures transformation of traditional knowledge systems to confront new realities. Computer literate community members are embracing Web 2.0 technologies—including online video, searchable knowledge databases and geographical information systems—and reducing their digital divide from more affluent communities in order to archive, communicate and protect their cultural heritage.

As noted by the Chairperson of the UN Permanent Form on Indigenous Issues, Vicky Tauli-Corpuz, "Free Prior and Informed Consent (FPIC) requires processes that allow and support meaningful choices by indigenous peoples about their development path". In this context, field trials on the application of participatory video (PV) as a practical tool to apply a human rights based approach to development have been growing with the support from a number of innovative programmes and donors[17]. In the future, PV and other Web 2.0 technologies hold great promise regarding efforts to 'shift paradigms' in development thinking beyond the persistent 'literary divide' between the formal and informal sectors in order to:

- Include so-called "hard to reach" groups using Participatory Action Research through not-literate forms of documentation and dissemination;
- Build on local identity and self esteem through the use of storytelling/oral history to document and share local knowledge, co-design education projects, capture local development realities;
- Increase voice on the legal empowerment of the poor and define non-income based indicators of poverty;
- Share knowledge and local solutions to development problems;
- Build on the potential of oral testimonies as a conflict resolution tool by building understanding through video exchanges and web-based participatory poverty assessments;
- Directly communicate video messages made by poor and vulnerable communities at inter-governmental and international gatherings.

A critical contemporary need is to understand how the construction of knowledge societies and the transmission of ethnoecological knowledge are changing as people alter their lifestyles in the face of pervasive demographic shifts: migration to seek higher standards of living elsewhere, displacement from homelands under pressure from conservation initiatives and agricultural development, and flight from

17 see www.insightshare.org; www.conversationsearth.org; www.sgp.undp.org; http://content.undp.org/go/newsroom/2009/may/indigenous-groups-bear-witness-to-climate-change-damage-.en

climate change and natural disasters. Under these conditions, do dynamic knowledge societies lose some of their traditional ecological savoir and savoir-faire over time? In which circumstances does the transformation of ecological knowledge in multilocal communities accelerate or diminish? Is knowledge of biological resources and landscapes transmitted between generations and cultures in situ and ex situ? How do certain foods, medicinal plants and other resources become 'icons of identity' in new places of residence? Does the transformation of environmental belief, knowledge and practice affect peoples' adaptation to new places and the viability of their eventual return to their homeland? How do dynamic knowledge societies adapt to government initiatives of access and benefit sharing, agricultural development, land redistribution, nature conservation, resettlement and to the power of money, market and media—or 'bioimperialism' (Shiva 1997)?

A key concept to understand these issues is resilience, the ability of communities to adapt and survive in the face of cultural, economic and social change brought on by globalization (Shiva 2005). Some migrants maintain their use of traditional biological resources, and transmit this practice to younger generations, even in cases when the people staying at home are losing knowledge and beliefs due to demographic changes, poverty, drought and other factors.

A continuing focus on ethnoecology is motivated by the central place that a connection to land and biological resources occupies in the construction of identity among indigenous peoples and local communities. This 'sense of place' is formulated as both an ethnographically substantiated reality and as a politicized concept that raises contentious debate on indigenous status and land rights. Elements of natural and cultural landscapes are imbued with meaning and mobilised as powerful symbols of cultural identity, and individuals discursively construct images of themselves and their homeland using either contemporary or historical features of ethnobiological knowledge systems.

A central tenet of this idea is that members of local and indigenous communities are the global citizens best placed to confront environmental and social change. Local and indigenous communities constitute dynamic knowledge society capable of adapting to global transitions. Researchers and advocates argue that their role in creating anthropogenic forests, agroecosystems and cultural landscapes is rooted in their knowledge systems and lifestyles, which are the world's largest repertoire of dynamic approaches to landscape management and resource use. They engage in cultural rediversification, hybridise traditional and newly acquired beliefs, and in many cases enhance bio-cultural resilience in the face of global change.

Since the time of the Rio Earth Summit in the early 1990s, a number of international organisations have been in the process of embracing this diversification movement, exemplifying Nietschmann's "bio-cultural" axiom referred to above. In particular, the Global Environment Facility (GEF) Small Grants Programme (SGP), which was launched by the United Nations Development Programme (UNDP) in 1992 as a pilot initiative to test whether community-based approaches could produce tangible and lasting global environmental benefits in relation to the pressing "global" problems of biodiversity loss, climate change, protection of international waters and related problems of land degradation and chemicals, has gradually grown in prominence and visibility amongst participating countries.

Entering into its eighteenth year of operations in June 2010, the SGP has been able to directly support over 12,500 small-scale projects with local and indigenous communities in close to 122 developing countries. Operating through a pioneering model of decentralized governance, small grants up to $50,000 are approved directly at the national level through National Steering Committees which include representatives from civil society (with majority membership), government, academia, the private sector, media, UNDP and other national donor partners.

The decentralized approach of the SGP has proven popular with both governments, as well as civil society for its fast and direct delivery of grants to communities, while promoting community ownership.

In particular, SGP beneficiary grantees are able to provide the needed co-financing both in cash as well as in-kind through their labour, skills, and contributed materials. In defense of the 'local action, global impact' mantra repeated by citizens advocacy groups worldwide, an Independent Evaluation of the SGP by the GEF Evaluation Office concluded in 2007 that the SGP has a "*slightly higher success rate in achieving global environmental benefits and a significantly higher rate in sustaining them than GEF medium-and full-size projects*".

A number of commentators note that indigenous peoples and local communities are in the frontline of the struggle to protect the environment and challenge dominant models of economic development. Loosely networked through international policy processes and venues, civil society organisations at the global level are amassing an impressive experience implementing multilateral environmental agreements (MEAs), codes of ethical conduct and best practice in conservation. A sector of civil society that is largely carbon neutral, they bear the brunt of global climate change while innovating new modes of prevention, adaptation and mitigation.

The role of local knowledge systems in environmental protection and risk mitigation is recognized in articles 8j and 10c of the 1992 Convention on Biological Diversity (CBD) and is further developed in the 2007 United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). The way that indigenous people articulate their identity is premised on their unique connection to the land and natural environment as recognized by these and other multilateral environmental agreements.

A challenge is to fill the gap in our knowledge of common trends in the way that knowledge and practice shift in displaced knowledge societies, or if this process of transformation depends largely on local context. There is a need to examine in detail the phenomenon of return: how temporary or permanent repatriation leads to a hybridization of ecological knowledge and practice, and sustains diasporas over time by maintaining access to land and resources. This analysis would address broader questions of the decontextualisation, dehistorization and reinvention of local knowledge and practice.

One important goal is to gain insight into whether knowledge societies at various scales, local, regional, national, pan-regional, and global, can be threatened to the point of extinction by displacement and other global trends, or if the process of social change is better characterized as a transformation and reconstruction of social networks, knowledge and practice. The outcomes of this analysis will be of interest to a wide range of audiences, from academics interested in globalisation, identity, ethnobiological knowledge and cultural change, innovation studies, and intellectual property protection, to indigenous peoples concerned by the future of their lifestyles, livelihoods and land tenure.

B.1.3.b TRADITIONAL KNOWLEDGE, INTELLECTUAL PROPERTY AND BENEFIT SHARING

The term "biopiracy" emerged around the time that the CBD entered into legal force in 1993. The use of the word is intended to draw attention to complaints that corporations from the industrialised world are claiming ownership of, free riding upon, or otherwise taking unfair advantage of, the genetic resources and traditional knowledge (TK) of developing countries. While some corporations have been complaining about "intellectual piracy" perpetrated by people in developing countries, various nations counter that their biological, scientific and cultural assets are being "pirated" by these same businesses.

The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) is annex 1C of the Agreement Establishing the World Trade Organization, which was the main outcome of the Uruguay Round trade negotiations held under the auspices of the General Agreement on Tariffs and Trade (GATT). It has become the most important and far-reaching international accord in the field of intellectual property. It establishes workable global standards of protection and enforcement for virtually all of the most important intellectual property rights (IPRs), such as patents, copyrights and related rights, and trademarks, in a single agreement. As such, it has major implications for knowledge-based industries seeking to trade profitably in many different countries.

TRIPS Article 27.3(b) concerns exceptions to patentability in the area of biotechnology. It permits WTO members to exclude from patentability "plants and animals other than micro-organisms, and essentially biological processes for the production of plants or animals other than non-biological and microbiological processes." Developing country representatives continue to express concerns about TRIPS, including that this part of TRIPS legitimizes the "biopiracy" of genetic resources and traditional knowledge (TK). The CBD-TRIPS relationship and the protection of TK and folklore have proved to be quite controversial. One key developing country demand that has been pushed quite strongly is that of disclosure of origin. Disclosure of origin would require inventors to disclose the source of genetic resources and/or traditional knowledge relevant to an invention being patented.

At the November 2001 Doha Ministerial Conference of the WTO, members adopted a Ministerial Declaration. The latter clarified Members' commitment to opening up negotiations on issues relating to Article 27.3(b) to include the relationship between the TRIPS Agreement and the CBD, and the protection of traditional knowledge and folklore. Much of the subsequent discussion has focused on how best to address a wide range of moral, political, and economic concerns about "patenting life" and "biopiracy."

There are at least five reasons why biopiracy has become such a prominent issue, and IPRs, particularly patents, have become central to debates on this matter. These reasons are as follows:

1. There is a conviction widely held among developing countries and non governmental organizations (NGOs) that biodiversity and associated TK have tremendous economic potential.
2. Patent claims increasingly incorporate biological and genetic material including life forms within their scope.
3. Many developing countries and NGOs hold that this feature of the patent system enables corporations to misappropriate genetic resources and associated TK or at least to unfairly free-ride on them.
4. Contemporary intellectual property law protects the innovations produced by industries based mainly in the developed world for more effectively than those in which the developing countries are relatively well-endowed.
5. There is a popular perception that as a consequence of reasons 2–4, the unequal distributions and concentrations of patent ownership and the unequal share of benefits obtained from industrial use of genetic resources are related closely and causally.

For biopiracy to mean anything at all, it cannot be considered merely as a matter of law but as also one of morality, ethics and of fairness. Accordingly, we need to acknowledge that distinguishing between acts of biopiracy and legitimate practices is not always obvious. The difficulty in drawing the line is compounded by the deliberate vagueness in the way the term is applied. To illustrate this point, it may be useful to explain and distinguish the terms 'theft', 'unfair free-riding' and 'misappropriation' by pointing out that they can encompass a broad continuum of activities from criminal acts causing serious harm, to legal but unfair activities, and even to legal, fair and socially-welfare enhancing uses of other people's property. For example, free-riding does not require there to be a victim, whether we speak of the person whose knowledge or goods have been freely ridden upon or of society as a whole. Indeed, some acts of free-riding may be of benefit to society and should therefore be allowed. Behind much of the debate about biopiracy is disagreement on whether and to what extent such terms as theft, misappropriation and unfair free-riding should apply.

The vast majority of countries formally recognize that cross-border exchange of genetic resources and TK be carried out in compliance with the principles of the CBD. Nonetheless, complaints about biopiracy persist. The problem with the debate on a definition of biopiracy is that if parties cannot agree on what it is, then it is impossible to measure or agree on a course of action.

One extreme view is that all bioprospecting is biopiracy. If so, the answer would be to ban access outright. If biopiracy is not such a serious problem, then such a ban would not need to be enforced too rigorously, since legal enforcement of higher-stakes areas of the law would have to take priority. If biopiracy causes demonstrable economic or cultural harm, the country should invest in enforcing the ban. On the other hand, if the problem is that provider countries or communities are unable to negotiate beneficial agreements, the answer may be to improve the provision of legal and technical assistance so they can. If the problem is that the patent system legitimizes or encourages misappropriation, then we may need to improve the standards of examination, ban patents on life forms and natural, or even modified, compounds, or incorporate a disclosure of origin requirement according to which genetic resources and TK used in an invention should be fully disclosed in the patent application. In short, how biopiracy is defined goes a long way towards determining what parties should do about it.

Ultimately, for the biodiversity-rich countries, the main challenges are to enhance economic and social welfare through the more effective use of biodiversity at local and national levels, and how to ensure that TK holders and the societies responsible for generating and maintaining TK are better able to negotiate effectively with both corporations and governments interested in their knowledge and resources. It is hoped that the International Regime under negotiation for the CBD COP10 in Nagoya, Japan, in October 2010 will support such goals.

B.1.3.c BIODIVERSITY, TRADITIONAL KNOWLEDGE AND THE PATENT SYSTEM

Biodiversity has historically been a foundation for human innovation and a central object of human efforts to innovate to address problems ranging from agriculture, to medicine and more recent efforts to adapt to climate change. The ability to share, exchange and utilize knowledge and resources is central to the human capacity for innovation and adaptation to emerging needs and problems.

The provision of incentives for innovation has come to be seen as central to the future welfare and competitiveness of countries. The problem that countries confront is identifying the right type and balance of incentives to promote innovation in desired areas such as agriculture or medicine to address needs and promote economic development (Scotchmer 2004). Regulated incentives through IPRs, and patents in particular, have been justified as necessary instruments to enable companies and organizations to attract capital, to protect their investments, and secure a return from their investments. On a wider level it has been argued that patents may have a role to play in attracting Foreign Direct Investment, technology transfer and enhanced trade in goods and services (i.e. World Bank 2001). The 1990s witnessed the dramatic expansion of the patent system as a particular form of incentive through the extension of patentability to all areas of invention, with limited exceptions, under the TRIPS agreement. This was accompanied by facilitated access to potential protection in multiple countries through the Patent Cooperation Treaty.

The patent system now encompasses over 60 million documents dating to the 19th Century. In 2007 an estimated 1.85 million patent applications were filed worldwide, approximately 760,000 grants were awarded, and 6.3 million patents were estimated to be in force (WIPO 2009). It is now increasingly recognised that the dramatic expansion of the system precipitated by TRIPS has generated system level problems in the form of a flood of often poor quality applications and strategic behaviour by applicants that is undermining the integrity of the system (Guellec & Pottelsberghe 2007). In 2007 there were an estimated 4.2 million outstanding patent applications with the United States accounting alone for 28.4% of the backlog (WIPO 2009: 9, 44).

The extension of patentability to all areas of invention has proved particularly controversial in the case of biodiversity and TK. It has raised substantive questions with respect to human rights, ethics, the freedom of scientific research, the economic implications for developing countries and healthcare systems and the environmental consequences of the promotion of patented technologies. Arriving at a balanced view on the relationship between biodiversity, TK and the patent system is a significant challenge.

In the context of the negotiation of an international regime on access to genetic resources and benefit-sharing a principal concern has been addressing the problem of "biopiracy" or "misappropriation" of genetic resources and the knowledge, innovations and practices of indigenous peoples and local communities. The problem of biopiracy is linked with high expectations of potential economic value that are grounded in historic examples. Table 1 sets out a range of historic examples along with cases that have been flagged as biopiracy. Counts of publications are broken down into those referencing a species or genus in the claims, and the overall number of grants. The documents are then grouped into their respective families (groups of related applications linked to an original parent application) to reduce duplicate publications to their parent or "priority" filing. The internationalisation of demand for protection is reflected in the number of countries with family member filings.

TABLE 1: A sample of patent cases for biodiversity and traditional knowledge.

Case	Country	Patent Counts	Claims	Grants	Patent Families	Family Countries
Azadirachta *(Azadirachta indica)*	India	1,314	160	282	610	57
Lepidium meyenii	Peru	137	39	20	78	18
Hoodia *(Hoodia gordonii)*	Southern Africa	532	107	52	196	49
Enola (*Phaseolus vulgaris***)**	Mexico	1	1	1	1	1
Catharanthus roseus	Madagascar	1,398	75	334	561	65
Banisteriopsis caapi	Amazonia	5	1	1	5	4
Thermus aquaticus	United States	7,514	446	2,561	2,451	70
Tolypocladium inflatum	Norway	409	33	160	150	65
Oryza sativa **and genome**	Asia	6,274	1,801	1,541	2,640	68

SOURCE: *Thomson Innovation. Main patent jurisdictions only, all years to April 2010.*

Two of the examples in Table 1 pre-date the CBD and have been used as exemplars for the economic potential of biodiversity and TK in debates on access and benefit-sharing (ABS). The Rosy Periwinkle (*Catharanthus roseus*) which is endemic to Madagascar, and also used in traditional Chinese medicine, is famous as the source of two classes of compounds Vincristine and Vinblastine used in chemotherapy with estimated market values in 2001 of US$100 million (Karasov 2001). *Tolypocladium inflatum* is a fungus that was isolated from a soil sample taken in Norway and is the source Ciclosporin that is widely used as an immunosuppressant in transplant surgery. In the context of debates on ABS it has been suggested that Norway could have received approximately US$24.3 million in 1997 if a 2% royalty rate had been applied to the revenue generated from Ciclosporin (Svarstad *et al.* 2000). Patent activity involving, or inspired by, these species is ongoing across a range of sectors from agriculture, to foods, pharmaceuticals, biotechnology and nanotechnology and demonstrates enduring interest in these species and their useful components.

In the field of biotechnology the discovery of a microorganism, *Thermus aquaticus*, originating in Mushroom pool in Yellowstone National Park in the mid-1960s, was the origin of the Taq DNA polymerase enzyme that is widely used in the Nobel prize winning Polymerase Chain Reaction (PCR) for the amplification of DNA sequences. The patent on the enzyme was reportedly sold for $300 million in 1991 and generated annual revenues of $100 million for the patent owner. The revenues generated by Taq DNA polymerase subsequently led to the promotion of the potential of bioprospecting as a source of revenue for national parks (Oldham 2004a). Enzymes from extremophile organisms such as as *Thermus thermophilus*, originating from extreme environments such as the deep sea bed (Arico & Salpin 2005) or Antarctica, are an ongoing focus of bioprospecting and research and development (Lohan & Johnston 2003). However, in a sign of the complexity of patent cases, the high cost of patented Taq for researchers was a major focus of criticism on the patenting of research tools that inhibited research (NIH 1998). In 2003 the foundational United States patent for Taq DNA polymerase was revoked for inequitable conduct, or fraud, before the United States patent office.

Other examples have been used to illustrate the problem of biopiracy for developing countries in the period following the adoption of the CBD, notably *Azadirachta indica* or neem (tea tree) whose medicinal, antifungal and antibacterial properties are well known in the Indian subcontinent. A patent involving neem held by W.R. Grace & Co granted in 1994 was a landmark biopiracy case and was revoked by the European Patent Office in the year 2000 based on TK as prior art[18]. However, this case also exposed the high costs and lengthly procedures involved in contesting patents for developing countries in a system perceived to be weighted towards patent holders. Efforts in India have focused on the creation of a prior art database, the Traditional Knowledge Digital Library (TKDL), of written TK that can be accessed by patent examiners in Europe and the United States. Patent activity for *Azadirachta indica* and its chemical components continues across a range of sectors from agriculture to pharmaceuticals, cosmetics, waste water treatment and biotechnology.

In Amazonia, the liana *Banisteriopsis caapi* is a component in the medicinal drink Ayahuasca that is regarded as sacred by many Amazonian peoples. In 1986 a US citizen was awarded a United States plant patent that became the focus of a campaign to revoke the patent in 1999 by the Coordinating Body of Indigenous Organizations of the Amazon Basin (COICA). The plant patent was initially revoked on the grounds of prior art in 1999, reinstated on appeal and has now expired. This example highlights the importance of species in the cosmologies and value systems of indigenous peoples. Banisteriopsis and its chemical components, notably harmine and harmaline alkaloids, also found in Syrian Rue or *Peganum harmala*, continue to be a focus of activity with recent patent filings relating to imaging for neurological disorders and Parkinson's disease suggesting the importance of biodiversity in addressing serious human afflictions but raising questions about the rights of indigenous peoples and benefit-sharing.

Lepidium meyenii (maca) is a root vegetable grown by indigenous peoples in the Peruvian and Bolivian Andes that has aphrodisiac properties and is the subject of a variety of patent claims that are being contested by the Peruvian Institute for the Defence of Competition and Intellectual Property (INDECOPI). In July 2003 INDECOPI filed objections before the European Patent Office (EPO) opposing the application on the basis of prior art. In 2007 the US company that filed the original patents in the United States and Europe was taken over by the French company Naturex which specialises in foodstuffs, flavourings and nutraceuticals. In June 2007 Naturex announced that it would grant free patent licenses to 100 per cent Peruvian owned companies for the manufacture and sale of maca extracts (Naturex 2007). The company also reported that it was increasing the price it paid to Maca growers in the Andes as part of measures to demonstrate fairness in its dealings with Peru. This demonstrates that companies can seek to find constructive approaches to meet the ABS requirements of the CBD. However, as of February 2010, the company has continued to pursue patent protection despite repeated statements by the EPO that the claims to Maca extracts are obvious from the prior art and lacking in an inventive step (European Patent Office 2010).

18 See the European Patent Register entry for patent EP436257 confirming final revocation in May 2005.

Hoodia gordonii is a succulent plant distributed in Botswana, Namibia and South Africa. The human rights, benefit-sharing and conservation dimensions of the Hoodia case involving the San people of southern Africa, a research institution and companies have been extensively discussed elsewhere (Laird & Wynberg 2008). We focus here on the intellectual property dimensions of this case. In 1997 the South African Council for Scientific and Industrial Research (CSIR) applied for patents for pharmaceutical compositions having appetite suppressant activity from *Hoodia gordonii*[19]. Hoodia became an international focus of attention when the CSIR entered into a licensing agreement with the UK pharmaceutical and functional food company Phytopharm who also filed for patents. Phytopharm in turn entered into a licensing agreement with Pfizer who filed for patents on pharmaceutical compositions. Upon closing its Natureceuticals group Pfizer was replaced by Unilever who also filed for patents in areas such as in vitro multiplication of Hoodia plants. In December 2008 Unilever withdrew from the collaboration with Phytopharm citing safety and efficacy concerns following an estimated 20 million Euros in expenditure and precipitating a 30% collapse in Phytopharm's share value. Phytopharm has reportedly secured access to the intellectual property portfolio generated by Unilever and is seeking new partners[20].

This complex case demonstrates a need to attend to the welfare of a particular species and genus, the people whose knowledge proved central to the identification of utilizations of a particular species, and the challenges posed by a combination of free-riding in the market and competition in the intellectual property landscape. This includes a need to recognise the risks that can confront companies engaged in product development in competitive markets while raising questions about the wider benefit-sharing dimensions arising from the pursuit of intellectual property.

The final example in Table 1 draws attention to the rise of genomics and the transformation of biodiversity into informational good (Oldham 2004 b). This can be illustrated through the case of *Oryza sativa* (rice) and references to the term genome in patent claims. Rice is the world's major food crop and the rice genome was mapped in three separate initiatives in 2002 by Syngenta and Myriad Genetics, the Beijing Genomics Institute and Monsanto. A completed high resolution genome map by the International Rice Genome Sequencing Project was announced in December 2004 with Monsanto and Syngenta contributing their data to the initiative.

Patent activity in the realm of genomics has focused on patent claims to DNA and amino acid sequences and, on occasions, to entire genomes. Of the 5,249 documents where the claims were available 4,697 (89.4%) referred to sequences in their claims. One consequence of these types of claims is that they are frequently written to encompass percentages of sequence identity such that a sequence with similar identity will fall within the scope of the claims (Oldham 2004 b). The result is legal uncertainty about whether a similar sequence of interest, including from organisms with a shared evolutionary history, fall within the scope of a patent's claims (Dufresne & Duval 2004).

These types of claims are significant for researchers seeking to use sequences and for biodiversity-rich developing countries in the context of their own efforts to engage in research and development for key genetic resources[21].

Patent activity for biodiversity and TK involves a range of different organisms, industry sectors, markets and technologies that access and manipulate biodiversity on different levels. One emerging lesson from patent landscape analysis is that new areas of research and development involving biodiversity will emerge over time such as proteomics, systems biology, synthetic biology and, more recently, metabolic engineering (Oldham & Cutter 2006). Because the patent system helps to make underlying trends in science and technology visible, it provides important insights into human engagement with biodiversity across a range of fields. At the same time, the controversies that have surrounded patent activity in the

19 This is frequently reported as 1995. However, the earliest accessible priority date for the filing in South Africa is the 15th of April 1997.

20 Phytopharm website, accessed 23/04/2010

21 In response to these problems patent offices have increasingly tightened their rules in a variety of ways focusing on a requirement to specify the function of claimed sequences.

realm of genomics are also encouraging wider debates within scientific communities about the relationship between property rights and alternatives including "open source" approaches, that merit wider discussion.

From an economic perspective, patents should perhaps be seen for what they are: one of a suite of possible incentive measures available to governments to promote innovation. Patents attract particular attention because of the nature of the monopoly they provide and the increasing contribution of rent transfers from licensing intellectual property to national economies (OECD 2006). However, as noted above, it is now widely recognised that the system is being abused by a flood of low quality applications and low quality patent grants. This undermines the long term purpose of the system in terms of the disclosure of new and useful inventions for public use and its potential role in technology transfer.

The quality and integrity of the system matters for developing countries seeking to realize the promise of benefit-sharing embodied in the third objective of the CBD and it matters to indigenous peoples seeking to ensure that their human rights are respected[22]. From a biodiversity policy perspective this is particularly telling because it has been repeatedly demonstrated that pharmaceuticals of natural origin are a major source of approved pharmaceuticals. "Mother Nature" will rarely be beaten as a source of new and useful products (Newman & Cragg 2007). Recognising that both developing and developed countries have an interest in biodiversity and TK inside the patent system and the integrity of that system could be an important step towards the realization of the third objective of the CBD.

It is also important to recognise what this incentive system is not good at: that is addressing diseases affecting millions of people in the developing world. An exclusive focus on the potential value of biodiversity and TK in the patent system obscures the reality that greater economic benefits are likely to be realised by developing countries by identifying the appropriate mix of incentives to spur research and innovation directed to the neglected afflictions of their own citizens. A starting point for that in areas such as genomics is the promotion of international research collaborations directed towards the sequencing of the genomes of organisms causing neglected diseases. At the same time, TK is more likely to be efficacious where it is applied to conditions to which it is directed in its context, rather than the pursuit of blockbuster drugs. Seen from this perspective trends towards "open innovation" and "open source" approaches to collaborations in research and development are more likely to yield real benefits than what will often prove to be the speculative pursuit of potential economic value through the patent system.

B.1.3.d LOCAL ADAPTATION CAPACITY DEVELOPMENT FOR BIODIVERSITY CONSERVATION AND DEVELOPMENT UNDER LOCAL AND GLOBAL CHANGE

Changes in local and global contexts, be they technological, organizational, institutional as well as cultural, have forced local communities to explore new adaptation strategies to confront emerging environmental threats. In this regard, there is a convergence of literature away from a simplistic assessment of ecological and human vulnerability towards the scholarship of developing local adaptation capacity development (Adger 2006; Gallopin 2006; McLaughlin and Dietz 2008; Pant and Hambly-Odame, 2009a). Suppport to local adaptation capacity development which involves emergent properties of biophysical, technological and social systems has been gaining momentum in response to both climate change, erosion of cultural diversity, as well as the closing/opening of national and international markets.

In response to the urgent challenge posed by climate change impacts, a Global Partnership for Community-based Adaptation (CBA) is being formed under the auspices of the UN. Recognising the vital importance

22 The quality and integrity of the patent system also matters for developed countries. A 2009 European Commission competition inquiry into the pharmaceutical sector revealed that in 2007 the market for prescription and non-prescription medicines in the European Union was worth Euro 214 billion per year. Pharmaceutical companies were found to be engaged in anticompetitive practices using patents to extend patent lifetime through secondary filings and to delay the early entry of generics to European markets. This imposes costs upon European health systems, taxpayers and European lives.

of TK and human innovation, CBA seeks to build the capacity of local communities adapt to a changing climate. Adaptive strategies are generated through participatory processes, building on existing cultural norms, and addresses local development issues that make people vulnerable to the impacts of climate change in the first place. Specifically, the partnership will aim to:

- Dramatically increase international resources to support community-based adaptation.
- Utilize these resources to directly assist poor and vulnerable communities in their efforts to strengthen their adaptive capacities and resilience.
- Ensure these resources reach adaptation 'hot spots'—areas and affected communities in greatest need.
- Learn by doing with an emphasis on knowledge-sharing among CBA practitioners and funders, and promoting good practices.

As noted in Section B1.3.a above, in relation to the SGP model, small grants are a proven mechanism for providing timely and effective assistance directly to communities and local civil society partners. In this regard, a pilot GEF full-size CBA project in 10 countries[23] has been using the SGP mode of engagement of civil society to improve livelihoods and strengthen resilience if adaptation measures identified through climate risks assessments are put into practice.

Notably, the purpose of the approach will be to support:

- Vulnerability assessment and mapping

✓ Community-based vulnerability and risk assessment; including gender analysis and consideration of special vulnerabilities of women, children and the disabled;
✓ Participatory research.

- Climate-related natural disaster reduction and adaptation

✓ Natural disaster management at the local level (e.g. prevention and rehabilitation related to drought, floods, and other natural disasters);
✓ Community adaptation through livelihoods diversification;
✓ Women's empowerment for CBA implementation;
✓ CBA capacity building initiatives for strengthening local governance and local service delivery.

- Conflict resolution and prevention

✓ Prevention and resolution of conflicts due to shift in ecosystem boundaries and increased competition for access to natural assets.

- Creation of innovative financing mechanisms

✓ Capacity-building of local communities, CBOs, womens' groups, and NGOs to access national, regional and multi-lateral funding mechanisms.

- Promotion of volunteerism

✓ Application of volunteerism for development within the context of the CBA funded projects;
✓ Utilization of volunteerism as a means for community partners to become active participants in their own development planning;
✓ Promotion of South-South cooperation.

- Knowledge management and policy development

✓ Introduction of CBA risk management into national development strategy and plans;
✓ Subject to the relevant prior and informed consent of indigenous peoples and local communities, capturing, codifying, sharing of indigenous knowledge related to CBA;

From the innovation systems perspective, capacity development involves technological innovation, organizational innovation, institutional innovation, as well as individual creativity, learning and action

23 namely Bangladesh, Bolivia, Guatemala, Jamaica, Kazahkstan, Morroco, Namibia, Niger, Samoa, and Vietnam.

(Hambly-Odame et al. 2007; Pant et al. 2008). Developing local capacity to adapt to changes in biophysical, technological and social systems, also referred to as capacity to innovate within the literature of innovation studies, entails the development of collective context-specific skills, practices, routines, institutions and policies to put existing and new knowledge, including the knowledge of local and indigenous communities, into productive use in response to changing technological, economic, social, climatic and environmental challenges and opportunities (Hall 2005). Adaptation capacity is an emergent property of a system that comes through the interrelationships and interactions among various elements of the system, such as expert knowledge-based adaptation strategies, and local and indigenous knowledge-based adaptation strategies (Morgan 2005).

BOX 1. AGRICULTURAL BIODIVERSITY CONSERVATION AND DEVELOPMENT IN THE HIMALAYAN FOOTHILLS

Pant and Ramisch (2010) present a case study of agricultural biodiversity conservation in the Himalayan Foothills of Nepal. Agricultural biodiversity is found in the rice and finder millet varieties and cultural diversity is represented by the traditions of the two caste groups (Tagadhari and Matwali). In Nepal, rice is considered a prestigious, high status food that only the affluent can afford to eat regularly, whereas finger millet is generally considered as a neglected, low-status food crop. Even though both caste groups grew and consumed both rice and finger millet, Tagadhari had richer rice food traditions and associated preference for local crop varieties and management practices, while Matwali held more finger millet landraces and food traditions than their Tagadhari neighbours.

In addition to castes, gender and class also shape agricultural biodiversity conservation and utilization. Elderly women held rich knowledge and skills for preparing traditions foods, specifically a number of rice breads. Socialization through upbringing was only the way for intergenerational transfer of knowledge and skills regarding culinary traditions. Moreover, wealthier households had both the land to maintain more local crop diversity and the means to prepare a wider range of the festive foods derived from this diversity, as compared with poorer households.

This case study illustrates that the observed diversity of local rice and finger millet varieties and their complex associations with caste- and class-based preferences represent important cultural goods that are valued at community level as a way of life exemplified by the celebration of rituals and festivals involving local crop varieties.

By way of a general statement, capacity development involves changes at the level of the individuals, including human knowledge, skills, attitudes and actions; changes in organizations, networks and systems; and changes in enabling environments, such as systemic changes in institutions, policy and governance (CIDA 2000). The processes of capacity development for biodiversity conservation also needs to address the potential ideological divide over biodiversity conservation, its utilization for 'development' and poverty reduction, as well as the rights and access to benefits at various levels—individual, organizational, inter-organizational, networks and systems.

In this regard, the following questions about adaptation capacity development for biodiversity conservation may be presented:

1. What are the effective ways to facilitate innovation processes in biodiversity conservation, utilization and benefit sharing, moving beyond the conventional 'paradox' of conservation and development?
2. How do we develop innovation capacity in biodiversity conservation, utilization and benefit-sharing while addressing seemingly intractable social problems, such as food crisis, hunger and social exclusion?
3. How do we build on adaptive and innovation capacity, and capacity to put existing and new knowledge, including local and indigenous knowledge, into productive use in response to changing technological, economic, social, climatic, and environmental challenges and opportunities?

As noted in the introduction, human cultural diversity coevolves often with biological diversity. Many areas with high biological diversity are also inhabited by indigenous peoples (Posey 1999b). The

Declaration of Belem by the International Congress of Ethnobiology in 1988 affirms this inextricable link between biological and cultural diversity.

SCIENCE AND PRACTICE OF CONSERVATION AND UTILISATION OF BIODIVERSITY IN AGRO-ECOSYSTEMS

Critics argue that an increasing divide between 'science' that deals with genetically modified used organisms, and local and indigenous knowledge and practices has compromised the development impacts of agricultural research, specifically the poor adoption of new technologies. The notion that formal research systems are the principal source of innovation is however being challenged by the innovation systems thinking where all relevant stakeholders, including researchers, development practitioners, local and indigenous people, rural farmers and urban consumers, are potentially considered as creative and innovative in their respective domains (Edquist 1997; Lundvall 1992; Nelson 1993). The interaction between producers, regulators and users of knowledge and technology is crucial for greater effectiveness. In this context, an innovation systems approach refers to the network of public and private stakeholders engaged in the production, exchange, regulation, adaptation and application of knowledge, bringing new products, new processes and new forms of organization into economic, environmental, social and cultural use (World Bank 2006).

Although the innovation systems approach recognizes that research is still a major source of innovation, it challenges the status quo of scientific communities in terms of their reluctance to broaden the notion of innovation beyond the practices of normal or 'paradigm-based' science as referred to in the classical literature of the philosophy of science (Kuhn 1962). For example, ex situ conservation and utilization of genetic material for scientific research and development under the aegis of normal science has often overlooked the local and indigenous practices of biodiversity conservation and development (see Jarvis et al. 2000).This implies a need for postnormal science that is characterized by an involvement of multiple stakeholders and deliberation on extended facts to solve complex problems that the humanity is facing nowadays (Bidwell 2009; Funtowicz and Ravetz 1992).

While the normal scientific research is based on the linear model of science-society relationships, either focusing on science-push or demand-pull mode of research practice, "postnormal" scientific research is embedded in innovation systems approach. Gibbons et al. (1994) discuss two modes of knowledge production: Mode I disciplinary knowledge production and Mode II interdisciplinary, intersectoral and interorganizational knowledge production (see also the overall introduction to this Technical Series).

Pant (2010) proposes two modes of research and development participation. Firstly, mode I research participation, which can be characterized as science-led paradigm that brings science into society, such as the participatory plant breeding. This is an expert-led research process and experts invite farmers' intellectual inputs whenever they feel necessary (Witcombe et al. 2006). This approach of participatory research and development is still preoccupied by expert mind-sets and believe on best practices or best bets. Nevertheless, this approach of research and development meets the two characteristics of postnormal science because there is every possibility to engage diverse stakeholder groups in deliberation of extended facts, mainly the experiments being moved to farmers' fields. Mode II research and development participation that brings society into science, and sceptics often stereotype this mode of research and enough to commit the problem of unconfirmed field observations (Sinclair and Cassman 2004). Nevertheless, society-led research participation is the one that can genuinely integrate local and indigenous knowledge and practices into expert knowledge systems.

The CBD provides rights to national sovereignty over genetic resources, as well as to local and indigenous communities, to counterbalance the interests of an unbridled expanding free market regime. This has, however, been only a symbolic victory because the legal IPR instruments for protecting and compensating local and indigenous knowledge, and property rights under the WTO agreement on TRIPS are much weaker than the protection mechanisms available for expert innovators (Brush 1996; Brush 2007; Eyzaguirre 2007).

BOX 2. SOURCES OF CORE COMPETENCE FOR CONSERVATION AND UTILIZATION OF BIODIVERSITY

BOLIVIA: Association of Palqui Producers (APROPALQUI)
Municipality of Cotagaita, Department of Potos, Bolivia
GEF SGP small grant: US$18,712

In Cotagaita, Bolivia, Palqui tree (*Acacia feddeana*, Fabaceae) forests or stands are community-owned and have traditionally been used to feed cattle. Due to the rapid increase of population growth, using palqui to feed cattle has however endangered the regeneration capacity of this forest species. The semiarid ecosystem is fragile and subject to pressure from uncontrolled grazing and unsustainable use of forest resources. Loss of the vegetation layer has created soil erosion, reducing the production of the Palqui fruit and prevents the community from benefiting from its byproducts: tostado (roasted beans), mates (herbal teas), pito (flour), and cookies. A project was submitted to the SGP in Bolivia to develop agroforestry activities to sustainably manage the native palqui forests for the benefit of community members.

The project began by selecting three areas for use as productive palqui fields. Using 50 acres of demarcated space, preservation-oriented management was used to monitor soil and health of palqui trees. The next stage involved practical training in the conservation and management of palqui plantations and the enhancement of farmer knowledge through community workshops and practical visits. Training included by-product processing techniques, handling and processing of equipment, marketing and management of economic resources, workshops on medium-term evaluation techniques, and capacity building through the creation and consolidation of the Association of Palqui Producers (APROPALQUI).

The project generated an increase in income of families in the community. Thus, they have decided to reinvest profits in an effort to strengthen stockpiling facilities. Financial benefits have led families to take conservation seriously, preventing unrestricted access to cattle and reducing unregulated felling of palqui trees. Seed banks have also been created to ensure sustainable growth of the trees. The project represented success in meeting community needs while protecting the environment.

Along with CBD the protection of traditional cultural expressions (TCEs) as objects of trade and artefacts of cultural value, as the sovereign right of nation states to formulate and implement cultural policies, as well as measures for the protection and promotion of human cultural diversity has been gathering apace (Graber 2006). The protection of TCEs is a new field and the multilateral framework has yet to explore the intersection between TCEs and the biodiversity conservation objectives of the CBD (Pant and Ramisch 2010).

No single organization or policy instrument (e.g., CBD, TRIPS, WIPO, UNESCO, or other related conventions) is likely to be sufficient to ensure effective conservation of biodiversity and cultural diversity by itself. Nevertheless, the principles enshrined in these international standard-setting agreements can be regarded as a point of departure for negotiations and subsequent capacity development of multiple stakeholders engaged in conservation, utilization and benefit sharing of biodiversity (Rosendal 2006).

B.1.3.e INDIGENOUS PEOPLES' CONSERVED TERRITORIES AND AREAS CONSERVED BY INDIGENOUS PEOPLES AND LOCAL COMMUNITIES: ICCAS

A close association is often found between a specific indigenous people or local community and a specific territory, area or body of natural resources. When such association is combined with effective local governance and conservation of biodiversity, we speak of "ICCAs". More specifically ICCAs are defined by the IUCN as "*natural and/or modified ecosystems, containing significant biodiversity values, ecological benefits and cultural values, voluntarily conserved by indigenous peoples and local communities, both sedentary and mobile, through customary laws or other effective means*" (Borrini-Feyerabend *et al.* 2004a).

As noted in the introductory section, throughout the world, indigenous peoples and local communities relate to biological diversity, use it for their livelihoods and perceive it as essential in their lives.

Biodiversity intertwines with their knowledge, practices and spiritual and material values and is closely related to their "common rights" over land and natural resources. Despite the enormous global importance of state-property and private property, communal ownership and control (and/or community-based decisions and action) still encompass a vital proportion of the land and water bodies significant for our global biological and cultural diversity (SCBD 2010: 40-41). A regional example provides an indication of the importance of the phenomenon. The indigenous territories in the Amazon Basin cover more than 197 million hectares, or 25% of the total forest area of the Amazon basin (RSIAR 2009). Not all these territories can be classified as ICCAs (see below), but many indeed can, and their contributions are critical for the conservation of Amazons' biodiversity[24].

ICCAs include cases of continuation, revival or modification of traditional practices, at times of ancient origin, but they also include new initiatives, such as restoration and innovative uses of resources taken up by indigenous peoples and local communities in the face of new threats or opportunities. Several of them are secluded ecosystems with minimum human influence, while others accommodate various kinds of regulated uses in areas ranging from very small to large stretches of land and waterscapes.

Three features are important to identify an ICCA:

- A well defined people or community possesses a *close and profound relation* with an equally well defined site (a territory, area or species' habitat)—a relation embedded in local culture, sense of identity and/or dependence for livelihood and well being.
- The people or community is the major player in decision-making and implementation regarding the management of the site, implying that a local institution has the *de facto and/or the de jure capacity to enforce regulations*. Other stakeholders may collaborate as partners, especially when the land is owned by the state, but the local decisions and management efforts are predominant.
- The people's or community's *management decisions and efforts lead to the conservation* of habitats, species, genetic diversity, ecological functions/benefits and associated cultural values, even when the conscious objective of management is not conservation alone or per se (e.g., objectives may be livelihood, security, religious piety, safeguarding cultural and spiritual places, etc.).

BOX 3. A COMMUNITY CONSERVED AREA IN THE COASTAL ENVIRONMENT OF SENEGAL

The organisation that gathers the fishermen of the eight villages of the rural municipality of Mangangoulak (Casamance, Senegal) has recently introduced new fishing rules in its traditional fishing grounds, now known as Kawawana, a Diola acronym for *Kapoye Wafwolale Wata Nanang* ("our natural heritage that we want to preserve"). Kawawana is a Community Conserved Area (see section B.1.3.e for a detailed discussion of ICCAs). The fishers' organisation has identified the boundaries, internal zoning and fishing regulations in each zone, as well as the means for ensuring that these regulations are respected and their results are followed up. Interestingly, it has done so on the basis of the national decentralisation law, which assigns to the level of the rural municipality the authority and responsibility over natural resources.

The value of Indigenous Peoples' Conserved Territories and Areas Conserved by Indigenous Peoples and Local Communities (ICCAs) was initially recognised by the Convention on Biological Diversity (CBD) at its 7th summit in Kuala Lumpur, Malaysia, in 2004. In a nutshell, CBD COP 7 recognised the importance of indigenous peoples and local communities in the governance of of natural habitats for the conservation of biodiversity. At Kuala Lumpur, the 188 countries signatory of the CBD adopted a programme that encourages the recognition and support of ICCAs and the socio-cultural values that they involve. An ICCA requires a well-defined community (for Kawawana, the fishers' association and the people it represents) and a well-defined resource area (the traditional fishing grounds of Mangangulak), which are linked by strong ties (in this case, the local culture and community livelihoods). In addition, the community should have the power to decide how to manage the natural resources (governance power) and its decisions should lead to conserving the natural environment.

In the sense just described, Kawawana can be taken as an excellent example of a "new" ICCA with roots in local tradition and history. What is crucial is that it has now received the official recognition of the Regional Council of Casamance and of its Governor, creating a precedent in the country and the region. The experience of putting into operation the ICCA of Kawawana—the first of its kind in Senegal—opens thus new prospects for more participa-

24 As a matter of fact, some of them do also overlap with state-declared protected areas. See Zambrana and Maturana, 2008.

tory, equitable and efficient coastal and marine conservation in West Africa. And, if it will succeed in eliminating free access, it will contribute to restoring the fisheries for all users of the system, including non-local users.

What characteristics have made this possible in Mangagoulack and not elsewhere? On the one hand, the communities of Mangagoulack maintain a strong sense of common identity and internal solidarity, both crucial to effective community-based work. On the other, they benefitted at crucial moments in their process from some specific technical and financial support (provided by Cenesta, GEF-SGP and FIBA). Such support was sensitively provided and followed the detailed requests that the fishers' organisation had itself identified.

ICCAs cover a very wide range of natural ecosystems and species, including agricultural, pastoral and hunting and gathering landscapes, forests, wetlands and coastal and mountain areas. Many of them are Sacred Natural Sites[25]. Equally impressive is the diversity of traditional and modern institutions and rules that actually govern ICCAs, and the variety of their motivations and objectives[26]. Such diversity, designed through time to fit specific ecological and social situations, is the true wealth of ICCAs. It is also their relative weakness, however, as state government may not be comfortable dealing with idiosyncratic institutions that may not fit a country's legal and procedural requirements.

CONSERVATION ROOTED IN HISTORY AND CULTURE

The crucial feature of ICCAs is their variety and complexity. The conservation practices of indigenous peoples and local communities depend on an astonishing variety of meanings and values related to concepts such as "nature", "environment" and "conservation", a variety that underpins the relations between humans and nature that find expression in diverse ICCAs all over the world. While all ICCAs by definition include precious bio-cultural diversity conserved in a voluntary and self-organised way, the related beliefs, practices, and institutions are all context-specific. Moreover, as lively socio-cultural phenomena, ICCAs change in tune with history and society. Some disappear, others survive in old or new forms, and some emerge anew. Most systems by which contemporary indigenous peoples and local communities govern and manage their natural resources are a blending of old and new knowledge, practices, tools and values of different origin. In the struggle to cope with the scale and pace of socio-cultural change, some ICCA institutions have been *de jure* replaced by state governance, but remain *de facto* alive and effective. In other cases, change has been powerful enough to affect the community's capacity to manage the local resources in a sustainable way: customary institutions have broken down or have been replaced by state institutions, and genuine local ICCAs are just a memory, or nearly so[27]. Yet in others, even overpowering change has been unable to destroy them: innovative, more complex ICCAs have emerged from the pre-existing ones.

BOX 4: Indigenous peoples and their territories

From the perspective of many indigenous peoples, the relationship between peoples and nature (what others call "management" and "governance") cannot be separated from knowledge (science) and the moral/ ethical foundations of society. This insight is embedded in the concept of "territory"-- an archetypical entity related to the "common good of people and/in nature".

In the sense just described, many indigenous peoples believe they have been "conserving" nature for thousands of years. They did so while living with it and from it, but their relationship with their territories is much more complex, intimate, and more vital, for them, than "setting aside" land and resources for conservation, as done by modern societies for protected areas.

(see also : Posey 1999a, Mallarach 2008)

25 Sacred Natural Sites (SNS) are cultural and spiritually orientated places such as sacred groves, lakes, rivers and mountains. See: Dudley et al., 2005; Wild and McLeod, 2008; Mallarach, 2009.

26 See Borrini-Feyerabend et al. 2004; Kothari, 2006; IUCN CEESP, 2008a; IUCN/CEESP, 2008b; IUCN/CEESP, 2010; see also www.ICCAforum.org and www.iccaregistry.org:

27 In the French island of Corse it is said that, in the past, the village forests were collectively managed according to locally agreed rules. Currently, however, most such forests are either under state control (including for protected areas) or privately owned. This has opened the way to frequent summer fires, which endanger local biodiversity by shrinking the habitats unique to the island.

Over the last two centuries, the formal policies and practices that dominate conservation and development have largely ignored ICCAs, when they did not actively threaten them. Even today, while neglect and harm give way to emerging recognition and support, the interface between state-based institutions and the customary institutions of indigenous peoples and local communities remains ridden with conflicts. Some relationships are respectful, but many are affected by misunderstandings, mistrust and well-intentioned initiatives that turn up sour. In fact, even current serious interest on individual ICCAs and community conservation overall[28] is still far from dispelling the two main stereotypes that continue to plague conservation: the romantic view of indigenous peoples and traditional communities living in total harmony with nature and the view of people as parasites, necessarily degrading the ecosystems in which they live (Kothari, 2008). Both are unrealistic and wrong.

The majority of ICCAs are managed neither solely with a purely utilitarian/ functional approach, nor with a purely spiritual/aesthetic one. Most often, there is a combination of motivations with the following being remarkably common[29]:

- benefitting through time from *environmental products and functions* (e.g., food, medicinal plants, water) and specifically preserving them for moments of climatic, economic or political crises or exceptional scarcity (ICCAs are one of the very few *safety nets* and *disaster prevention means* available to many communities);
- embodying *spiritual or religious values*[30] and/or an important part of *cultural identity*, expressed through historical association and embedded memories, a sense of unique *responsibility* ("we are one with that body of nature") or something simple but life-enhancing, such as *pride* in a wood grove regenerated by the community, or *delight* in a local nature reserve;
- symbolizing and rendering concrete some form of *political autonomy*, and at times also *economic and cultural autonomy*, the ability to control one's lives and environment, to sustain the community and protect it against external influences and threats.

Related to the variety of main purposes, we find a variety of management objectives in the minds of peoples and communities governing ICCAs that is very similar to the variety of official objectives for protected areas declared and run by state governments. These objectives, which can be found alone but much more often in combination for the same ICCA, include:

- *strict protection*, i.e. for ICCAs managed to avoid any type of disrespect, disturbance or change. Typical examples are sacred sites, the territories of un-contacted peoples living in voluntary isolation, and community based wildlife sanctuaries. Many of the strictly protected areas on the planet are set aside because of links with a local faith or a major world faiths (Dudley *et al.* 2005), such as the cemeteries of marabous in Morocco, serving as unique repositories of plant biodiversity. Examples of territories of un-contacted people living in voluntary isolation—a form of ICCA recognised by national governments—include the Cuyabeno-Imuya and Tagaeri-Taromenane territories in Ecuador and the Yuri (Aroje) territory of Río Puré, in Colombia, which spans alone over one million ha[31]. An example of strictly protected wildlife sanctuaries set up and run by a local community is the recently-created Khonoma Tragopan Sanctuary in Nagaland, India[32];
- *preservation of large ecosystems in their natural state*, i.e. for ICCAs managed to conserve socio-cultural values (including limited hunting and herding and the recognition of ancestral rights), environmental functions (such as provision of clean drinking water, and prevention of floods, landslides and siltation of freshwaters), and/or ecotourism. Examples include many Indigenous Protected Areas in Australia, the *várzea* reserves in Brazil, the broad territories of indigenous peoples

28 The IUCN Commissions CEESP and WCPA have collaborated on this subject for over a decade.

29 Local narratives vary greatly among peoples and communities but these basic motivations can often been identified.

30 Sacred Natural Sites have been receiving increasing attention from conservation practitioners. See Verschuuren et al., 2010.

31 This ICCA—set out to protect the legitimate desire of the Yuri people to be let on their own—is recognized as an official protected area with the explicit objective of guaranteeing the survival of that people "without contact with the rest of society".

32 See http://www.ecosensorium.org/2009/07/khonoma-green-village-of-india.html , accessed 2010.

in the Arctic (Ferguson & Viventsova 2007) and some of the *resguardos* of Colombia (ASATRIZY and Riascos, 2008), some of which are fully recognized as national parks (e.g., Alto Fragua-Indiwasi (Zuluaga et al. 2003) and Yaijogé Apaporis[33]);

- *conservation of specific natural features*, i.e. for relatively small ICCAs that focus on one feature in the landscape, such as the Dindefelo waterfall in Senegal or the limestone caves of Kanger Ghati National Park, in India;
- *conservation of species or habitats with restricted resource use*, i.e. for ICCAs where resource extraction is either forbidden or highly and effectively regulated by local communities. Examples include sacred crocodile ponds in Mali; protected heronry in India (e.g. in Veerapuram village, Andhra Pradesh) (Pathak 2009: 116-118); areas reserved for sport hunting in Namibia (Weaver & Petersen 2008); and wetlands preserved by duck trappers in Iran, which provide unique stepping-stone habitats for the Siberian cranes[34]. Another excellent example of this type of ICCAs is the Orito–Ingi Sanctuary (Colombia), a crucial repository of plant biodiversity essential for traditional medicine. The Sanctuary is conserved by traditional shamans and officially recognised as part of the national system of protected areas (e.g, a *de-jure* ICCA[35]);
- *conservation of landscapes/seascapes*, i.e. community-shaped landscapes and seascapes where people derive and embed cultural values, such as the biosphere reserve of Minorca (Spain) (Borrini-Feyerabend *et al.*, 2004b), the customary migration territories of the Kuhi, Sashavan, Bakhtiari and many other nomadic tribes of Iran (Farvar, 2003), the potato park of Peru (Argumedo 2008), or the Satoyama landscapes of Japan (Bélair et al., 2010). Many such ICCAs involve grasslands established and maintained to allow seasonal grazing of livestock, which also provide habitats for wild herbivores and for grassland and savannah plant and animal species. Inherent to the management practices of such ICCAs is the flexibility of rules—such as rules for access, use, protection, restoration, etc.—which change in response to seasonal, environmental and social conditions. Another key characteristic is their aim to serve the "common good". The traditional knowledge, skills and social acceptance of their governing institutions are all the more crucial for both good governance and management effectiveness (Kilani *et al.* 2007). In the coastal and marine environment, seascape ICCAs can be defined as areas of harmonious interaction between people and the coastal environment that succeed to conserve both fishery productivity and biodiversity[36]. The phenomenon is widespread in Japan (their Japanese name is Satoumi) and throughout the Pacific (Govan *et al.* 2009);
- *sustainable and biodiversity-friendly use of natural resources*, i.e. for the ICCAs that proved the main sustainable source of food, medicines and timber and non-timber forest products for communities throughout the world. Examples here are as abundant as human cultures, from village-managed nut and fruit forests in Central Asia to traditional river fisheries in Laos (Baird 1999), from tribal pastoral territories in Mongolia (Schmidt 2006) to community forests in the Italian Alps (Casari 2007). A combination of sustainable use of natural resources and landscape conservation aims characterises many communities that conserve local agro-biodiversity. Endogenous bio-diverse species and varieties may depend on retaining community control over land and resources (Sarmiento 2008) or, as is often the case in the industrialised world, on establishing new community organisations and alliances to fight against the homogenization of local economies and livelihoods (Bassols Isamat *et al.* 2008).

ARE ICCAS "PROTECTED AREAS"?

Many ICCAs qualify as protected areas (PAs), as defined in the CBD PoWPA[37] or by the IUCN (Dudley 2008). The latter, in particular, sees *ICCAs* as *one of the four main governance types* that can "achieve the

33 See http://www.cbd.int/protected/implementation/highlights/?headerid=907bb86a-e682-4c2d-a65d-bc00e28c3b27 ; accessed 2010.

34 See http://www.scwp.info/iran/fereydoon.shtml accessed 2010.

35 See http://parquesnacionales.gov.co/PNN/portel/libreria/php/frame_detalle.php?h_id=2911&patron=01 accessed 2010; and Stolton and Dudley, 2010.

36 Shinichiro Kakuma, personal communication, 2010.

37 See CBD Programme of Work on Protected Areas, 2004; CBD Review of implementation of the programme of work on protected areas, 2008; Report from CBD SBSSTA 2010.

long-term conservation of nature with associated ecosystem services and cultural values" (the fourth column, type D in the IUCN protected area matrix of Table 2). This does not mean that ICCAs are always recognised as part of national protected area systems by the relevant government authorities or communities. In general, ICCAs are officially recognised if the requirements prescribed by governments are met and if the relevant communities so desire. Notably, however, this recognition is neither automatic nor necessary for many ICCAs to exist and fulfil their conservation and livelihood roles. Some communities prefer to maintain their ICCAs without any official PA status. Others believe that such recognition would prevent or mitigate a variety of threats and mobilise needed support. Indigenous peoples and local communities are to judge whether a declaration of their ICCA as a protected area under their own governance institutions is possible and strengthens support to their rights under the UNDRIP and other policy instruments (Stevens 2010 (in press)). State governments, on their part, may or may not yet possess—or be willing to use—the legal instruments to recognise ICCAs as part of their national protected area system and support them as such without hampering their unique governance arrangements.

TABLE 2: "The IUCN protected area matrix": a classification system for protected areas comprising both management category and governance type (Dudley 2008)

Governance types / Protected area categories	A. Governance by government			B. Shared governance			C. Private governance			D. Governance by indigenous peoples & local communities	
	Federal or national ministry or agency in charge	Sub-national ministry or agency in charge	Government-delegated management (e.g. to an NGO)	Transboundary management	Collaborative management (various forms of pluralist influence)	Joint management (pluralist management board)	Declared and run by individual land-owner	...by non-profit organizations (e.g. NGOs, universities, co-operatives)	...by for profit organizations (e.g. individual or corporate land-owners)	Indigenous bio-cultural areas and territories—declared and run by indigenous peoples	Community conserved areas —declared and run by local communities
I a. Strict Nature Reserve											
Ib. Wilderness Area											
II. National Park											
III. Natural Monument											
IV. Habitat/ Species Management											
V. Protected Landscape/ Seascape											
VI. Managed Resource Protected Area											

BENEFITS AND VALUES OF ICCAS

Most ICCAs are part of the long-term livelihoods strategies of indigenous peoples and local communities, i.e., they closely relate to their productive life and cultural identities. Their benefits are of various kinds, and the conservation of biodiversity *per se*—no matter how effectively achieved—may not be first or most important in peoples' mind. Nevertheless, ICCAs undoubtedly provide important biodiversity benefits and have significant potential for responding to global change, including climate-related. A meta-study by Molnar et al. (2004) estimates that the *global forest area under community conservation* (370 million hectares) is *at least as significant as the area conserved by state governments in forest protected areas*. Their estimate takes into account the ancestral territories of first nations in North America and the Amazon, the *ejidos* in Mexico, the indigenous forests and *pàramos* of the Andean region, the forest-agriculture mosaics in South America, the village and collective forests and sacred groves of Africa and the community-managed and jointly-managed forests of Asia. They mention that their estimate of community conserved forests could double or triple if traditional agro-forestry or agro-pastoral systems and forest areas in Soviet Russia, Europe and the Middle East would be included. A broad estimate of global coverage is also given by Kothari: ICCAs *may cover as much land as government-designated protected areas* (Kothari 2006), or about 12% of terrestrial surface. Even in the coastal and marine environment, despite less visible recognition, the contribution of ICCAs is significant throughout the world (Day *et al.* 2007). Overall, ICCAs protect threatened wildlife, maintain ecosystem functions and benefits, provide ecological connectivity across the landscape and offer time-tested examples of sustainable use of wild resources and agro-biodiversity.

Besides their contributions to the conservation of biodiversity—which they supply, incidentally, at little to no cost to society at large[38]—ICCAs *secure the needs of millions of people for water, food, energy, medicine, shelter, fodder, income, recreation and spiritual sustenance*. Uniquely, ICCAs also embed ancient knowledge about livelihood resources, provide disaster prevention and safety nets in times of stress and acute need, offer a concrete foundation for cultural identity and pride, and strengthen the rights and responsibilities of indigenous peoples and local communities to land and natural resources through local governance—*de jure* and/or *de facto* (Borrini-Feyerabend *et al.* 2004a; Govan et al., 2009; Pathak 2009).

The visibility of the larger benefits to society provided by ICCAs has been highlighted in debates regarding the contributions of local communities to climate change adaptation and forest and biomass-based mitigation.[39] As previously noted, the GEF Small Grants Programme has espoused support for ICCAs as part of its 4th Operational Phase (OP4) running from 2007 to 2010, supporting a large number of community-led initiatives, as well as a range of national workshops, regional studies, and international exchanges such as through the facilitation of a pilot Registry of ICCAs in collaboration with the UNEP World Conservation Monitoring Centre (WCMC).

Communities may in the future stand to receive compensations for their contributions through a variety of mechanisms, such as REDD, REDD+ and REDD++ schemes[40]. As in the case of payments for ecosystem services (PES), such compensations present opportunities to support communities in their conservation and livelihoods activities. They also present risks, however, in particular of attracting the attention of profiteers, harming the governance structures and values that have sustained ICCAs up to now, and/or strengthening embedded inequities. Indigenous peoples and local communities need to be thoroughly informed and empowered to deal with those issues in ways that they feel are appropriate. Governmental and non-governmental organisations and donors engaged in compensation schemes bear a responsibility to ensure transparency, accountability and effective empowerment of communities— within as well as outside the scope of recognising ICCAs as official protected areas.

38 A fact well documented and highlighted by Molnar et al., 2004.

39 See www.sgp.undp.org and Kothari 2008.

40 See Poffenberger and Smith-Hanssen, 2009; Initiatives to Reduce Emissions from Deforestation and Forest Degradation (REDD) are labeled REDD+ when they also include conservation, sustainable forest management and enhanced carbon sinks. Some also argue for the inclusion of agricultural activities, referred to as REDD++ (Simone Lovera, personal communication, 2010).

ARE ICCAS UNDER THREAT?

Because they frequently have no legal recognition within a country, and may also not be recognised or respected by private entrepreneurs and neighbouring communities, ICCAs are vulnerable through land and water being appropriated or "reallocated" to a variety of alternative uses. To non-members of the relevant communities, many ICCAs appear as natural, "unmanaged" and "unutilised" ecosystems—all the more coveted for resource extraction. Within indigenous peoples and local communities, ICCAs may also suffer as a result of changing value systems, increased pressure on natural resources and other internal tensions. Threats can be *external* (such as imposed development and resource exploitation processes; expropriation of community land; war, violent conflicts and movements of refugees; poaching and unauthorised extraction of timber and plant resources; climate change; etc.) and *internal* (such as changing values and acculturation into dominant society; loss of traditional knowledge; increasing pressure on resources; persistent or new inequalities between economic and social classes and gender groups within the community; etc.). In much of the above, the main drivers of change —combining external and internal threats— are new opportunities to access and use natural resources for profit-making activities. This may bring in welcome cash for a variety of development needs but can also be a door for corruption and mis-governance, ushering divisions, conflicts and social disruption[41]. As the disparity of power in modern societies increases exponentially, many indigenous peoples and local communities, at the bottom of the ladder, have fewer and fewer chances to resist. In some countries they are even denied legal existence as "peoples" and "communities", and denied the chance of collectively owning or possessing use rights for land and natural resources (Herzenni, 2008)

A global registry of ICCAs in the world is just beginning to be developed by UNEP/WCMC (Corrigan & Granziera 2010). So far, thus, there is little data on the extent of ICCAs existing, let alone under threat. But problems are undoubtedly serious. For example, in the last 50 years, 90% of sacred forests of Xishuangbanna Dai Autonomous Prefecture (Yunnan Province, China) have been damaged or destroyed (Pei 2010, in press). A rather comprehensive assessment in India points to widespread ICCA damage and threats from "development" projects (Pathak 2009). The juniper forests, grazing land and ceremonial grounds of the Borana of Ethiopia have been—literally—devastated in the last few decades (Bassi & Tache 2008). Anecdotal evidence from all over the world abounds with tales of loss, destruction and unwanted change imposed upon cultures and natural resources, at times against strenuous resistance. Moreover, for many indigenous peoples and local communities, just a few elders remain who can pass on to the youth the "local knowledge" and values that sustained their ICCAs through time. Indeed, if we wish to conserve ICCAs, it is urgent to act.

APPROPRIATE RECOGNITION AND SUPPORT FOR ICCAS AND SITUATED TRADITIONAL KNOWLEDGE

Much of the future of ICCAs and of situated or embodied TK discussed in this chapter depends on their larger context—the local, national, and international forces affecting them. Perhaps like at no other point in their history, both the fate of ICCAs and the meaningful continuation of emic experiences of biocultural diversity, as outlined in the various sections above, require the wider recognition and support of enlightened policies and institutions. Recent work has focused on ways by which appropriate recognition and support can be provided (IUCN/CEESP 2010), but it is clear that no external support, alone, can completely "secure" the future of ICCAs and their related worldviews and embodied wisdom and practices.

41 In East Africa, for example, a combination of strict and exclusive conservation with lucrative opportunities for tourism or hunting, has been driving land expropriation from the weakest members of society. Typical alliances for this include government members, private foreign investors and conservation organizations, as conservation is purported as a rationale for evictions and expropriations. In Tanzania alone, the Maasai are possibly facing eviction in the Ngorongoro Conservation Area, they were expelled from Loliondo (bordering the Serengeti) in conflict with the Ortello Business Company and they have grievances with the Thompson ecotourism company. Further examples include conflicts between the Grumeti reserves and neighboring communities, conflicts surrounding the plan to double the size of the Ruaha National Park, the forced evictions of pastoralists from the Ihefu wetlands in 2008, and of other communities in Southern Tanzania, to leave room for hunting grounds (all of these went almost un-recorded). (Yves Hausser, personal communication, 2010).

Appropriate recognition and support will only be effective if it will meet the other essential ingredient; the renewed commitment, integrity and hard work of the most directly concerned: the indigenous peoples and local communities at the frontline of conservation.

REFERENCES

Adger, W. 2006. Vulnerability. Global Environmental Change **16**:268-281.

Agrawal, A. 1995. Dismantling the divide between indigenous and scientific knowledge. Development and Change **26**:413–439.

Alexiades, M. 2009. The cultural and economic globalization of traditional knowledge systems. Pp. 68 -98 in Heckler, S. (ed). 2009. Landscape, Process and Power: Re-evaluating traditional environmental knowledge. Oxford and New York: Berghahn.

Altieri, M. and L. Merrick, (1987) 'In-Situ Conservation of Crop Genetic Resources Through Maintenance of Traditional Farming Systems', Economic Botany **41**:86-96.

Amend, T., Brown, J. , Kothari, A. , Phillips, A. and Stolton, S. (eds), 2008. Protected landscapes and agrobiodiversity values IUCN & GTZ , Heidelberg, Germany

Anonymous. 1999b. Caution: Traditional knowledge. Nature 401:623, 14 October 1999.

Argumedo, A. 2008. "The Potato Park, Peru: Conserving agrobiodiversity in an Andean Indigenous Biocultural Heritage Area", pages 45-58 in Amend T., Brown J., Kothari A., Phillips A. and S. Stolton (Eds.), Protected Landscapes and Agrobiodiversity Values, Vol.1, IUCN & GTZ, Kasparek Verlag, Heidelberg (Germany).

Arico, S and Salpin, C., 2005. Bioprospecting of Genetic Resources in the Deep Seabed: Scientific, Legal and Policy Aspects. United Nations University.

ASATRIZY and Juan Carlos Riascos de la Peña, 2008. Umu-Kaja Yepa—Territorio de la Asociación de Autoridades Tradicionales Indígenas de la Zona de Yapú, Vaupés, Colombia, Report for Cenesta, IUCN/CEESP and GTZ, 2008.

Association for Molecular Pathology et al v. United States Patent and Trademark Office et. al. 2010. United States District Court, Southern District of New York. Case 1:09-cv-04515-RWS. 29/3/2010.

Baird, I.B., 1999: The co-management of Mekong River inland aquatic resources in Southern Lao PDR.

Bassi, M. and B. Tache, 2008: "The Borana conserved landscape, Ethiopia", pages 105-115 in Amend et al. 2008.

Bassols Isamat, E., J. Falgarona Bosch, JM Mallarach Carrera and B. Perramon Ramos, 2008. "Agrobiodiversity conservation in the Garrotxa Volcanic Zone Natural Park, Spain", pages 33-44 in Amend et al. 2008 (op.cit.)

Bélair C., Ichikawa K., Wong B.Y. L., and Mulongoy K.J. (Eds.), 2010: Sustainable use of biological diversity in socio-ecological production landscapes. Background to the 'Satoyama Initiative for the benefit of biodiversity and human well-being, Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 52.

Berkes, F. 1999. Sacred Ecology. Philadelphia, PA, Taylor and Francis

Berkes, F., J. Colding and C. Folke. 2000. Rediscovery of Traditional Ecological Knowledge as Adaptive Management. Ecological Applications 10:1251-1262

Berkes, F. and N.J. Turner. 2006. Knowledge, Learning and the Evolution of Conservation Practice for Social-Ecological System Resilience. Human Ecology **34**(4):479-492.

Bidwell, David. 2009. "Is Community-Based Participatory Research Postnormal Science?" Science, Technology and Human Values **34**:741–761.

Borrini-Feyerabend, G., A. Kothari and G. Oviedo, 2004a: Indigenous and Local Communities and Protected Areas. Towards equity and enhanced conservation, IUCN/WCPA Best Practice Series no. 11, IUCN Cambridge (UK).

Borrini-Feyerabend, G., J. Rita Larrucea and H. Synge, 2004b. "Participatory management in the Minorca Biosphere Reserve, Spain", in Synge, H. (ed.), European Models of Good Practice in Protected Areas, IUCN and Austrian Government, Vienna.

Brokensha, D., D. Warren and 0. Werner (eds.), 1980. Indigenous Knowledge Systems and Development. Lanham, MD: University Press of America.

Brush, S. B. 1996. Is Common heritage outmoded? in Valuing local knowledge: indigenous people and intellectual property rights, edited by S. B. Brush and D. Stabinsky. Washington, D. C.: Island

Brush, S. B. 1989. 'Rethinking Crop Genetic Resource Conservation', Conservation Biology **3**(1):19-29.

Brush, Stephen, and Doreen Stabinsky (eds), 1996. Valuing Local Knowlege. Washington: Island Press.

Casari, E.,2007: "Emergence of Endogenous Legal Institutions: Property Rights and Community Governance in the Italian Alps", Journal of Economic History, 67:1:191–226.

CIDA. 2000. "Capacity Development: Why, What and How." Pp. 1-8 in Capacity Development—Occasional Series Vol. 1. No. 1. Ottawa: Canadian International Department Agency.Clément, D. 1998. L'ethnobiologie/Ethnobiology. Anthropologica **40**:7–34.

CIDA. 2007. "Farmers' Rights and Protection of Traditional Agricultural Knowledge." World Development **35**:1499-1514.

Clement, D. 1998. The historical foundations of ethnobiology (1860-1899). Journal of Ethnobiology **18**:161-187.

Corrigan, C. and A.Granziera, 2010. A handbook for the Indigenous and Community Conservaed Areas Registry, UNEP-WCMC, Cambridge (UK).

Day, J.C., J. Senior, S. Monk and W. Neal (eds.), 2007: First International Marine Protected Areas Congress, 23-27 October 2005, Conference Proceedings, IMPAC1 2005, Geelong (Australia).

Dudley, N., L. Higgins-Zogib and S. Mansourian, 2005: Beyond belief—Linking faith and protected areas to support biodiversity conservation, WWF, Gland (Switzerland).

Dudley (ed.), 2008. Guidelines for Applying Protected Areas Management Categories, IUCN/ WCPA Best Practices in Protected Areas Series, Gland (Switzerland).

Dufresne, F & Duval, M (2004) Genetic sequences: how are they patented? Nature Biotechnology **22** (2):231-232 arguing that sequence claims are heterogenous and a source of legal uncertainty.

Edquist, C. (Ed.). 1997. Systems of Innovation: Technologies, Institutions, and Organizations. London; Washington: Pinter.

Ellen, R. and Harris, H., 2000. Introduction. In: Ellen, R. and Parkes, P. eds. Indigenous environmental knowledge and its transformations: critical anthropological perspectives. Harwood Academic Publishers, Amsterdam, 1-33.

Escobar, A., 1998: "Whose Knowledge, Whose nature? Biodiversity, Conservation and the Political Ecology of Social Movements." Journal of Political Ecology **5**: 53-82.

European Patent Office, 2010: European Patent Office European Register record for EP1180006 entitled Annex to the communication dated 18/02/2010. https://register.epoline.org/espacenet/regviewer

Eyzaguirre, P. 2007. The impact of collective action and property rights on plant genetic resources. World Development 35:1489-1498.

Farvar, M. T., 2003. Mobile pastoralism in West Asia: myths, challenges and a whole set of loaded questions. Policy Matters **12**:31-41.

Ferguson, M. and K.Viventsova, 2007: Community Conserved Areas in the Circumpolar Arctic: Preliminary description and assessment of their legal status, threats and needs, report for CENESTA/ IUCN CEESP and GTZ.

Funtowicz, S. O., and J. R. Ravetz. 1992. Three types of risk assessment and the emergence of post-normal science. Pp. 251-73 in In Social theories of risk, edited by S. Krimsky and D. Golding. Westport, CT: Praeger.Escobar, A., 1991: "Anthropology and the Development Encounter: The Making and Marketing of Development Anthropology." American Ethnologist **18**(4):658-682.

Gallopin, Gilberto C. 2006. "Linkages between vulnerability, resilience and adaptive capacity." Global Environmental Change **16**:293–303.

Gibbons, Michael, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott Scott, and Martin Trow. 1994. The new production of knowledge: the dynamics of science and research in contemporary societies. London: Sage.

Gliessman, S., 1981. 'The Ecological Basis for the Application of Traditional Technology in the Management of Tropical Agroecosystems', Agro-ecosystems **7**:173-85.

Govan, H. et al., 2009. Community Conserved Areas: A review of status & needs in Melanesia and Polynesia, ICCA regional review for CENESTA /TILCEPA /TGER/ IUCN/ GEF-SGP.

Graber, Christoph B. 2006. "The New UNESCO Convention on Cultural Diversity: A Counterbalance to the WTO?" Journal of International Economic Law **9**:553-574.

Guellec, D and Pottelsberghe, B., 2007. The Economics of the European Patent System: IP Policy for Innovation and Competition. Oxford: OUP.

Hall, A. 2005. Capacity Development for Agricultural Biotechnology in Developing Countries: An Innovation Systems View of What it is and How to Develop it. International Journal of Development **17**:611-630.

Hall, A., M. V. K. Sivamohan, N. Clark, Sarah Taylor, and G. Bockett. 1998. "Institutional developments in Indian agricultural R&D systems: emerging patterns of public and private sector activity." UK/ India: Natural Resources Institute (NRI)/National Centre for Agricultural Economics and Policy Research (NCAP).

Hall, A., Bockett, G., Taylor, S., and M.V.K. Sivamohan. 2001. "Why Research Partnership Really Matter: Innovation Theory, Institutional Arrangements and Implications for Developing New Technology for the Poor." World Development 29:783-797.

Hall, A., Clark, N., Taylor, S. , and R. V. Sulaiman. 2001. Institutional learning through technical projects: Horticultural technology R&D systems In India. AgREN Network Paper 111.

Hambly Odame, Helen, John Fitzsimons, Laxmi P. Pant, and Peter Sykanda. 2007. Innovations in Farm Families and Rural Communities: Capacity Development for Broadband Use in Southern Ontario, in Working Paper Spring 2007. Toronto/Guelph: Ontario Ministry of Government Services/University of Guelph.

Heckler, S. (ed). 2009. Introduction. Pp. 1-17 in S. Heckler (ed.) Landscape, process and power: Re-evaluating traditional environmental knowledge. Oxford and New York, Berghahn.

Herzenni, A. 2008. Aires forestières communautaires conservées dans le Haut Atlas central, Maroc, Report for Cenesta, IUCN/CEESP and GEF SGP.

IUCN/CEESP, 2008a: Governance as key for effective and equitable protected area systems, Briefing Note no 8.

IUCN/CEESP, 2008b: Recognising and supporting indigenous and community conservation—ides and experiences from the grassroots, Briefing Note no 9.

IUCN/CEESP, 2010: Strengthening what works— Recognising and supporting the conservation achievements of indigenous peoples and local communities, Briefing Note no. 10.

Jarvis, D., L. Mayer, H. Klemick, L Guarino, Melinda Smale, A. Brown, M. Sadiki, B. Sthapit, and T. Hodgkin. 2000. A training guide for in situ conservation on-farm. Rome, Italy: International Plant Genetic Resources Institute.

Karasov, C., 2001. Who reaps the benefits of biodiversity? Environmental Health Perspectives **109,** December 2001:582-587

Kilani, H., A. Serhal and O. Llewlyn, Al-Hima, 2007. A way of life, IUCN, Amman and Beirut.

Kothari, A. (ed.), 2006. Community conserved areas: towards ecological and livelihood security. Parks, **16** (1): 3- 13, 2006.

Kothari, A., 2006: special issue on Community Conserved Areas, Parks, IUCN WCPA, vol. 16, no.1.

Kothari, A., 2008: "Protected areas and people—the future of the past", Parks, 17, 2:23-34

Kuhn, Th. S. 1962. The Structure of Scientific Revolutions. Chicago: The University of Chicago Press.

Laird, S & Wynberg, R., 2008. Access and Benefit-Sharing in Practice: Trends in Partnerships Across Sectors. CBD Technical Series No. 38. Secretariat of the Convention on Biological Diversity.

Lohan, D & Johnston, S., 2003: The International Regime for Bioprospecting: Existing Policies and Emerging Issues for Antarctica. UNI/IAS Report. Tokyo: United Nations University/Institute of Advanced Study.

Lundvall, B.-Å. 1992. National systems of innovation: towards a theory of innovation and interactive learning. London: Pinter Publishers.

Maffi, L. and E. Woodley. 2010. Biocultural Diversity Conservation: A Global Sourcebook. London, Earthscan.

Mallarach J.M. (Ed.), 2008. Protected Landscapes and Cultural and Spiritual Values. Volume 2 in the series Values of Protected Landscapes and Seascapes, IUCN, GTZ and Obra Social de Caixa Catalunya. Kasparek Verlag, Heidelberg.

Mallarach, J.M. (Ed), 2009. Protected Landscapes and Cultural and Spiritual Values, IUCN, Gland (Switzerland).

McLaughlin, Paul, and Thomas Dietz. 2008. "Structure, agency and environment: Toward an integrated perspective on vulnerability." Global Environmental Change 18:99-111.

Molnar, A., S. Scherr and A. Khare, 2004. Who conserves the world forests? Community driven strategies to protect forests and respect rights, Forest Trends and Agricultural Partners, Washington DC.

Morgan, P. 2005. "The Idea and Practice of Systems Thinking and Their Relevance for Capacity Development." Maastricht: European Centre for Development Policy Management.

Nature 1999a. Asian scientists call on UNESCO to protect indigenous knowledge. Nature 397:376, 4 February 1999.

Nature 1999c. ICSU seeks to classify "traditional knowledge". Nature **401**:631, 14 October 1999.

Naturex, 2007. Naturex Plan Will Promote Peruvian Maca Growers and Communities. Press release 19/06/2007.

Nelson, R. R., 1993. National Innovation Systems: A Comparative Study. Oxford: Oxford University Press.

Nelson, F. (ed.), 2010. Community Rights, Conservation and Contested Land—the Politics of Natural Resource Governance in Africa, Earthscan, London.

NIH, 1998. Report of the National Institutes of Health (NIH) Working Group on Research Tools. June 4 1998

Newman, D & Cragg, G., 2007. Natural Products as Sources of New Drugs over the Last 25 Years. Journal of Natural Products 70: 461-477

Nietschmann, B.Q., 1992. The interdependence of biological and cultural diversity. Occas. Pap. 21, Cent. World Indig. Stud.

Norgaard, R., 1984. 'Traditional Agricultural Knowledge: Past Performance, Future Prospects, and Institutional Implications', American Journal of Agricultural Economics **66**: 87478.

OECD, 2006. OECD Science, Technology and Industry Outlook 2006. Organisation for Economic Co-operation and Development.

Oldham, P., 2004 a. Global Status and Trends in Intellectual Property Claims: Microorganisms. Global Status and Trends in Intellectual Property Claims. Issue No. 2

Oldham, P., 2004 b. Global Status and Trends in Intellectual Property Claims: Genomics, Proteomics and Biotechnology. UNEP/CBD/WG-ABS/3/INF/4

Oldham, P., 2009. An Access and Benefit Sharing Commons? The Role of Commons/Open Source Licenses in the International Regime on Access to Genetic Resources and Benefit-Sharing. UNEP/CBD/WG-ABS/8/INF/3

Oldham, P and Cutter, AM, 2006. Mapping global status and trends in patent activity for biological and genetic material. Genomics, Society and Policy **2** (2). 62-91.

Pant, L P. 2010. "Bridging the research-practice divide in organic and low-external input agriculture." in The Seventh Annual Conference for Social Research in Organic Agriculture. University of Guelph, Guelph, Ontario, Canada.

Pant, L P., Helen Hambly Odame, A. Hall, and R. V. Sulaiman. 2008. "Learning Networks Matter: Challenges to Developing Learning-Based Competence in Mango Production and Post-Harvest in Andhra Pradesh, India." UNU-MERIT Working Papers #2008-069.

Pant, L P., and J. Ramisch. 2010. "Beyond Biodiversity: Culture in Agricultural Biodiversity Conservation in the Himalayan Foothills." in Beyond the Biophysical: Knowledge, Culture and Politics in Agriculture and Natural Resource Management, edited by L. German, J. Ramisch, and R. Verma. New York: Springer.

Pant, L.P., and H. H. Odame. 2009a. Innovation systems in renewable natural resource management and sustainable agriculture. African Journal of Science, Technology, Innovation and Development **1**:103-135.

Pathak, N. (ed.), 2009. Community Conserved Areas in India: a Directory, Kalpavriksh, Pune/Delhi.

Pilgrim, S.E., L.C. Cullen, D.J. Smith, and J. Pretty. 2008. Ecological Knowledge Is Lost in Wealthier Communities and Countries. Environmental Science & Technology, Vol. 42, No. 4, Pp. 1004-1009.

Pei, S. The Road to the Future? The Biocultural Values of the Holy Hill Forests of Yunnan Province, China. in Verschuuren et al, opp.cit, 2010 (in press).

Poffenberger, M. and K. Smith-Hanssen, 2009. Forest communities and REDD Climate Initiatives, Asia Pacific Issues no. 91

Posey, D. A. 1999a. Cultural and spiritual value of biodiversity: A complementary contribution to the global biodiversity assessment, in Cultural and spiritual values of biodiversity, edited by Darrell A. Posey. London: UNEP/Intermediate Technology Publications.

Posey, D. A. 1999b. „Introduction: Culture and Nature—The Inextricable Link.“ in Cultural and Spiritual Values of Biodiversity: A Complementary Contribution to the Global Biodiversity Assessment, edited by Darrell A. Posey. UK: Intermediate Technology Publications.

Posey, D. A., Dutfield, G., 1996: Beyond intellectual property: toward traditional resource rights for indigenous peoples and local communities, IDRC.

Renard Y., Kothari A., Pimbert M., Borrini-Feyerabend G., Farvar T., 2007. Sharing Power: Learning-By-Doing in Co-Management of Natural Resources Throughout the World, IUCN, Gland, Switzerland

Rosendal, G. K. 2006. Balancing access and benefit sharing and legal protection of innovations from Bioprospecting Impacts on Conservation of Biodiversity. The Journal of Environment & Development **15**:428-447.

RSIAR (Red Socioambiental de Información Amazónica Georeferenciada), Amazonia 2009—Areas Protegidas y Territorios Indígenas, 2009 accessed on 2010.

Sarmiento, F., 2008. The conservation of the farmscapes of the Quijos River in the tropical Anes, Ecuador, pages 22-30 in Amend, T., J. Brown, A. Kothari, A. Phillips and S. Stolton (eds.), Protected Landscapes and Agrobiodiversity Values, IUCN and GTZ Kasperek Verlag, Heildelberg (Germany).

SCBD, (Secretariat of the Convention on Biological Diversity), Global Biodiversity Outlook 3, Montreal (Canada), 2010.

Schmidt, S., 2006: "Pastoral Community Organization, Livelihoods and Biodiversity Conservation in Mongolia's Southern Gobi Region", USDA Forest Service Proceedings RMRS-P-39, pages 18-28.

Scott, J., 1986. 'Everyday Forms of Peasant Resistance', Journal of Peasant Studies **13** (2): 5-3 5.

Scotchmer, S., 2004. Innovation and Incentives. Cambridge: MIT Press.

Shiva, V.,1993. Monocultures of mind: perspectives on biodiversity and biotechnology. USA: Zed Books.

Shiva, V., 1997. Biopiracy: the plunder of nature and knowledge. Toronto: Between The Lines.

Shiva, V., 2005. Globalization's New Wars: Seed, Water & Life Forms. New Delhi: Women Unlimited.

Sinclair, T.R., and K.G. Cassman. 2004. "Agronomic UFOs?" Field Crops Research 88:9-10.

de Soysa, I., and N. P. Gleditsch, 1999. "To Cultivate Peace: Agriculture in a World of Conflict. PRIO Report 1/99." Oslo: International Peace Research Insitute.

Splechtna, B.E. (ed.) 2009. Proceedings of the International Symposium: Preservation of Biocultural Diversity—a Global Issue, BOKU University, Vienna, May 6—8, 2008, University of Natural Resource Management and Applied Life Sciences, Vienna, Austria. 169p.

Stevens, S., "Implementing the UN Declaration on the Rights of Indigenous Peoples and International Human Rights Law Through Recognition of ICCAs", *Policy Matters* 17, 2010 (in press).

Stolton, S. and N. Dudley, 2010. Vital Sites—The contribution of protected areas to human health, research report by WWF and Equilibrium Research.

Svarstad, H., Dhillion, S., Bugge, H., 2000. 'From Norway to Novartis: Bioprospecting within an open access regime', Biodiversity and Conservation 9 (11).

Sylla, S. and J. Larivière, Les Aires du Patrimoine Communautaire, undated, accessed 2010.

Traditional Knowledge Digital Library. http://www.tkdl.res.in/tkdl/langdefault/common/

Verschuuren, B; Wild, R.G.; McNeely, J.A; Oviedo G; (Eds) Sacred natural sites: Conserving nature and culture, Earthscan, London, 2010 (in press).

Warren, D. M., J. Slikkerveer and S. Titilola (eds) 1989. Indigenous Knowledge Systems: Implications for Agriculture and International Development. Studies in Technology and Social Change, No. 11. Ames, Iowa: Technology and Social Change Program, Iowa State University.

Warren, D. M., J. Slikkerveer and D. Brokensha, 1991. Indigenous knowledge systems: the cultural dimensions of development. London: Kegan Paul International.

Weaver, L.C. and T. Petersen, 2008: "Namibia communal area conservancies", pp. 48–52 in Baldus et al. (eds.) Best Practices in Sustainable Hunting.

WIPO, 2009. World Intellectual Property Indicators. Citation at 8.

World Bank, 2001. Global Economic Prospects and the Developing Countries 2002. Washington: The International Bank for Reconstruction and Development/The World Bank.

Wild, R. and C. McLeod (eds.), Sacred Natural Sites—Guidelines for Protected Area Managers, Best Practice Protected Area Guidelines no. 16, IUCN/WCPA, Gland (Switzerland), 2008.

Witcombe, J. R., S. Gyawali, S. Sunwar, B. R. Sthapit, and K. D. Joshi. 2006. Participatory Plant Breeding is Better Described as Highly Client-oriented Plant Breeding. II. Optional Farmer Collaboration in the Segregating Generations. Experimental Agriculture **42**:79-90.

Zambrana Avila, G. and C. Sylva Maturana, 2008. Áreas de Conservación Comunitarias en el Marco de las Políticas Públicas en Bolivia, Report for CENESTA/ IUCN/CEESP and GTZ.

Zuluaga, G., J.I. Giraldo and M. Gimenez Larrarte, 2003. Un ejemplo de conservación bio-cultural—el Parque Nacional Natural Alto Fragua Indiwasi en Colombia, Policy Matters, special issue on Community Empowerment for Conservation **12**:171-180.

B.2 THEORETICAL BACKGROUND PAPERS

B.2.1 AN ALTERNATIVE CONCEPTUAL FRAMEWORK FOR SUSTAINABILITY: SYSTEMICS AND THERMODYNAMICS

Peter Hobson & Pierre L. Ibisch

ABSTRACT

The conventional view held by many scientists was that a thorough understanding of nature in all its diversity and complexity could best be achieved by an ever increasing detailed analysis of its single pieces, in other words, adopting an atomistic approach to the study of the individual components within a system, and by observing cause-effect behaviour between them. However, such technomorphic reductionism does not factor in emergent properties of systems, variability and non-linear processes across scales, which leads to problematic misunderstandings. In this paper, a systemic approach to sustainability is developed setting out some of the philosophy and science underpinning current understanding of complex systems and thermodynamics. Ecosystem theory, based on systems theory and ecosystem thermodynamics, facilitates a better understanding of the relationship between natural and anthropogenic systems. It also sets out clear parameters and measurable boundaries to systems in terms of productivity, carrying capacity, limits of change, resilience, as well as factors in the unpredictable nature and uncertainty of system behaviour. Systems, to a certain extent, are open to both energy and material flow but continue to maintain definition and integrity in rather the same way as does a cell with a permeable membrane. A central feature to systems ecology is the transformation of energy through and across system-scale boundaries of ecosystems, encompassing thermodynamics, chemistry, and both biological and ecological energetics.

Structure and function of complex systems are defined by an 'uneasy' relationship between apparent chaotic events and self-ordering constructs. The resulting uncertain and unpredictable performance of natural systems requires a post-normal approach to analysis and management. However, in a global society increasingly governed by (cost-)efficiency, predictability, measurable targets and informed practice there is very limited scope for building 'post-normal' science into mainstream policy and practice. Sustainability defines the single or multiple states of dynamic equilibrium—the ultimate 'gravitation' of systems towards attractor basins. Any external gradient that causes fundamental shifts in a system, enough to create a hysterisis effect, will inevitably bring about destabilization and loss of sustainability. Functional and evolving systems that are able to return or shift to operating points without losing fundamental and typical emergent properties develop sustainably. However, sustainability does not imply a maintaining of the status quo, but may describe a system undergoing a building phase towards complexity through the increasing evolution of sub-systems (attractor basins) or indeed shifts in meta-state of existing attractor basins. A complex system is organised hierarchically with nested adaptive cycles working to feedback mechanisms.

Thermodynamic efficiency seems to be the major driver of system organization and evolution. Evolution could be defined as a process that, under the physical laws of nature, produces systems, which are able to self-organize, multiply, reproduce themselves and diversify at the cost of increasing entropy in other systems. This leads to increasing opportunities of interactions between systems and corresponding complexification of systems of ever higher order. In the global ecosystem, the role of biodiversity in maintaining dynamic equilibrium in complex ecosystems is fundamental and cannot be undervalued. A system is likely to shift towards improvements in matter recycling and increases in information. This process of internalising and re-cycling energy and matter transference (self-ordering) reduces the exchange of materials across borders between systems and this has advantages of retarding the lowering of energy

flux and increasing energy-efficiency. Thermodynamic efficiency can be taken as a measure of system sustainability in terms of auto-regulating the system and maintaining it at in a certain operating point. As a consequence of the dramatic transformation of natural ecosystems to cultural landscapes, the Earth system is losing its resilience and capabilities to dissipate energy, there is less biomass storage in the system, and dissipative structures are undergoing simplification. During the very brief period of civilization the advances of technology have created a false sense of limitless resources and opportunities.

Society has been tricked into thinking that both science and technology are able to skip round problems of energy and material shortages, and that there is ultimately an answer to the dilemma of energy-exergy-entropy. For too long civilization has been living through the myth that laws can be broken and re-written, and under this false sense of security society continues to be driven ever forwards beyond the limits of nature's boundaries.

"*Previously the discourse was about a single machine, or reaction, or discrete phases; now it concerns structures, cycles, systems, and feedbacks (positive as well as negative): complex wholes with their own histories and even explicit anthropocentric evaluations. The term 'system' has become indispensable, as it conveys something about the sort of complexity that is not mere complication or confusion*" (Funtowicz & Ravetz 1997).

If we look for a general blueprint that explains the composition and relationships between all living and non-living components that make up the world, a common theme is apparent, across all scales, namely, the phenomenon of interaction between different elements. These relationships that are governed by boundary-maintaining entities or processes result in the emergence of increasingly complex constructs that can be defined as *systems* (Laszlo & Krippner 1998). The interaction of system components can be of different nature, but always involves the exchange of energy, material and/or information. This apparent 'open' exchange of material and energy suggests that there exist in a system multiple pathways of influence between the diversity of components that ultimately leads to a certain level of self-organization. For instance, in a solar system the various sized bodies that include planets, moons, asteroids, and dust and gas particles influence each other by gravitational energy causing regular rotations and movements around a central star. In a biological population the individuals exchange information and matter, e.g. in the form of gametes and DNA that influences the pattern, structure, behaviour and ultimate survival of the larger construct—the population. Similarly, in social systems such as a political party, a non-government organization, or a community-based action group the members often operate to principles of informed complex networks—so-called "shadow systems" (Stacey 1996), exchanging information in the form of ideas and arguments. In all kinds of systems the interaction does not only lead to a more or less temporary boundary-maintaining process, but also implies that this complex entity is characterized by *emergent properties* that cannot be explained by the collective description of the character and behaviour of each individual component.

Concepts of systems have been around for centuries, but the emergence of a coherent theory that unites several ideas into a single thesis was developed during the 1940s and 50s as a result of the works of several key researchers, von Bertalanffy, Rapoport, Boulding, Ashby, Mead, Bateson and Churchman, among others. Around this time the *Society for General Systems Research* was established, and by 1950 Bertalanffy had his paper on "*An Outline for General Systems Theory*" published in the *British Journal for the Philosophy of Science*, Vol 1, No. 2. Later, in 1968, von Bertalanffy produced a detailed thesis of his work in a book, titled "*General system theory: foundations, development, applications*" in which he defined the term systems theory. His intention was to widen the concept of biological and mathematical systems to apply to all systems in general. By the 1940s and 1950s the combined works of Wiener, Ashby, von Neumann and von Foerster had provided a theoretical and mathematical framework for concepts of complexity, self-organisation and adaptive systems. The collective efforts of these various scientists working on the same theme but in different disciplines contributed towards the development of a 'supertheory' (Luhmann 1987), initiating new scientific approaches and influencing historical-political decisions (Becker 2004). According to a *systemistic* worldview, everything, whether concrete or abstract, is a system or part of a system, and systems have emergent properties that are not observed in the separate components. Thus, any problem that is manifest in the emergent properties of a system should be approached in a systemic way rather than in isolation (Bunge 2000).

In this paper, a systemic treatment of the concept of sustainability is developed. The thesis also builds on the understanding and findings of other authors who have already claimed that a systemic perspective on the nature-society continuum provides a clearer frame of reference for effective analysis, and a more appropriate basis for understanding the urgent problems we face on Earth (e.g., Kay 2008, Kay & Boyle 2008). Accepting the premise that all environmental and social constructs are systems or part of a system, then where components are observed to interact and form systems, a logical question would enquire about the nature of the force that drives systems towards assembling and self-organizing. This question has, in part, been answered through on-going research into thermodynamics. However, rather less is understood about the relationships between the environment, rapidly evolving social systems, and the concept of sustainability in the context of both thermodynamic and non-equilibrium thermodynamic sciences. This paper explores the application of principles and concepts of non-equilibrium thermodynamics to problems of environment—culture relationships and sustainability.

While the post-normal and transdisciplinary concepts related to systemics and thermodynamics have stimulated and enriched general sustainability science, we feel that they have not sufficiently been introduced into biodiversity conservation and the discourses related to the implementation of the Convention on Biological Diversity. Just as systemics provides general explanations for the function and dysfunction of both biological-ecological and cultural entities, it is also the necessary means of carrying out the analysis of interlinkages between biodiversity and development.

B.2.1.a SCIENCE, THE ORIGINS OF SYSTEMS ECOLOGY, AND "THE ORDER OF THINGS"

Life on planet Earth is made up of an extremely complex combination of elements that coalesce and bond to form compounds at the molecular scale which in turn, organise themselves into recognizable shapes and forms at incremental scales of higher magnitude. The final result is the formation of seemingly stable complex constructs that make up the diversity of life forms, from the simplest of organisms to the emergence of immense biomes that cover the surface of the planet. This perception of a hierarchical "nature" has been the subject of intensive and increasingly more sophisticated scientific study through the centuries, and has included the works of Plato, Aristotle, Copernicus, Galileo, Ficino, Odum, and Patten, amongst others. The early conceptual frameworks that included the works of Ficino and Descartes, and more specifically the mechanistic clock analogy of Leibniz-Clarke, adopted an intuitively mechanistic understanding of nature as a construct of mechanical components and their manifold 'gears' working together in a predictable way. The dramatic advancement made in science and technology in the late 19th and especially 20th century gave rise to the development of a constructivist-technomorphic base paradigm that worked towards an improved understanding of both nature and social complex systems such as organizations (Malik 2008). Even (conservation) biologists were using technomorphic metaphors, such as the famous rivet-popper hypothesis (Ehrlich & Ehrlich 1981), comparing the species of an ecosystem with constructive parts of an airplane. Similarly, in a more recent publication in Science (Baliga 2008), the processes and functions of a cell were explained using a gear metaphor. The underlying principle to the constructivist-technomorphic paradigm is that the design and construction of nature is based on the assemblage of all its parts that collectively contribute to the purposeful function and adaptation of the whole system.

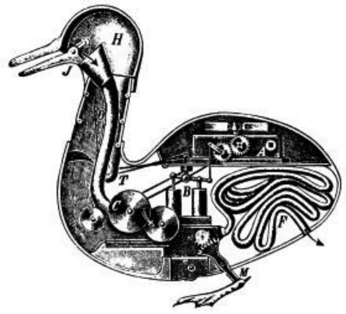
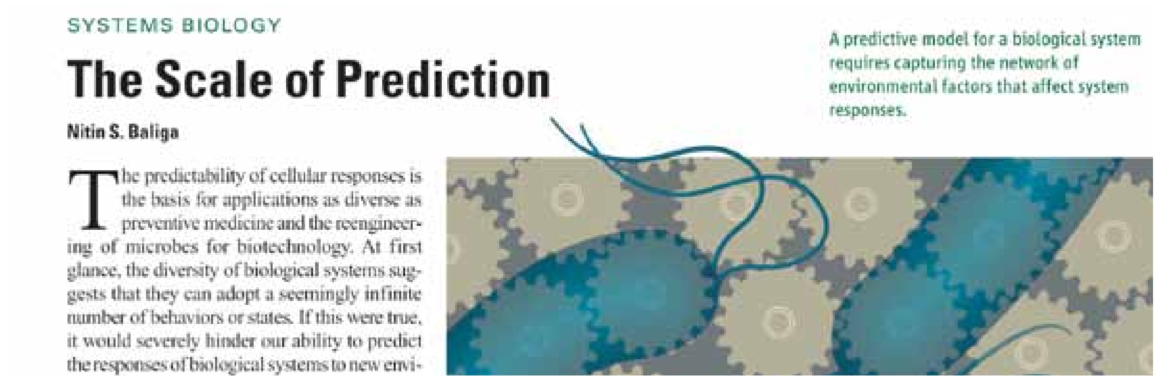


FIGURE 1: Technomorphic view of nature in the 17th and 18th century: Illustration of the automatic duck by Jacques de Vaucanson (1783). The efforts to build functioning mechanic animals is in line with Descartes' view on nature who argued that the physical structure and function of all none-human animals could be explained through reductionist principles and described as "automata".



SYSTEMS BIOLOGY

The Scale of Prediction

Nitin S. Baliga

A predictive model for a biological system requires capturing the network of environmental factors that affect system responses.

The predictability of cellular responses is the basis for applications as diverse as preventive medicine and the reengineering of microbes for biotechnology. At first glance, the diversity of biological systems suggests that they can adopt a seemingly infinite number of behaviors or states. If this were true, it would severely hinder our ability to predict the responses of biological systems to new envi-

FIGURE 2: Example of technomorphic illustration and explanation of systemic processes in living organisms (extract from Baliga 2008).

The conventional view held by many scientists was that a thorough understanding of nature in all its diversity and complexity could best be achieved by an ever increasing detailed analysis of its 'components and gears'. This philosophy also proposed that nature existed in balance and order, working to predictable patterns of behaviour (Wu & Loucks 1995). A logical extension to this idea was that constructs of nature evolved along predictable linear pathways towards higher levels of order and complexity that finally gave rise to a phase of stability—a mature kinetic state. In the first half of the 20^{th} century, Clement's model for vegetation succession from bare earth to climax community, was held up by many ecologists as a fine example of this phenomenon. These predictable models also provided convenient metaphors and much needed evidence to justify practices in environmental management and rural land use practice including agriculture, forestry and landscape design. In all cases it offered the necessary verification for maintaining the status quo or 'fast-tracking' nature to create an instant desired state. This school of science was institutionalised across the western world and provided the underpinning theory to much of human activity and development including mechanistic environmental and conservation practices. Many of the principles and processes recognised in this strand of science continue to be practiced today despite fundamental shifts in scientific understanding of the unpredictability and indeterministic tendencies of nature. Modern cultural landscapes represent spatial analogies of the equilibrium-based scientific philosophy. For instance, agriculture operates to 'grid lines' of utilizable cropping land that is fixed in space and managed on tight, predictable cycles or rotations. Similarly, urban design and planning relies on permanency in order to function within and across space. Often, the same approach is adopted by biodiversity conservation for more natural landscapes despite the unpredictable patterns and behaviour of nature. A common strategy is to first organise biodiversity features according to predetermined categories and then prioritise them using measures of importance and value. Once notified they become fixtures in space and time—targets for clear and unambiguous management objectives that promote the status quo (Hobson 2004). Any shift in the status of these targets away from expectations of conservation value or quality triggers a management response to restore the feature back to favourable status. The myths and assumptions that prevail in the corresponding ***equilibrium paradigm*** are that nature can be corrected, 'fixed', restored, steered, constructed and maintained indefinitely using prescriptive management based on scientific evidence. These principles resonate with Clementsian ideas of sere stage development and final static states of equilibrium. There is little consideration of scale-dependent dynamics, emergent properties and indeterministic tendencies of nature.

THE EMERGENCE OF 'NEW' THINKING ABOUT SYSTEMS

By the beginning of the twentieth century Clementsian ideas of nature as a superorganism, and more specifically, vegetation dynamics operating to linear patterns towards a steady state climax community occupied many themes in ecology. Despite criticisms of his theory by eminent ecologists, such as Henry Gleason and Arthur Tansley and later Robert Whittaker, significant Clementsian views persisted up to the end of the twentieth century. By the 1960s this view was more comprehensively challenged by the emergence of "*systems ecology*" which revolutionised the way scientists thought about the natural world. Leading ecologists including Odum (1983, 1994a), van Dyne (1966), or Patten (e.g., 1978) believed that physical and biological elements in ecosystems could be modelled using principles of cybernetics and computer simulation. A central feature to systems ecology is the transformation of energy through and across system-scale boundaries of ecosystems, encompassing thermodynamics, chemistry, and both biological and ecological energetics. This perception of the natural world was developed further by Odum who introduced the concept of holism and the "macroscope" of ecosystems science. The theme of "macroscope" and holism was encapsulated in the work carried out by scientists in the late 1960s and early 1970s as part of the International Biological Programme (IBP). The objective of this ambitious programme was to amass data on species, energy and material flows, food chains and trophic structures for deciduous and coniferous forests, grasslands, and tundra biomes. Ultimately, complex systems models were generated to study the effects of disturbances and human impacts. However, this particular aspect of the programme failed due to the unforeseen complexities and relationships encountered in ecosystem dynamics and function.

Despite this set-back scientists had started a new generation of complex systems thinking that made significant headway in the use of modelling in ecology, and also in the way that ecosystems were studied. The first attempt made to apply systems ecology in such a way that described planet earth as a single self-regulating complex system was in the highly popularised but controversial Gaia Hypothesis proposed by James Lovelock (1987; compare Lenton 1998, Godderis & Donnadieu 2009). The regulation of the biosphere by living organisms was likened to homeostatic mechanisms in organisms and cybernetic controls in automated machines—a "*cybernetic system with homeostatic tendencies*". Although this idea drew on elements of mechanistic thinking, it presented a fundamental shift away from the perception of perfect balance in nature, as the principle of homeostasis or negative feedback dynamics implied constant change. In fact, ecosystems were believed to be perpetually out of balance and under the influence of indeterministic disturbances. The Gaia hypothesis has contributed towards a better understanding of the relationship between complex systems theory and global ecology and this in turn has provided society with a more sophisticated description of an Earth as a complex system subjected to periods of uncertainty and indeterministic tendencies.

Recognisable landscapes and systems in nature and society, such as mires, forests, savannahs and traditional pastoral cultures appear to be stable but can suddenly shift and establish themselves as something new. This 'regime-changing' phenomenon can occur because of complex interactions within a system that have influence across scales. Small, localized interactions serve as sources of adaptation and events that feed up to higher levels of organisation, and conversely, large-scale emergent constructs exert constraint on the behaviour and states at smaller scales (Kinzig *et al.* 2006). This 'uneasy' relationship between apparent chaotic events and self-ordering constructs defines the structure and function of complex systems, and in nature, is the source of diversity. However, there is a real dilemma with this strand of science that makes for uncomfortable relationships with both policy makers and managers. The irreducible uncertainty of complex systems complicates efforts to design either experiments or models that provide unequivocal or predictable evidence in the way that traditional 'normal' science based on more Newtonian principles is able to do. Consequently, in a global society increasingly governed by (cost-)efficiency, predictability, measurable targets and informed practice there is very limited scope for building 'post-normal' science into mainstream policy and practice. The more 'reliable' and predictable problem-solving methods and outcomes of reduction science prevail in policy and the wider social environment. This is despite growing support for non-equilibrium ecology and complex systems theories helped by recent research into problems of climate change. This situation has rather less to do with differences in schools of thought in the science world and is more about the relationship between science and policy. Modern constructs of society and economics rely on predictions, certain 'guarantees' of stability in socio-economic and environmental systems to the extent that it promotes self-fulfilling experimentation and modelling. In other words, you validate your actions rather than generate probabilistic scenarios that force you to take decisions based on 'best case scenario' and risk aversion.

COMPLEX SYSTEMS AND POST-NORMAL SCIENCE

Characteristically, reductionism decomposes a system into pieces and then attempts to understand how the system works by adding them together and observing cause-effect behaviour between them. It does not factor in emergent properties of systems, variability and non-linear processes across scales. In this example a predictable, mechanical operation would only occur if the different components within a system were not allowed any freedom at all (Allen 1990). Alternatively, a *post-normal* science (Ravetz 1986, Funtowicz & Ravetz 2008) such as complexity science, has widened the vocabulary used in science by offering more appropriate narratives and metaphors to explain the patterns and functions of systems. The intelligence and learning in complex systems come from within—intercausative, rather than from outside and looking in (Allen 1990). Through this more enlightened approach scientists have begun the process of describing in detail the character and behaviour of ecosystems in terms of complex systems.

Complex systems are hierarchical constructs made up of systems nested one inside another at different levels, the ***holons***[42]. Energy and material flow not only occurs across scales between these different levels but also from outside the system (Kay 2008). This idea proposes that systems, to a certain extent, are open to both energy and material flow but continue to maintain definition and integrity in rather the same way as does a cell with a permeable membrane. The cell model might help explain how systems are able to operate to negative feedback processes as well as self-regulate and order themselves. A system without definition or structure would collapse into a state of chaos under the influences of stressors. The processes and dynamics operating in a system are typically non-linear and are self-reinforcing, creating emergent properties and leading to self-organisation. Catastrophic behaviour, moments of unpredictable change, are the norm, leading to irreducible uncertainty. Despite the unpredictable nature of systems, self-ordering is possible through feedback loops that are responsible for autocatalytic cycling of materials and energy rather than as a result of linear causal mechanical factors. A consequence of this phenomenon is that complex systems strive for optimum status rather than minimum or maximum, and that there may not necessarily be an equilibrium point or a preferred state for the ecosystem. Rather there may be multiple steady states, none of which is the 'right' one (Kay 2009). The actual state an ecosystem occupies is a function of its history (Kay 2000). The principle of 'meta-states within states', a heterogeneous system, is the possible source of resilience and equilibrium that contributes to the systems' sustainability.

As well as being holarchic, systems also organise and maintain themselves at **'attractors'** by feedback loops (Schneider & Kay 1994). Within a defined '**attractor basin'** a system will appear to be in an equilibrium state. However, there can be more than one attractor in a system as there may not be an

42 The concept of holonics was suggested by Arthur Koestler (1967; compare Koestler and Smythies 1969); the term holon implies that the world consists of parts which are a relatively autonomous whole (= hol-) while, at the same time, being a part (= -on) of something larger. "Parts and wholes in an absolute sense do not exist in the domains of life. The concept of the holon is intended to reconcile the atomistic and holistic approaches. (…) More generally, the term "holon" may be applied to any stable biological or social sub-whole which displays rule-governed behaviour and/or structural Gestalt-constancy. Thus organelles and homologous organs are evolutionary holons; morphogenetic fields are ontogenetic holons; the ethologist's "fixed action-patterns" and the sub-routines of acquired skills are behavioural holons; phonemes, morphemes, words, phrases are linguistic holons; individuals, families, tribes, nations are social holons" (Koestler 1969).

ecologically preferred state. When gradients are applied (these define a 'force of environmental change' such as pollution), to a system and move it from its equilibrium position, it will respond by attempting to dissipate or degrade the effects of the disturbance in order to maintain its state within the attractor basin (Baldwin *et al*. 2004a). Furthermore, other attractors may also emerge in the system that contribute to the degradation and dissipation of the effects of the gradient (Baldwin *et al.* 2004a). As more of these sub-systems, each within their own attractor basins, emerge the 'super-system' develops complexity and self-organising tendencies. This phenomenon again, describes the spatio-temporal heterogeneity of a system and depicts the emergence of dissipating structures at different scales in response to a stressor. The growth in sub-systems leads to increasingly more complex landscapes with multiple systems of similar ecological states at any one time. Incremental change in the gradient or 'stressors' does not necessarily elicit incremental change in an ecosystem. More typically, the ecosystem may appear unaffected and continue to function as before. A system is able to maintain stability by self-organising and developing internal structures—diversity of form and function, the very stuff of biodiversity. Over time self-organising processes result in the emergence of certain key characteristics including stable dissipative structures (complex cycles and diverse, representative species); the growth of the physical-biological structure (biomass); growth in complexity of the network between the components; and growth of 'information' (increase in the proportion of more complex organisms with K-strategy to those with r-strategy) (Jørgensen 2006).

The position of a system within its attractor basin is defined by a threshold (May 1977). Systems that flip over this threshold—the '***tipping point'***, can shift between attractors and can thus re-organise themselves around new attractors (states). However, once the threshold is reached then a small external 'force' can cause dramatic, irreversible change to the ecosystem (Kay 2009). The threshold of a system represents a boundary of 'tolerance'; it helps to define the functional integrity of the system. Thresholds also create distinction between the dynamics operating from within a system and external forces or gradients that may operate at different levels of magnitude and frequency. There are boundaries either side of threshold points that signify levels of unstable equilibrium between regimes. These 'precarious' zones represent the capacity for resilience in a system, that is, the ability of a system to absorb disturbance and still retain essentially the same function, structure, identity and feedbacks (Walker *et al.* 2006). Both changes in ecological conditions and management practice can determine whether a system crosses thresholds, and a regime shift represents a loss of resilience, in which existing structures, functions and feedbacks give way to new ones. During such an event, the hierarchical structure of systems suggests that multiple thresholds across scales of space and time are crossed, essentially, a cascade effect, that can create change in ecological, social and economic domains. The new emergent regime has the characteristic of being highly resilient and resistant to natural recovery or to attempts through management to restore the original system. Regime shifts are not just the result of interactions occurring within a particular domain but can happen because of interactions across ecological, economic and social domains (Carpenter & Brock 2004).

The findings of the Millennium Ecosystem Assessment presented a stark picture of declining ecosystem functionality across almost the entire planet. What is meant by loss of functionality? It refers to the functioning that enhances the ecosystem's adaptive capacity and reduces the risk of abrupt and dramatic change. If the explanation for ecological thresholds is used to describe this loss, then we can expect to approach a tipping point at which the Earth's systems undergo a dramatic and irreversible change (Lyytimäki & Hildén 2007, Rockström *et al*. 2009a, b). The cause for much of this decline of functionality, and the ultimate switch of ecosystems to new states is due to various anthropogenic pressures (Walker & Meyers 2004). Human-generated systems and disturbance regimes have introduced novel structures and feedback loops within and between ecosystems, often through management practices that operate to objectives of maintaining the status quo or facilitating smooth change (Lyytimäki & Hildén 2007). The consequences of a regime shift are difficult to predict as they rarely if ever result in a linear shift from one state to another; rather, they often generate possibilities of several alternative states and points of no return.

The complex nature of system structure and dynamics complicates attempts to distinguish between non-linear processes or stochastical events (Matius *et al.* 2006). It is difficult to establish the degree of force or strength of gradient that results in regime shift in systems. In fact, there are problems with singling out any one stressor from the number of likely interacting factors that triggers an abrupt change in ecosystem quality. Attempts to understand human-induced regime change is further confounded by poor definitions of system thresholds (Groffman *et al.* 2006). In the examples of badlands all over the world with degradation of land and soils, it is possible to present a scenario based on the principles of complex systems theory. Certainly, we can demonstrate the application of system hierarchy and cascade effects and feedback loops between meta-systems. For instance, the loss of biodiversity over time can also represent a loss of photosynthesis and subsequent loss of biomass. This in turn, affects carbon sequestration, soil organic matter and ultimately, soil structure and composition. Resulting changes in soil conditions will affect water and nutrient retention and capacity. Inevitably, both the nutrient cycling and hydrological regime will suffer as a result, finally, leading to ecosystem dysfunctionality or even collapse.

Theoretical problems of the kind just described can lead to ambiguity and confusion amongst managers and policy makers. Understandably, practitioners would prefer to work with prescriptive models that demonstrate tangible outcomes. What has emerged in the last two decades is a divergence between a body of science and practice that holds to principles of reductionism and prescriptive management, and a growing school of thought that embraces a post-normal approach that is more familiar with fuzzy logic and adaptive management of uncertain and unpredictable complex systems. In ecological science and its application we find even a 'hybrid approach': on the one hand, complex systems are carefully modelled, amongst others taking into account non-evidence-based scenarios. On the other hand even some system scientists believe that they just need to produce models that are sufficiently complete and sophisticated in order to predict future systems' performance. Actually, to some extent both philosophies, normal and post-normal, are applied in global policy and practice. However, this in turn can also create incompatibilities and confounding problems that contribute to the ongoing decline of ecosystem functionality and diversity. For instance, in working models for sustainable development, outcomes are based on agreed compromises between social, economic and environmental interests rather than on a unifying principle of a fully integral complex system. This partisan approach perpetuates competition for resources between the three domains, all the while claiming the moral high ground through demonstrable efforts towards conflict resolution. More effective models for sustainable development are needed that attempt to build a practical framework around theoretical concepts (see below).

THE ADAPTIVE CYCLE AND PANARCHY: AN APPROPRIATE MODEL DEPICTING COMPLEX SYSTEMS

The adaptive cycle first proposed by Holling (1986) and later refined by both Holling and Gunderson (Gunderson *et al.* 1995, Gunderson & Holling 2002) provided an elegant conceptual model for a complex system that is operating to both indeterministic and self-organising behaviour. This metaphor provides a convenient framework for our understanding of the state, dynamics and functionality of a system. Furthermore, it complements the previous model, attractor basins, by completing the basic description of a complex system. The attractor basin provides us with a spatial model—the ecosystem landscape or horizontal plane, whilst the adaptive cycle offers the scale-dependent functional character of a system—the vertical plane. Biological and socio-economic systems, appear stable at certain periods of their lifecycle until an event shifts them into a brief period of chaos. What then follows is a more protracted period of recovery through a process of self-organising that can either lead to some measure of re-semblance towards the original state or to the emergence of a new system. The complex nature of a system is manifest not just in the connections within but also the linkages and relationships that occur across scales. A complex system is organised hierarchically with nested adaptive cycles working to feedback mechanisms. Together they form a ***panarchy***[43]. The panarchy describes how a healthy system can evolve and adapt, thus creating opportunity while being kept safe from other systems that otherwise might destabilize it because of their nature and higher energised state. Each level is allowed to operate at its own pace, protected from above by slower, larger levels but invigorated from below by faster, smaller cycles of innovation. The adaptive cycle model identifies four distinctive phases in a system, which are destruction, reorganization, growth and conservation (Gunderson & Holling 2002). Together these phases unite system organization, resilience, and dynamics. An adaptive cycle that alternates between long periods of aggregation and transformation of resources and shorter periods that create opportunities for innovation is proposed as a fundamental conceptual model for understanding complex systems from cells to ecosystems, and more recent interpretations of the structure and function of human societies. The four phases of the adaptive cycle are:

- growth or exploitation (r)
- conservation (K)
- collapse or release (omega, 'Ω)
- reorganization (alpha, a).

Of the two major phases (or transitions), the first, often referred to as the 'foreloop', from r to K, is the slow, incremental phase of growth and accumulation. The second, referred to as the 'backloop', from Omega to Alpha, is the rapid phase of reorganization leading to renewal. During the slow transition from exploitation to conservation, stability and connectedness in an ecosystem increases, contributing to an accumulation and storage of nutrients and biomass. Competition between species leads to a relatively small number of them becoming dominant whilst the remaining majority are much reduced but retained in scattered clusters across the patchy landscape. Long periods of 'maturity' can lead to systems becoming over-connected and brittle, a state in which collapse or revolt ('Ω phase) can occur. This is typically a short transitional period that rapidly moves into the next phase of reorganisation (a) in which the system slowly regains organisation that was lost in the revolution.

The hierarchical organisation of adaptive cycles across space and time helps scientists to understand and explain how systems can briefly generate novel recombinations. These narrow windows of events open briefly, but the outcomes of these disturbances do not normally trigger cascading instabilities of the whole 'panarchic complex' because of the stabilizing nature of nested holarchies. In essence, larger and slower components of the holarchy provide the 'memory' and legacies of the past to allow recovery of smaller and faster adaptive cycles.

HOW DO WE NOW APPLY THE MODEL OF PANARCHY TO THE CONCEPT OF SUSTAINABLE DEVELOPMENT?

Failed attempts, so far, to construct a working anthropocentric model for sustainable development point to tensions between nature and culture, and are manifest in the conflicting interests emerging from a growing and developing global society. It is less likely to be a result of deficiencies in science and technology. Furthermore, attempted resolutions to this dichotomy often represent flawed strategies of avoiding contradictions (Proctor 1998). The nature-culture antagonism that expresses modern man's approach to his natural environment is a complex manifestation of an essentially simple principle centred on the exploitation of natural capital to service socio-economic advancement. Unlike early hunter-gatherer communities, modern-day society has de-coupled itself from nature, a transition that has largely come about through advances in technology (see Ibisch & Hobson, B.2.2., in this document). Technocentrism is now the norm that defines and drives culture, thus re-enforcing perceptions of the externalization of nature in concept and practice (Haila 2004). Prolonged human impact that prevents an ecosystem from

43 Panarchy: a form of governance (-archy; suffix meaning "rule," from Latin -archia, from Greek -arkhia, from arkhos "leader, chief, ruler," from arkhe "beginning, origin, first place") that would encompass (pan-; prefix meaning "all, whole, all-inclusive," from Greek, combining form of pas [neut. pan, masc. and neut. gen. pantos] "all", all others). It was first used in a socio-economic context by de Puydt (1860).

returning to equilibrium will result in a break-down in energy-dissipative properties, and a shift from complex self-organising structures to more simple and inefficient systems. In this scenario an increase in positive feedback mechanisms and inefficient energy loss (leaky systems) will hasten an ecosystem towards comprehensive collapse. The scale of human impact on the natural world forces a reappraisal of post humanist perspectives, which reject the ontological separations of nature and culture (Braun 2004, Franklin 2006, Haila 2000).

To develop a better understanding of sustainability and to build frameworks for good practice, both policy and management need an appropriate template and reference point. The use of reference sites is a widely accepted practice in ecological studies and in environmental restoration programmes. The term defines an ecosystem or landscape that is either "free-willed" or unaffected by human disturbance. In reality there are very few examples of untrammelled ecosystems remaining across the globe. Furthermore, it is philosophically debatable whether human-free landscapes provide a realistic representation of the natural world of today. However, it is possible to agree on a definition that recognises an ecosystem that is functioning according to the internal forces of the system and is not in any way modified or engineered by human design or activities. Examples of unmodified ecosystems can still be found in the more remote parts of the World. Some of these have provided appropriate sites for the study of ecosystem function and dynamics.

COMPLEX SYSTEMS THEORY, BIODIVERSITY AND SUSTAINABILITY

Evolution—the starting point: More recently, theories about systems complexity and hierarchical levels of organisation ranging from genomic systems to macro-scale ecosystems have been used in attempts to explain Darwinian evolution (Winther 2008). The central tenant to ***'systemic Darwinism'*** is that in order to explain the origins of biological complexity over such large time scales it is necessary to integrate and embed systems theory. Systemic Darwinism explores the extent to which three intertheoretical relations, namely, self-organising dynamics, cladistics, and function (evolutionary genetics) can be used to describe evolution. Laszlo (2009) puts it this way: "*Evolution: A cosmic process specified by a fundamental universal flow toward ever increasing complexity that manifests itself through particular events and sequences of events that are not limited to the domain of biological phenomenon but extend to include all aspects of change in open dynamic systems with a throughput of information and energy. In other words, evolution relates to the formation of stars from atoms, of Homo sapiens from the anthropoid apes, as much as to the formation of complex societies from rudimentary social systems*". A novel characteristic of living systems or systems established and organized by organisms (including human individuals and all social systems) is the capability of self-referential reproduction and multiplication, the autopoiesis (Varela *et al.* 1974).

The autopoietic nature of evolution suggests that the driving processes such as selection can be more complex than often understood and described. For instance, there is a debate on natural selection between two broad camps, those that argue the case for genic selection as championed by Dawkins (2006), and other biologists advocating hierarchical selection (Wade & Goodright 1998). Whilst the evidence for genic selection is convincing, it does not offer a satisfactory explanation for altruistic behaviour observed in certain social species. For instance, in certain primate societies, just as in human culture, traits that include fidelity, obedience and sharing are apparent but cannot be directly explained by "selfish gene" principles. Behaviour that would work against individual survivorship benefits higher levels of organisation—groups, families, societies. Consequently, clans, groups or tribes with a higher frequency of altruists are likely to survive, grow and develop further, as well cope more effectively with changing environmental conditions. Examples in nature where it could be argued that complex social behaviour has evolved in certain 'higher' taxa in response to living in unpredictable environments include Suricate meerkat, African lion, Hyena, African wild dog, Dog-faced baboon, and Gelada baboons, African elephant, and many Cetacean species. In each case the immediate concerns and needs of the individual are seemingly sacrificed for the 'greater whole' of the family/clan/community. However, especially in human social systems it has been seen that 'altruistic' behaviour can indeed be more or less directly rewarding and this is based on concepts of reciprocity (see below). Species that survive by social systems have evolved more complex behavioural patterns and mechanisms of communication, in some cases, rudimentary forms of language. In all cases these species have been highly successful in surviving extreme/high-stress environments, and utilising limited resources.

Another example of ecosystem complexity emerging through evolutionary pathways includes co-evolution. This phenomenon describes the tendency of different parts of a whole system to develop in a complementary way that makes them compatible. Nature reveals many forms of this relationship including commensal and symbiotic species. Also learning and absorptive capacity co-evolve with each other influencing the other (Lane *et al.* 2002). Increasing complexity and diversity in both symmetric and asymmetric interactions between organisms can contribute to the driving forces of evolution (Mitchell & Newman 2002). The evolutionary pathway of all of the diverse life forms follows a course set out by a 'blueprint'. This blueprint or template ensures the construction of structural and compositional diversity in nature—that in turn provides the means of overcoming chaos by acting to maintain continuity during change and transitions. However, it is a mistake to assume that evolution drives all life forms towards increasing complexity. This popular misconception is based on the preoccupation by science with the relatively small number of complex organisms that inhabit the "right-hand-tail" of the complexity distribution. The far greater mass of simpler organisms including the Prokaryotes and Protoctista that make up over 50% of the Earth's biomass are generally overlooked. More realistically, evolutionary forces drive systems towards increasing complexity only in a reduced number of subsets of nature.

ECOSYSTEM FUNCTION AND STABILITY

Historical perspectives of the diversity- stability hypothesis urge caution when searching for evidence of ecosystem stability and relationships between this and biodiversity (McCann 2000). Whilst several recent studies in this field have suggested that diversity can be expected to promote ecosystem stability it is unclear just what the driving forces are to this phenomenon. For instance, are there elements of more subtle trophic interactions between weakly interacting species in a system that are fundamental in regulating the more destabilizing consumer-resource interactions of dominant or keystone species (McCann 2000)? Furthermore, how is ecosystem stability defined? In general ecological terms it can be defined as both the optimum and permanent state of a population (Law & Morton 1996). This generality masks rather more intuitive considerations of dynamic stability and the ability of a system to defy change—resistance and resilience. A debate that focuses on dynamics and resilience in ecosystem stability is more likely to explore aspects of function and interactions between components as well as variability rather than obsess on species counts or the tendencies of certain charismatic taxa. This pathway of scientific exploration inevitably drifts outside the more traditional territory of equilibrium ecology and dynamics and into the realms of non-equilibrium paradigm. More recently, studies, particularly by Tilman and various collaborators working on plant community diversity and stability (Tilman & Downing 1994, Tilman *et al.* 1996), have converged on the finding that diversity tends to correlate positively with ecosystem stability. This relationship is not a direct linear one but rather has more to do with the collective effects of individual species responses to variable background processes—described as the ***averaging effect*** (Doak *et al*. 1998). These studies make clear that the findings cannot be used to infer that diversity has a direct causative effect on ecosystem stability. For instance, examination of this relationship at greater scales between ecosystems fails to support these findings (Sankaran & McNaughton 1999). Rather, a clearer relationship emerges between functional diversity and ecosystem function and stability (Hooper & Vitousek 1997). There is rather less research on functional diversity and ecosystem stability, particularly, at the level of trophic structure and dynamics. However, one examination of the grassland ecosystem of the Serengeti identified a positive correlation between a number of stability measures and diversity (McNaughton 1985). Beierkuhnlein & Jentsch (2008) interpreted their results of a series of experiments in line with the "*insurance hypothesis*" (Yachi & Loreaeu 1999) that species diversity contributes to the buffering of climate change impacts and increases resilience of ecosystems, due to species-specific responses. It has also been found that community responses are not exclusively controlled by intrinsic responses, as stress-induced invasions may modify ecosystem stresses: e.g., in grasslands and heath systems, heavy rainfall events increased invasibility, and drought reduced it (Kreyling *et al*. 2008).

Both theory and empirical evidence point towards an understanding that the persistence of complex systems depends on the variability (fluxes) of populations and the changes in dynamics between species. These differential species responses influence the functionality of the whole system by weakening the destructive potential of competitive exclusion and thus stabilising a system and increasing its resilience to change (McCann 2000). In conclusion, the role of biodiversity in maintaining dynamic equilibrium in complex ecosystems is fundamental and cannot be undervalued.

ENERGY FLOW, CHAOS AND SELF-ORDERING IN NATURAL SYSTEMS

Solar energy creates existence, and nature is the only system that has the capacity to build and concentrate material substances from an external source, the sun (Wall 2005). It is this capability of nature to build structure and order within a system that enables it to conserve and store the energy for use at a later time. Stored energy that can be accessed from within the system is referred to as **exergy (usable energy)**. The relationship between exergy and biological structures defines the complexity of systems, and more complex systems demonstrate greater efficiency at degrading incoming energy (Baldwin *et al*. 2004b). Exergy creates structures, and the more structures to evolve in a system, the greater the efficiency in capturing and banking it for future use—"***exergy capital***" (Wall 2005). However, this is not the complete story. Inevitably, exergy destruction occurs as a result of unpredictable disturbance events or from exploitation by elements within a system. New sub-systems emerge within the super-system—'matter-simplifying' species that interact with primary producers by breaking down accumulative matter and releasing it back into the system thus contributing to the feedback processes Baldwin (2004). In Holling's adaptive cycle this is demonstrated by the shift in state from a position of conservation to that of change—the release or transference of energy. It is the destruction of exergy that creates the necessary change in systems that allows for evolution and adaptation (Wall 2005). The description of the universe or an ecosystem in complete equilibrium implies that there is no exergy. Conversely, the ultimate conservation state of exergy in a system would describe a situation in which everything could be returned to an original state and changes could be reversed. In this scenario time would have no meaning or direction (Wall 2005). However, this is not how natural systems work, rather, change is integral to system dynamics; exergy is destroyed; time has defined trajectories; and the whole process is irreversible.

Self-ordering in natural systems is not enough to promote and sustain biodiversity. Without renewing processes and periodic disruptions natural competition and the constraints of order restrict opportunities for the re-assemblage of new forms of diversity. In other words, biodiversity functions at the 'fuzzy' boundary between chaos and order—the "ChaOrd" zone (Huston 1994). The frequency, scale and force of disruption are a determining factor in creating appropriate conditions for biodiversity. Too much disturbance degrades the ecosystem and ultimately drives it towards a regime shift. Biodiversity provides a system with its ecological integrity and helps maintain it at its optimum operating point or equilibrium. The extent to which a system is moved from this point is determined by the force of environmental change. Natural, disturbance and **stress** affect ecosystems as either on-going events—intermediate disturbance, or as novelties—catastrophic impacts. Small scale shifts that result in the emergence of metastates provide an ecosystem with the necessary resilience and adaptation to changing conditions. For instance, changing climatic conditions induce geographical range shifting of biological systems such as populations or species. The reduction of resource availability can also lead to a decrease of sub-system density (e.g., individuals per area). Under extreme conditions the shift of an ecosystem to new operating points can induce dramatic changes to its complexity, functions and characteristics. Consequently, it experiences **degradation or even collapse**. Ecological examples would be forest ecosystems that lose structurally important species which are replaced by others, better adapted to new conditions (e.g., increased aridity or higher grazing intensity), and that degrade to grasslands. The corresponding *adaptive degradation* is related to important changes of emergent properties such as ecosystem functions (e.g., living biomass production, water filtration, soil formation). In extreme cases of degradation, especially when it occurred very abruptly and fast, the internal organisation of systems breaks down, and, ultimately, ecological integrity is lost in a **collapse** (e.g., extinction of a population or species; loss of ecosystems due to erosion following structural degradation).

The ability of a system to recover from disturbance and return to an optimum operating point describes its **resilience**. Biodiversity is fundamental to ecosystem resilience, and the more species there are together with a strong contingency of specialists the greater the functionality and integrity of the system. Functional and evolving systems that are able to return or shift to operating points without losing fundamental and typical emergent properties **develop sustainably** (Ibisch 2010). However, as change is inevitable, **sustainability** does not imply a maintaining of the status quo, but more appropriately, may describe a system undergoing a building phase towards complexity through the increasing evolution of sub-systems (attractor basins) or indeed shifts in meta-state of existing attractor basins. In both cases the super-system develops resilience and adaptation to change. In this description sustainability does not imply active human intervention but rather a natural process manifest in emergent properties of functional systems. **Sustainability**, when applied to 'free-willed' systems, defines the single or multiple states of dynamic equilibrium—the ultimate 'gravitation' of systems towards attractor basins. Any external gradient that causes fundamental shifts in a system, enough to create a hysterisis effect, will inevitably bring about destabilization and loss of sustainability. In response to this shift a new regime will emerge with its own attractor basins and parameters of sustainability or the system will decline to a point of no return (Lyytimäki & Hildén 2007).

As stated in the previous paragraphs, the condition and behaviour of nature is defined by its relationship with energy. The persistence of life on earth is a measure of the ability of ecosystems to avoid equilibrium by moving themselves away from the point of entropy. To better understand this relationship between systems and energy there is a need for new concepts and metaphors to complement the theories of adaptive cycle and complex systems theory. There are clear advantages to examining systems through the study of energetics– energy is easily measured and can provide empirical evidence for the performance, capacity, and limitations of systems. By the turn of the 20th century scientists were familiar with some of the basic principles of **thermodynamic**s. However, more recently, these principles have been developed and used to describe the behaviour and performance of ecological and social systems.

B. 2.1.b THERMODYNAMICS AS A PRIMARY DRIVER OF SYSTEMS

THERMODYNAMIC EFFICIENCY AS AN OVERARCHING PRINCIPLE IN NATURE

At the end of the 19th century, Boltzmann (1886) attempted to develop a better understanding of nature by describing the apparent order observed in nature using the second law of thermodynamics. His explanation of ordered nature was of a system in transient state that would inevitably decay towards death and disorder. However, confounded by the obvious contradictions between heat death of the universe and the evolution of complex ecosystems on earth, Boltzmann recognised the need for an alternative perspective to describe the relationship between living systems and energy. Over half a century later this same paradox preoccupied another scientist, Schrödinger (1944), who described two fundamental processes that were responsible for the coherent patterns and dynamics of nature. The more obvious process was "order from order" that conveyed the consistency of inherited traits and form under the control of DNA, that is then passed on from generation to generation. The second more complicated process was "order from disorder" that explained the ability of nature to apparently defy the second law of thermodynamics by moving a system away from a state of entropy through the continuous biological evolution of self-organising constructs (compare Nicolis & Prigogine 1977).

At the organismic level, autotrophic beings such as plants are assembled from a 'disordered soup' of carbon molecules. This creation of order from disorder can happen only because of the use of energy that is taken from other systems in which entropy inevitably has to increase. The green plants use solar energy, and the corresponding increase of entropy would happen in the sun anyway. The situation is different in the case of the derived heterotrophic organisms. On the one hand, the decomposers are important in terms of thermodynamic and material efficiency because they recycle nutrients required for the establishment of new and more systems; they live from energy provided by other disintegrating systems. On the other hand, the consumers can create order only at the cost of increased entropy in other living systems on Earth. Order of autotrophic or other heterotrophic organisms is naturally disrupted by the generation and ultimate ordering of the next trophic structure—the consumers. At each stage of ordering energy is both utilised and also lost to heat. This suggests woeful inefficiencies in the hierarchical structuring of nature, particularly, in the simplified analysis of food chains. However, natural systems are rarely constructed along such simplistic lines of organisation. For instance, competition amongst plants is strongly influenced by the activities of herbivores—one of the principle drivers of change and evolution in the plant world. This relationship between producer and consumer encourages increasing diversity in plant form and function, for instance efficiency gains in the dissipation of energy. In this context, it is important to acknowledge that the biomass that can be established by consumers is thermodynamically limited—and it must be always at the order of magnitude smaller than the biomass of autotrophic organisms (compare Odum 1971). At the same time, the diversity of heterotrophic lifeforms can be much larger than the diversity of autotrophic ones, because they have many more options for gaining energy by exploiting existing autotrophic or other heterotrophic systems.

Another implication that becomes obvious, is that whenever heterotrophic organisms appropriate and turnover a significant amount of energy provided by and dissipated in autotrophic organisms, this will lead to decreasing **thermodynamic efficiency** of the ecosystem—which is a measure of its sustainability in terms of auto-regulating the system and maintaining it in a certain attractor basin. Incoming energy is degraded at all scales in an ecosystem and in landscapes dissipating structures manifest as spatially heterogeneous patches (vegetation formations), biomass accumulation, and trophic complexity. As more species assemble in a landscape the interconnections between the living and non-living components become increasingly more complex. The measure of this emerging complexity and the corresponding increase in functionality would indicate the amount of incoming energy being captured, dissipated and degraded by the system. The efficiency of this process would also show in the complexity of trophic connections, specialization of the resource niche, and the extent of recycling and biomass accumulation (Kay & Schneider 1992). Evolution is the driving force behind system organisation and as such could be defined as a process that, under the physical laws of nature, produces systems, which are able to self-organize, multiply, reproduce themselves and diversify at the cost of increasing entropy in other systems. This leads to increasing opportunities of interactions between systems and corresponding complexification of systems of ever higher order (Ibisch 2010). The ability of systems to self-organise enables them to evolve and function some distance away from thermodynamic equilibrium. In other words, they exist in a non-equilibrium, quasi stable state by avoiding entropy (Kay 1992). Biodiversity is the 'solution' to the thermodynamic problem of maximising the degradation of solar energy. However, as mentioned before, a system's ability to exchange energy with the outside environment comes at a cost of increasing the entropy of the larger environment. The signatures of a thermodynamically efficient system include the following:

- the emergence of stable dissipative structures (complex cycles and diverse, representative species)
- growth of the physical-biological structure (biomass)
- growth in complexity of the network between the components
- and growth of 'information' (increase in the proportion of more complex organisms with K-strategy to those with r-strategy) (Jørgensen 2006).

An increase in the input of 'exergy' and material can push a system beyond a boundary from thermodynamic equilibrium. The system responds by using the exergy to construct and maintain its structure. As a result of the dissipation of this exergy, the system retains its position away from thermodynamic equilibrium. Over time, the continued influx of exergy prompts a response of more emergent structures to degrade the exergy. This behaviour promotes increased complexity and corresponding efficiency in acquiring resources and constructing more dissipating structures. Plants utilise the incoming solar energy to produce complex compounds and stored energy. The stored potential energy of the producers is then exploited by consumers and ultimately chains of these trophic groups will build up in complexity within a system. The result to the incoming energy is that it is degraded as it passes through the various biological processes of respiration and metabolism. These "chains of events" are referred to as **'energy degrading chains'** (Kay & Schneider 1992). However, there is a finite point to this process and eventually the system will reach a critical state beyond which self-organisation breaks down and chaos ensues. This rather suggests that ecosystems operate on 'boom—bust' cycles of collapse and re-invention and yet this is not what is witnessed in most cases. What prevents a system from flipping between these two extreme ends of dynamics? Certainly, the interaction both within and between species across all trophic levels plays a central part to the maintaining of ecosystem equilibrium and resilience. The sheer mass of numbers and diversity of forms presents a picture of chaos with little sense made of the relationship between any specific event and interaction. For instance, in a grassland ecosystem the pursuit of a small rodent by a bird of prey has no rationale connection to the pollination of a flower by a bee or to the fungal attack of a soil nematode. Yet, the intricate and apparently chaotic events that play out across space and time generate the self-ordering feedback mechanisms that regulate the energy flux in an ecosystem.

Complementary to the process of building order and structure by means of energy degrading chains is another essential function that involves the mechanical and physiological break down of compounds—**'matter simplifying'** (Kay & Schneider 1992). This process makes available the essential compounds and elements needed in energy degrading chains, and both functions may occur at the biological level within trophic groups or between trophic levels. Thermodynamically efficient, dissipative systems can respond to environmental change in different ways depending on the level of disruption.

THE PARADOX OF OPEN SYSTEMS AND ENERGY CONSERVATION IN NATURAL SYSTEMS

In previous sections of this paper a description of systems characterised them as self-organising constructs operating under feedback mechanisms and open to the exchange of energy and material. However, ecosystems are spatially and temporally constrained. For instance, the physical environment, microclimate and availability of free or mobile resources restrict the extent, size and shape of ecosystems. Equally, temporal influences including large-scale evolutionary changes and much shorter time lines representing responses to periodic disturbance also help define ecosystems. These spatio-temporal references create the distinctive patterns and mosaics that give a landscape its character. A well-defined ecosystem has strong interactions among its components that are not expressed across its boundaries (Jørgensen 2007). This is partly due to the coinciding of discontinuities in abiotic conditions, and also in the distribution of species. The diminishing of self-recognising tendencies at boundaries puts limits on the exchange of matter and energy. Vegetation dynamics play a fundamental role in defining the parameters of terrestrial ecosystems; they are the means of harnessing the raw energy of the sun and converting it into bio-chemical factories. The efficiency, or more correctly, inefficiency of plants as energy capturers sets the thermodynamic limits of an ecosystem. At its most efficient, nature can just about harness between 2% - 3% in the form of plant biomass production (Vitousek *et al*. 1986). In equatorial regions plants operate at their most efficient allowing ecosystems to optimise their trophic structures, diversity of species and accumulation of biomass. However, even the very largest equatorial ecosystems are bounded by spatio-temporal constraints and energy conversion inefficiencies that create a landscape of semi-closed multi-systems. This limitation to system growth falls below the thermodynamic expectations of a system and are more likely to be a result of ecological constraints to trophic transfer of energy. That is not to suggest that a system very close to physical limits cannot still continue to grow.

Rather, a system is likely to shift towards improvements in matter recycling and increases in information (Jørgensen *et al*. 2007). This process of internalising and re-cycling energy and matter transference (self-ordering) reduces the exchange of materials across borders between systems and this has advantages of retarding the lowering of energy flux and increasing energy-efficiency. "*To this end, functional units with minimal openness may be readily recognised at every fractal level: atoms with electrons distributed in orbitals about the nucleus; molecules with several atomic nuclei and electrons in molecular orbitals; molecular aggregates from water (H2O, H+ and OH-), salts and macromolecules, with clusters stabilised by electrical interaction; cells with their functional organelles; organisms with their different cell aggregates and organs*" (Ripl & Wolter 2002).

In ecosystems the dissipative ecological unit (DEU) is the smallest functional unit of a functional ecosystem (e.g., Ripl 2003). "*For single-celled organisms, the efficiency principle already applies: the more effectively the cell can turn over the material running through structured cyclic processes and the fewer losses it makes, then the more stable and thus more survivable it becomes. Thus, the intake of food needed for operating processes is minimised. In multicelled organisms, this efficiency criterion is supplemented by the synergetic division of labour between cells and cell tissue—and by the organism's internal transport systems. (…) In addition, multicellular organisms minimise a part of their irreversible losses by cycling material internally*" (Ripl & Wolter 2002).

At larger scale breaks, for instance, intra-specific and inter-specific levels of organisation, close coupling between two organisms can improve efficiencies in capturing energy and material, and there are numerous examples of this relationship. For example, symbiotic nitrogen fixation between plants and bacteria, mycorrhyzal associations between fungi and plants, the mutual existence between algae and fungi in lichens, and between algae and certain species of Coelentorates or Crustacea; and so it continues even in higher life forms. More obvious interactions among organisms cover such familiar topics as competition, predation or herbivory. Patterns of organisation that promote energy efficiency occur at different fractal hierarchies within a system by following the same principles and adopting the Dissipative Ecological Unit (DEU) (Ripl & Wolter 2002). At these higher levels of organisation energy and matter-transferring pathways are a function of the complex network between the components. Furthermore, as a system grows and adapts, the corresponding networks increase and change. Ultimately, a system becomes too complex to be able to apply laws of thermodynamics and a more holistic and unifying theory is called for—Ecosystem Theory (Jørgensen & Fath 2004).

In recent years a number of scientists have worked towards developing an ecosystem theory, in particular, Jørgensen and Fath (2004) have proposed a conceptual model consisting of eight basic laws. This has since been modified to nine laws that unite principles of thermodynamics and systems theory (Jørgensen 2007). The nine laws are stated as follows:

1. *All ecosystems are open systems embedded in an environment from which they receive energy-matter input and discharge energy-matter output*
2. S*ystems have many levels of organisation and operate hierarchically.*
3. *Thermodynamically, carbon-based life has a viability domain determined between about 250-350K.*
4. *Mass, including biomass, and energy are conserved.*
5. *The carbon-based life on earth, has a characteristic basic biochemistry which all organisms share.*
6. *No ecological entity exists in isolation but is converted to others.*
7. *All ecosystem processes are irreversible.*
8. *Biological processes use captured energy (input) to move further from thermodynamic equilibrium and maintain a state of low-entropy and high exergy relative to its surroundings and to thermodynamic equilibrium.*
9. *After the initial capture of energy across a boundary, ecosystem growth and development is possible by (1) an increase of physical structure (biomass); (2) an increase of the network, more cycling or; (3) an*

increase of information embodied in the system.

(Jørgensen 2007)

The relationship between complex system structure and thermodynamics is described in the growth and development of an ecosystem. Young ecosystems capture much of the incoming energy through the build up of biomass (Growth form I). This is a period of high productivity, the 'autotrophic' phase of an ecosystem, when net primary production is greater than 1 (Brewer 1994). However, as systems mature and experience physical and ecological constraints they move towards greater complexity, the heterotrophic phase—a process of increasing networks and information (growth forms II & III). By this stage of development energy captured by the ecosystem has levelled off and net primary production would come close to 0. Apart from an increase in trophic structure there are also changes in species strategies, a shift in emphasis from generalists and r-strategists to specialists and k-strategists (Jørgensen 2006). This period in the ecological history of an ecosystem represents the period of sustainability.

Ecosystem theory draws together much of the thinking and research on systems theory and ecosystem thermodynamics. It offers appropriate narratives and metaphors for understanding the relationship between natural and anthropogenic systems. It also sets out clear parameters and measurable boundaries to systems in terms of productivity, carrying capacity, limits of change, resilience, as well as factor in the unpredictable nature and uncertainty of system behaviour. In other words, ecosystem theory provides a robust baseline on which to build an informed framework for sustainable development.

NON-EQUILIBRIUM THERMODYNAMICS AND SUSTAINABILITY

There is a long-standing dispute about the application of thermodynamics to sustainability science. Especially the work of Georgescu-Roegen (e.g., 1971) has stimulated a debate about the relevance of entropy. A common misunderstanding in this debate is that entropy is often represented as an anthropogenic problem on Earth, rather than an inevitable consequence of thermodynamics as defined in the second law (e.g., compare Schwartzman 2008). The increase in entropy in the wider environment is the necessary requirement for the emergence and maintenance of self-organized systems, it is nature's evolutionary pathway to survival. The debt of self-organizing systems to chaos is the environmental increase in entropy. Consequently, the critics of the so-called neo-Malthusians (who describe the existence of limits to human growth), claim that a "*sustainable societal self-organization on the planet Earth is only limited by the low-entropy solar flux, a limit with no practical consequences far into the future, with the entropic debt paid as the heat flux to space, the ultimate heat sink*" (Schwartzman 2008). These technology-believing critics overlook the enormous complexity of natural ecosystems, their functions and services the anthroposystem depends on. Of course, theoretically, it would be possible to design a solarized and almost dematerialized world where almost any ecosystem service is replaced by solar power (or atomic fusion power) fuelled technology, including artificial photosynthesis for food production. This, however, seems to be mere science-fiction ignoring most of the known emergent properties of natural and social systems. In natural systems sustainability can be defined as the sum of the relationships between energy and biodiversity, more specifically, the interconnection of three fundamental processes of energy utilisation. These are: (1) energy input from the sun that creates existence; (2) the dissipation and storage of exergy that creates structure; and (3) the destruction of exergy that creates change (Wall 2005). In complex, thermodynamically efficient systems the energy and materials are recycled and the net primary production approaches 0 value. The development of structures and biomass in a system constitutes the "exergy capital", the necessary surplus 'banking' of material that provides insurance against entropic collapse.

Exergy capital takes many forms in our Earth's system; the most obvious are coal, peat deposits, oil, natural gas, plant and algal growth and detritus, as well as other trophic life-forms. These structures and forms transcend across scales from the very large biomes to smaller units of vegetation—logs and leaf litter strewn across the forest floor. Rather than wasteful, natural systems are efficient in harnessing exergy to create new structures, the stuff of biodiversity. A small proportion of material is stored away in the lithosphere, but this 'banked' matter is not waste, rather, it has played a key role in shaping the planet over the last few billions of years. By removing a proportion of biomass from the biosphere and storing it in the lithosphere, new opportunities arose for species to evolve and expand into the 'space' made available. Global catastrophic events in the past such as extreme volcanic activity have unleashed some of this stored biomass in the form of debris and carbon dioxide, causing wide scale destruction across large tracts of the planet.

Our relationship with energy and the planet's exergy capital is unique. The advancement of technology has made it possible to tap into exergy capital reserves, including coal, oil and natural gas that are out of the reach of other species. There are two aspects to this exploitation: resource depletion and environmental destruction (Wall 2005). Materials extracted from the lithosphere, both organic and mineral, are processed into derivatives that are either more concentrated, refined, distilled or volatile versions of the original parent substance. Damage to the environment occurs at all stages of this conversion process. In most cases there is no recycling of material substances. Instead, processes that are more typical of positive feedback mechanisms are applied to extract substances from the lithosphere, utilize the refined products and re-deposit the residue as toxic waste in all other four geo-spheres (Wall 2005). The accumulation of toxic waste and by-products may take nature millions of years to repair. Furthermore, as material in the lithosphere is depleted, the quality of remaining deposits decreases and so more exergy is required to extract what is left. An assessment of the extent of human exploitation of natural and exergy capital claims that between a third and a half of the Earth's land surface has been transformed by human development, and one third of the planet's terrestrial ecosystem production (Vitousek *et al.* 1997). Growth of the anthroposystem and improved quality of life has placed excessive dependence on specific energy forms, specifically electricity that is generated by non-sustainable and non-renewable energy sources (Dincer & Rosen 2005). The total energy consumed by civilisation is calculated at 1012 Watts (13 Terra watts) and in the next fifty years it is expected to reach a level of 2312 Watts (30 terra watts) (Daily *et al.* 1994). If thermodynamic laws and principles of sustainability are to be applied, then optimum levels of energy utilization are estimated at 2 to 4 Tera Watts, which would extrapolate to a global population of 1.5 to 2 billion people. What is more, 75% of the world's energy is utilized by the industrialised economies that make up only 25% of the world population.

The laws of thermodynamics make it quite clear that on matters of energy there is an inevitable single direction to go with no way back. As work is done the quality of energy is degraded and as a result systems move closer towards entropy. This inherent production of entropy cannot be reversed (Schmitz 2008). Since the dawn of civilization, but more significantly in the last 200 years, the rapid development of socio-economic systems, including the dramatic transformation of global ecosystems to cultural landscapes, has accelerated the degradation of the planet's exergy capital. The global ecosystem is simply getting hotter, it is losing its resilience and capabilities to dissipate energy, there is less biomass storage in the system, and dissipative structures are undergoing simplification. During the very brief period of civilization the advances of technology have created a false sense of limitless resources and opportunities. Society has been tricked into thinking that both science and technology are able to skip round problems of energy and material shortages, and that there is ultimately an answer to the dilemma of energy-exergy-entropy. It is the belief that 'laws' can be made and broken that lulls civilization into a false sense of security and drives it ever forwards beyond the limits of nature's boundaries.

So far, we have set out some of the philosophy and science underpinning current understanding of complex systems and thermodynamics. These sections provide the necessary theory to the environmental elements of sustainable development. However, to complete the foundations for sustainable development it is necessary to provide an account of human evolution and development, and the intimate relationship between civilization and the natural world (see next chapter, Ibisch & Hobson, B2.2., in this document).

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REFERENCES

Allen, P.M. 1990. Why the future is not what it was : New models of evolution. Futures **22**:555-570.

Baldwin, J. S., R. Murray, B. Winder and K. Ridgway. 2004a. A non-equilibrium thermodynamic model of industrial development: analogy or homology? Journal of cleaner production **12**:841–853.

Baldwin, J. S., R. Murray, B. Winder and K. Ridgway. 2004b. A non-equilibrium thermodynamic model of industrial development: analogy or homology? Journal of cleaner production **12**:841–853.

Baliga, N. S. 2008. Systems biology—The scale of prediction. Science **320**:1297–1298.

Becker, F. 2004. Geschichte und Systemtheorie: Exemplarische Fallstudien. Campus-Verl., Frankfurt/ Main.

Beierkuhnlein, C. & A. Jentsch (2008): A single drought event of 100-year recurrence enhances subsequent carbon uptake and changes carbon allocation in experimental grassland communities. J.Plant Nutr.Soil Sci.-Z.Pflanzenernähr.Bodenkd. **171**:681-689.

Boltzmann, L. 1886. Der zweite Hauptsatz der mechanischen Wärmetheorie [PS, 25] (Vortrag, gehalten in der feierlichen Sitzung der Kaiserlichen Akademie der Wissenschaften am 29. Mai 1886.) (The second law of thermodynamics. Populäre Schriften, Essay 3, address to a formal meeting of the Imperial Academy of Science, 29 May, 1886, reprinted in Ludwig Boltzmann. 1974. Theoretical physics and philosophical problem, S. G. Brush (Trans.). Boston: Reidel.

Braun, B. 2004. Querying posthumanismus. Geoforum **35**:269–273.

Brewer, R. 1994. The science of ecology. 2nd ed. Fort Worth: Saunders.

Bunge, B. 2000. Systemism: the alternative to individualism and holism. Journal of Socio-Economics **29**:147–157.

Carpenter and W. A. Brock. 2004. Spatial complexity, resilience, and policy diversity: Fishing on lake-rich landscapes. Ecology and Society **9**.

Daily, G. C., A. H. Ehrlich and A. H. Ehrlich. 1994. Optimum human-population size. Population and environment **15**:469–475.

Dawkins, R. 2006. The selfish gene. 2. ed., 30th anniversary ed. /. Oxford Univ. Press, Oxford.

Dincer, I. and M. A. Rosen. 2005. Thermodynamic aspects of renewables and sustainable development. Renewable & sustainable energy reviews **9**:169–189.

Doak, D. F., D. Bigger, E. K. Harding, M. A. Marvier, R. E. O'Malley and D. Thomson. 1998. The statistical inevitability of stability-diversity relationships in community ecology. American naturalist **151**:264–276.

Dyne van, G. M. 1966. Ecosystems, s*ystems ecology and systems ecologists. ORNL-3957* (Oak Ridge, Tenn.: Oak Ridge National Laboratory).

Ehrlich, P. R. and A. H. Ehrlich. 1981. Extinction: The causes and consequences of the disappearance of species. Random House, New York.

Franklin, A. 2006. Burning cities: a posthumanist account of Australians and eucalypts. Environment & planning, society and space **24**:555–576.

Funtowicz, S. and Ravetz, JR. 2008. Post-normal sciences in C. J. Cleveland, editor. Encyclopedia of Earth, Washington, D.C.

Funtowicz, S. O. and J. R. Ravetz. 1997. The poetry of thermodynamics—Energy, entropy/exergy and quality. Futures **29**:791–810.

Georgescu-Roegen, N. 1971. The entropy law and the economic process. Harvard Univ. Pr., Cambridge/ Mass.

Georgescu-Roegen, N. 1975. Energy and economic myths. Southern Economic Journal **41**:347-381.

Godderis, Y. and Y. Donnadieu. 2009. Biogeochemistry: Climatic plant power. Nature **460**:40–41.

Groffman, P., et al. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems **9**:1–13.

Gunderson, L. H. and C. S. Holling. 2002. Panarchy. Understanding transformations in human and natural systems. Island Press, Washington.

Gunderson, L. H., C. S. Holling and S. S. Light. 1995. Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, New York.

Haila, Y. 2000. Beyond the nature-culture dualism. Biology & Philosophy **15**:155–175.

Haila, Y. 2004. Making sense of the biodiversity crisis: A process perspective. PAges 54-83 in Oksanen, M. and J. Pietarinen (eds). Philosophy of Biodiversity. Cambridge: Cambridge University Press.

Hobson, P. B. J. 2004. Evaluating biodiversity for conservation: a victim of the traditional paradigm in M. Oksanen and J. Pietarinen, editors. Philosophy and biodiversity. [based on a seminar held in Aug. 1999 at the University of Turku, Finland]. Cambridge Univ. Press, Cambridge.

Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pages 292–320 in W. C. Clark and R. E. Munn, editors. Sustainable development of the biosphere. Cambridge Univ. Pr., Cambridge.

Hooper, D. U. and P. M. Vitousek. 1997. The effects of plant composition and diversity on ecosystem processes. Science **277**:1302–1305.

Huston, M. A. 1994. Biological diversity. The coexistence of species on changing landscapes. Cambridge Univ. Press, Cambridge.

Ibisch, P. L. 2010. Global change management: eine systemische Utopie der Nachhaltigkeit im Angesicht der Apokalypse in E. Deutscher and H. Ihne, editors. "Simplizistische Lösungen verbieten sich". Nomos, Baden-Baden.

Jørgensen, S.E. 2007. An integrated ecosystem theory: Ann-Eur. Acad. Sci. EAS Publishing House, Liege.

Jørgensen, S.E. 2006. Application of holistic thermodynamic indicators. Ecological Indicators **6**:24–29.

Jørgensen, S.E. et al. A new ecology : systems perspective. 1 udg. Oxford, UK : Elsevier Science.

Jørgensen, S.E. and B.D. Fath. 2004. Application of thermodynamic principles in ecology. Ecological Complexity **1**:267–280.

Kay, J. J. 2000. Ecosystems as self-organising holarchic open systems: narratives and the second law of thermodynamics. Pages 135–160 in S. E. Jørgensen and F. Müller, editors. Handbook of ecosystem theories and management. Lewis Publishers, Boca Raton, Fla.

Kay, J. J. 2008. Framing the situation. Pages 15–34 in D. Waltner-Toews, editor. The ecosystem approach. Columbia Univ. Press, New York.

Kay, J. J. and M. Boyle. 2008. Self-Organizing, Holarchic, Open Systems (SOHOs). Pages 51–78 in D. Waltner-Toews, editor. The ecosystem approach. Columbia Univ. Press, New York.

Kay, J. J. and E. D. Schneider. 1992. Thermodynamics and Measures of Ecosystem Integrity, in D. H. McKenzie, D. E. Hyatt and V. J. McDonals, editors. Ecological Indicators, Volume 1: Proceedings of the international Symposium on Ecological Indicators. Elsevier, Fort Launderdale, Florida.

Kinzig, A. P., P. Ryan, M. Etienne, H. Allison, T. Elmqvist and B. H. Walker. 2006. Resilience and regime shifts: assessing cascade effects. Ecology and Society **11**:20.

Koestler, A. 1967. The ghost in the machine. Arkana, London.

Koestler, A. 1969. Some general properties of self-regulating open hierarchies order (SOHO), in: Koestler, A. and J. R. Smythies, editors. Beyond Reductionism New Perspectives In The Life Sciences. Houghton Mifflin Co.

Koestler, A. and J. R. Smythies, editors. 1969. Beyond Reductionism New Perspectives In The Life Sciences. Houghton Mifflin Co.

Kreyling, J., L. Ellis, C. Beierkuhnlein & A. Jentsch 2008. Invasibility of grassland and heath communities exposed to extreme weather events—additive effects of diversity resistance and fluctuating physical environment. Oikos **117**:1542-1554.

Lane, P.J., B. Koka and S. Pathak. 2002. A thematic analysis and critical assessment of absorptive capacity research. Academy of Management Proceeding, BPS, M1:M6.

Laszlo, A. 2009. The Nature of Evolution. World Futures: Journal of General Evolution **65**:204-221.

Laszlo, A. and S. Krippner. 1998. Systems theories. Their origins, foundations, and development. Pages 47–74 in J. S. Jordan, editor. Systems theories and a priori aspects of perception. North Holland, Amsterdam.
Law, R. and R. D. Morton. 1996. Permanence and the assembly of ecological communities. Ecology **77**:762–775.
Lenton, T. M. 1998. Gaia and natural selection. Nature **394**:439–447.
Lovelock, J. E. 1987. Gaia: a new look at life on Earth. Oxford University Press, Oxford
Luhmann, N. 1987. Soziale Systeme: Grundriß einer allgemeinen Theorie. 1. ed. Suhrkamp, Frankfurt am Main.
Lyytimäki, J. and M. Hildén. 2007. Thresholds of sustainability: policy challenges of regime shifts in coastal areas. Sustainability: Science, Practice and Policy **3**:61–69.
Malik, F. 2008. Strategie des Managements komplexer Systeme: Ein Beitrag zur Management-Kybernetik evolutionärer Systeme. Haupt Verlag, Bern.
Matius, M., E. Hernandez-Garcia and P. Colet. 2006. Report on different threshold scenarios and mechanisms, together with representative models of them. Stream 2-D2.1. THRESHOLDS of Environmental Sustainability integrated Project.
May, R. M. 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. Nature **269**:471–477.
McCann, K. S. 2000. The diversity-stability debate. Nature **405**:228–233.
McNaughton, S. J. 1985. Ecology of a grazing ecosystem—the Serengeti. Ecological monographs **55**:259–294.
Mitchell, M. and M. Newman. 2002. Complex systems theory and evolution in M. Pagel, editor. Encyclopedia of evolution. Oxford Univ. Press, Oxford.
Nicolis, G. and I. Prigogine. 1977. Self-organization in nonequilibrium systems: From dissipative structure to order through fluctuations. Repr. Wiley, New York.
Odum, E. P. 1971. Fundamentals of ecology. 3d ed. Philadelphia: Saunders.
Odum, H. T. 1983. Systems Ecology, New York: John Wiley.
Odum, H.T. 1994a. Ecological and general systems: an introduction to systems ecology. Univ. Press of Colo., Niwot.
Patten, B. C. 1978. Systems approach to the concept of environment. Ohio Journal of Science **78**:206-222.
Proctor, J. D. 1998. Geography, paradox and environmental ethics. Progress in human geography **22**:234–255.
Puydt, P. E. de. 1860. Panarchy: First published in French. the Revue Trimestrielle, Bruxelles.
Ravetz, J. R. 1986. Usable knowledge, usable ignorance: incomplete science with policy implications. Pages 415–432 in W. C. Clark and R. E. Munn, editors. Sustainable development of the biosphere. Cambridge Univ. Pr., Cambridge.
Ripl, W. 2003. Water: the bloodstream of the biosphere. Phil. Trans. R. Soc. Lond. **358**:1921-934.
Ripl, W. and K. D. Wolter. 2002. Chapter 11: Ecosystem function and degradation in P. J. B. Le Williams, D. N. Thomas and C. S. Reynolds, editors. Phytoplankton productivity. Blackwell Science, Oxford.
Rockström, J., et al. 2009. A safe operating space for humanity. Nature **461**:472–475.
Sankaran, M. and S. J. McNaughton. 1999. Determinants of biodiversity regulate compositional stability of communities. Nature **401**:691–693.
Schmitz, J. E. J. 2008. Approaching the world's environmental problems through the Second Law (Entropy Law) of Thermodynamics in C. J. Cleveland, editor. Encyclopedia of Earth, Washington, D.C.
Schneider, E. D. and J. J. Kay. 1994. Complexity and thermodynamics: towards a new ecology. Futures **26**:626–647.
Schrödinger, E. 1944. What is Life? Cambridge: Cambridge University Press.
Schwartzman, D. 2008. The limits to entropy: Continuing misuse of thermodynamics in environmental and Marxist theory. Science & Society **72**:43–62.
Stacey, R. D 1996. Strategic management and organisational dynamics (2nd ed), Pitman, London.
Tilman, D. and J. A. Downing. 1994. Biodiversity and stability in grasslands. Nature **367**:363–365.

Tilman, D., D. Wedin and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature **379**:718–720.

Varela, F. G., H. R. Maturana and R. Uribe. 1974. Autopoiesis: the organization of living systems, its characterization and a model. Biosystems **5**:187–196.

Vitousek, P. M., P. R. Ehrlich, A. H. Ehrlich and P. A. Matson. 1986. Human appropriation of the products of photosynthesis. Bioscience **36**:368–373.

Vitousek, P. M., H. A. Mooney, J. Lubchenco and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science **277**:494–499.

Wade, M. J. and C. J. Goodright. 1998. Perspective: The theories of Fisher and Wright in the context of metapopulations: When nature does many small experiments. Evolution **52**:1537–1553.

Walker, B. H., A. P. Gunderson, A. P. Kinzig, C. Folke, S. R. Carpenter and L. Schultz. 2006. A handful of heuristics and some propositions for understanding resilience in socio-ecological systems. Ecology and Society **11**.

Walker, B. and J. A. Meyers. 2004. Thresholds in ecological and social–ecological systems: a developing database. Ecology and Society **9**.

Wall, G. 2005. Exergy capital and sustainable development. Proceedings of the 2nd International Exergy, Energy and Environment symposium.

Winther, R. G. 2008. Systemic Darwinism. Proceedings of the National Academy of Sciences of the United States of America **105**:11833–11838.

Wu, J. G. and O. L. Loucks. 1995. From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. Quarterly review of biology **70**:439–466.

Yachi, S. and M. Loreaeu. 1999. Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. Proceedings of the National Academy of Sciences of the United States of America **96**:1463–1468.

B.2.2 THE INTEGRATED ANTHROPOSYSTEM: GLOBALIZING HUMAN EVOLUTION AND DEVELOPMENT WITHIN THE GLOBAL ECOSYSTEM

Pierre L. Ibisch & Peter Hobson

ABSTRACT

This paper, in a transdiciplinary approach, draws together concepts and evidence from biological, anthropological, paleoecological, historical, political and economic research and presents a comprehensive theory to explain past, present and future evolution of the anthroposystem in terms of natural sciences and system theory.

Pleistocenic African *Homo sapiens* evolved as a biological subsystem in a systemic play of changing habitat conditions and existing traits. Many important physical and psychological traits date back to this time of early human evolution. Above-needs consumption emerged as a distinctive social trait, as well as the ability to recognise unsustainability, and to incentivize individuals to practice ecological rationality. We see evidence that nature-culture antagonism and increasing alienation from ecosystems started very early in human evolution. The ability demonstrated by *Homo sapiens*, to alter ecosystems in such a way as to 'cheat' the natural laws of carrying capacity and resource depletion, adapting intelligently to arising consequences, might help explain why locally unsustainable patterns of behaviour continued unchecked through the course of human evolution. It is even probable that unsustainable ecosystem 'management' and subsequent resource shortage in many cases triggered technological innovations. There are manifold examples of feedback loops of drivers and consequences of cultural evolution. Especially, agricultural development spawned a social revolution including changes in organization, cosmovision and religion. Improvements in social organisation and the development of economic constructs were relatively rapid and demanded political and regulatory frameworks if they were not to collapse. Population growth expanded dramatically around these social hubs putting pressure on local resources and setting off conflicts and warfare with neighbouring centres over territory and much needed natural capital. The emergence of urban centres greatly increased demands for material and energy, altered the spatial configuration of the landscape, and also contributed to the unsustainability by subtle socio-psychological and political effects. Finally, information technology brought more and more ever better educated people together allowing exchange and fusion of ideas, leading to innovations and accelerating cultural evolution.

Cultural and technological evolution led to the creation of ever more interconnected subsystems of the anthroposystem and to the formation of systems of higher order on the local, regional and finally the global level. The globalization of the anthropo-subsystem, in the sense of expanding networks, both at the institutional and the individual level, has greatly increased concerns of achieving and maintaining sustainability. Human travel and trade marked the beginning of the atopization of ecosystem use. Communities no longer depended exclusively on local ecosystem goods and services. Globalization, together with urbanization, has contributed to the apparent de-coupling between culture and nature. A combination of freedom of choice and loosely defined membership to various social structures has fostered a perception of individual liberation from systems of higher order. This fuels notions of a sustainability that is dependent on the functioning of economical and financial systems and independent from ecosystems.

Modern trade is completely exosomatic, and a mainly fossil-fuel-dependent driver of economic growth. By the late 19th century, world trade started to decouple from world production, growing much more rapidly and leading to increasing openness of more and more local and regional systems. This contributes to hiding environmental costs and masking inter-dependency between economic and natural systems. The externalization of environmental costs in so-called developed countries implies that the negative

consequences of the (over)use of ecosystem services is exported to other territories. Environmental problems including contamination, ecosystem degradation, fragmentation and conversion manifest in landscapes beyond the boundaries of origin but may not impact on local systems until some time later, once critical levels of tolerance have been exceeded. In this context it is important to highlight that humans depend on ecosystem services that are not just produced locally. In the short run, the most important challenge is to address problems of climate change in order to avoid catastrophic events that are likely to effective the survival of human civilization. The conservation of *global* regulating ecosystem services, especially those related to hydroclimatic processes, is at least of equal importance as the maintenance of the *local* provisioning and supporting services.

Present-day landscapes and their biodiversity cannot be understood without knowledge about history and prehistory (Balée & Erickson 2006a). If we want to apprehend the current problems of biodiversity loss and how it is interrelated with human development it is necessary to analyze the trends and the mechanisms that drive the current situation and continue to be relevant. A lot of evidence indicates that the history of human development and subsequent anthropogenic biodiversity loss is not a sequence of coincidental events, which simply happened. Without invoking teleological or theological interpretations it is possible to see the paradox that biological and cultural evolution are a theoretically open-ended, and, in retroperspect, a tendentially directional process that can be explained on the basis of natural science and systems theory (see Hobson & Ibisch, B.2.1. in this document). The same paradox, based on characteristics of non-equilibrium open systems, implies that it is impossible to predict and explain single events, while it is feasible to explain and predict trends and patterns.

Evidence for the existence of systemic drivers and constraints that are derived from long-term biological and cultural evolution is compelling, and suggests that information and understanding based on the current situation or recent history only is limited. Although in the history of nature conservation much has been written about the development of conservation through history, specifically, the ethical and cultural element of conservation, surprisingly, in current discourses about applied biodiversity conservation and policy, anthropo-evolutionary and historical perspectives are commonly absent.

Conservation is more often discussed and dealt with in the context of the current relationship between the diverse cultural heritage, in particular that of indigenous peoples, and biodiversity (compare the CBD's article 8j; see also e.g., Alcorn 1993, Orlove & Brush 1996, Hames 2007, see also Herrmann *et al*., B.1.3. in this document). In contrast, fundamental principles of social evolution and environmental history, and the types of issues and problems that have emerged from a long evolutionary and historical partnership between society and nature are mostly neglected. In particular, there is urgency for research and the development of comprehensive theories that focus on factors and aspects of human culture responsible for creating the system-immanent mechanisms of unsustainability.

This paper draws together various concepts and evidence from biological, anthropological, paleoecological, historical, political and economic research and presents a comprehensive theory to explain human evolution in terms of natural sciences and system theory. Cultural evolution, history of mankind and even the ecologically unsustainable performance of people are seen as the continuation and part of biological evolution of a species that was and still is an integral part of a holarchical subsystem, the Earth's ecosystem. Things that are often treated as purely cultural in humans "*have deep roots in our animal past and thus are quite likely to rest on direct genetic foundations*" (Hamilton 1975). Additionally, with Prigogine *et al*. (1977), we are convinced of the need that "*the basis for any natural law describing the evolution of social systems must be the physical laws governing open systems, i.e., systems embedded in their environment with which they exchange matter and energy.*" This might be a trivial statement for many modern anthropologists and many natural scientists, but it is far from being part of general knowledge and education.

Homo sapiens evolved as a biological subsystem of a concrete local ecosystem: a small population of Pleistocenic African primates that started a new evolutionary lineage. Common to all other forms of animal life, the evolution of humans was a result of a systemic process of interaction with other species as well as with the abiotic components of its 'home' ecosystem. What is particularly distinguishing about human evolution from that of other animal species is the emergence of intelligent, self-reflective individuals, whose complex social behaviour and cognitive skills extend far beyond the boundaries of instinctive behaviour. Complex social behaviour exists in many taxonomic groups including insects, birds and mammals but it is the sophistication and subtlety in human behaviour that allows for forward planning, anticipation of outcomes, constructivism, and application of reason to actions that sets this species apart from all others, and by some considerable margin. The ability to exercise social cooperation has given rise to the ever accelerating formation and complexification of subsystems driven by interacting people, communities and the wider society. The result is the emergence of a complex anthroposystem that is not driven just by biological interactions and corresponding rules and restrictions, but also by the emergence of cognitive constructs that serve as complex metaphors for the physical heterogeneity. Furthermore, the evolution of intelligence has allowed for increasingly complex abstract interpretations of reality that lead to social interactions with an inherent logic (which however can be explained as traits that have arisen during biological evolution). Furthermore, the development of intellectual skills to 'read' and anticipate the thoughts and actions of others (theory of mind and Cognitive Hierarchy Theory) has greatly advanced human social systems. Even human empathy, prospection, intentionality and strategic ecosystem management come into the play. However, the systemic nature of evolution—both biological and cultural suggest that it is not a sequence of accidental events and chaotic diversification; but rather, it is the tendential creation of order—at the cost of energy turn-over and the increase of entropy in other systems—and, thus, a certain driveness along "evolution's arrow" (Stewart 2000).

Balée & Erickson (2006b) try to construct a conflict between natural and system sciences on the one hand, and historical ecology on the other. They repudiate the idea that human systems adapt to the environment and claim that "*the concepts of the ecosystem, systems ecology, and cultural ecology ultimately tend to deny human agency in positively shaping the environment over time*". This interpretation applies rather simplistic and mechanistic principles of systemics to anthropology. An alternative thesis is offered in this paper that argues the case that special circumstances including the complex interaction of a diverse range of social systems at several scales as well as interactions with holarchically nested metasystems as part of the global ecosystem have given rise to a "supertramp" species capable of modifying the environment it lives in according to its needs.

History is littered with examples of large scale changes to local and regional landscapes as a result of human behaviour including wars, trade and socio-economic development. For instance, centuries ago, in the far east, large reservoirs were constructed at Angkor wat; the Beijing-Hangzhou Grand Canal was built in China; and an estimated 70,000,000,000 kg/m^3 of stone, earth and brick were extracted from the surrounding landscape to create the 6,000 km long Great Wall of China. Equally, in Eastern Europe, long-standing battles between the Russians and the Tartars were responsible for the creation of the Zasechnaya cherta (Abatis line) that extended for more than 1,000 km and included extensive earthworks and impenetrable belts of forest and scrub. Patterns of human activity across the globe share similarities that would indicate the evidence for local distinctiveness in human landscape interactions is rather weak. A cultural materialism that simply explains cultural differences with local differences of ecosystemic resources falls far too short. What is more, evidence for increased local and regional biodiversity that can be related to human social behaviour (Balée & Erickson 2006b) is not incompatible with a strictly systemic theory that follows the principle that humans arose as a part of nature and are still nature, and thus, are not freed from the laws and restrictions of nature. Historical ecology proposes that "*the human species is itself a principal mechanism of change in the natural world, a mechanism qualitatively as significant as natural selection*" (Balée & Erickson 2006b)—this is definitely true; therefore, nowadays, we even have to speak about anthropogenic global change.

Nature is objective, and unlike human cultural society, there is no value-based judgement, no sense of "good" or "bad". Thus, we do not search for the "*ecologically noble savage (Homo ecologicus, the idealized human species that is inherently custodial and nurturing of nonhuman nature) nor (…) the ecologically ignoble savage (Homo devastans, the idealized human species that is biologically programmed to destroy nonhuman nature)*" (Balée & Erickson 2006b). Nature plays out its role according to a set of laws and processes, including thermodynamics, evolution, and chaotic, indetermanistic disturbance patterns. Humans, by contrast, observe, rationalise, anticipate, plan, design, and change the course of outcome to suit their needs. In their work Delcourt and Delecourt (2004) integrate ecosystem theory with certain theories in social science to propose "Panarchy theory". This concept explains the complex interactions between humans and their environment as adaptive responses that result in self-organized hierarchical systems. *Homo sapiens* would have started to act as a keystone species in Pleistocene ecosystems, which were metastable, non-equilibrium adaptive systems. Aggregation of panarchical levels contributed to the establishment of increasingly complex social systems that continued to interact with the environment, and out of this relationship emerged new transforming strategies in ecosystem management (Delcourt & Delcourt 2004).

Common to all species and ecosystems, human social systems are subjected to the same laws and dynamics involving the exchange of energy, matter and/or information. Energy and material flows, are correlated with the size of the population. However, beyond a certain size and complexity of the anthroposystem energy and material flow also correspond to emergent properties which cannot be fully explained by the analysis of biological and ecological system characteristics. Thus, the anthroposystem starts to turn over more energy and matter than required for the maintenance of the biological system components—the individuals. On the one hand, the impact of the anthroposystem grows disproportionally, and on the other hand, its hypercomplex integration in practically all ecosystems on Earth and the globalization of energy, material and information flow makes these impacts ever more indirect and atopic—and thus less predictable.

Paradoxically, as social systems have become more sophisticated the interactions between the numerous subsystems have also evolved from a predominance of material exchange towards a more information-based process. Examples of this transition are found in most aspects of society. For instance, in the world's financial system and many other technologically driven business transactions between customers and providers involves the transference of information, much of it in virtual format. This seeming decoupling of social systems from ecosystem-imposed restrictions triggers an accelerating emotional and conceptual alienation of an ever increasing percentage of people from the ecosystems they depend on. The existence of highly evolved, abstract social systems, which are rather dematerialized, nourishes the fundamental misunderstanding that social systems can exist disconnected from the rest of nature and that further evolution (or even growth!) of the anthroposystem can be decoupled from energy and material flow in ecosystems.

The combination of various factors, detailed in the following points, contribute to this de-coupling and inevitably lead to unsustainability and environmental disfunctionality.

1. a tendency towards locally-simplifying, 'un-natural' (=cultural) and a static perception of the human environment in contrast to a complexifying world with exploding information and knowledge (complexity trap, knowledge trap and alienation-from-nature trap)
2. increasingly atopic, globalized uses <u>and</u> changes of ecosystems neither directly influenced by local action nor perceived locally (globalization trap)
3. strong systemic drivers that, for the sake of apparent system stability, growth and prosperity, reconfirm and enhance growth of energy and material turn-over of the anthroposystem that fuels non-linear changes in Earth's ecosystems (system trap).

We are convinced that the past and future evolution of the anthroposystem can be systemically analyzed and that any approach to sustainable human development must take into account the relevant system components and the system-inherent drivers and directions of change.

B.2.2.a A SYSTEMIC TOUR DE FORCE THROUGH EARLY EVOLUTION OF HOMO SAPIENS: BIOLOGICALLY DRIVEN ALIENATION FROM NATURE AS AN INEVITABLE COST FOR THE BENEFITS OF CULTURAL DEVELOPMENT

BIPEDALITY AND MEAT-FED, ESCALATING BRAIN GROWTH LEAD TO SYSTEMIC CONSTRAINTS FOR EVOLUTION

The origin of the genus *Homo* and the species *Homo sapiens* can be tracked back to pleistocenic Eastern Africa, where our ancestors evolved in a systemic play of changing habitat conditions and existing traits (McHenry 2009). Relevant habitat changes seem to be related with drying climate and the expansion of open savannahs which favoured further development of upright, bipedal locomotion (uplifted head and good overview over savannah, more efficient translocation; McHenry 2004a, 2004b). Other distinctive evolutionary developments included the loss of hair and the development of sweat glands, both prerequisites to an active, almost frenetic existence. The already habile 'great ape hands' then could be further developed allowing the evolution of handcraft skills. Increasing handcraft activities, and the development of technology demanded higher intelligence and ever more sophisticated thought processes.

The evolution of *Homo* out of *Australopithecus* is also related to a shifting of diet from a rather vegetarian nutrition towards more meat consumption, which may have started with cooperative stealing from other predators, scavenging and bone-cracking (Aiello & Wells 2002, Stiner 2002). Ungar *et al.* (2006) suggest that early *Homo* species developed dietary adaptations for flexible, versatile subsistence strategies that would have served them well in the variable African paleoenvironments. Definitely, there was a use of a variety of other food resources than just mammalian meat such as invertebrates, fruits, seeds etc. (Aiello 2002). However, increased reliance on mammalian meat and fat appears to have encouraged the development of both a larger body and brain. Aiello (2002) identify a diversion of energy towards brain metabolism at the expense of gut tissue. Inevitably, dietary changes towards higher dependency on energy-rich food led to increased costs of survival and reproduction. Furthermore, the same authors concluded that these increased costs would have been met by adaptations in energy stores such as increased tendency to store fat against leaner times; reproductive schedule; social interaction; changes in body form and leg length; and in foraging strategies favouring the evolution of division of labour.

SECONDARY ALTRICIALITY AND SOCIAL COOPERATION

Human infants have about 9% higher energy requirements than similar size apes, and increasing energetic costs have been related with the prolongation of growth rates and secondary altriciality (Foley *et al.* 1991). Human neonates are much more helpless than those of our ape relatives, and it has been suggested that they function more as a fetus rather than an infant (Rosenberg & Trevathan 1995). The increasing brain and head size of the neonates, in combination with decreased size of the bony birth-canal as consequence of the adaptation to bipedal locomotion, additionally contributed to the extreme helplessness of the neonates as well as the need for an assisted birth (Rosenberg 1995, Trevathan 1996). In fact, the evolution of bipedality and larger craniums contributed towards 'altruistic' behaviour during the birth process, and this, in turn, triggered social cooperation among group members and the elaboration of cultural systems (Trevathan 1996). Coqueugniot *et al.* (2004) concluded from the detailed analysis of a skull of *Homo erectus* that secondary altriciality was established quite late in the genus *Homo*, maybe in the common ancestor of *Homo sapiens* and *Homo neanderthalensis*, and that *H. erectus* was characterized by only a short period of brain maturation in the extramaternal environment. Bipedality and the birth-canal changes serve as good examples of how in the course of evolution evolved features, which themselves can start to act as systemic constraints and feedback-selection factors narrowing the corridor of future evolution. Thus, clearly, organismic evolution is not exclusively dependent on environmental factors of the ecosystems.

Extended parenting in humans not only originates from earlier primate behaviour but also shares similar characteristics with less developed primates. In humans this will have been another important factor for enhancing the formation of rather stable family groups or clans. Together with the increasing need for high-energy-dense food, the division of labour and the development of ever more sophisticated foraging and finally hunting behaviour was inevitable. Hunting in groups, as well as other evolving cultural interactions between members (such as assisted birth, education of children), contributed to the growing development of cognitive abilities and communication, especially language (Coqueugniot 2004). The rise of modern language, related to rapidly increasing cultural complexity, is thought to date back to approximately 40,000 yBP (Cunningham 1999). However, more recent findings that document the spread of humans across African and to the other continents suggest that the development of language started much earlier (Khoisan matrilineal ancestry: 90-150,000 yBP, out-of-Africa dispersal: 60-70,000 yBP; Behar *et al.* 2008). There is further evidence to suggest that Neanderthals shared with modern humans the same FoxP2 gene for language, and that there were many examples of material proxies for symbolic communication (Soressi & D'Errico 2007). This might push the date back for language development even further. Sophisticated oral communication revolutionized the development and transference of experience and knowledge between groups and across generations. It also represented a significant driver for greatly increased cognitive skills, in particular, the ability to reason, the very hall marks of *Homo sapiens* (which make us think that we are so different from the rest of species) (see also below).

Conscious and complex social cooperation that manifest in cumulative culture are among the most important innovative and autapomorphic features of *Homo sapiens.* However, these traits are rooted in the behaviour of earlier ancestral species. Clearly, cooperation in humans first evolved through natural selection within families and clans ('"kin-selection"; e.g. Hamilton 1975, Axelrod & Hamilton 1981). The individual advantages of cooperation have been explored applying the approach of game theory by explaining how cooperation based on reciprocity can evolve. Of course, in the case of intelligent organisms, conscious game-playing develops into a very sophisticated form of behaviour involving complex memory, complex processing of information to determine the next action as a function of the interaction so far, a better estimate of the probability of future interaction with the same individual, and a better ability to distinguish between different individuals (Hamilton 1975). Simple reciprocity-based cooperation often proves to be a much more successful strategy than denial of cooperation and defection (Axelrod 1984). In social groups there is a reward for cooperation even in the absence of reciprocity: reputation. Cooperative people tend to have a positive reputation which indirectly favours cooperation through better positions in society and better access to resources and power.

The importance and relevance of power, leadership and reputation increased measurably with the development of larger and more complex social system, and as behaviour evolved reputation started to work as another motor of human socio-economic and intellectual development. Over time, status symbols e.g. related to ornaments without direct function as well as personal property and above-needs consumption emerged as a distinctive social trait. This particular aspect of the human character became an important driver of cultural development in the fields of design, arts, and architecture, and more recently, a trigger for the "industrious revolution" (de Vries 2009). When it became important to practice reciprocal cooperation and judge the relevance of reputation and status symbols cheating and lying were logical inventions. Thus, it was necessary to improve the abilities of discriminating interacting partners in order to decide if cooperation appeared to be promising or not (Hamilton 1975)—*en passant* fuelling intelligence and brain development. The detection of cheating cries for punishment because it violates the principles of societies based on cooperation. Clearly, here we can see the origin of morality, the definition of good and bad or false and wrong—and also the starting point of collective justice (Hamilton 1975).

SPEAKING, THINKING, PROSPECTING, BELIEVING AND THE DISCOVERY OF (UN-) SUSTAINABILITY

The development of language was the invention of a complex symbol system that required the capability of abstraction and reflection. It seems logical that another distinctly human characteristic, the ability for self-referential (autopoietic), and self-reflection emerged as complementary traits. The ability for deep self-reflection implied an awareness of the future and individual mortality. The human brain developed the capability to rapidly assimilate and rationalise substantial amounts of information gathered from observations of the surroundings. Furthermore, the mind had the capacity to convert these observations into complex abstracts and metaphors to suit cultural constructs; information was used to internal models of the external world which are fed by memory (past), perception (present) and simulation (future) (Gilbert & Wilson 2007). Neuroimaging studies show that both the prefrontal cortex and the medial temporal lobes are especially activated by prospection (Gilbert 2007). This is the same brain region, which made significant progress in *Homo heidelbergensis (*thought to be close to a common ancestor of *H. sapiens),* and also in *H. neanderthalensis,* which lived in Africa and Europe 200-600,000 yBP. This part of the brain is related to inhibitory control and goal-maintenance, abilities related to advanced social cooperation (Dubreuil 2010). More complex cognitive tasks such as perspective taking, complex categorization, or semantic processing have been related to changes in the brain's temporoparietal cortex; these occurred later in the evolution of *Homo sapiens*, when symbolism, art and cumulative culture arose (Dubreuil 2010). Recent findings also indicated that European *H. neanderthalensis* demonstrated behavioural modernity and the emergence of symbolism (Zilhao *et al.* 2010). Social cooperation, human cognitive abilities, language and culture are not the result of co-evolutionary processes peculiar to one species only but rather can be explained as emergent properties arising from a process of systemic escalation during hundreds of thousands of years (Dubreuil 2010).

The fact that humans started to predict the consequences of events they have never experienced by simulating those events in their minds, developing prospection and 'pre-experience' (Gilbert & Wilson 2007) can be considered a revolutionary cognitive innovation (very relevant for both unsustainable and sustainable behaviour). Unfortunately, human simulations of future events tend to be unrepresentative, essentialized, abbreviated and decontextualized and thus commonly lead to erroneous predictions (Gilbert 2007). However, the really important fact is that with *Homo sapiens*, for the first time in evolution, the (simulated) future started to have an impact on present decision-making and thus present events (Willke 2002)—a highly relevant emergent property of the anthroposystem.

Through a process of continual enquiry about the future and personal fate, early *thinking humans* were quick to recognise the paradox of knowledge and 'knowing', that enquiry reveals the extent and depth of ignorance (compare Socrates, in his apology, as echoed by Plato: "*I know that I do not know*")—an increasingly shocking awakening of self-consciousness, a real loss of 'innocence'. The awareness of non-knowledge especially related to death and life after death but also to manifold natural events and features. The sense of vulnerability born out of ignorance gave rise to spirituality and the development of religion that would provide answers and orientation in a frightening world. Sooner or later religion became an important driver of social organization and human development. Faith encouraged humans to extend intellectual and cultural frontiers. Alongside the norms of morality also came feelings of guilt and responsibility. Finally, motivation for social cooperation was lifted up to a completely abstract level of reciprocity and gain of reputation—humans aspired towards seeking acknowledgement in the eyes of god(s). Manifest in nurtured moralistic tendencies and behaviour is the ability to recognise *unsustainability*, and to incentivize individuals to practice ecological rationality.

EARLY BIAS TOWARDS SOCIAL SYSTEMS

Social cooperation and verbal communication laid the foundation for a completely new dimension of systemic interaction in the form of thought or spoken information. The door was open for the evolution of ever more complex social systems whose function was not genetically programmed and chemically regulated (as in social insects). The cooperation-based social systems benefited the individuals, kins and their fitness, and thus were reinforced by evolutionary feedbacks. As humans evolved as part of an increasingly complex social system, it was advantageous to the individual to focus on successful societal membership rather than invest time and effort on ecosystems. Membership of ecosystems was taken for granted, and threats arising from ecosystems—such as predators, food shortages or other extreme events—could be buffered and mitigated by social groups and technological development. This paper maintains that the development of the nature-culture antagonism and increasing alienation from ecosystems started very early in human evolution as a consequence of social and cultural capabilities, and that an individual's investment in developing social skills is under biological control. Clearly, the nature-culture antagonism became ever more relevant in the course of the Neolithic and especially the industrial revolution and was increasingly elaborated conceptually and culturally.

B.2.2.b SPREAD AND RISE OF THE ANTHROPOSYSTEM AND CHANGING INTERACTION WITH OTHER ECOSYSTEM COMPONENTS

DENSITY-DEPENDENT CULTURAL EVOLUTION

Social cooperation, culture and technology (especially the use of fire and later of clothes) allowed humans to spread beyond the limits of their original habitat. In fact, it was more than geographical expansion—it was the first time in evolution that a species was actively amplifying its ecological niche, despite the insignificant evolutionary changes to its genetic and biological make-up. In common with all other species, human reproduction and exploitation of the ecosystem follows principles of non-equilibrium thermodynamics, that is, energy turn-over maintaining individuals, populations, and social systems by utilising the energy stored in other species and parts of the ecosystem. Unless there is a restriction of energy or material resources (e.g., nutrients), in biological systems, reproduction tends to be accompanied by an increase of numbers of subsystems (multiplication of individuals and populations) and growth, i.e. increasing turn-over of energy and matter and of energy stored in biomass of the system. Proliferation of (sub)systems increases their density thus favouring interaction and complexity. Understandably, it took a relatively long time for humans to spread around the continents before reaching critical densities that would trigger the development of systems of higher order with new, innovative emergent properties.

Indirect genetic evidence indicates that sub-Saharan African populations fit models for population growth beginning in the Late Pleistocene which then would have facilitated the evolution of Late Pleistocene cultures (long before the development of agriculture; 41 thousand yBP) (Cox *et al.* 2009; compare Mellars 2006). The structure of early settlement dynamics in Africa implies the formation of small, independent human communities typified by delayed cultural development whilst African populations remained isolated from each other (50,000-100,000 yBP). It was not till later, once more favourable climatic conditions prevailed, that range expansion occurred and cultural development advanced more noticeably (Behar *et al.* 2008). The achievement of reaching critical population density marked a threshold or tipping-point triggering a new phase of cultural evolution after a long lag period without significant cultural progress. This is despite biologically determined modern cognitive capacities that evolved 100-150,000 years earlier. It has been demonstrated that demography is a major determinant in the maintenance of cultural complexity and that variation in regional subpopulation density and/or migratory activity results in spatial structuring of cultural skill accumulation (Powell *et al.* 2009). Thus, demographic factors can explain geographic variation in the timing of the first appearance of modern behaviour without invoking increased cognitive capacity. Modernity in this context describes technological and cultural complexity, including the first consistent presence of symbolic behaviour including systematically produced microlithic stone tools, grinding and pounding stone tools; improved hunting and trapping technology; it is probable that this cultural evolution should have led to a systemic positive feedback on population density (Powell *et al.* 2009). For instance, in South Asia, a significant demographic transition in the subcontinent, dating to 35,000–28,000 yBP coincided with a period of ecological and technological change, especially related to new diminutive stone blade (microlithic) technology (beginning 35,000-30,000 yBP) (Petraglia *et al.* 2009).

A CLEVER, OMNIVOROUS SPECIES WITH REDUCED VULNERABILITY AGAINST RESOURCE DEPLETION: THERMODYNAMIC SYSTEM EFFICIENCY DRIVES TOWARDS UNSUSTAINABLE HUMAN BEHAVIOUR

Advances in cultural and technological complexity together with an increase in population density marked a significant change in human impacts on ecosystems. Humans had already evolved unique hunting techniques that included deliberate selection of the reproductive core (prime adults) of ungulate populations (Stiner 2002). This unconventional strategy was potentially disruptive to prey population dynamics, but was locally feasible for omnivorous predators that were able to opportunistically switch to other food sources whenever the density of favoured prey declines from hunting pressure (Stiner 2002). Furthermore, range shifting/expansion was an adaptive strategy against consequences of local resource overuse.

These findings go some way towards explaining the rather sudden historical extinction of certain megafaunal species on all the main continents. The popular hypothesis holds that Pleistocenic megafaunal extinctions on most continents and islands could have been linked to the appearance of modern man (e.g., Martin & Klein 1984, Roberts *et al.* 2001, Alroy 2001, Brook & Bowman 2002, Steadman 2002, Delcourt 2004, Diniz-Filho 2004, Barnosky *et al.* 2004, Faith & Surovell 2009). However, hunting was not solely responsible for species loss everywhere; and at least in some regions an intersection with climatic change was a more likely reason (Barnosky 2004). Scientific evidence indicates that the period of elapse between human arrival and major faunal extinction events was highly variable on oceanic islands as well as on continents (Steadman *et al.* 2002). The more likely scenario for mass extinction of large fauna was a combination of hunting pressure coupled with a massive change in vegetation, mainly related to the human use of fire (e.g. for hunting purposes; "*overburn*"; Williams 2006).

Delcourt & Delcourt (2004) in their findings on the history of Pleistocenic Eastern North America nomadic hunters concluded that several factors contributed to the demise of mega fauna. In their analysis they demonstrated how "*natural ecological systems*" were transformed to "*culturally managed ecosystems*", "*shifting in balance through time and space from predominantly natural adaptive cycles to ones increasingly interlinked with anthropogenic activities*". Human cultures would have evolved as part of nature but became a unique ecological factor with long-term impact. With increasingly unstable late Holocene climates, prehistoric Native Americans also would have contributed to ecosystem degradation by over-exploitation of wood resources and by intensive cultivation of introduced crops.

Biological evolution seems to select for sustainable systems by default. The laws of thermodynamics, when applied at all levels, favour forms and functions in biodiversity (and wider environment), that are efficient at degrading or dissipating energy and generating exergy capital. However, this did not mean that abrupt dramatic system changes were autiomatically avoided. The perception is of nature operating in balance, with little evidence for stochastical changes in populations or of wholesale depletion of resources. In most cases the self-regulating forces are very effective in local ecosystems.

The ability demonstrated by *Homo sapiens*, to alter ecosystems in such a way as to 'cheat' the natural laws of carrying capacity and resource depletion might help explain why locally unsustainable patterns of behaviour continued unchecked through the course of human evolution. Improvements in hunting strategies as well as the development of technology made allowances for smaller sized hunting parties and this in turn triggered greater individual task specialization within cooperative networks (Stiner 2002). It was the emergence of increased efficiencies in transference of both energy and material, made possible through improved cooperation, which enabled humans to extend beyond their ecological envelope despite the biological constraints associated with their life history (Hamilton *et al*. 2009). Astonishingly, we clearly see a case of how increased thermodynamic system efficiency led to a feedback loop fuelling cultural evolution, system growth, increased resource needs and consequent unsustainable behaviour.

CULTURAL PROGRESS IN SESSILE CONDENSING POPULATIONS AND THE RISE OF HUMAN IMPACT ON ECOSYSTEMS

A dependence on meat not only asserted human claims as a top predator but also set limitations to population growth and abundance. This explained why most carnivorous Eurasian hominids were also the most highly dispersed (Stiner 2002). Early human societies partly resolved this problem by establishing settlements along coastlines where food was relatively accessible, in plentiful supply, rapidly replenished and diverse enough to ensure optimum foraging opportunities. Under these conditions humans were able to migrate rapidly along coastlines, even across to new continents (Walter *et al*. 2000). Coastal systems also acted as vital gateways to human movement and contact, from early hominid expansion to the rise of the coastal and riverine civilisations (Bailey 2004, Petraglia & Alsharekh 2003).

Early coastal communities lived as hunter-gatherers, existing according to the ‘rhythms’ of nature and leaving little evidence of their activities from one generation to the next. However, this changed significantly at the onset of agricultural development. The establishment of agriculture in some regions, approximately 10,000-7,000 yBP, was possibly triggered by an improvement in climatic conditions and the coincidental domestication of crops and animals (Gupta 2004). This transition changed profoundly the trophic status of human society, and the relationship it had with the natural environment. Humans had, in part, broken free of the inter-dependency between populations and resource availability. Instead, cultures were able to select a wide variety of energy-rich food to cultivate and harvest. Furthermore, it soon became possible to generate a surplus to requirements, and this presented opportunities to provision for times of little. Those cultural societies that developed a crop-based form of agriculture, particularly in fertile regions, were able to build settlements and communities around the arable lands. In less fertile areas such as the tropical rain forests a more flexible system of shifting cultivation was practiced. Societies that chose a pastoral existence were required to move with the seasons and practice a typical nomadic lifestyle. In regions with infertile soils, like in the tropical rain forests, even farmers were forced to move regularly (shifting cultivation).

Despite the obvious benefits agricultural brought to many cultures, both hunter-gatherer and pastoral societies persisted throughout history, in many cases choosing not to adopt the more sophisticated agricultural lifestyle (Johnson & Earle 2000). One theory for this diversity of lifestyles is the concept of multilinear evolution where each kind of adaptive solution to a given environmental situation contains its own set of possibilities for further cultural evolution (Johnson 2000). It is plausible that in many cases the scarcity of natural resources and the relative unfavourableness of habitat impeded further social complexification (compare Diamond 1997). But it was not only the abiotic habitat and the availability of usable species. Each society had to adapt not only to the local ecosystems but also, increasingly to other neighbouring or invading social systems (Johnson 2000). What is certain is that the sessile agrocentric cultures would not have evolved as they did without significant interactions with nomadic pastoralists. For hundreds of years, nomadic peoples played a key role in historical processes, for instance, in Asia and Europe (e.g., Mirow 2009). They triggered warfare and miltary technological progress (see below), but also catalyzed the exchange of technological innovations between rather isolated sessile states.

In areas of high ecoregional and biological diversity, for instance in mountainous regions, a differentiation and specialization of cultures and land use types has been observed where different ethnic groups with separate backgrounds and economies persist in neighbouring ecosystems, exploiting different ecological, mostly altitudinally defined zones (e.g., in Pakistan, Johnson 2000; the Carpathians; and the tropical Andes). Often the agriculture-based, high-density groups excluded others from the prime lands, but allowed and benefited from vertical exchange of products (Johnson 2000, Murra 1972, VanBuren 1996).

It is probable that unsustainable ecosystem 'management', like overhunting ungulates, and subsequent resource shortage in many cases triggered technological innovations in attempt to resolve these problems (Delcourt & Delcourt 2004). Life-style changes that encouraged an increase in population density also prompted development in task and labour-sharing behaviour and this, in turn, promoted improved organizational development of the social systems in order to guarantee access to resources (and mitigate arising conflicts, see below). Often this process was achieved by the establishment of systems of higher order. Delcourt & Delcourt (2004) describe the various panarchical levels of human-ecosystem interaction and the related social complexification as well as the spatial expansion. The following levels largely correspond to their classification and terminology (which was also informed by the concepts proposed by Johnson (2000):

1. Foraging mode of subsistence of autonomous, local, mobile groups
(unlimited movements in vaguely defined home ranges minimizing competition; < 100 persons/100 km^2)
⇨ increasing human density, intensification of food resource use, depletion, competition, semi-sessile lifestyle push towards a more complex organization ⇨

2. Forager-horticulturalist mode of sedentary villagers
(several hundreds of people in territories of 300-500 km^2)
⇨ sedentary human village groups adopt ownership sense of land tenure; ancestor-granted stakeholder rights and rituals bind people in their ecological neighbourhoods; intensification of land use and population growth lead to conversion of ecosystems at landscape and regional scales ⇨

3. Chiefdoms and national states
(thousands to ten-thousands of people in defended territories of up to 10^5 km^2)
⇨ local groups are more interlinked and are governed by more comprehensive institutions; arising social stratification; establishment of leading elites who control production and re-distribution of agricultural commodities; arising trade of high-status items; accumulation of material wealth; ideological direction of ceremonies and rituals; rising importance of military dominion and often conquest of new territories ⇨

4. Agrarian nation states and empires
(e.g., Maya state: 3-14 Mio. people, $1.6x10^5$ km^2, Inca empire: 8-14 Mio. people, $9x10^5$ km^2)
⇨ elaborated social stratification; states centrally controlled by ruling elite governed by military might, merchant class maintained economic control over rural agriculturalists.

This evolution and increase in sophistication of social systems has happened convergently various times through the early history of mankind. However, in nearly all cases the original set of environmental and social conditions of founder societies were unique. Recently, Spencer (2010) demonstrated, using archaeological data from six areas in the Americas and Eurasia where primary states emerged in antiquity, that there is a correspondence in time between the first appearance of state institutions and the earliest expansion of the state's political-economic control to regions lying more than a day's round-trip from the capital. It was apparent that state building and complexification was dependent on subsystem density, spatial extension and transport/communication technology. According to the territorial-expansion model the success of growing social systems and "*long-distance expansion not only demanded the bureaucratization of central authority but also helped provide the resources necessary to underwrite this administrative transformation*" (Spencer 2010)—here we find a feedback loop self-catalyzing state and nation-building once a critical mass of subsystems has evolved.

Apart from the well known complexly organized cultures and empires, especially those with prominent architectural testimony (e.g., Egyptians, Inca, Maya), many other chiefdoms and states also were able to significantly change ecosystems and biodiversity, even in landscapes commonly seen as virgin and untouched by humans (e.g., the chiefdoms of the eastern Bolivian Amazon and upper Xingu River, or the major polities along the Amazon River in late prehistory (Balée & Erickson 2006b). In some cases they may have persistently changed ecosystems that remained in states different from the one prevailing before the anthropogenic change, even after the dawn of the complex social systems, and this, as in Bolivian Amazon (Beni flooded savannas, forest islands), may even have been related to regionally enhanced geo- and biodiversity (Balée & Erickson 2006b)

INTERWOVEN CULTURAL FEEDBACK LOOPS: NATION-BUILDING, WARFARE, RELIGION, AND THE DEVELOPMENT OF GOVERNMENTAL AND LIFE-STYLE SYSTEMS

Agricultural development spawned a social revolution including changes in organization, cosmovision and religion. Improvements in social organisation and the development of economic constructs were relatively rapid and demanded political and regulatory frameworks if they were not to collapse. Population growth expanded dramatically around these social hubs putting pressure on local resources and setting off conflicts and warfare with neighbouring centres over territory and much needed natural capital. Humans are predisposed to aggressive behaviour within the species, a common trait shared by a close relative, the Chimpanzee (e.g., Wrangham 1999). Evidence of warfare in early and mid-Neolithic societies is rare (at least, there is very little reference to it in cave paintings) (Pericot 1961, cited by Hamilton 1975). However, as civilizations emerged out of settlements war featured much more prominently in recorded history (Hamilton 1975). In agrarian and sessile societies that developed concepts of value, reputation and status attached to the ownership of land and goods, stealing and robbing would have become a more rewarding business but at the same time would also have sparked off conflicts.

Social development towards more complex systems coupled with increases in population density, helped by a change in diet, introduced new threats and vulnerabilities, particularly to agrarian societies. For instance, the fortunes of farmers were much more dependent on climate, weather and soil conditions. In some densely populated parts of Eurasia certain sectors of society suffered from nutrition-related health problems and this was reflected in individual stature (Stiner 2002). Furthermore, the political and economic status of individuals also changed, creating a social diaspora between the rich and poor. In extreme cases famines started to influence political events and the course of history, a problem that has persisted through to modern times (e.g., French revolution, emigration from Europe to North America, famines and economy-motivated migrations across sub-Saharan Africa). In China, dynasty changes have been seen to coincide with internecine wars which were often triggered by famine or density pressure (Chu & Lee 1994). Thus, in densely populated states the re-distribution of agricultural commodities and the management of arising scarcity, poverty and potential unrest, especially in the lower strata, became a crucial issue of overall system stability fostering more and more authoritative and suppressing systems of governance. Societies or the ruling subsystems of societies needed to protect themselves against threats: social parasitism, internal disorder and external aggression of ever closer co-existing communities. This explains the rise of chiefs and finally kings protecting ordinary people by managing more and more organized armies. From the early beginnings of chieftains and principalities emerged larger feudal systems, in some cases, empires, that offered some measure of protection to the population masses. These asymmetric systems developed the first resource protection policies, and in some cases they were related to the establishment of hunting reserves for the elites—a conservation theme that appeared in various cultural contexts and until recent times. Biodiversity conservation, here, was a by-product of asymmetric resource allocation.

It was not uncommon for young feudal systems to develop their own dynamics and logics and even decouple from the processes responsible for their emergence. Consequently, warrior chiefs and kings strongly influenced the development of social systems without necessarily supporting the needs of the people or the overall sustainability of the community. In fact, the industrious activities of the community were exploited as a source of wealth for the ruling members (Williams 2006). Population was even managed and shifted within the landscape for the sake of power and socio-economic 'progress' (e.g., *mitima* policy of the Inca [Wachtel 1982], immigration policy of the Chinese Ming dynasty to create a densely-settled core of the country [Williams 2006], or the Great Elector's policy of inviting immigrants in order to re-establish a viable state of Prussia after depopulation through the 30 years' war). For as long as these feudal states existed in relative isolation a certain degree of stability persisted across regions. It wasn't until the development of more effective transport and information communication systems that the relative stability of these states became more fickle. Ironically, technological advancements in both fields propagated warfare and conflict, and in some cases societal organization, advancement and complexification were actually retarded by violence (negative feedback).

Large scale warfare had a significant impact on local and regional ecosystems. In some cases, population down-turns following war led to the recovery of degraded ecosystems (e.g., in depopulated Europe after the 30 years' war, although the war itself had fuelled degradation, such as in Pomerania where the Swedes cut down large areas of forests; Williams 2006). However, under different circumstances, for instance in northern Vietnam during the late Holocene, it was warfare rather than agriculture that contributed to fire regimes and subsequent landscape degradation (Li *et al.* 2009).

The selection pressure for the advancement of military technology and warfare was strong in all agrarian states. On all continents, in all periods of history, it were the efficiently armed, warlike nations that succeeded conquering or even eliminating the more peaceful and less armed ones (from warlike Bantus largely replacing the khoisaniform peoples [Hamilton 1975] to the Inca conquering Aymara cultures in the Central Andes, or to Europeans destroying or seriously harming indigenous cultures in Africa, America and Asia). In fact, all the sub-global or intercontinental European empires arising in the 16th century were "gunpowder empires" McNeill (1993), cited by Osterhammel & Petersson 2007).

The processes of social evolution that led to the development of settlements and later feudal systems existing in conflict were a natural phenomenon free of any value judgement; it was neither good nor bad. Neither biological nor cultural evolution lead to the 'survival of the fittest' but rather to comparative advantages for systems that under given conditions can grow and use resources more efficiently and rapidly than others. However, this does not mean that these systems are well adapted to change of conditions or will be more persistent than others. Rather, there are sufficient examples that show that systems' evolution can regularly drive into dead ends, extinction and collapse (see below).

In some cases feudal oppression itself, once decoupled from the motifs related to the distribution of commodities and system stabilization, led to sociopolitical unrest (e.g., European Peasants Revolt of 1524; Williams (2006). Consequently, there was strong pressure for the elites and especially the chiefs, kings and emperors in the more advanced states to fortify and justify their authority and suppressing action. Oppression was not the only means of exerting influence on the masses. Evidence from around the globe indicate that leaders also engaged with religion thus combining the development and integration of state and religion to varying degrees of influence. In some cases rulers established positions of deity or divinity thus sealing their complete authority over the people. The interwoven feedback-loop of religious, governmental and life-style systems became a powerful driver for cultural evolution. Commonly, the kings of agrarian nations promoted themselves as divine representatives or deities, often related to the notably most important power, the sun. This invited public loyalty to the both the state and its rulers, to the extent that enormous efforts were made towards the construction of various monuments and effigies, as well as building up military operations. These efforts did not necessarily have a direct or short-term benefit, such as improved access to (food) resources.

The transition from hunter-gatherer societies to agrarian systems very often[44] led to the decrease in the number of deities and goddesses. This suggested that a significant part of nature ceased to hold any reverence in the minds of people (e.g., plants and animals). Agrarian societies developed dependence from other components and processes of the ecosystems, especially those related to soils and weather. After overcoming pantheistic worship through a de-coupling process with nature, the focus on human self-awareness and self-importance was sharpened. New representations of gods took on human qualities but also with a functional role in controlling the various forces of nature such as sun, seasons, weather, earthquakes, flooding, earth's fertility etc. Increasingly, societies adopted a functional aspect towards nature, dividing it crudely into "useful" and "harmful." This provided the necessary justification (even spiritual) to tame the beast in nature, remove all unnecessary obstructions to progress including the "wilderness" (wild woods, wetlands and scrub). Farmers started to intentionally manage and reshape ecosystems according to their needs, building mounds, hills, canals and terraces, and expanding open grasslands at the cost of forests. The shaping of landscapes marked a new era in the relationship between humans and nature. With new technology at hand the comparative ease at which change could be affected instilled a sense of power and ownership over nature, once the force that dictated human survival. Humans had now elevated themselves to the status of "god's stewards". Fortified by a moral imperative to secure and preserve the needs of human beings, societies around the world embraced the responsibilities of pushing back the frontiers and instilling a new kind of order, a human order, on the natural world.

The most advanced reduction and abstraction of god(s) has been achieved by the related but competing religious cultures of the subtropical Near East region. These religions were built on earlier concepts of oligo- and monotheistic religions of the region: the Jewish, Christians and Muslims, the three 'book religions'. In all three cases, God, is no longer confined to specific elements of nature but rather takes on an "all-present" persona, unconstrained by space, time or matter. The immediate interpretation of this is that all creation is the action of god. In the case of the Christian faith, "all life and all elements on earth but also beyond are the loving action of God, who continues to care for all aspects of existence". Jesus is quoted as saying, "Are not five sparrows sold for two pennies? Yet not one of them is forgotten by God" (Luke, 12:6–7). This belief is also echoed in the Islamic faith, "To him belongs every being that is in the heavens and on earth" (Qur'an: 030.026). However, interpretation of these preachings has been characteristically selective, if not corrupted to suit the needs of the elite. For instance, in medieval Europe, interpretations of Christian doctrine emphasised the importance of civilizing of so-called barbaric cultures that followed more animistic and less abstract religions, and with the 'domestication of nature'. Religion served as an important societal cement, fostering nation-building and the motivation of defence against multiple invasions by aggressive nomadic peoples.

The medieval story of European colonization and deforestation was tightly related to the mission of religious actors—"*the Benedictines, and then later the Carthusians, Premonstratensians, and particulary the Cistercians, were the shock troops of clearing*" (Williams 2006). In Europe up till the period of enlightenment, religion and governmental organization of social systems were inseparable. While the Christian church on the one hand hindered scientific progress (for instance, trying to prohibit revolutionary Copernican ideas), on the other hand, the significant infrastructural and intellectual resources of monasteries and churches supported further European cultural evolution. The technological creativity of medieval Europe has even been related to the ideological power displayed by Western forms of Christianity (White 1978). The multiple feedback relationship of population growth, complexification

44 But not always and automatically; e.g., compare Iftekhar Iqbal (2008): "In Western traditions, the forest has often been considered the hostile "other" of civilization, but this was not the case everywhere and at every historical stage. In the Hindu pantheon, for instance, the forest has a "character"; there have been numerous forest deities who keep the kingdom of the forest alive, and in the forest live the sages who cater to the spiritual and social needs of the people. Moreover, forests were a place to retire in later life of the Brahmin. Material forces of deforestation do not neutralize such popular perceptions of the forest as a pristine provider of both material and immaterial well-being. In fact, the idea of deforestation rather than the forest itself was alien to many communities in the tropical world".

and urbanization of medieval society as well as the religiously supported aspiration for power, expansion and (economic) growth laid the foundation for a process of ever accelerating and globalizing ecosystem degradation led by the so-called 'Western civilization'.

INTEGRATION, INTELLIGENCE AND INNOVATIONS

The emergence of urban centres greatly increased demands for material and energy but also altered the spatial configuration of the landscape (Mirow 2009). The networking between state systems referred to the trade of goods, political contact and cultural exchange. For instance, states in the Near and Middle East and Northern Africa were linked by a network of trade; goods were transported from the Mediterranean to the Baltic sea and vice versa. In some cases considerable distances were covered. The Olmecs travelled 500 km north and south to gather commodities which were not available in their territory (Mirow 2009). Right across Eurasia and Africa large extensive trading routes were established including the trans-Saharan route and the Silk trail.

Trade and commerce should have triggered cultural (and maybe even biological) evolution: "*Mercantile operations (…) need complex models in the minds of their operators, just as military ventures do. The main difference is in more emphasis on prudence and less on daring. It is probable that civilization has given steady selection for the intelligence needed for this mercantile kind of preparatory modelling. The intelligence that gives a good appreciation of the real principles involved in a new technology, as opposed to seeing it as a kind of magic, is probably also constantly favoured, since improvers of a technology avoid the arrows of contempt and penury that face pioneers and can do very well*" (Hamilton 1975). Possibly more important than biological selection for 'mercantile intelligence' was the increasing exchange of ideas and technological innovations. Some innovations, and especially those in the field of information technology (information documentation, storage, diffusion, communication), were very effective in feedback-fuelling the process of innovation generation.

Technological progress enabled urban centres with high population densities to grow. In part, this was made possible by a combination of improved food production; the reduction of impacts of density-dependent diseases (medical treatments, finally even vaccination), and a dramatic development in transport and communications. Information technology brought more and more ever better educated people together allowing exchange and fusion of ideas, leading to innovations. Rapid cultural evolution followed the same principles as that of biological evolution: 1. replication, 2. multiplication, 3. diversification, 4. densification and finally 5. complexification. Innovation and cultural progress can be seen as density-dependent processes with intellectual subsystems that are partly refreshed by travelling, reading, and interactions with other communities. In several cases throughout history, the scientific and technological status of certain civilisations grew substantially as a result of immigration (e.g., Russia, USA). The injecting of new life into society through intellectual exchange and immigration of talented individuals is an essential component to the development of civilisations. "*when starved of access to a large "collective brain" by isolation from trade and exchange, people may experience not just less innovation, but even regress*" (Ridley 2009).

The emergence of numerous centres of civilisation across a diverse global landscape, each operating semi-independently, led to the inevitable diversification of traditions, language, and ultimately culture ("cultural mutations", Ibisch 2010). These "cultural mutations" also include small technological changes and deviations—partially occurring as mistakes or recombination of practices (as in biological evolution), and partially intentionally, because humans with their prospective capacities invent changes (and these changes do not have an analogue in biological evolution). Cultural mutations are assessed by selection, just as are biological ones. Rogers & Ehrlich (2008) provide meaningful evidence (in the case of Polynesian canoes) of two sets of related cultural traits, one tested against the environment and the other not. Both evolve at different rates in the same populations. Natural selection apparently slows the evolution of functional structures that are relevant to the survival of the canoe users. On the other hand, symbolic designs diversify more rapidly. The authors conclude that cultural change, just like genetic evolution, can follow theoretically derived patterns.

A number of authors compared technological innovations with biological mutations, and others concluded that there were no suitable biological analogies (e.g., Mirow 2009). However, this paper maintains that *innovations* also exist in biological evolution, but normally do not depend on single mutations. Rather, it is about the combination of traits, a consequence of cumulative mutations, which from a certain critical point, an evolutionary tipping-point onwards, leads to new emergent properties and non-linear evolution of the biological or cultural system. Examples of this phenomenon include fundamental innovations such as feathers and wings, lungs, oral language, or boats and metallurgy. A significant difference in cultural evolution is that innovations can easily be exchanged, facilitating a reticulate evolution, which does exist only to a certain degree in plant evolution. Successful social systems of higher order, such as empires, more or less systematically 'forage' for innovations in order to maintain growth and expansion.

As in biological evolution, the combination of certain traits that could be called pre-adaptations (which originated for another purpose, but then became fitness-relevant in another context), together with selective pressures has a strong potential of producing convergent results. Evolutionary convergence provides strong evidence for the systemic nature of evolution and corresponding system-immanent mechanisms, without the existence of a higher plan, and thus leading to comparable and more or less projectable patterns. The phenomenon of cultural convergence used to be rarer in the past. However, important cultural achievements such as agriculture, writing or state-building were produced independently on several occasions through history. It is also a well-known phenomenon that certain ideas and theories arise periodically, and under a certain intellectual climate. An example of this is the theory of evolution developed twice and dependently by Darwin and Wallace. Today, thanks to intensive networking and excellent access to existing information coupled with very high densities of educated, idea-developing people, convergent evolution of ideas is a common outcome of modern society. The modern age of open information access has created the paradox of the 'parallel innovation syndrome' that is to say, the discovery of a new concept, theory or principle by one scientist in isolation and ignorance of the identical discoveries by another or others elsewhere. This growing phenomenon has raised the levels of competition between innovators and this in turn has acted as a feedback mechanism in accelerating scientific and technological evolution. "*The capacity for ideas to have sex on the Internet is likely to accelerate cultural evolution still further*" (Ridley 2009).

DISTRACTING MULTIPLE SYSTEM MEMBERSHIP AND A RECORD ALIENATION FROM NATURE

Cultural and technological evolution led to the creation of ever more interconnected subsystems of the anthroposystem. Relatively 'smaller' systems do not only connect to each other, forming systems of higher order, such as clans organizing themselves in states, and states working together in confederations, but also parallel systems evolve and interact in a complex way. At another level, individuals can simultaneously act as members of ecological and social systems. Here we have to distinguish between mandatory and facultative membership (Ibisch 2010). Mandatory memberships are fundamental and refer to being part of an ecosystem with its energetic and material constraints or of a biological population belonging to the species *Homo sapiens*. Facultative membership can be temporary and extremely multiple. It refers to the participation in actual or virtual (internet-based) social networks, in schools or companies, in sport clubs, in professional associations etc. Likewise, social systems of higher orders can form part of various kinds of systems; for instance, states can be members of trade organizations, political and military treaties, of conventions or formal supranational unions with state-like structure such as the European Union

In earlier societies, membership in social systems was quasi-mandatory. For instance, medieval craftsmen had no chance to leave behind the membership in guilds and their rules. In some stratified societies it was (or still is) extremely difficult or impossible to change the stratum, classes or castes. As it is, industrialization and later fossil-energy-fuelled democratization and liberalization have increased the number of facultative individuals. This has made it much easier in modern times for individuals to opt out of basic social systems that were for a long time a mandatory part of social life. Individuals now have the option to withdraw their membership from various social orders such as political parties, dedicated professional bodies or even from the family. The freedom of choice, thanks to cheap energy and transport of goods and persons (for people with above-average to economical resources) is enormous and comprises the selection of places of where to stay as well as the consumption of ecosystem goods produced everywhere in the world (Ibisch 2010). The globalization of the anthropo-subsystem, in the sense of expanding networks, both at the institutional and the individual level, has greatly increased concerns of achieving and maintaining sustainability. Historical boundaries between communities, cultures and civilisations are dismantling and bringing about de-territorialisation (Scholte cited by Osterhammel & Petersson 2007) and atopia (Willke 2001). Apart from the acceleration of energy and material turnover within ever larger and more complex systems, the psychological effects on the participants of these systems are significant. A combination of freedom of choice and loosely defined membership to various social structures has fostered a perception of individual liberation from systems of higher order. In particular, members of the social elite such as the policy makers, industrialists, scientists, economists, and even the "intelligencia" move between continents without any need to leave the culturally sterile environments of airports, air-conditioned offices and hotels. This fuels notions of a sustainability that is dependent on the functioning of economical and financial systems (Ibisch 2010).

The urban masses have also become divorced from the local ecosystem surrounding them. Cities are designed and constructed to accommodate the socio-economic needs of a technocentric society. In all cases the urban fabric is made up of processed material that is then structured and ordered to create a microtypology that appears distinct from the surrounding landscape. Towns and cities behave very differently from the surrounding ecosystem, often supporting a unique assemblage of species (many introduced), and also a distinctive microclimatic. Opportunities for native biodiversity are limited under these conditions, and in most cases urban environments export problems to the surrounding ecosystem. Much of the urban green space is either gardens or parks with very little remaining of the original landscape. Even rivers are grossly engineered to fit in with the urban fabric. The green space typology is the spatial metaphor for cultural and artistic expression; it does not necessarily need to have any environmental function. Consequently, less importance is attached to the biodiversity needs or ecosystem services of these sites despite the potential they might offer. This metaphoric and abstract representation of nature identifies one of the levels of apparent de-coupling between culture and nature. However, there are examples of a more extreme level that go beyond reshaping landscapes and genetically engineering nature. The use of artificial vegetation including turf, potted plastic foliage and flowers offers something nature cannot—a sense of permanency, perpetual flowering, all year ground greenery, a quasi-utopic environment. This form of cultural extensionism is rather more than just a de-coupling from nature; it also represents elements of a schism between reality and a fantasy world, another "Avatar." The ultimate frontier is the creation of spatial representations of computer-generated virtual worlds—variations on the theme of Disney World. In some of the most recently built urban-architectural spaces of the last decade, dominated by concrete and glass materials, nature has been reduced to a very minor role, or is superficially cited by artistic elements rather than really displayed.

The development of media and broadcasting technology has re-introduced nature into the lives and houses of the masses. This very detached and virtual exposure to nature introduces an element of naivety into the relationship, it presents nature as benign and unthreatening, a "cosy" and safe nature. Furthermore, it also widens public appreciation of the diversity and forms of nature that they would not normally encounter in the local environment—polar bears, tigers, Komodo dragons, and killer whales. These species very quickly inherit iconoclastic status that ranks them in importance above other forms of biodiversity. Watching charismatic 'beasts' and wild nature under controlled conditions in many cases may even reconfirm the nature-culture antagonism.

The rapid expansion of urban culture and its various manifestations has generated a society of 'omnipotent creators', modern city planners with access to energy and technology that allows them to go beyond former limits. The desire for humans to create artificial environments free from the constraints of nature is responsible for the generation of bizarre structural phenomena including buildings almost a kilometer high, artificial islands (The Palm Jumeirah, Jebel Ali, World Islands), or airconditioned beaches[45], all to be found in Dubai, as well as the plan to establish an energy-efficient model city in a hostile desert ecosystem: Masdar City, Abu Dhabi, "*the world's first carbon-neutral zero waste city*", head- quarters of the *International Renewable Energy Agency (IRENA)*[46]. Conservation and development actors, such as WWF, praised the initiative: "*Masdar City is fast developing into a global showcase of sustainable development in action, and a driving force for the world's renewable energy sector. The City is a focal point for the global sustainability community, a place where the world's leading minds and experts meet and connect to advance renewable and clean technologies. It is hard to imagine a more appropriate location for an international agency concerned with promoting renewable energy*" (Goncalves 2009). Technologists and technocrats are making an obvious statement that the replacement of fossil energy by renewable sources will be the panacea for all problems on Earth, leaving behind all restrictions defined by ecosystem boundaries and properties.

The process of urbanization has not just generated enormous environmental problems and costs but also contributed to the unsustainability of the global anthroposystem. Specifically, socio-psychological effects and combined political consequences of urbanization have impacted heavily on the well-being and welfare of individuals and populations. In other ways, urbanization of much of the world's population has skewed public opinion on issues of global sustainability and biodiversity conservation. Urban voters are predominantly responsible for steering policy in all matters to do with the environment and society (Ibisch 2010). In other words, those furthest removed from nature have the strongest voice, and may over-rule the opinions of rural communities on issues about the environment.

The rapid transition towards a globally modernised society has left behind just remnant populations still living in or near 'wilderness'. These last remaining refuges have been adopted as the new form of recreation for the privileged and educated few in the industrial states. As the number of middle class grows around the world rural countries and regions are targeted as travel destinations. In a short period of time these landscapes and cultures develop the venire and qualities of a tourist resort. Any legacies of the natural system are soon lost and replaced by more induced or artificial aspects of nature.

Urbanisation has also removed large sections of the population away from the living landscape, the agricultural lands that provide food for the cities. In the minds of city folk the connections and relationships between food on the plate and 'life in the field' are fuzzy. The detachment of city dwellers from the source of all the goods and services provided by the surrounding landscape and beyond has been compensated for by the development of a sophisticated transport network. It is possible to import all the necessary goods into a city including clean drinking water. It is common for ordinary lower or middle class people of industrialized countries to consume food that has originated from various continents. Even the ingredients of single products commonly represent a mixture of ecosystem products from various biomes and ecoregions. Dietary habits are no longer influenced by seasonality or local scarcity. In all industrialized countries, thanks to container-shipping and controlled-atmosphere storage, it is now possible for supermarkets to offer fruits like strawberries or apples all year round. Similar changes have even taken place in many developing countries, where in the last 10-20 years the culture of supermarkets has been established, and where at least upper middle class people have been integrated into subtle global trade and material flows. Increasingly, even lower-income people are more dependent on

45 "*Chill out, you beautiful people, the Versace beach is refrigerated*" (J. Leake, The Sunday Times, December 14, 2008).
46 www.masdar.ae

intercontinental trade systems of staple food such as rice. This inevitably raises the vulnerability of these sectors of society to sudden and unpredictable shifts in either the production or transport of food as witnessed during the rice crisis of 2008 (Boris & Crépu 2009).

Many of these life-style changes that have happened in the last 30-40 years have gone unnoticed by many because of the speed and apparent seamless transition of progress. The acceleration of wealth for many has set new standards of living which in turn have greatly raised demands for material goods and services beyond traditional expectations. Fuelled by ever more sophisticated marketing strategies of self-maintaining commerce systems, consumption 'wants' have become the most powerful single driver of societies' complexification, globalization and economic growth. A global scale aspiration towards a middle class life-style has put untold demands on natural resources. At one level, it has accelerated technological innovation, and contributed towards the evolution of a more complex global society. However, it has come at a high price to long-term social sustainability and biodiversity.

THE ERA OF NATURE-NEGLECT AND NEOCLASSICAL ECONOMICS

Economic and financial systems have gradually evolved away from the influences of the political system. Internationally operating organizations and business companies have evolved into transnational bodies, which in the globalizing world, have turned out to be powerful "*lateral world systems*" (Willke 2001, 2003). This aspect of globalization has materialised from the interactions of both individuals and groups that have eventually created networks within growing numbers of organizations; it is a phenomenon which is based on various processes that have a long history (Osterhammel & Petersson 2007). Everything began locally with agricultural surplus, subsequent urban condensation, and an increasing division of labour, with people adopting different professions as well as expanding mercantile exchange. In various cultures, these processes, convergently, led to quantum leaps in the development of symbol systems: letters, writs and money. The division of labour, together with the invention of money, also initiated new subsystems of the states; among their emergent properties there was 'economic growth' and laboral dependence, with significant feedback impacts on governance systems, technological progress and ecosystems.

To effectively serve a global economy transnational and (sub)global financial systems have emerged. These systems, like most others, have evolved their own dynamics and system-immanent logics, leaving behind the original *raison-de-être*—a phenomenon especially addressed in the course of the end of the current decade's financial and economic crisis. Current, sophisticated elements of financial systems have adopted a more virtual form, being nothing else than the transaction of information but still with meaningful impact on economies. For example, the performance of financial systems driven by share holder interests or other mechanisms even more decoupled from original function can have a strong influence on the availability of investment money for either intervening in ecosystems or either protecting them. In fact, 'virtual economics' appears to operate independently of the real material-based systems, but still influence the judgement and behaviour of people. This level of sophistication marks the preliminary end-point of the evolution of the neoclassical economical systems that appear to function detached from natural capital and ecosystems services.

The economies' of prehistoric cultures depended exclusively on the use and extraction of natural resources, nowadays called natural capital. The only man-made capital was represented by some hunting implements (Czech 2000). Over time, the division of tasks and increased exploitation of the ecosystem increased the value of human capital. An economic culture centred on community-based activities kept the focus on agricultural land produce, associated technology, craft, and labour (Czech 2000). The simple equation was more land use by more labour applied by more people led to more growth. As Brian Czech (2000) pointed out, "*somewhere in the transition from classical to neoclassical economics, capital was added to the list, so then we had 'land, labour, and capital'* ". This capital formed the economic infrastructure, tools and machines made available through the processing of natural resources and the consumption of exergy stored by ecosystems (such as wood, coal or finally especially oil). This infrastructural capital became so abundant and dominant in the direct environment of working people that at a certain point it appeared to be a decisive factor for production and economic growth. It was the generation and accumulation of implements and tools that caught the interest of the early neoclassical economists. These artifacts came to represent the new commodity at the expense the land and natural resources. Ultimately, this new found capital together with labour formed the basis for commercialisation of the economy (Czech 2000). Advanced forms of capitalism demonstrate how production and earnings can be achieved virtually, without labour, using exclusively man-made capital, or in the case of modern financial tools such as derivates and futures, symbols of capital only. However, the complex and abundant flows within the finance system forget that this "abstracted economy" (Kunstler 2005) represents nothing other than movements and re-distribution of values that ultimately are (or should be) backed up by real material resources.

The apparent multiplication and decoupling of financial values from natural resources—which has been understood by many people for the first time when the recent global financial and economic crisis gained momentum—are possible because the corresponding values do represent only the option of purchasing natural resources. If all financially wealthy people at once wanted to withdraw their bank savings or even purchase real land, wood or food for their money, it would instantly expose the mismatch of virtual economic commodities, actual money, and existing resources. However, history has proved several times the vulnerability and fragility of current economic models. For instance in times of hyperinflation money loses any significant worth, sophisticated neoclassical economies collapse, and even 'valuable' things such as gold or diamonds become extremely cheap in the face of diminishing natural resources such as food, timber and water. In extreme cases of collapse populations quickly revert back to bartering with food and 'tools of the trade' (agricultural seeds, livestock, implements and so forth).

The hidden costs to the environment and the masked inter-dependency between economic and natural systems have set new challenges to re-engage both systems by accounting for natural capital. This task has become the new frontier of *ecological economics,* a very different brand of economics from the more conventional model of environmental economics that simply assigns economic value to natural resources (Czech 2000). The recent emergence of new models for evaluating biodiversity, in particular global ecosystem services (Costanza *et al.* 1997) has stimulated interest and activity across a broad spectrum of society not just within the conservation community. This recent development spawned the TEEB-study (*The Economics of Ecosystems and Biodiversity;* TEEB 2008, 2009). The first TEEB report included a critical discussion of economists' attempts to assign monetary values to biodiversity. The problems are particularly related to the expectations and value-judgements of future generations about goods and services. For this purpose economists developed the habit of discounting, based on assumptions that any product or service will lose value over time as technology finds ways of replacing them, and as economic growth leads to higher incomes and increasing purchasing capacity. The phenomenon could be a called a kind of "*colonization of the future*" (Leggewie & Welzer 2009). There are obvious difficulties with the application of this principle to renewable, evolving natural resources. Actually, future generations may assign higher values than we do to certain resources such as clean water and wood-producing forests, as they begin to diminish. Correspondingly, negative accounting rates have been suggested for taking into account the changes in value of diminishing resources (Ehrlich 2008, Ehrlich & Ehrlich 2009).

Concerns for the needs of future generations introduce an ethical dimension into economic modelling. All measures of fiscal worth used in socio-economics become invalid under considerations of collapsing global ecosystems. If the loss of regulating ecosystem services, such as carbon sequestration, pushed the climate system towards a tipping-point beyond which dangerous run-away climate change would happen, then the value of the corresponding systems would be infinite. Existing economic and development models that promote accelerated loss of natural capital and that trigger processes that may lead to downward turns in the status of the Earth system are arguably unethical. In this scenario biodiversity conservation would be locked into a perpetual process of crisis management of treating problems generated by ongoing activities of unregulated economic growth. There would be an end-point to this scenario and that is the final collapse of all functional ecosystems.

There are limits to growth on a planet that is already heavy populated and utilised, and with much reduced availability of resources (as suggested by the milestone study of Meadows *et al.* 1972, compare also Meadows *et al.* 1992). However, more realistically, it is the likely loss of ecosystem services that will impact most severely on economic growth and sustainability rather than the scarcity of resources itself. "*The conventional response to the dilemma of growth is to appeal to the concept of 'decoupling'. Production processes are reconfigured. Goods and services are redesigned. Economic output becomes progressively less dependent on material throughput. In this way, it is hoped, the economy can continue to grow without breaching ecological limits—or running out of resources*" (Jackson 2009). Unfortunately, there is no evidence that it is realistic to achieve an absolute decoupling of economic growth from energy turnover and material throughput. For instance, "*despite declining energy and carbon intensities, carbon dioxide emissions from fossil fuels have increased by 80% since 1970. Emissions today are almost 40% higher than they were in 1990—the Kyoto base year—and since the year 2000 they have been growing at over 3% per year. (…)The truth is that there is as yet no credible, socially just, ecologically-sustainable scenario of continually growing incomes for a world of nine billion people. In this context, simplistic assumptions that capitalism's propensity for efficiency will allow us to stabilise the climate or protect against resource scarcity are nothing short of delusional. Those who promote decoupling as an escape route from the dilemma of growth need to take a closer look at the historical evidence—and at the basic arithmetic of growth. Resource efficiency, renewable energy and reductions in material throughput all have a vital role to play in ensuring the sustainability of economic activity. But the analysis* [done by Tim Jackson] *suggests that it is entirely fanciful to suppose that 'deep' emission and resource cuts can be achieved without confronting the structure of market economies*" (Jackson 2009). A detailed analysis of the flaws and myths of current neo-classical models of economics are presented by several authors, including Herman Daly (e.g., Daly 1972, 1996).

Still, many conservationists seek to reconcile economic growth and biodiversity conservation; compare: "*The larger challenge is to allow human society to meet its potential and share the fruits of economic growth while sustaining a biosphere that not only sustains full ecological functions but retains its living diversity*" (Adams *et al.* 2004). But: "*Even 'green growth' is not sustainable. There is a limit to the population of trees the earth can support, just as there is a limit to the populations of humans and of automobiles. To delude ourselves into believing that growth is still possible and desirable if only we label it 'sustainable'" or color it 'green' will just delay the inevitable transition and make it more painful*" (Daly & Townsend 1993). From an ecological perspective it is simply impossible to envision alternatives to steady-state economy or even degrowth[47]. A macabre but organic metaphor of putting monetary value to Earth's biodiversity for the sake of permanent growth of the anthroposystem is the discussion among cancer cells in a body that assess the economic value of brain cells, the lungs or the heart.

The myth that economic growth and technological progress can provide the ultimate solution to all problems of modern society is understandable if naive. Undeniably, in the short term, economic growth has improved the well-being of many but selected numbers of individuals. From an *ex post* perspective, history provides evidence for repeated technological solutions in times of social and economic crisis; humans have designed and planned their way out of trouble. There is little substance to this argument as in many cases in the past, complex human societies degraded or collapsed when they were challenged by serious problems such as epidemical events, severe conflicts and wars or (anthropogenic) environmental changes (see below). Often the solution to density-dependent problems that led to starvation, disease outbreaks, armed conflicts and mass killings, was not technology, but simply emigration—nothing else than increasing use of natural capital/land. In fact, emigration has been a common and repeating theme throughout human history. The development of fossil fuel technology transformed the human-nature

47 The debate about degrowth and alternatives to GDP growth rates as indicator of development is gaining momentum, even among (inter)governmental institutions and in high-ranking scientific journals (compare, e.g., Degrowth conference Barcelona 2010—www.Degrowth.eu; EU-Initiative: http://www.beyond-gdp.eu/; Editorial Nature 2010; see also Fournier 2008).

relationship by removing many of the constraints and dependencies on landscape resources. The result was a rapid increase in population numbers tied in with a technologically-driven so-called 'green' revolution. A more assertive population in control of its own food supply and powered by technology triggered off an expansion in global trade; mobility; and information systems. It also brought about a profound change in social psychology—a new found dependency, self-confidence, and a belief that the world could be shaped and designed to accommodate the needs and wants of society beyond the boundaries and constraints once set by nature. Humans had finally moved from a position of being merely another species existing according to the laws of nature to one of master of his own destiny and governor of the system.

Belief in progress as a synonym of technological advancement and economic growth is thought to represent a secularized monotheism, a continuation of the old tradition of belief, a predilection in divine mission (Gray 2010). In this sense, society has found justification through religious belief to excuse themselves from the laws of nature. Whether religion in all its form is seen as a destructive force that plays on human intelligence and drives humans further from their evolutionary ties is debatable, but it is clear that it provided the necessary material and social glue for human cultural evolution.

Significant numbers of today's society have woken up to the problems and potentially destructive forces of unbridled technology and modernity, and are now seeking a means of 'cleansing' themselves from all the ailments it has brought with it, an alternative way of life. Understandably, many are turning back to traditional cultural pathways including religion. In a number of cases the strength of feeling about modern life issues and problems is producing religious zealots, extremists and ideologists, often creating backlashes and problems of a different kind. Religion is an essential part of human culture, but it needs to evolve and enfold many of the complex issues that represent modern society. There are some attempts of dialogue between the main faiths and the scientific community. This partnership needed to build into a more effective theoretical and practical framework that is better able to address problems of population explosion, resource depletion, valuing of other life forms and natural systems.

GLOBALIZATION OF THE ANTHROPOSYSTEM, INCREASING SYSTEM OPENNESS AND THE GLOBALIZING BIODIVERSITY AND DEVELOPMENT CRISIS

Social evolution led to the formation of systems of higher order on the local, regional and finally the global level. The ultimate establishment and condensation of worldwide networks that has given rise to socioeconomic globalization has been described as "space-time compression" (Harvey 1989, cited by Osterhammel & Petersson 2007). Pre-modern societies did not exist in total isolation but at the same time could not be described as globalized. The globalization of political and economic networks did not arise simultaneously[48]. Similarly, other aspects of culture such as religion that spread across the world and eventually united occurred, sometimes hand in hand with economic and/or political development, but other times independently. Either way, the partnership between religion, politics and economic development was an essential development to the success and persistence of emerging empires. In cases where this alliance did not really exist such as the Mongolian empire, collapse followed after a short while (Osterhammel & Petersson 2007). That said, the most powerful form of global integration was the migration of people and the exchange of goods and services. This form of integration was particularly relevant to the status of global biodiversity.

Human travel and trade marked the beginning of the atopization of ecosystem use. Communities no longer depended exclusively on <u>local</u> ecosystem goods and services. Through trade, systems with limited

48 E.g., first impulses of continental integration, e.g., expansion of the Islam and Mongolian expansion; establishment of the Spanish and Portuguese worldwide empires since 1500; multilateral interdependence between Europe, Africa, Asia and America until the middle of the 18th century; strongly deploying trade interlinkages especially with the rise of the industrial revolution, but contraction and dissolution of European empires; export of European institutions in the 19th century; world and globalization crises because of the world wars, and finally the evolution of world-politics and policy in the 20th century (Osterhammel & Petersson 2007).

resources and opportunities tapped into other more productive ecosystems thus increasing inflow of material and energy. It was mainly the wants of the elites that facilitated spatial integration of state systems. Today, even staple foods are transported intercontinentally.

Globalization, together with urbanization, has contributed to the de-coupling between culture and nature: "*escaping from the natural constraints to energy flows*", that has significantly increased the exosomatic metabolism flow of the society[49] (Giampietro & Mayumi 2009). „(…) *The food system consumes ten times more energy than it provides to society in food energy. However, since in the U.S. the exo/endo energy ratio is 90/1, each endosomatic kcalorie (each kcalorie of food metabolized to sustain human activity) induces the circulation of 90 kcalorie of exosomatic energy, basically fossil*" (Giampietro & Pimentel 1993). The pre-industrialized societies represented relatively closed systems with the sun providing the main source of energy. While the maximum density of energy input obtained from biomass harvested from agro-ecosystems has been calculated at about 0.05W/m^2, the typical energy use for a city (including residential, retailers, industry) is in the order of magnitude of 10-30W/m^2 (Smil 2003), cited by Giampietro (2009). Energy budgets of food production illustrate how deep societies are caught in a 'fossil energy trap'; e.g., in the United States, the energy input-output ratio of wheat, is 1: 2.57 calories, with about 90% of the input being fossil-energy-based (Pimentel 2009b). Similar ratios apply to other crops such as corn or potatos.

Modern trade is completely exosomatic, and a mainly fossil-fuel-dependent driver of economic growth. By the late 19th century, world trade started to decouple from world production, growing much more rapidly and leading to increasing openness of more and more local and regional systems (Osterhammel & Petersson 2007). Between 1948 and 1958, world production grew by 5.1%, and between 1958-1970 even by 6.6%. In the corresponding periods trade grew by 6.2% and 8.3% respectively (Lewis 1973, cited by Osterhammel & Petersson 2007). If a comparison was to be made between *global ecosystem production* and trade, the decoupling would be even more striking. Only a minimum increase in global net primary production (amongst others, as consequence of global warming) can be expected. Clearly, the ecosystem-based agricultural production has problems catching up: for instance, the world exports of merchandise and commercial services between 2000 and 2004 grew by 9%[50]; in the same period the world rice production virtually stagnated without any growth[51]. Global food production is steadily increasing but at a much slower pace than economic growth, and at the cost of primary production in natural ecosystems such as forests (that have to be transformed to agro-ecosystems). There are clear limits to growth based on net primary production of plants because of the limited availability of space, nutrients and water. Economic growth, in an era of industrialization, has been decoupled from the productive capacity of ecosystems by the increase of exosomatic metabolism flow and the transformation of stored exergy of the Earth's system (e.g., chemical industry based on oil).

Countries such as Germany that are strongly integrated into economic globalization generate an enormous flow of commodities, including ecosystem products. For instance, Germany, in 2007 exported 6.7 million km^3 of timber (90% to Austria and China), and at the same time imported about 4 million km^3 of timber (42% from Sweden and Czech Republic)[52]. Economic growth, in this case, does not mean anything else than increasing mobility of products, which is made possible by the use of (fossil) energy with more social systems participating in material and energy flows.

The globalization of markets and trade creates and multiplies its own selective pressures on people and states. In the case of many developing countries and transformation countries the degree of openness

49 The differentiation of endosomatic and exosomatic metabolism has been especially proposed by Lotka (1956) and Georgescu-Roegen (1975). Both kinds of metabolism are related to flows of energy and material transformed by humans with the socioeconomic process—endosomatic metabolism is mainly defined by the energy transformation by the human bodies, and the exosomatic metabolism refers to energy transformation by people and social systems that use machines and burn various energy sources.

50 WTO International trade statistics 2005, www.wto.org/english/res_e/statis_e/its2005_e

51 www.beta.irri.org

52 Federal Agency for Statistics—Statistisches Bundesamt (www.destatis.de).

towards global markets correlates with the socio-economic situation of the inhabitants. At the same time, higher rates of trade liberalization, system openness and participation in financial systems are rewarded by more subsidies and support by the international finance system, a positive feedback loop (Bodenstein 2006). Following the collapse of communism, central European countries such as Poland and the Czech Republic were able to rapidly integrate into global markets. Consequently, these states demonstrated higher rates of economical development and growth than neighbouring countries such as the Ukraine that for various (political) reasons maintained a more closed economic system (Bodenstein 2006; compare Geyer *et al*., B.1.2.b. in this document). The communistic countries of central and Eastern Europe contributed about 30% to global economic production but participated in global trade only to an extent of 4% (Oatley 2004, cited by Bodenstein 2006).

In the currently 'transforming countries', rapid integration into global markets and trade has lead to: (a) more material wealth of an increasing number of individuals, (b) improved food security, (c) liberalization of individuals with ever more options for both consumption and mobility, as well as (d) independence from scarce and insecure local biodiversity services. There are only a few remaining cultures or political systems that have remained closed to globalization. Amongst the transformation states of central Europe the effects of global trading and internationalisation of the economy has also imported familiar problems of ecosystem degradation and biodiversity decline. Additionally, economic growth has been achieved partly at the cost of externalization of environmental costs by the import of products demanded for consumption and production. The development of international trade in animal and dairy products is a typical example of structural changes that have occurred in the older EU countries and which are now also repeated (much faster) in the new accession states. Originally, cattle were produced in a rather extensive way using vast local areas for grazing and hay production. The intensification of productivity (per animal and per farm) forced the farmers to industrialize animal production by introducing indoor breeding programmes, and purchasing of mixed provender produced from crops imported from other continents, such as soybeans from South America[53]. As a result of modernising agricultural systems, the traditional small farmer was replaced by fewer but much larger agro-industrial facilities. This also had a profound effect on the shape and character of the landscape. Especially in mountain regions, such as the Alps or the Carpathians, this process lead to the expansion of forest or tree plantation areas (often related with the loss of species diversity in cultural landscapes); in regions with better soils pastures were converted into cropland.

Those transformation states that have not experienced a meteoric growth in economy have also not managed to integrate effectively either into global markets or into regional (political, military and economical) treaties. Consequently, they show a poorer performance in social welfare development and economic growth, but retain greater biodiversity across the landscape. Furthermore, they do not export less environmental costs to other countries, an example being the Ukraine (compare Geyer *et al*., B.1.2.b. in this document).

The socioeconomic changes in transformation and developing countries have lead to abandonment of rural areas and increasing urbanization. Apart from the socio-psychological and social consequences of creating the growth of a poor urbanized strata with people who lose their connectedness to nature and local cultures (see also above), this phenomenon also has ecological relevance because it contributes to fuelling energy use and material flows. Poor urban people have a much higher ecological footprint than rural dwellers, because they increasingly have to use motorized transport, rely on fossil energy for domestic use, and consume imported staple foods such as rice produced on other continents instead of eating locally produced food.

53 This change of production regimes and continued globalization of agricultural markets has created an enormous dynamic in several production countries that take over a considerable portion of the environmental costs of consumption in the industrialzed world. E.g., in Bolivia from 1992 to 2007 the soybean production grew about 400% while population in the same period increased only by 53% (data from FAO, http://faostat.fao.org/,and INE, www.ine.gov.bo/).

Poor (rural) people in 'less socio-economically open' countries continue to depend more directly and more profoundly on local biodiversity than relatively better off in 'well-developed countries'. Consequently, some authors consider biodiversity dependence of the poor as "*a form of last resort, in the absence of alternatives*" and suggest "*that the poor may need to break their dependence on biodiversity in order to improve their livelihood outcomes*" (Vira & Kontoleon 2010). Evidence from transformation countries, indicate that whenever local people escape from subsistence economy and the dependence from *local* ecosystem services, and integrate into globalized material and energy flows they tend to be better off (unless they end up in urban slums). Global economic development has compensated for the (total) local loss of ecosystem services, and also externalized all environmental costs of individual and community lifestyles. However, any notion that global development has unshackled societies from the constraints and limitation imposed by nature is grossly misunderstood. The concept of ecosystem services defines the profound reliance of humanity on biodiversity that without it there would be no past, present or future.

The externalization of environmental costs implies that the negative consequences of the (over)use of ecosystem services is exported to other territories. Environmental problems including contamination, ecosystem degradation, fragmentation and conversion manifest in landscapes beyond the boundaries of origin but may not impact on systems until some time later once critical levels of tolerance have been exceeded (e.g., in post-second world-war Western Europe, compare acid rain in Scandinavia caused in industrial areas e.g. in Germany). For instance the environmental (and social!) impacts of intensive and large-scale sugar, fodder or biofuel production were exported by high-consumption countries to remote areas, such as Amazonia or Indonesia (where people were and are anxiously seeking entrances to globalized economy). Tragically, arising awareness of environmental problems and natual resource shortage is compensated by the export of environmental costs instead of developing locally and globally sustainable solutions (compare also Freudenberger *et al*., B.1., in this document). Developed countries with a high population density and a "respectable" cover of remaining semi-natural ecosystems buy their national 'sustainable' development from countries, mostly in the south. E.g., Germany is covered by forests to an extent of about 30%. This is possible, in spite of high consumption rates, thanks to intensive fossil-fuel utilizing agriculture and the import of agricultural commodities produced elsewhere. In China, currently, it is possible to observe enormous efforts of halting deforestation and forest over-use; afforestation is strongly promoted, and protected area managers in some regions see improving conditions for biodiversity conservation because of rapidly increasing rural exodus and urbanization. Of course, the consequences of this structural change of agriculture and forestry production are exploding demands regarding the import of ecosystem services and products—triggering ecosystem degradation elsewhere.

In the last few decades there has been an accelerating change to the world's ecosystems, global environmental change including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems. These changes are likely to alter the capacity of the Earth to sustain life (US Global Change Research Act, 1990). Global change has always existed and was driven mainly by astronomic and geological forces. The globalization of the anthroposystem in the last few centuries, and especially in the last number of decades, has led to anthropogenic global environmental change made of manifold facets and processes that are increasingly interlinked. Most of the corresponding processes are the result of small local actions that can give rise to measurable global impacts:

1. **Change of atmospheric composition** mainly by the use of exergy of the Earth system stored both in living organisms (wood) and in fossil sediments (coal, gas, oil) (especially impacting 2, 3, 4; especially impacted by 2, 3, 4).
2. **Land cover changes** mainly by deforestation in forest biomes and the spread of agricultural production systems (especially impacting 1, 3, 4, 5; especially impacted by 1, 3, 4).
3. Subsequent **climate change** caused by changed atmospheric composition and land cover (especially impacting 1, 2, 4, 5; especially impacted by 1, 2, 4).
4. **Changes of ecosystem functionality and extension by the reduction/elimination of system com-**

ponents (e.g., species, forests, soils) and by reducing the extent of ecosystem types (including energy dissipation, exergy storage, hydroclimatic cycles etc.) (impacting 1, 3; impacted by 1, 2, 3, 5).

5. **Reduction of the evolutionary potential of biodiversity** by the loss of genetic and species diversity (directly impacting 4; especially impacted by 2, 3).

The compounded effects of global environmental change result in complex and multiple impacts on human development. Anthropogenic climate change is generating feed-back loops, for instance, globalization of socioeconomic subsystems have led to anthropogenic global environmental changes that will have knock-on effects for future generations and the environment. The dramatic release of stored exergy in the form of oil, coal and gas has the potential to trigger a shift in the global ecosystem system to a new operating point. Earth has not only become "*hot, flat and crowded*" (Friedman 2008) but, on top of that, also biologically impoverished, thermodynamically inefficient, socially unbalanced and unfair. The anthroposystem is facing a complex environmental crisis at a time of increasing scarcity of critically required resources. These issues and problems are surfacing at a time of social change. The world is divided along strong politic and religious lines as well according to economic zones. Social and political tensions can only add to mounting environmental problems, particularly as the two are inextricably linked. Solutions to environmental problems must not only take into account the planetary boundaries (Rockström *et al.* 2009), but also factor in social structures and complexity. Climate change can be also understood as cultural and political crisis (Leggewie & Welzer 2009). And it is not the only one. As in all systems synergies and non-linear changes are relevant phenomena; definitely, there are cultural and political thresholds beyond which multiple stresses in social systems can lead to runaway political chain-reactions.

It is important to understand the complex nature of all "*converging catastrophes*" (Kunstler 2005). All aspects of human well-being are vulnerable, in particular, the availability and security of food and water. All lessons learnt from human history indicate that heavily stressed social systems will respond in unexpected and non-linear ways. Increasingly, scientists warn of social perils triggered by global environmental change (e.g. Welzer 2009), and first systematic and quantitative analyses of history show strong correlations of socio-economic processes and temperature changes. In a recent study by (Zhang *et al.* 2007) they show that "*long-term fluctuations of war frequency and population changes followed the cycles of temperature change*", and even that "*worldwide and synchronistic war–peace, population, and price cycles in recent centuries have been driven mainly by long-term climate change*". They identify an additional dimension to the classic concepts of Malthusianism and Darwinism. Other authors such as (Burke *et al.* 2009) have confirmed these findings in studies that indicate that historically there have been strong linkages between civil war and temperature in Africa, with warmer years significantly increasing the probability of war. Work by Burke *et al* (2009) presents quantitative estimates for armed conflict increasing by as much as 54% by 2030 (an additional 393,000 battle deaths if future wars are as deadly as recent wars). However, this extrapolation is not taking into account other parallel stress-provoking processes that may further exacerbate the problem.

The most relevant lesson we have to learn in the face of global environmental change is that all humans depend on ecosystem services that are not just produced locally. In the short run, the most important challenge is to address problems of climate change in order to avoid catastrophic events that are likely to effective the survival of human civilization. The conservation of global regulating ecosystem services, especially those related to hydroclimatic processes, is at least of equal importance as the maintenance of the local provisioning and supporting services. All communities, settlements and nations are reliant on local, regional and global ecosystem services. A subsistence farmer in Africa should be equally concerned about preserving the carbon banks in the boreal forests of the north as they are for the neighbouring forest that provides wood, food and medicine.

ABOUT COMPLEXIFICATION, DEVELOPMENT, COLLAPSE AND SUSTAINABILITY OF SOCIO-POLITICAL SYSTEMS

"*We can learn much about our own predicament from the interactions of the four thermodynamic principles, Energy, Entropy/Exergy, and Quality. In our culture, quality is increasingly embodied in sophisticated matter-energy systems, rather than in inherited cultural forms. Our civilisation thus depends on massive throughputs of energy, transformed at a frantic rate by an enslaved technological quality, and producing entropy at an accelerating pace. This latter manifests partly in the lower, material hierarchical dimensions, as the 'wastes' or 'pollution' that threaten to poison or choke our industries, cities, and selves. It is also there in the higher hierarchical dimensions as the loss of 'quality of life', a staleness of social existence, the creation of profoundly alienated masses, and of a constantly threatening degeneration of the functional quality of the support systems, both material and social, on which we all depend. The injections of exergy, in the form of ever more complex systems intended to prevent or remedy these structural ills, carry their own costs, and can eventually overload the societal system and contribute to its collapse, as in the case of declining civilisations like Rome*" (Funtowicz & Ravetz 1997).

According to the preceding sections we can summarize that development of societies is rather an open-ended process of *evolution* following systemic rules, rather than a deterministic *development* towards a prescribed state. Analogous to biological evolution, the subsystems of humankind, regularly experienced growth, multiplication, diversification and finally condensation, complexification and self-organization in systems of ever higher orders. This process was normatively perceived as progress, especially when apparent limits to growth were overwhelmed by spatial expansion and/or technology and individual access to resources was achieved. In a spatially restricted context, earlier or later, growth of systems leads to competition with other systems that demand similar resources. Once a critical population density was achieved, human history started to be shaped by conflicts about space and space-dependent resources and corresponding warfare. The systemic escalation of environmental factors that allowed higher population densities and higher densities of competing political systems, which was accompanied by high investments in warfare technology (together with the availability of correspondingly required resources such as iron/steel; compare Diamond 1997), led to the situation that some nations arrived earlier at the point where they were able to conquer other political systems and trigger political and economic globalization. This evolution of complexifying and globalizing political systems was fuelled by the use of fossil energy, especially required for the facilitation of interactions in the form of exchange of material, information and individuals. Concentration of people, division of labour and increasing efficiency of the overall economic systems led to social inequities and corresponding unrest. Revolutions became systemically unavoidable (compare Fulcher & Rochow 2007), commonly promoting individual rights and opportunities. Individual freedom and mobility together with ever increasing opportunities for multiplication, reproduction and storage of information caused an explosion of information and knowledge. In a feed-back loop, information-driven technological progress and complexification of people and social systems trigger ever higher turnover rates of individual energy and material use and also political change. The permanent increase and acceleration of resource use by the globally condensing and complexifying social system, in the last decades, allowed a historically outstanding technological progress which almost made one forget that social systems can also decomplexify, de-grow or collapse.

Collapse of systems of higher order is nothing else than a form of reorganization, and mostly allows system evolution to continue towards higher thermodynamic efficiency. There is even programmed collapse of systems, such as the death of organismic individuals, which has evolved in the course of natural selection. In biological evolution, decomplexification of ecosystems and (mass) extinctions regularly led to re-organization of the global Earth system, and always, the direction towards higher thermodynamic efficiency was picked up after more or less extreme events, which humans tend to normatively call 'catastrophies'. As explained above (see Hobson & Ibisch, B.1.1. in this document), the adaptive cycle of complex systems includes a phase of more or less significant revolt, instability and degradation before entering the phase of reorganization. Comparable phases can be identified in the development of abiotic, biological, ecological and social systems. A corresponding phenomenon has been described by historians and archaeologists, normally without referring to complex system theory.

For instance, Stanish (2001), who studied the processes of first-generation state formation in South America, supports the theory of earlier authors such as Marcus & Flannery (1996) or Feinman & Marcus (1998) who suggested a dynamic model of periodic expansion and collapse of archaic states. "*State polities emerge through the incorporation of other groups* (…). *As one polity peaks and begins to break down, former lower-level settlements regain their autonomy, after which the process of consolidation, expansion, and dissolution continues again*" (Stanish (2001), referring to Marcus (1998)).This dynamic cycling, for instance, happened in the Maya area, as well as in the Titicaca basin, where the Tiwanaku culture followed the Pucara one, showing four cycles before the Inca conquest (Stanish 2001). We can also find examples from other cultural contexts, such as the process of German state and nation-building. Everything started with rather diverse autonomous and culturally different states that started to interact more intensively and were brought together under different systems of higher order such as the Holy Roman Empire of the German Nation, the German Confederation, the German Empire, the Third Reich or the Federal Republic of Germany. Each phase of (re-)organization and integration was preceded by a phase of crisis and disintegration. In the course of historical development of the systems of higher orders, the subsystems do not stay how they used to be, but evolve influenced by their own traits as well as by systemically interacting environmental factors moderated by the functional context of the systems of higher order they work in.

Whether an abrupt loss of organizational complexity is called 'collapse' or 'deregulation' might be a simply semantic question. Recently, various researchers (see McAnany & Yoffee 2010) questioned Jared Diamond's popular collapse monography about failing societies (Diamond 2005). On the one hand, Diamond shows that human societies under various ecological conditions and in different historical-socioeconomic contexts faced severe systemic crises and that they often did not respond adequately. On the other hand, the collapse sceptics provide evidence or theories that in some cases the collapse was less absolute than claimed by Diamond (e.g., on Easter Island), they show contradicting approaches proposed in Diamond's earlier works—e.g., an apparently deterministic development approach with few options of choice as explained in Diamond (1997), versus inadequate responses to crises—and they argue that cultures that still partially exist, e.g. through their language, such as the Mayas, cannot have collapsed, rather they simply would have changed and adapted to changing conditions (McAnany 2010). From a systemistic perspective many of the identified contradictions are not absolute or even not valid. Cultural attributes such as language can persist as emergent properties of systems of lower order; their maintenance cannot be used as an argument against the collapse of a system of higher order such as an empire. "*We today, who face similar problems* [as those societies that collapsed or suffered from severe decline] *and could face similar fates, will not be consoled by the thought that our grandchildren might exhibit resilience*" (Diamond 2010).

In many cases in history socio-political systems had few chances of really choosing to fail or persist, because they simply are complex systems with decision-making driving on the border of chaos, and order being influenced by the interrelated interactions of very high numbers of subsystems. Some empires such as Napoleonic France or Hitler's Germany collapsed because of stressing to many other neighbouring systems and, in the latter case, the rarely arising (sub-)global political system of interacting states on different continents. Other empires, such as colonialistic Spain, Great Britain or Soviet Union, did not collapse to non-existence, but were degraded to much smaller relic states—they simply overgrew without being able to centralistically dominate the enormous diversity within the large empire comprising manifold social, cultural and political subsystems. Other non-imperialistic processes of continental confederation building instead followed evolutionary, self-organizing and efficiency-driven complexification and growth; good examples might be the United States of America and the European Union. However, this peaceful process of self-organization does not mean that these political constructs are not vulnerable against disturbances and change. Currently, in 2010, the EU is providing an example of the potential negative consequences of complexification and the building of systems of higher order: the economic crisis of single small member states such as Greece is challenging the stability of the common currency and even the political integration. Complex or even hyper-complex systems arising by self-organization can function more efficiently, but suffer from increasing vulnerability against disturbances that may occur only in a few subsystems. Thus, degradation and collapse are always an option. This leads back to the arising risks for the current informationally, politically, economically, financially and especially environmentally globalizing and hyper-complexifying human society on Earth. As the globally interlinked society produces emergent properties that can be categorised as global environmental change and that establish ever more linkages between socio-economical development of more and more states as well as environment and development, efficiency of the whole system decreases and vulnerability grows with non-linear tendency, especially as critical tipping-points of environmental systems are approached.

It is important to point out that stressed systems of higher order rarely decomplexify in a gradual way and without abrupt changes. Normally there are reasons of energetic and functional efficiency that do not allow a smooth return to lower complexity and lower energy turnover. In the case of the agricultural societies, due to the achieved relatively high population numbers and densities and the corresponding changes in the supporting ecosystems, it was completely impossible to return to a state of hunter and gatherer communities—although it might have been desirable for a majority of malnourished individuals. If a more or less highly-developed agricultural state collapsed, falling apart into smaller and less complex subsystems, at least at some times in history, this has meant reduced agricultural production and re-distribution of commodities or loss of protection against aggressive invaders—and thus, a decrease of population with fatal consequences for many individuals.

On the other hand, it was only in times of expansion, growth and complexification that social systems could provide or realistically promise a wealthier and safer future to their members. Thus, the individual demand for a better and more secure access to resources immanently has always driven human societies to growth whenever the conditions allowed it. In history there does not seem to exist any evidence that human societies willingly decided to deregulate and decomplexify. Actually, this describes the growth trap the globalized society is caught in while the limits to further material and energy consumption or turnover cannot be ignored any longer. "*A long time we could not take note of the meta crisis, which has been mounting up in the background of our apparently undamaged living environment, because our, in comparison to the rest of the world, relatively comfortable and safe living conditions saved ourselves from being confronted with the existential problems of the present*" (Leggewie & Welzer 2009[54]).

THE RECONCILIATION OF SOCIAL SYSTEMS WITH ECOLOGICAL SYSTEMS: A HOLARCHICAL ECOSYSTEM APPROACH

Arguments in support of the widening rift between nature and culture are compelling and have been covered in this paper. Equally, the growing mismatch between socio-political systems and ecosystems (e.g., Freudenberger *et al.*, B.1.1. in this document), as a result of exporting and importing ecosystem products, have contributed to the widening gap between society and nature.

The understanding of interlinkages between biodiversity conservation and human development is a result of recent research (e.g., Fisher *et al.* 2008, Roe & Elliott 2010a). Modern studies also focus on the spatial overlap between poverty, ecosystem services and biodiversity loss (e.g., Sachs *et al.* 2009, Turner *et al.* 2010, Roe & Elliott 2010b). Still, there remains an urgent need to investigate problems relating to global change and human development. Often it is argued that conservation activities designed to meet *local* people's basic needs deserve more attention (e.g., Kaimowitz & Sheil 2010). Equally important is

54 Citation translated into English by the authors.

the need for special priorities for conservation action that targets the functionality of the overall *global* system.

The combined effects of ecosystem alienation—'problem of the fit', and the globalization of resource use (Folke *et al*. 2007, Cash *et al*. 2006, Cumming *et al*. 2006) do nothing for "*reconciling human existence with ecological integrity*" (Westra 2009). This reconciliation must begin conceptually accepting that the whole anthroposystem, comprising all social and economic subsystems, is part of and supported by the global ecosystem. Likewise, human subsystems can be embedded in subsystems of the global ecosystem, but depend on atopic ecosystem services provided outside local or regional territories.

The identification of real system boundaries is relevant beyond academic theories. Too often managers and even scientists describe for instance protected areas, as *socio-ecological systems* in terms of compartmentalised and discrete units although they might simply represent overlapping parts of greater systems which are holarchically nested within larger entities. Rather less, if anything, is made of the behaviour of the collective system. Consequently, socio-ecological management units do not coincide with real existing complexes of interactions. This can cause management failure because of an oversight or neglect of external influencing factors generated beyond the boundaries of the managed area. Thus, it is an important principle of the CBD's ecosystem approach that ecosystems shall be managed within the limits of their functioning. However, world-wide globalization of ecosystem uses and environmental threats complicate attempts to resolve all the environmental problems throughout the world. Ethical, political and technical frameworks for valuing environmental and social systems that also deal with complex interlinkages and interdependences across all system scales and dimensions are a prerequisite to an effective solution to global problems. The principal aim of this holarchical framework would state the desire for the effective functioning of the global ecosystem above all other concerns. Existing economic and commercial measures of achieving objectives and outcomes towards this aim are inadequate and should not obstruct or hinder more ideal-seeking behaviour towards protecting ecosystems and their services. A commitment to meeting this ultimate aim goes beyond values of "*global public good*" (Crabbé & Manno 2009) that can be purchased, used and taxed, and "*far higher than the value (or sum of values) of its components*" (Crabbé 2009). It is about the priceless evaluation of a planet that ensures our own survival. The promulgation of an Earth ethic should be a key enterprise of biodiversity conservation (compare Pimentel 2009a). A seriously implemented, more radical Ecosystem Approach can bring us closer to this kind of ethic and to effective conservation (see Ibisch *et al*., A.2., in this document).

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REFERENCES

Adams, W. M., R. Aveling, D. Brockington, B. Dickson, J. Elliott, J. Hutton, D. Roe, B. Vira and W. Wolmer. 2004. Biodiversity conservation and the eradication of poverty. Science **306**:1146–1149.

Aiello, L. C. and J. C. K. Wells. 2002. Energetics and the evolution of the genus Homo. Annual Review of Anthropology **31**:323–338.

Alcorn, J. B. 1993. Indigenous people and conservation. Conservation Biology **7**:424–426.

Alroy, J. 2001. A multispecies overkill simulation of the end-Pleistocene megafaunal mass extinction (vol 292, pg 1893, 2001). Science **293**:2205.

Axelrod, R. M. 1984. The evolution of cooperation. Basic Books, New York.

Axelrod, R. and W. D. Hamilton. 1981. The evolution of cooperation. Science **211**:1390–1396.

Bailey, G. 2004. World prehistory from the margins: the role of coastlines in human evolution. Journal of Interdisciplinary Studies in History and Archaeology **1**:39–50.

Balée, W. L. and C. L. Erickson, editors. 2006a. Time and complexity in historical ecology. Columbia Univ. Press, New York, NY.
Balée, W. L. and C. L. Erickson. 2006b. Time, complexity and historical ecology. Pages 1–12 in W. L. Balée and C. L. Erickson, editors. Time and complexity in historical ecology. Columbia Univ. Press, New York, NY.
Barnosky, A. D., P. L. Koch, R. S. Feranec, S. L. Wing and A. B. Shabel. 2004. Assessing the causes of Late Pleistocene extinctions on the continents. Science **306**:70–75.
Behar D.M. et al.(2008) The dawn of human matrilineal diversity. Am J Hum Genet **82**:1130–1140.
Bodenstein, T. 2006. Systemwandel und Handelsliberalisierung: Die Integration der Transformationsländer in die Weltwirtschaft. Pages 235–256 in S. A. Schirm, editor. Globalisierung: Forschungsstand und Perspektiven. Nomos Verl.-Ges., Baden-Baden.
Boris, J.-P. and J. Crépu. 2009. Krieg um den Reis/Main basse sur le riz. Ladybirds Films, ARTE Editions.
Brook, B. W. and D. M. J. S. Bowman. 2002. Explaining the Pleistocene megafaunal extinctions: Models, chronologies, and assumptions. Proceedings of the National Academy of Sciences of the United States of America **99**:14624–14627.
Burke, M. B., E. Miguel, S. Satyanath, J. A. Dykema and D. B. Lobell. 2009. Warming increases the risk of civil war in Africa. Proceedings of the National Academy of Sciences of the United States of America **106**:20670–20674.
Cash, D. W., W. N. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard and O. Young. 2006. Scale and cross-scale dynamics: Governance and information in a multilevel world. Ecology and Society **11**.
Chu, C. Y. C. and R. D. Lee. 1994. Famine, revolt, and the dynastic cycle—population-dynamics in historic China. Journal of population economics **7**:351–378.
Coqueugniot, H., J. J. Hublin, F. Veillon, F. Houet and T. Jacob. 2004. Early brain growth in *Homo erectus* and implications for cognitive ability. Nature **431**:299–302.
Costanza, R., et al. 1997. The value of the world‘s ecosystem services and natural capital. Nature **387**:253–260.
Cox, M. P., D. A. Morales, A. E. Woerner, J. Sozanski, J. D. Wall and M. F. Hammer. 2009. Autosomal resequence data reveal Late Stone Age signals of population expansion in Sub-Saharan African foraging and farming populations. Plos One **4**.
Crabbé, P. and J. Manno. 2009. Ecological integrity as an emerging global public good in L. Westra, editor. Reconciling human existence with ecological integrity: Science, ethics, economics and law. Earthscan, London.
Cumming, G. S., D. H. M. Cumming and C. L. Redman. 2006. Scale mismatches in social-ecological systems: Causes, consequences, and solutions. Ecology and Society **11**
Cunningham, D. L. 1999. Language and human evolution. Lambda Alpha Journal **29**:54–66.
Czech, B. 2000. Shoveling fuel for a runaway train: Errant economists, shameful spenders, and a plan to stop them all. Univ. of California Press, Berkeley, Calif.
Czech, B. 2009. The neoclassical production function as a relic of anti-George politics: Implications for ecological economics. Ecological Economics **68**:2193–2197.
Daly, H. 1972. The steady state economy. W. H. Freeman and Co Ltd., London.
Daly, H. E. 1996. Beyond growth: The economics of sustainable development. Beacon Press, Boston, Mass.
Daly, H. E. and K. N. Townsend. 1993. Valuing the earth: Economics, ecology, ethics. MIT Press, Cambridge, Mass.
Delcourt, P. A. and H. R. Delcourt. 2004. Prehistoric Native Americans and ecological change: Human ecosystems in Eastern North America since the Pleistocene. Cambridge University Press, Cambridge.
Diamond, J. 2010. Two views of collapse. Nature **463**:880–881.
Diamond, J. M. 1997. Guns, germs, and steel: The fates of human societies. Norton, New York, NY.
Diamond, J. M. 2005. Collapse: How societies choose to fail or succeed. Penguin Books, New York, NY.
Diniz-Filho, J. A. F. 2004. Macroecological analyses support an overkill scenario for late Pleistocene extinctions. Braz J Biol **64**:407–414.
Dubreuil, B. 2010. Paleolithic public goods games: why human culture and cooperation did not evolve in one step. Biology & Philosophy **25**:53–73.

Ehrlich, P. R. 2008. Key issues for attention from ecological economists. Environment and Development Economics **13**:1–20.
Ehrlich, P. R. and A. H. Ehrlich. 2009. The dominant animal: Human evolution and the environment. Island press text ed. Island Press, Washington, DC.
Faith, J. T. and T. A. Surovell. 2009. Synchronous extinction of North America‘s Pleistocene mammals. Proceedings of the National Academy of Sciences of the United States of America **106**:20641–20645.
Feinman, G. M. and J. Marcus, editors. 1998. Archaic states. School of American Research Press, Santa Fe, NM.
Fisher, R., S. Maginnis, W. Jackson, E. Barrow and S. Jeanrenaud. 2008. Linking conservation and poverty reduction: Landscapes, people and power. Earthscan, London.
Foley, R. A., P. C. Lee, E. M. Widdowson, C. D. Knight and J. H. P. Jonxis. 1991. Ecology and Energetics of Encephalization in Hominid Evolution. Philosophical transactions of the royal society of London Series B- Biological Sciences **334**:223–232.
Folke, C., L. Pritchard, JR, F. Berkes, J. Colding and U. Svedin. 2007. The problem of fit between ecosystems and institutions: Ten years later. Ecology and Society **12**.
Fournier, V. 2008. Escaping from the economy: the politics of degrowth. International Journal of Sociology and Social Policy **28**:528—545
Friedman, T. L. 2008. Hot, flat, and crowded: Why we need a green revolution, and how it can renew America. 1st ed. Farrar Straus and Giroux, New York.
Fulcher, J. and C. Rochow. 2007. Kapitalismus. Reclam, Stuttgart.
Funtowicz, S. O. and J. R. Ravetz. 1997. The poetry of thermodynamics—Energy, entropy/exergy and quality. Futures **29**:791–810.
Giampietro, M. and D. Pimentel. 1993. The tightening conflict: Population, energy use, and the ecology of agriculture. NPG Forum Ser: http://eco2bcn.es/publications_mgiampietro.html.
Giampietro, M. and K. Mayumi. 2009. The biofuel delusion: The fallacy of large scale agro-biofuel production. 1. ed. Earthscan, London.
Gilbert, D. T. and T. D. Wilson. 2007. Prospection: Experiencing the Future. Science **317**:1351–1354.
Goncalves, E. 2009. WWF International praises United Arab Emirates bid to host International Renewable Energy Agency Headquarters: Goncalves, Eduardo. Quote in press release. Available from http://www.masdar.ae/en/mediaCenter/newsDesc.aspx?News_ID=107&fst=mc&nws=1&MenuID=55&CatID=44.
Gray, J. 2010. Humanismus ist ein Aberglaube: Interview. Der Spiegel:136–140.
Gupta, A. K. 2004. Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. Proceedings of the National Academy of Sciences of the United States of America **87**:54–59.
Hames, R. 2007. The ecologically noble savage debate. Annual Review of Anthropology **36**:177–190.
Hamilton, M. J., O. Burger, J. P. DeLong, R. S. Walker, M. E. Moses and J. H. Brown. 2009. Population stability, cooperation, and the invasibility of the human species. Proceedings of the National Academy of Sciences of the United States of America **106**:12255–12260.
Hamilton, W. D. 1975. Innate social aptitudes of man: an approach from evolutionary genetics. Pages 133–153 in R. Fox, editor. Biosocial anthropology. Malaby Press, London.
Harvey, D. 1989. The condition of postmodernity: An enquiry into the origins of cultural change. Blackwell, Malden, Mass.
Ibisch, P. L. 2010. Global change management: eine systemische Utopie der Nachhaltigkeit im Angesicht der Apokalypse in E. Deutscher and H. Ihne, editors. „Simplizistische Lösungen verbieten sich“. Nomos, Baden-Baden.
Iftekhar Iqbal. 2008. Review of Williams, Michael, Deforesting the Earth: from prehistory to global crisis, an abridgment. H-Environment, H-Net Reviews.
Jackson, T. 2009. Prosperity without growth: Economics for a finite planet. Repr. Earthscan, London.
Johnson, A. W. and T. K. Earle. 2000. The evolution of human societies: From foraging group to agrarian state. Stanford Univ. Pr., Stanford, Cal.

Kaimowitz, D. and D. Sheil. 2010. Conserving what and for whom? Why conservation should help meet basic human needs in the tropics. Pages 245–259 in D. Roe and J. Elliott, editors. The Earthscan reader in poverty and biodiversity conservation. Earthscan, London.

Kunstler, J. H. 2005. The long emergency: Surviving the converging catastrophes of the twenty-first century. Atlantic Monthly Press, New York, NY.

Leggewie, C. and H. Welzer. 2009. Das Ende der Welt, wie wir sie kannten. Klima, Zukunft und die Chancen der Demokratie. S. Fischer Verlag, Frankfurt am Main.

Lewis, W. A. 1973. Growth and fluctuations. 1870-1913. George Allen & Unwin.

Li, Z., Y. Saito, P. X. Dang, E. Matsumoto and L. V. Quang. 2009. Warfare rather than agriculture as a critical influence on fires in the late Holocene, inferred from northern Vietnam. Proceedings of the National Academy of Sciences of the United States of America **106**:11490–11495.

Lotka, A. J. 1956. Elements of Mathematical Biology: (formerly published under the title "Elements of Physical Biology" 1925). Dover Publications, New York.

Marcus, J. and K. V. Flannery. 1996. Zapotec civilization: How urban society evolved in Mexico's Oaxaca Valley. Thames and Hudson, London.

Martin, P. S. and R. G. Klein, editors. 1984. Quaternary extinctions: A prehistoric revolution. Univ. of Arizona Press, Tucson.

McAnany, P. A. and N. Yoffee, editors. 2010. Questioning collapse: Human resilience, ecological vulnerability, and the aftermath of empire. Cambridge University Press, Cambridge.

McHenry, H. M. 2004a. Origin of human bipedality. Evolutionary Anthropology **13**:116–119.

McHenry, H. M. 2004b. Uplifted head, free hands, and the evolution of human walking. Pages 203–210 in D. J. Meldrum and C. E. Hilton, editors. From biped to strider: The emergence of modern human walking, running, and resource transport. Kluwer Academic/Plenum, New York.

McHenry, H. M. 2009. Human Evolution. Pages 256–280 in M. Ruse and J. Travis, editors. Evolution: The first four billion years. Belknap Press of Harvard Univ. Press, Cambridge, Mass.

McNeill, W. H. 1993. The age of gunpowder empires, 1450-1800 in M. Adas, editor. The forging of global order, Philadelphia.

Meadows, D. H., D. L. Meadows, J. Randers and W. W. Behrens III. 1972. The limits to growth. Universe Books, New York.

Meadows, D. H., D. L. Meadows and J. Randers. 1992. Beyond the limits: Global collapse or a sustainable future. Earthscan Publications, London.

Mellars, P. 2006. Why did modern human populations disperse from Africa ca. 60,000 years ago? A new model. Proceedings of the National Academy of Sciences of the United States of America **103**:9381–9386.

Mirow, J. 2009. Weltgeschichte: Mit 15 Karten. Piper, München.

Murra, J. V., editor. 1972. Visita de la provincia de Léon de Huánuco en 1562, I. Universidad Nacional Hermilio Valdizán, Huánuco, Peru.

Oatley, T. H. 2004. International political economy: Interests and institutions in the global economy. Pearson/Longman, New York.

Orlove, B. S. and S. B. Brush. 1996. Anthropology and the conservation of biodiversity. Annual Review of Anthropology **25**:329–352.

Osterhammel, J. and N. P. Petersson. 2007. Geschichte der Globalisierung: Dimensionen, Prozesse, Epochen. Orig.-Ausg., 4., durchges. Aufl. Beck, München.

Pericot, L. 1961. The social life of Spanish palaeolithic hunters as shown by levantine art in S. L. Washburn, editor. Social life of early man. Routledge, London.

Petraglia, M. D. and A. Alsharekh. 2003. The Middle Palaeolithic of Arabia: Implications for modern human origins, behaviour and dispersals. Antiquity **77**:671–684.

Petraglia, M., et al. 2009. Population increase and environmental deterioration correspond with microlithic innovations in South Asia ca. 35,000 years ago. Proceedings of the National Academy of Sciences of the United States of America **106**:12261–12266.

Pimentel, D. 2009a. The ecological and energy integrity of corn ethanol production in L. Westra, editor. Reconciling human existence with ecological integrity: Science, ethics, economics and law. Earthscan, London.

Pimentel, D. 2009b. Energy inputs in food crop production in developing and developed nations. Energies **2**:1–24.

Powell, A., S. Shennan and M. G. Thomas. 2009. Late Pleistocene demography and the appearance of modern human behavior. Science **324**:1298–1301.

Prigogine, I., P. M. Allen and R. Herman. 1977. Long term trends and the evolution of complexity. Pages 41–62 in E. Laszlo and J. Bierman, editors. Goals in a global community: the original background papers for goals for mankind; a report to the Club of Rome Vol. 1. Pergamon Press, New York, NY.

Ridley, M. W. 2009. [Epub ahead of print] When ideas have sex: the role of exchange in cultural evolution. Cold Spring Harb Symp Quant Biol.

Roberts, R. G., T.F. Flannery, L.K. Ayliffe, H. Yoshida, J.M. Olley, G.J. Prideaux, G.M. Laslett, A. Baynes, M.A. Smith, R. Jones, B.L. Smith. 2001. New ages for the last Australian megafauna: Continent-wide extinction about 46,000 years ago. Science **292**:1888–1892.

Rockström, J., et al. 2009a. A safe operating space for humanity. Nature **461**:472–475.

Rockström, J., et al. 2009b. Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society **14**(2):32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/

Roe, D. and J. Elliott. 2010a. Biodiversity conservation and poverty reduction: an introduction to the debate in D. Roe and J. Elliott, editors. The Earthscan reader in poverty and biodiversity conservation. Earthscan, London.

Roe, D. and J. Elliott, editors. 2010b. The Earthscan reader in poverty and biodiversity conservation. Earthscan, London.

Rogers, D. S. and P. R. Ehrlich. 2008. Natural selection and cultural rates of change. Proceedings of the National Academy of Sciences of the United States of America **105**:3416–3420.

Rosenberg, K. and W. Trevathan. 1995. Bipedalism and human birth: The obstetrical dilemma revisited. Evolutionary Anthropology **4:**161-168.

Sachs, J. D., et al. 2009. Biodiversity conservation and the Millennium Development Goals. Science **325**:1502–1503.

Smil, V. 2003. Energy at the crossroads: Global perspectives and uncertainties. MIT Press, Cambridge, Mass.

Soressi, M. and F. D'Errico. 2007. Pigments, gravures, parures. Les comportements symboliques controversés des Néandertaliens in B. Vandermeersch, B. Maureille and Y. Coppens, editors. Les néandertaliens. Éd. du Comité des Travaux Historiques et Scientifiques, Paris.

Spencer, C. S. 2010. Territorial expansion and primary state formation. Proceedings of the National Academy of Sciences of the United States of America **107**:7119–7126.

Stanish, C. 2001. The origin of state societies in South America. Annual Review of Anthropology **30**:41–64.

Steadman, D. W., G. K. Pregill and D. V. Burley. 2002. Rapid prehistoric extinction of iguanas and birds in Polynesia. Proceedings of the National Academy of Sciences of the United States of America **99**:3673–3677.

Stewart, J. 2000. Evolution's arrow: The direction of evolution and the future of humanity. Chapman Press, Rivett A.C.T.

Stiner, M. C. 2002. Carnivory, coevolution, and the geographic spread of the genus Homo. Journal of archaeological research **10**:1–63.

TEEB—The Economics of Ecosystems and Biodiversity. 2008. The Economics of Ecosystems and Biodiversity: An interim report.

TEEB—The Economics of Ecosystems and Biodiversity. 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers: Summary: Responding to the Value of Nature.

Trevathan, W. R. 1996. The evolution of bipedalism and assisted birth. Medical Anthropology Quarterly **10**:287–290.

Turner, W., T. Brooks and K. Brandon. 2010. Conservation priority areas, poverty, and payments for ecosystem services: a global view: Paper presented at "Linking biodiversity conservation and poverty reduction: what, why and how?": 28-29 Apr 2010, London.

Ungar, P. S., F. E. Grine and M. F. Teaford. 2006. Diet in early *Homo*: A review of the evidence and a new model of adaptive versatility. Annual Review of Anthropology **35**:209–228.

VanBuren, M. 1996. Rethinking the vertical archipelago—Ethnicity, exchange, and history in the South Central Andes. American Anthropologist **98**:338-&.

Vira, B. and A. Kontoleon. 2010. Dependence of the poor on biodiversity—which poor, what biodiversity? Paper at the Symposium "Linking Biodiversity Conservation with Poverty Reduction: What, Why and How?": April 28-29, London.

Vries, J. de. 2009. The industrious revolution: Consumer behavior and the household economy, 1650 to the present. Reprinted. Cambridge Univ. Press, Cambridge.

Wachtel, N. 1982. The mitimas of the Cochabamba valley. Pages 199–236 in G. A. Collier, editor. The Inca and Aztec states, 1400-1800. Academic Press, New York.

Walter, R. C., et al. 2000. Early human occupation of the Red Sea coast of Eritrea during the last interglacial. Nature **405:**65-69.

Welzer, H. 2009. Klimakriege: Wofür im 21. Jahrhundert getötet wird. 4. Aufl. S. Fischer, Frankfurt am Main.

Westra, L., editor. 2009. Reconciling human existence with ecological integrity: Science, ethics, economics and law. Earthscan, London.

White, L. T. 1978. Medieval religion and technology. University of California Press, Berkeley.

Williams, M. 2006. Deforesting the earth: From prehistory to global crisis. Abridged ed. University of Chicago Press, Chicago, Ill.

Willke, H. 2001. Atopia: Studien zur atopischen Gesellschaft. Suhrkamp, Frankfurt am Main.

Willke, H. 2002. Dystopia: Studien zur Krisis des Wissens in der modernen Gesellschaft. Orig.-Ausg., 1. Aufl. Suhrkamp, Frankfurt am Main.

Willke, H. 2003. Heterotopia: Studien zur Krisis der Ordnung moderner Gesellschaften. 1. Aufl. Suhrkamp, Frankfurt am Main.

Wrangham, R. W. 1999. Evolution of coalitionary killing. Yearbook of physical anthropology **42**:1–30.

Zhang, D. D., P. Brecke, H. F. Lee, Y.-Q. He and J. Zhang. 2007. Global climate change, war, and population decline in recent human history. Proceedings of the National Academy of Sciences of the United States of America **104**:19214–19219.

Zilhao, J., et al. 2010. Symbolic use of marine shells and mineral pigments by Iberian Neandertals. Proceedings of the National Academy of Sciences of the United States of America **107**:1023–1028.

B.2.3 STRATEGIC SUSTAINABLE DEVELOPMENT: A SYNTHESIS TOWARDS THERMODYNAMICALLY EFFICIENT SYSTEMS AND POST-NORMAL COMPLEX SYSTEMS MANAGEMENT

Peter Hobson & Pierre L. Ibisch

ABSTRACT

Fundamental issues to do with unsustainable human development and energy management that lead to converging crises such as biodiversity loss or climate change require urgent attention if global society is to progress in a sustained way in the long-term. Measures of thermodynamic efficiency go beyond the obvious relationship between society and energy resources, to also include the way humans utilize the physical and biological landscape. A number of metrics are proposed in the assessment of environmental sustainability including the use of exergy. However, attempts to measure the sustainable use of the physical landscape and living biota are more problematic because of the complexity of nature. Nevertheless, there is emerging scientific evidence in support of the idea that there is a strong relationship between vegetation pattern and thermodynamic factors. Furthermore, an examination of land cover type and microclimatic patterns suggest that mature and complex ecosystems have the highest levels of exergy and are better able to dissipate solar radiation. This suggests that more complex, thermodynamically efficient systems are more resilient to environmental change.

Both landscape ecology and industrial ecology provide a range of useful proxy measures of thermodynamic efficiency for ecosystems. By reducing often confounding patterns and behaviour of complex systems to practical measurements of energy use it is possible to construct a robust framework for sustainable development. Human social systems mimic some of the non-equilibrium thermodynamic patterns found in nature. Materials and energy are processed and re-cycled through a nested hierarchy of semi-closed systems. However, there are fundamental differences between the two domains that relate to scale, structure, dynamics and feedback mechanisms, and it is this difference that may contribute significantly to the ultimate breakdown in natural systems, biodiversity loss and anthropogenic climate change. Most of Earth's biodiversity continues to exist outside the boundaries of protected areas and within the used landscape. This situation is unlikely to change in the future, although land use practices under the current scenario of "business as usual" will continue to drive down biodiversity and ecosystem services. To tackle problems of this magnitude and complexity a framework for sustainable development is needed that operates to optimum indicators for ideal-seeking systems based on non-equilibrium thermodynamics and complex systems theory.

An effective assessment of the sustainability of a system would include an ecosystem mapping exercise and the use of a predictor set of complementary proxy indicators; these could include, for instance, the quantity of energy input and utilization; exergy capacity (stored, usable energy in the system, carbon storage); and measures of various positive feedback processes (quantity of non-recyclable energy and material—waste material and heat loss/capacitance), or connectivity/connectedness). Adequate biodiversity indicators would comprise of biomass production/carbon storage; diversity of native primary producers (species richness); diversity of plant growth forms (functional groups, strategic types); and a "trophic tree index"—the number of functional groups of fauna and flora.

Science and technology should re-focus efforts towards eco-centric innovation, methods of working towards ideal-seeking systems using principles of thermodynamics. Fundamental to this change is the reform of neo-classical models of economy that embrace principles of ecological economics. The validation of the ecological economics model is underscored by the primary objective, which is to ground economic thinking and practice in the laws of thermodynamics. Success, goals and outcomes should not be exclusively measured in monetary worth, but also by using relative valuation and environmental accounting.

B.2.3.a THERMODYNAMICS-BASED SUSTAINABILITY

The relationship between energy and biodiversity sets the context for the evolution of life-forms and ecosystems and provides the means for advancing human civilization and generating wealth (Dincer & Rosen 2005). Energy use and transference within and between systems is governed by the laws of thermodynamics, which provide clear and unambiguous pathways to a more sustainable management of resources (Dincer & Rosen 2005). Currently, society is operating unsustainably and a combination of human-resource-related behaviour has contributed to a number of problems including biodiversity loss, global resource depletion, and energy-related environmental impacts. Fundamental issues to do with human development and energy management require urgent attention if global society is to progress in a sustained way in the long-term. Measures of thermodynamic efficiency go beyond the obvious relationship between society and energy resources, to also include the way humans utilize the physical and biological landscape.

Discussions on thermodynamics-based sustainability emphasize the importance of minimising the influence of subjectivity in formulating appropriate strategies and indicators in the process. A number of metrics are proposed in the assessment of environmental sustainability including the use of exergy (Dewulf & van Langenhove 2005). Exergy analysis quantifies energy use including losses and waste at various stages of its progress through a system (Dincer & Rosen 2005). Consequently, it is possible to calculate the amount of non-renewable exergy necessary for the life-cycle of a certain product or process (Sewalt *et al.* 2001; Hammond 2007). The loss of exergy from non-renewable sources is considered to be toxic to the environment. By contrast, renewable exergy sources do not produce any harmful effect since they can be recovered (Sewalt *et al.* 2001). It is easier to appreciate the quantitative benefits of thermodynamics in industrial systems that operate to mechanistic and measurable energy flows, and there has been a good deal of research on the use of exergy and other sustainable metrics to measure efficiencies in these systems (see Connelly & Koshland 2001, Dewulf & van Langenhove 2005). Furthermore, the potential use of exergy analysis in assessing the impact on the environment of waste material is significant (Dincer 2000).

However, attempts to measure the sustainable use of the physical landscape and living biota are more problematic because of the complexity of nature. Certain principles of energy and material transference used in industry can be applied to natural systems. Aspects of energy exchange, and conversion and the effects of mass (biomass in the case of biological systems) influence life-cycles of species and material as well as biological processes (Dewulf & van Langenhove 2005). For instance, by measuring the energy and material input into agro-ecosystems together with product output, it is possible to estimate the production of entropy (Steinborn & Svirezhev 2000). In a similar way, the entropy of a landscape can be assessed by measuring the differences between the values of biogeoceonosis sensitivity (sensitivity of both species and environmental attributes) and technogeochemical stresses (pollution, contamination and physical alteration) that result from human activity (Jankauskaite & Veteikis 2005). The ability of a landscape to process toxic waste and 'self-clean' is a measure of the extent of biomass deposition and circulation, which, in turn, is a proxy indicator of complexity, resistance and resilience to anthropogenic influence (Jankauskaite & Veteikis 2005). In other studies that have examined the organizational order of vegetation, a relationship between vegetation pattern and thermodynamic principles has been demonstrated (Zhang & Wu 2002). Taking it further, an examination of land cover type and microclimatic patterns suggest that mature and complex ecosystems have the highest levels of exergy and are better able to dissipate solar radiation (Wagendorp 2003).

More recent developments in landscape ecology have moved the science closer towards a holistic problem-solving discipline that explores connectedness and ordered complexity rather than conventional lines of enquiry based on reductionist and mechanistic approaches (Naveh 2000). Central to this concept is the recognition of the human ecosystem as a holarchic subset to the global ecosystem, and its reliance on the combined input of solar and alternative-based energy. This approach attempts to unify principles of ecology and thermodynamics into a coherent ecosystem thesis that offers appropriate metaphors and measures for sustainable development (Naveh 2000).

Both landscape ecology and industrial ecology provide a range of useful proxy measures of thermodynamic efficiency for ecosystems. By reducing often confounding patterns and behaviour of complex systems to practical measurements of energy use, it is possible to construct a robust framework for sustainable development. Thermodynamic modeling and measurements of ecosystem performance would provide the necessary guidance for policy on social and economic development towards a whole-systems approach. Furthermore, it would avoid potential conflicts between various global frameworks, for instance, the Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD). At the moment, there has been little effort to align the objectives for carbon management and ecological sustainability (e.g., Muys *et al.* 2003).

The next stage to the process of developing a unifying framework for sustainability is to link structural and functional attributes of biodiversity to thermodynamic measures of anthropogenic disturbance. So far, scientists have provided a theoretical framework for ecosystem thermodynamics (Holling 1986; Jørgensen 1992; Schneider & Kay 1994; Kay *et al.* 1999; Kay 2000). Attempts to attach measurable indicators of ecosystem exergy efficiency to this theory have brought us closer to defining the capacity and limits of global ecosystems (Jørgensen 2006). However, there are still gaps in the model that fail to take full account of temporal and spatial scales of biodiversity. Historical and environmental legacies of biodiversity configured across landscapes provide connectedness, and contribute to emergent properties that are difficult to categorise using principles of thermodynamics. What is more, land use has and continues to change these natural patterns, often leading to biodiversity degradation and ecosystem dysfunction. There is a need to devise a conceptual framework and practical set of measures for these aspects of biodiversity. The ecosystems theory makes a significant contribution towards capturing biodiversity value (Jørgensen 2007). A unifying concept for sustainability would combine principles of ecosystem theory and structural biodiversity.

Achieving sustainable development requires a holistic systems approach as suggested by Robèrt *et al.* (2002). They define five hierarchical and inter-dependent levels for a systems approach for *strategic sustainable development* (SSD). The following suggested principles broadly embrace the philosophy underpinning SSD. Macro socio-economic policy should be built on an ecological platform in which opportunities and constraints are identified in the context of ecosystem carrying capacity, resilience and thermodynamics. In this model the socio-economic infrastructure is an integral, scaled subset within the space-time dimensions of the natural system. This sets clearly defined limits on human population growth and utilization of energy and natural resources. It also requires a complete re-adjustment of the shaping and function of a cultural landscape. Patterns of use and processes would change profoundly to minimise loss of ecosystem complexity, structure and biodiversity in order to fit as best as possible within natural forms of thermodynamic efficiency. Such a strategy amounts to 'mimic-management', synchronicity with natural feed-back systems, disturbance regimes, and space-time heterogeneity. Conceptual coherence, inter-connectedness and dynamic time dimensions are factored into the framework. Management of human systems and cultural landscape is required to be adaptive and pro-active, flexible enough to factor in environmental uncertainty. This requires a shift away from human activities and systems that promote resistance and steady state to those that create resilience. In the landscape, practices that promote the retention of environmental legacies, specifically key functional ecosystems, including forests and wetlands, should become benchmarks for future development.

Achieving sustainable solutions is also about engaging with social values and individual behaviour. Existing 'life-value' references such as biodiversity, environmental mitigation, nature-worth, life-quality indicators and well-being that are currently traded as monetary-driven commodities would be re-valued under an ecosystem services credits system. As such, they would be traded and banked by organisations and governments operating to novel bio-economic structures and regulations.

Science and technology would re-focus efforts towards ecocentric innovation, methods of working towards ideal-seeking systems' using principles of thermodynamics. Essentially, it calls for a Radical Ecosystem Approach that combines principles of ecosystem theory and non-equilibrium thermodynamics (Ibisch *et al*., A.2., in this document).

B.2.3.b A POST-NORMAL SCIENCE PERSPECTIVE ON BIODIVERSITY AND SUSTAINABILITY

Biodiversity has been shaped by chaotic events that have generated order across scales of space and time. In a "neutral environment" devoid of life, the energy imported from the sun or generated from chemical and thermal reactions would soon reach a state of entropy according to the laws of thermodynamics, with no means of recycling energy and building exergy capacity. Living systems, on the other hand, have evolved a unique way of capturing the sun's energy and dissipating it through self-organizing and complexifying structures. Furthermore, feedback processes operating in semi-closed systems have improved functional efficiencies by recycling energy and material thus delaying the inevitable end-point of entropy, a very non-equilibrium thermodynamic characteristic.

Human social systems mimic some of the non-equilibrium thermodynamic traits found in nature. Materials and energy are processed and re-cycled through a nested hierarchy of semi-closed systems. However, there are fundamental differences between the two domains that relate to scale, structure, dynamics and feedback mechanisms, and this discourse is the cause of systems breakdown, biodiversity loss and anthropogenic climate change. Detailed scientific investigation has identified many of the causes and effects of these problems, and the findings of these studies have been used to inform policy on sustainable development. What then is the issue, and why are so many of the problems re-occurring and exhibiting accelerated tendencies towards collapse? There are growing concerns in various sectors of society that science is failing to provide adequate responses to the challenges facing humanity, and ultimately, is facing a crisis of confidence. Science has amassed a wealth of knowledge of the components, elements and attributes of the natural environment but little understanding of the interconnections and synergistic tendencies that binds them into a functioning complex system.

In some cases it is possible to find a plausible scientific reason for these failings whilst other problems remain beyond the powers of reasoning or action. For instance, density-dependent factors of population carrying capacity are readily explained through the relationship between population numbers and food availability using an interpretation of the Lotka-Voltera model. That is not to suggest that relatively linear models for cause and effect problems necessarily respond readily to equally simple solutions. For instance, attempts so far to address problems of population growth and over-exploitation of resources have failed because the human relationship with exergy capital is much more complex than this. Technology has made possible the extraction, processing and transportation of energy and material from more than one source, and this in turn, has de-coupled society from some of the constraining factors that bind the rest of nature. History provides evidence for this unique phenomenon of nature-culture de-coupling as far back as early hunter-gatherer societies. The discovery of fire provided a powerful tool for the dramatic transformation and shaping of the landscape. Later, the birth of agriculture catapulted civilization from hunter-gather to harvester of crops and animals, followed by the industrial revolution that accelerated the pace of human development and expansion into virgin landscape, and so it goes on. The consequences of these phenomena were a rapidly increasing population that was able to form semi-permanent settlements in concentrations higher than the natural carrying capacity of the original ecosystem. Each historical phase in human development has marked a fundamental change in our relationship with nature including the extent to which we are able to exploit exergy capital (compare Ibisch & Hobson, B.2.2., in this document). As a consequence, humanity has created multiple meta-systems within the biosphere, thus adding to the complexification of the global ecosystem. These developments have brought with them novel emergent, indeterministic properties that have added to the existing mountain of unknowns in the science world.

Here is the paradox, despite the mimicry and interconnections between cultural and natural systems, the popular world view (scientific and philosophical) is of a technocentric society that is able to grow and function unfettered by 'laws of nature.' This, in turn, has shaped modern society's perspective on the human-nature relationship. Societal segregation from the living world has naturally encouraged a reductionist perspective, the convenient compartmentalization of resources and systems that are then manipulated and changed in isolation. Human systems are complex but function in the wider environment along relatively simple linear frameworks. Material and energy are imported whilst waste, produce and heat are exported. Current scientific and technological efforts have failed to respond adequately to the problems associated with this open-ended relationship.

The case made here is not for more scientific study or even for improvements in science but rather for a fundamental change in perspective across all levels of society including science: the adoption of a post-normal science perspective based on the insights of complex system science (see above). A post-normal science perspective uses current scientific models and theories to ask a very different set of questions on which to build scenarios and attempt adaptive solutions to problems. Rather than seek out the individual signature and behaviour of each component in a system, post-normal science attempts to understand the extent of connectivity in a system and the emergent properties manifest in this relationship. It also aims to construct probabilistic scenarios based on knowledge of the factors impacting on a system(s), and adopt a multi-scaled, whole system approach to all lines of enquiry and problem-solving. A certain degree of reductionism is inevitable. For instance, the scientific categorization and classification of nature as well as the use of metaphors and language to describe form and function set cognitive limitations on the observed physical complexity. However, without these cultural constructs there would be no means of building any form of framework.

A system can be defined by form (structure) and function, a description used for biodiversity. Function is expressed and measured in terms of thermodynamic principles, specifically exergy and entropy. The rationale for this has been explained in detail in the preceding sections but in summary, all processes and outputs are dependent on exergy, and persistence is a function of the state of entropy in the system. System form defines the spatio-temporal structure across all scales. It includes the heterogeneity manifest in 'patches' or sub-systems as well as the connectedness and connectivity inherent at genetic and trophic levels. It also includes non-living biomass. The structure or form of a system has been described using the adaptive cycle metaphor, and at the moment it is the most appropriate model for representing inter-connectedness between holarchically arranged meta-systems. These properties can be measured using structural indicators such as biomass and connectivity (Jørgensen 2006). Inevitably, indicators for form and function of a system converge towards a unifying predictor set of measures for ecosystem health—the basis for ecosystem theory.

Natural ecosystems continue to evolve to avoid collapse towards entropy, and this involves the building of complexity into form and function. Ecosystems that appear to demonstrate all the characteristics of a self-ordering, holarchic organization (SOHO) (Kay 2008) can be described as ***"ideal-seeking systems***", and the best examples of these are likely to be found in "un-trammeled" landscapes, areas that have escaped human disturbance and alteration. Large tracts of "free-willed" ecosystems serve two vital roles, namely, the provision of ecosystem services to the wider landscape; and also as a baseline or template for the sustainable management of modified areas. Currently, about 12% of the earth's major ecosystems are protected from development, however, many of the protected areas are far from representing free-willed ecosystems, and the protected area system alone has not prevented the continued decline in global biodiversity and ecosystem degradation caused by human development. Most of Earth's biodiversity exists outside these areas in the used landscape. This situation is unlikely to change in the future, in fact, conditions can only get worse under the current scenario of "business as usual." To tackle problems of this magnitude and complexity a framework for sustainable development is needed that operates to optimum indicators for ideal-seeking systems based on non-equilibrium thermodynamics and complex systems theory. Guidelines for sustainable development indicators are set out in the following section.

INDICATORS OF SUSTAINABLE DEVELOPMENT

Energy, exergy and entropy

Energy and exergy are the drivers to system evolution and persistence. The dissipation of energy through a complex system may be difficult to track and measure but it is possible to record with reasonable accuracy the amount of incoming and outgoing energy. These two end points to energy transformation provide information about efficiency, state of entropy, and exergy capacity within a system. This strategy applies the "**black box principle**" that is to say, there are unknowables in the system (uncertainties) but these do not necessarily hinder the process of systems accounting and management (Fig. 1.). In most forms of industry, productivity and performance have traditionally been measured in terms of energy efficiency. More recently, these same measures have been applied to wider social infrastructures including domestic lifestyle. However, energy flow does not necessarily offer the most appropriate context for sustainable development and a more specific means of accounting and tracking is needed. Exergy is a more realistic form of assessing performance and behaviour in human systems. By focusing on the availability of usable energy (exergy), greater emphasis is put on the development of semi-closed systems that conserve and recycle energy and materials. For instance, the clustering of industry to minimize waste output by re-using by-products as alternative energy sources, "one industry's waste is another's energy." In semi-closed systems that recycle energy and material, it is much easier to budget energy use and also to construct working models for exergy capital and feedback mechanisms.

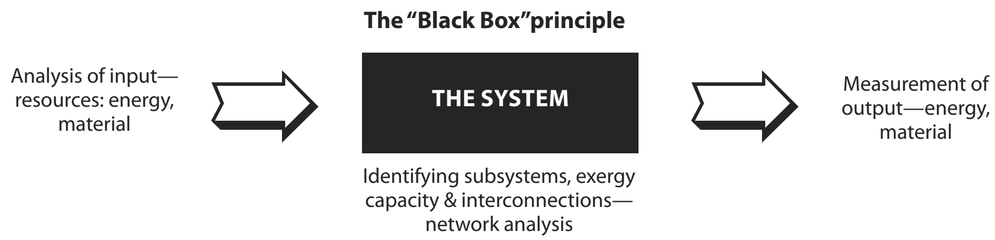

FIGURE 1: The blackbox principle in systems analysis.

It is more difficult to apply this form of energy accounting in large open landscapes where the exchange of energy and materials with the surrounding environment is unconstrained. In more industrialized regions of the world, a sophisticated grid system of energy budgeting and distribution operates to regional scale. However, they do not factor in substantial exchanges of energy that pass through rural or natural landscapes, or the losses of material and energy that result from land use change and management. What is more, changes in status of any one sub-system will trigger a cascade effect on others that may result in a release of energy and material. Therefore, we can expect on-going shifts in exergy capital across sub-systems. To address these issues it is essential to work to a holistic framework such as ecosystem services analysis. This process uses network analysis to reveal as many of the inter-relationships and pathways between meta-systems and their components. For instance, in agricultural landscapes surrogate measures of energy input-output would include accounting of fuel and material consumption together with the assessment of plant/animal productivity (biomass build-up), and final agricultural product output, energy storage and expenditure. This is a rather simplistic approach that would need refining to include a more complete network analysis to take account of the remaining biomass (part of the exergy capital), proportion of recycling of material and energy, and the extent of connectivity—the biodiversity. Similar forms of assessment would be carried out for river and wetland systems, forest landscapes, grasslands, mixed cultural systems amongst others. An effective assessment of the sustainability of a system would include an ecosystem mapping exercise and the use of a predictor set of complementary proxy indicators.

Such a predictor set would comprise an ecosystem services map—a network analysis for the holarchic system together with a range of proxy measures for ecosystem efficiency. These could take the following form:

- Quantity of energy input and utilization
- Exergy capacity (stored, usable energy in the system + carbon storage—resource banking)
- Positive feedback measures (quantity of non-recyclable energy and material—waste material and heat loss/capacitance)
- Connectivity/connectedness (biodiversity)

An ecosystem services assessment 'map' would provide a near-enough approximation of the structure and inter-relationships between the components of a system as well as the pathways between the different meta-systems in the larger holarchic construct. The ecosystem services 'map' constitutes the spatial representation of the adaptive cycle concept model. Energy and material dissipate within the systems and also move along the pathways between meta-systems. The quantity of energy and material that ends up as stored carbon (living and dead) together with the amount that is lost to heat (irreversible) is a function of exergy capital. These measures as well as aspects of biodiversity (diversity and functionality) indicate the level of sustainability in the system.

Biodiversity as a proxy measure of sustainable development

Healthy ecosystems contribute to the well-being of humanity, and the Convention on Biological Diversity calls upon member states to conserve and sustainably use biological diversity. The emphasis is characteristically anthropocentric and often focuses on the short-term consumption and extraction use value but understates the ecosystem functioning and services that are the life insurance of life on earth. It is understandable how ecosystem services and bio-commodities attract the interest of the commercial world; after all, you can't put a price on the intrinsic value of nature. That said, the message repeated in the Convention for Biological Diversity is emphatic, the planet's lifeline rests in biodiversity.

It is impossible to account for all biodiversity or to reduce the multidimensional concept down to a single formula or number (Purvis & Hector 2000). The current description of 1.75 million species worldwide more realistically represents 10% of the total. In fact, the rate of discovery of new species suggests an even higher figure than this (Purvis & Hector 2000). Uncertainties about biodiversity are complicated by estimates of species loss to the impacts of human development. Wilson (1992) used species-area relationships to derive an annual extinction rate of 27,000 species. The effect of this biodiversity loss on ecosystem function is less clear although there is mounting evidence to indicate that there is a strong connection between biodiversity and ecosystem function. For instance, diverse communities are more resilient and resistant to invasions (Stachowicz *et al.* 1999). Specifically, diverse plant communities exhibit a greater variety of positive and complementary interactions (Tilman 1999). Work by Zhang and Wu (2002) on vegetation dynamics suggests that the influences of structure and self-organisation of vegetation will affect the thermodynamic nature of an ecosystem, which in turn, will relate to the efficiency and stability of ecosystems.

Changes in structural attributes of vegetation generate unique spatial and temporal responses in various microclimatic variables including temperature, humidity and light (Zheng *et al.* 2000). Increased light and moisture conditions as a result of changes to vegetation structure can promote abundant growth of plant species as well as provide favourable habitat for some small mammals (Brookshire & Shifley 1997). However, human disturbance patterns that result in substantial losses or simplification of forest vegetation will cause noticeable changes in local temperatures (Chen *et al.* 1999, Heithecker & Halpern 2006). Jørgensen *et al.* (2000) suggest that the physical-biological structure, increased network linkage between components, and the increasing replacement of r-strategy species by K-strategy organisms are signatures of evolving ecosystem complexity.

In both terrestrial and aquatic systems the primary producers are the fundamental building blocks to biodiversity, ecosystem function and resilience. In adopting this pretext it is plausible to propose a predictor set of biodiversity indicators of sustainability to complement thermodynamic indicators. The proposed indicators are as follows:

- Biomass production/carbon storage
- Diversity of native primary producers (species richness)
- Diversity of plant growth forms (functional groups, strategic types)
- "Trophic tree index" the number of functional groups of fauna and flora.

Reducing biodiversity down to a small set of surrogate measures is a blunt tool to apply to sustainable development, but if it can be demonstrated that there are clear correlations between the different elements of biodiversity and these indicators then it offers an effective and measurable technique for sustainable development. Environmental indicators are only effective when applied using benchmark standards, and these are based on conditions prevailing in 'free-willed' landscapes. These untrammeled landscapes are a vital component to sustainable development, and in this instance they provide important reference sites for the effective management and restoration of cultural ecosystems.

The current debate on wilderness continues to raise contentious philosophical and ethical issues between the preservationists and the "utilitarianists" and yet the case for protecting wilderness can be made from both perspectives. Free-willed landscapes provide an essential practical function to global ecosystem function; consequently, we have a moral obligation to ensure that they are protected from human impact. The important question is how much wilderness can we afford to preserve and do we practicably need to ensure global sustainability. This presents us with the conundrum of balancing usable natural capital with environmental buffers—ecological legacies retained in a natural state for the ecosystem services they provide. There is no final answer to this question as change is inevitable and with it comes uncertainty and indeterministic tendencies, and it is impossible to generate "end-point" objectives and goals for moving targets. In such cases, the logical answer is to conserve as much wilderness as possible, and some more, applying the precautionary principle.

In summary, a predictor set of optimum indicators for sustainable development comprise a combination of non-equilibrium thermodynamic and biodiversity measures. These are based on benchmark standards drawn up from observations and studies of conditions in free-willed landscapes. Establishing a base line and benchmarks for sustainable development provides a pathway for the next stage of building a strategy around the principles of ecosystem theory, drawing on principles of non-equilibrium thermodynamics and complex system theory.

PREDICTOR SET OF OPTIMUM INDICATORS FOR SUSTAINABLE DEVELOPMENT BASED ON BENCHMARK STANDARDS TAKEN FROM REFERENCE SITES—FREE-WILLED LANDSCAPES

Non-equilibrium thermodynamic indicators
- Quantity of energy input and utilization
- Exergy capacity (stored, usable energy in the system + carbon storage—resource banking)
- Positive feedback measures (quantity of non-recyclable energy and material—waste material and heat loss/capacitance)
- Connectivity/connectedness (Biodiversity)

Biodiversity indicators
- Biomass generation/carbon storage
- Diversity of native primary producers (species richness)
- Diversity of plant growth forms (functional groups/strategic types)
- "trophic tree index" the number of functional groups of fauna and flora

2.3.3 GENERATING PRACTICAL MODELS FOR SUSTAINABLE DEVELOPMENT USING PRINCIPLES OF POST-NORMAL SCIENCE

A holistic systems approach to sustainable development describes a fully interrelated, cross-scale strategy for the long-term procurement of the optimal survival of the human species. In their proposal for a systems approach to *strategic sustainable development (SSD),* Robèrt *et al.* (2002) advocate a macro socio-economic policy that is built on an ecological platform. This idea (sometimes referred to as biomimicry) is not new but there is little evidence for significant practical development in this field. Furthermore, attempts at developing strategic sustainable development often ignore fundamental issues to do with scale and indeterministic tendencies, two key attributes of ecosystem dynamics. For instance, current structures for macro socio-economics are unsustainable because they are too open, are resource-hungry, and too inflexible to patterns of unpredictable change. Consequently, wastage of resources, boom-bust cycles, and regime instability or collapse are common features of most socio-economic systems around the globe. In just a few cases, typically, in societies that exist at the boundaries of environmental tolerance, there are some good examples of biomimicry, including energy and material recycling, principles of carrying capacity, and adaptive strategies to unpredictable change. However, they do not represent the norm as most of these societies survive in small numbers, in some cases, nomadic 'bands' moving across large tracts of landscape. New working models are needed to resolve problems associated with over-sized and increasing populations.

In ecosystem models the socio-economic infrastructure is nested within the larger holarchic construct of the natural system. This sets clearly defined limits on human population growth and utilization of energy and natural resources. It also requires a complete re-adjustment of the design and management of cultural landscapes to minimize the loss of ecosystem complexity, structure and biodiversity, and to maximize thermodynamic efficiency. Such a strategy requires synchronicity with natural feed-back systems, disturbance regimes, and space-time heterogeneity. Management practices must adopt adaptive and pro-active strategies that factor in environmental uncertainty. In conservation, this requires a shift away from human activities and systems that promote the status quo and steady state to those that create flexibility and adaptive resilience.

WORKING WITH LANDSCAPES

A multi-scaled approach to landscape management would apply principles of landscape ecology, specifically, two models: namely the patch-corridor-matrix model (Forman 1995) and the continuum model (e.g., Fischer & Lindenmayer 2006). Both provide appropriate metaphors for the required territorial design and management strategy of landscapes. At the largest scale, the new strategy would involve the retention of substantial tracts of untrammeled functional ecosystems, including marine, forests, peatlands (tundra), wetlands and mountains, a form of "ecosystem banking". These systems would provide the necessary insurance against catastrophic changes by securing the sources of biodiversity evolution and macro-environmental services. The scale of protection of these systems would be set by probabilistic models using both non-equilibrium thermodynamic and biodiversity indicators. For instance, empirical measures of thermodynamic conditions, and carbon storage at regional and global scale would give some indication of the specified limits for both core and buffer zones.

The pressures on land use of a growing population have led to the inevitable loss, fragmentation and degradation of ecosystems. This trend is unlikely to change in the near to mid future and thus calls for radical alternatives to current practice across all cultural landscapes. A number of existing initiatives, for instance, the pan-Europe strategy for biodiversity that includes Natura 2000, and the Emerald Network, provide practical models for mitigating against the effects of human impact on the natural environment. These schemes involve the conservation and creation of large green networks or corridors between protected areas or centres of biodiversity. However, the political will to fully implement eco-corridors across the region is weak. Hopes of developing a similar effective globe-wide strategy are unlikely without changes to policy. To succeed this scheme would require full integration into a larger spatial planning strategy at ecoregional, national and international levels. Specifically, it would target natural corridors such as hill ranges, altitudinal corridors from lowlands to the high mountains, riparian systems, forests and wetlands[55]. The size of these corridors would be proportional to the natural dynamics of the system. An example of large scale integrative design and planning is evident in the recent European Water Framework Directive strategy for the management of river catchments. It incorporates all systems that relate to the hydrological regime. Once more, this system management must be integrated into wider spatial strategy plans that include other complementary system strategies for biodiversity, forestry, and urban and rural planning. A combined synthesis of network analysis and ecosystem services across all meta-systems would provide the framework for fully integrated operational objectives and action.

The spatial realization of a fully integrated complex systems management strategy would typically appear hierarchical as well as highly variable in pattern and configuration (Fig. 2). Large tracts of self-willed ecosystems would abut cultural landscapes of varying degrees of modification but diffused with more natural ecosystem outliers and an intricate network of eco-corridors. Furthermore, practices of adaptive management in cultural landscapes would generate plasticity in the system with variable patch dynamics. At a finer scale, the retention of environmental legacies including flood plains, rank vegetation, coarse woody debris, scrub, wet flushes, ponds, wild populations, and others are an important element of maintaining permeability and functionality in modified landscapes. More natural disturbance patterns and succession dynamics in outlier patches will contribute to the wider environmental sustainability of the modified landscape.

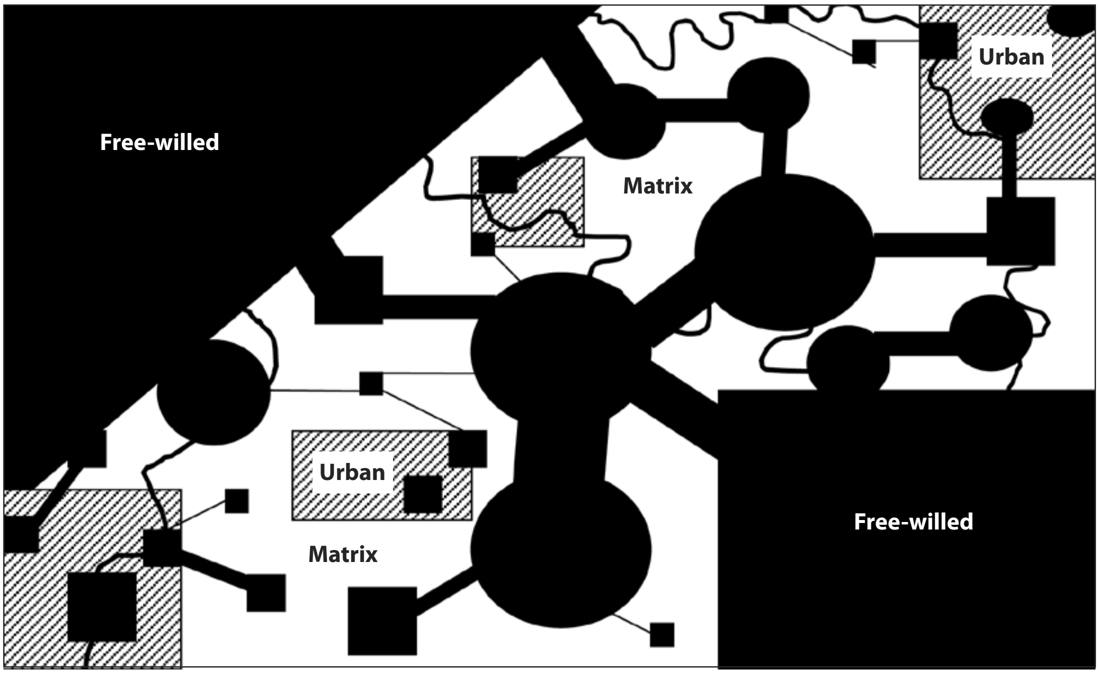

FIGURE 2: Schematic model of free-willed ecosystems with outliers and corridors.

55 In Bolivia, in the context of various conservation exercises on the national and sub-national scale, the combination of conventional targets of conservation planning (applying a fine-filter approach that identifies areas relevant for species richness and endemism as well as a coarse filter targeting ecosystem representation) and function and process-representing targets, such as mountain ranges, blocks of intact forest, or altitudinal corridors, has led to interesting results informing integrated conservation and development initiatives (Ibisch et al. 2002, 2006, 2007).

ON A SOCIAL FRAMEWORK FOR SUSTAINABLE DEVELOPMENT

Achieving sustainable solutions is also about engaging with social values and individual behaviour. In the current business as usual scenario most of global natural capital is traded and valued on an economic basis. This system imposes strict constraints on valuing the true worth of biodiversity to human survival and well-being as economic measures are not necessarily the best indicator. Existing 'life-value' references such as biodiversity, environmental mitigation, nature-worth, life-quality indicators and well-being could be evaluated using a range of non-market value approaches. For instance, a benefit transfer system can use economic information for a particular place and time to inform policy makers about the economic value of environmental goods and services at another place and time (Wilson & Hoehn 2006). Economic worth is either measured in monetary units or as value functions that are based on original value data or metadata (Loomis 1992, Woodward & Wui 2001). Such values, "vector values", can be derived from statistical evidence of services value, a form of environmental accounting of stocks and flows (carbon storage and transfer and exergy capital would be examples of vector values). As such, they could be traded and banked by organisations and governments operating to novel bio-economic structures and regulations.

Science and technology should re-focus efforts towards ecocentric innovation, methods of working towards ideal-seeking systems' using principles of thermodynamics. Thermodynamics can be used to greatly improve energy utilization and other systems. Exergy analysis provides the means for designing more efficient energy systems by reducing inefficiencies (Dincer & Rosen 2004). Energy efficiency and critical minimization of artificial or toxic residues is a core principle to industrial ecology, and industrial ecology models can be effectively worked into strategic sustainable development (von Korhonen 2004).

Fundamental to this change is the reform of neo-classical models of economy by embracing principles of ecological economics (compare Ibisch *et al.*, A.2., Ibisch & Hobson, B.2.2., in this document). Gross Domestic Product (GDP) is no longer an accurate or appropriate measure of a nation's prosperity and an alternative way of measuring social development is required that forces change to existing performance indicators (Jackson 2009). Human endeavour and prosperity should be evaluated using criteria that define capacity building in communities; meaningful work; and participation in society or creative endeavour (Jackson 2009). This requires a paradigm shift in social logic away from a commodified world to one that is based much more on human-centric values—participation, education and social cohesion. Under this system the economic domain is recognised as part of the biosphere and as such is based on infrastructural capital rather than natural capital. Ecological economics rejects the proposition that natural capital can be substituted for anthropocentric capital derived through the relentless pursuit of resource-hungry technology. Furthermore, the concept factors in irreversibility of environmental change, uncertainty and intergenerational equity. It is rather more adaptive to indiscriminate changes, relying on agent-based modelling techniques that recognise the value of 'self-organising systems.' This micro-system approach is complemented by macro-scale systems thinking that operates a holistic approach to deal with socio-economic interests. The validation of the ecological economics model is underscored by the primary objective, which is to ground economic thinking and practice in the laws of thermodynamics. Success, goals and outcomes are no longer exclusively measured in monetary worth, but also by using relative valuation and environmental accounting—biological and physical indicators of worth—a form of 'biodiversity financing.'

REFERENCES

Brookshire, B. L. and S. R. Shifley. 1997. An experimental approach to landscape research. Proceedings of the Missouri Ozark Forest Ecosystem Project Symposium.

Chen, J., S. C. Saunders, T. R. Crow, R. J. Naiman, K. D. Brosofske, G. D. Mroz, B. L. Brookshire and J. F. Franklin. 1999. Microclimate in forest ecosystem and landscape ecology. Bioscience **49**:288–297.

Dewulf, J. and H. van Langenhove. 2005. Integrating industrial ecology principles into a set of environmental sustainability indicators for technology assessment. Resources and conservation and recycling **43**:419–432.

Dincer, I. 2000. Thermodynamics, exergy and environmental impact. Energy sources **22**:723–732.

Dincer, I. and M. A. Rosen. 2004. Exergy as a driver for achieving sustainability. International journal of green energy **1**:1–19.

Dincer, I. and M. A. Rosen. 2005. Thermodynamic aspects of renewables and sustainable development. Renewable & sustainable energy reviews **9**:169–189.

Fischer, J. and Lindenmayer, D. B. 2006. Beyond fragmentation: the continuum model for fauna research and conservation in human-modified landscapes. Oikos **112**:473-480.

Forman, R. T. 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge Univ. Pr., Cambridge.

Hammond, G. P. 2007. Industrial energy analysis, thermodynamics and sustainability. Applied Energy **84:**675-700.

Heithecker, T. D., and C. B. Halpern. 2006. Variation in microclimate associated with dispersed-retention harvests in coniferous forests of western Washington. Forest Ecology and Management **226**:60-71.

Holling, C. S. 1986. The resilience of terrestrial ecosystems: Local surprise and global change. Pages 292–320 in W. C. Clark and R. E. Munn, editors. Sustainable development of the biosphere. Cambridge Univ. Pr., Cambridge.

Ibisch, P.L., N. Araujo & C. Nowicki (eds.) 2007. Visión de conservación de la biodiversidad del Corredor Amboró-Madidi. FAN/WWF/TNC/CI. Editorial FAN, Santa Cruz de la Sierra—Bolivia.

Ibisch, P.L., K. Columba, S. Reichle, R. Vides & H. Justinianano (eds.) 2002. Plan for the Conservation and Sustainable Development of the Chiquitano Dry Forest, Pantanal and Bolivian Cerrado: abridged version. Editorial FAN, Santa Cruz, Bolivia.

Ibisch, P.L., C. Nowicki, N. Araujo, R. Müller & S. Reichle 2006. Bolivia: targeting ecological processes and functionality, not the "living dead". Pages 83-84 in Dudley, N. & J. Parrish (eds.): Closing the gap creating ecologically representative protected area systems: a guide to conducting the gap assessments of protected area systems for the Convention on Biological Diversity. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 24.

Jackson, T. 2009. Prosperity without growth: Economics for a finite planet. Repr. Earthscan, London.

Jankauskaite, M. and D. Veteikis. 2005. Evaluation of landscape ecological polarization and its application in strategic territorial planning.

Jørgensen, S. E. 2007. An integrated ecosystem theory: Ann-Eur. Acad. Sci. EAS Publishing House, Liege.

Jørgensen, S. E. 1992. Parameters, ecological constraints and exergy. Ecological Modelling **62**:163–170.

Jørgensen, S. E. 2006. Application of holistic thermodynamic indicator. Ecological Indicators **6**:24–29.

Jørgensen, S. E. and F. Müller, editors. 2000. Handbook of ecosystem theories and management. Lewis Publishers, Boca Raton, Fla.

Kay, J. J. 2000. Ecosystems as self-organising holarchic open systems: narratives and the second law of thermodynamics. Pages 135–160 in S. E. Jørgensen and F. Müller, editors. Handbook of ecosystem theories and management. Lewis Publishers, Boca Raton, Fla.

Kay, J. J. 2008. An introduction to systems thinking. Pages 4–13 in D. Waltner-Toews, editor. The ecosystem approach. Columbia Univ. Press, New York.

Kay, J. J., H. Regier, M. Boyle and G. Francis. 1999. An Ecosystem Approach for sustainability: addressing the challenge of complexity. Futures **31**:721–742.

Korhonen, J. M. F. S. P. A. a. E. J. R. von. 2004. Management and policy aspects of industrial ecology: an emerging research agenda. Business Strategy and the Environment **13**:289–305.

Lloyd Connelly and Catherine P. Koshland. 2001. Exergy and industrial ecology. Part 1: An exergy-based definition of consumption and a thermodynamic interpretation of ecosystem evolution. Exergy, An International Journal **1**:146–165.

Loomis, J. B. 1992. The evolution of a more rigorous approach to benefit transfer: benefit function transfer. Water Resources Research **28**:701–705.

Muys B, Wagendorp T, Aerts R, Garcia Quijano J 2003. Ecological sustainability assessment of carbon conservation, sequestration and substitution projects using the exergy concept. Travaux **26**:67-85.

Naveh, Z. 2000. What is holistic landscape ecology? A conceptual introduction. Landscape and Urban Planning **50**:7–26.

Purvis, A. and A. Hector. 2000. Getting the measure of biodiversity. Nature **405**:212–219.

Robèrt, K. H., B. A. L. J. de Schmidt-Bleek, G. Basilie, J. L. Jansen, R. Kuehr, P. Price Thomas, M. Suzuki, Hawken P. and M. Wackernagel. 2002. Strategic sustainable development—selection, design and synergies of applied tools. Journal of cleaner production **10**:197–214.

Schneider, E. D. and J. J. Kay. 1994. Complexity and thermodynamics: towards a new ecology. Futures **26**:626–647.

Sewalt, M. P. G., M. E. Toxopeus and G. G. Hirs. 2001. Thermodynamics based sustainability concept. International Journal of Applied Thermodynamics **4**:35–41.

Stachowicz, J. J., R. B. Whitlatch and R. W. Osman. 1999. Species Diversity and Invasion Resistance in a Marine Ecosystem. Science **286**:1577–1579.

Steinborn, W. and Y. Svirezhev. 2000. Entropy as an indicator of sustainability in agro-ecosystems: North Germany case study. Ecological Modelling **133**:247–257.

Tilman, D. 1999. The ecological consequences of changes in biodiversity: a search for general principles. Ecology **80**:1455–1474.

Wagendorp, T. 2003. Thermal characterisation of land use impact at landscape scale. 3rd Earsel Workshop on imaging spectroscopy, Herrsching.

Wilson, E. O. 1992. The diversity of life. New ed. W. W. Norton, New York.

Wilson, M. A. and J. P. Hoehn. 2006. Valuing environmental goods and services using benefit transfer: the state-of-the art and science. Ecological Economics **60**:335–342.

Woodward, R. T. and Y.-S. Wui. 2001. The economic value of wetland services: a meta-analysis. Ecological Economics **37**:257–270.

Zhang, H. and J. Wu. 2002. A statistical thermodynamic model of organizational order of vegetation. Ecological Modelling **153**:69–80.

Zheng, D., Chen J., Song B., M. Xu, P. Sneed and R. Jensen. 2000. Effects of silvicultural treatments on summer forest microclimate in southeastern Missouri Ozarks. Climate Research **15**:45–59.

APPENDIX (A-D) RELATED TO THE SECTION B.1.1:

A VIEW ON GLOBAL PATTERNS AND INTERLINKAGES OF BIODIVERSITY AND HUMAN DEVELOPMENT: IN-DEPTH PRESENTATION OF MATERIAL, METHODS AND STATISTICAL RESULTS

Freudenberger, Lisa, Martin Schluck, Peter Hobson, Henning Sommer, Wolfgang Cramer, Wilhelm Barthlott & Pierre L. Ibisch

A. IN-DEPTH PRESENTATION OF MATERIAL AND METHODS

Spatial units of analysis

A shape file depicting the national state borders of the world was superimposed onto a shape file for the global ecoregions generated by Olson (2001) using the intersect overlay tool of ArcGIS (ESRI Environmental Systems Research Institute 2008). During this process national state borders and ecoregional borders were combined. Those countries that comprised more than one ecoregion were defined by more than one Ecopolitical Unit (EPU). Conversely, ecoregions encompassing more than one country became more than one EPU. Applying this procedure, 9042 units were created restricted by borders of national states and ecoregions—the EPU 9000. All analyses and calculations were accomplished using geographic information system software ArcGIS 9.3 (ESRI Environmental Systems Research Institute 2008) with the extensions Hawth's Tools 3.27 (Beyer 2004) and Tools for Graphics and Shapes (Jenness 2008) as well as with the statistical software package R (R Development Core Team 2010), statistical software Paleontological Statistic 2.00 (Hammer et al. 2001), multivariate statistical package MVSP 3.2 (Kovach 2000) and the calculation program Excel (Microsoft).

Analyzed variables

We included several different parameters in the analysis and examined the relationship and linkages between biodiversity, ecosystem services, human development and pressures on natural resources. The data used in the deeper analysis were selected from an initial set of 66 variables. The selected indicators derived from different sources and were originally available in different resolutions and formats. Some variables were available as grids or shapes on a relatively high resolution and some variables were available only on a country basis. We calculated one value per Ecopolitical Unit applying different procedures (see Appendix C Table C1). If the data were available as grid files the mean, coverage or heterogeneity value was calculated per EPU. If variables were available per ecoregion, the same value was assigned to all EPUs belonging to this ecoregion. If variables were available per country the same value was assigned to each EPU belonging to the same national state territory. In cases of overseas territories with limited sovereignty, for which no separate data are available, the same value was used as for (formerly) associated countries (see Appendix C. Table C2). This does not imply any political statement.

Statistical analysis & mapping

Statistical verification of the data included the use of various multivariate analyses together with inferential techniques. In particular with Principal Component Analysis (PCA) all 66 variables were included after applying the min-max normalization to all data and excluding EPUs with no data for one parameter. The axis loadings for all variables were used for a cluster analysis using unweighted pair group method and Spearman coefficient. To determine differences between two groups of high and low ranking units regarding a certain parameter boxplots and diagrams were created and Mann-Whitney-

U-Tests performed. Spearman rank correlation coefficients and scatter plots were performed excluding EPUs with no data for one parameter.

To show the distribution patterns of biodiversity and development indices as well as anthropogenic deterioration of nature today and in the future, different parameters were plotted on a choropleth bivariate map with a color code matrix in the legend. All maps were produced with geographic information system software ArcGIS 9.3 (ESRI Environmental Systems Research Institute 2008).

B. STATISTICAL ANALYSIS—DETAILED RESULTS AND DISCUSSION

Interactions and dependencies of biodiversity, ecosystem services, human development and negative impacts of past and future development are very complex and embedded in a global system of international flows of energy and material. Figure B1 shows the cluster analysis dendrogram with 66 variables based on 1406 EPUs. Different variables are clustered and show higher similarity in their spatial overlap than others. Not surprisingly, the climate variables maximum, minimum and mean temperature show the highest clustering indicating that climatic parameters are the primary drivers of the grouping of units and that the terrestrial biosphere is mainly structured by climatic conditions (Kreft & Jetz 2007). These variables can be seen as the key driver variables that describe preconditions for the development of ecological and embedded social systems. Another relationship becomes apparent looking at the clustering of the human appropriation of primary production (HANPP) with population density and the degree of urbanization. It is not surprising that especially in more densely populated and urbanized regions the amount of NPP appropriated by humans is higher. Furthermore, we can see from the dendrogram that the EPUs show similar spatial patterns for biocapacity and ecological deficit or reserve indicating that areas with high biocapacity are by tendency providing the areas with highest ecological reserves (this however is also historically determined). We can also see that language diversity and the total number of official languages per EPU being clustered. This could indicate an area effect for language diversity. Smaller EPUs can be found especially in very heterogeneous regions, either due to ecological heterogeneity or because of cultural diversity and resulting small national state territories. If cultural diversity is higher, we expect both a higher number of official languages and an increase in language diversity. We

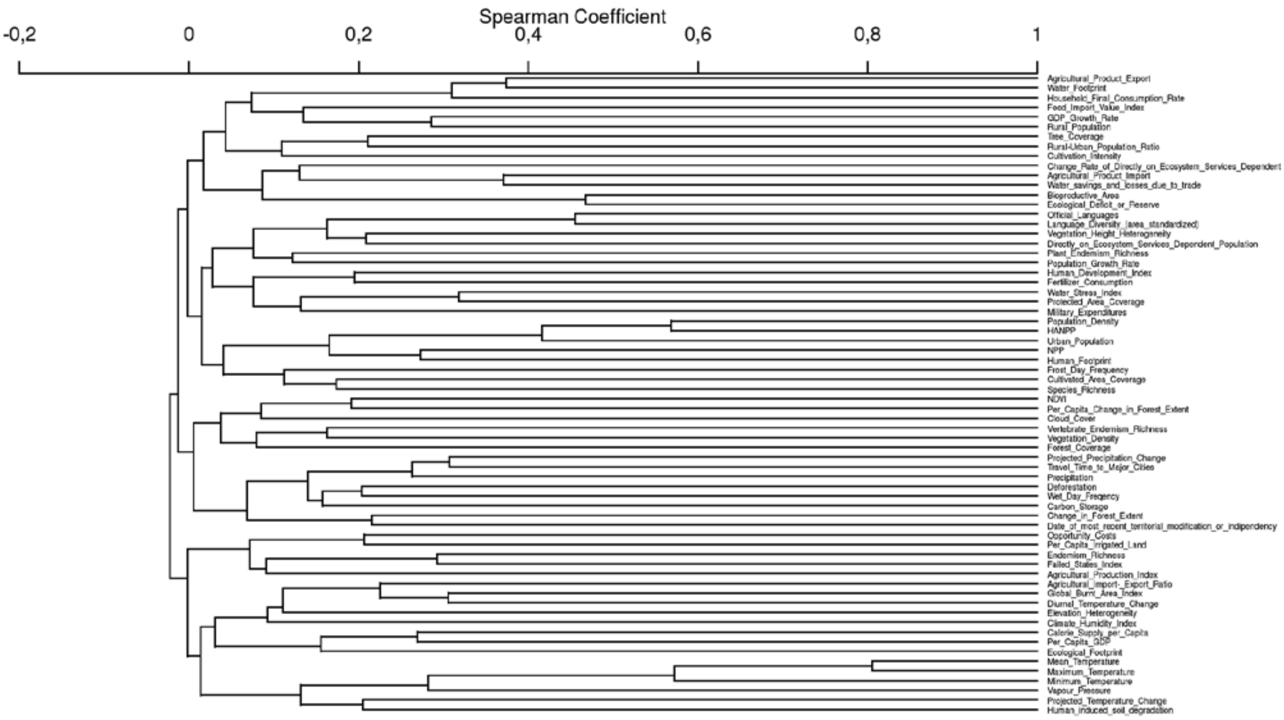

FIGURE B1: Cluster Dendrogram of 66 parameters related to important characteristics of global ecological and social systems according 1406 Ecopolitical Units with weighted pair group method and spearman coefficient similarity measurement. Data were normalized first and filtered by previous principal component analysis. A detailed description of the different parameters can be found in appendix C. table C1.

do also find spatial clustering of the value of agricultural product import and of the water that is gained due to trade with water intensive agricultural products. Accordingly we find the value of agricultural product exports to be clustered with the water footprint. This supports that countries with high agricultural import rates are saving large amounts of their own water resources, while nations exporting large amounts of agricultural products are exploiting their water resources. The cluster dendrogram gives us a rough idea about some structural interdependencies of different climatic, ecological, economic and social variables. We found general patterns, trends and structural characteristics that describe not only how humanity has developed and interacted with nature in the past but also how the world looks to day and where we might go from here.

How do the units differ? Grouped EPUs based on common social and ecological patterns

In order to show general differences between different variables we looked at grouped EPUs and how these groups are different from each other regarding further factors. As we can see from figure B2 EPUs with high and low vascular plant species richness showed remarkable differences regarding all variables, of which most were highly significant ($p<0.001$). The regions with high species richness showed lower carbon storage but higher vegetation density. Anderson *et al.* (2009) found similar results looking at the covariance between biodiversity and carbon storage. But our results are not in line with the conclusions from Strassburg *et al.* (2010) who found a positive correlation between these variables. Although they were also looking at species richness and carbon storage they considered species richness of mammals, amphibians and birds but not of plant species. Generally, it is difficult to show the interdependency between biodiversity and ecosystem services since there are no single variables available reflecting all levels of biodiversity and all ecosystem services that we obtain from nature. Biodiversity here is measured as species richness of vascular plants. This parameter can just serve as a proxy of biodiversity but we cannot make any assumptions about genetic or ecosystem diversity. Therefore we do not want our results to be seen as contradicting the assumption that biodiversity is providing indispensible ecosystem services to us. Based on our results, we state that species richness of plants is not an indicator for carbon storage as a particular ecosystem service, and that biodiversity in general cannot solely be measured as the number of species within one region.

Endemism richness, as another indicator of biodiversity, is higher in species rich areas (Figure B2). This is not surprising since endemism richness is methodologically a combination of endemism and species richness data. Figure B2 shows that the population density, especially urban population, is significantly lower in areas with low vascular plant species richness and higher in areas with high species richness. This interrelation has already been discussed widely in the scientific literature and is usually explained with similar climatic and ecological conditions, especially energy availability that has to be met to facilitate human population prospering and the development of species diversity (e.g. Chown *et al.* 2003; Evans & Gaston 2005; Luck 2007). But areas with high species richness are also the most threatened and impacted regions of the world today. Vascular plant species richness is significantly higher in areas with high Human Footprint Index values and in areas with high deforestation rates and cultivation intensity. Additionally species rich areas are characterized by lower Human Development Index values.

Although there are studies that find no strong congruence between species richness and threat (e.g. Orme *et al.* 2005) our study shows the opposite. A study by (Cardillo *et al.* 2004) emphasizes the relatively higher importance of biological traits for carnivores compared to exposure to external anthropogenic threats to withstand future environmental change. Even if this is the case, we argue that anthropogenic pressures and global change are decreasing resilience and therefore the ability to respond to environmental change.

Figure B3 shows the difference between low and high carbon storage EPUs in reference to other key variables. All variables showed highly significant differences for both groups of EPUs. Again we can see that carbon-rich areas are characterized by a lower vascular plant species richness supporting the results from figure B2. Surprisingly, endemism richness is showing the opposite trend. Furthermore, we can clearly see that carbon storage is higher in areas with high vegetation density despite the amount of carbon that is stored in the soil (Figure B3). But the result from figure B2 where we can find higher carbon storage in low biodiversity areas and low carbon storage in high biodiversity areas while vegetation density is showing the opposite trend, underlines that carbon is not only stored in living plants and forest ecosystems, but also in soil and litter especially in less complex ecosystems such as mires and bogs.

Looking at the demographic variables, high carbon storage areas show a low population density with a low urbanization rate (Figure B3). These areas are further characterized by a comparably low Human Footprint Index and low cultivation intensity but a higher deforestation rate. The reason for this might lie within the correlation between forest cover and carbon storage. Current deforestation only takes place in forested areas and therefore carbon-rich units are achieving comparably high deforestation rates. In addition carbon-rich areas have a higher development index than low carbon storage areas but still provide ecological reserves rather than function as ecological deficit areas. Considering important ecosystem services like carbon storage, it becomes clear that the ecological reserves they provide are not only important to the local population but also to humanity in general.

The comparison between EPUs belonging to the group of more developed and less developed countries showed significant differences for all variables (Figure B4). EPUs in countries that are less developed show higher vascular plant species richness and higher endemism richness. Although carbon storage is higher in more developed countries, vegetation density shows the opposite trend, which can be again explained by soil and litter carbon storage. Less developed areas show significantly lower cultivation intensity but higher deforestation rates and higher (mostly rural) population densities. The higher deforestation rates in less developed areas are also in line with the results of Rodrigues *et al.* (2009) and Ewers (2006). Also the Human Footprint is by tendency higher in the less developed regions of the world. Associating lower deforestation rates and lower Human footprint index values with a higher nature conservation efforts and investment our results could be seen as supporting the hypothesis that wealthier countries are showing more interest in conservation (Mills & Waite 2009). However, since less developed countries show a significantly higher ecological reserve while the more developed world is contributing much more to the global ecological deficit, we can assume that resources from less developed countries are not exclusively used to satisfy the needs of the local population but are rather exported to other nations of with ecological deficits. Therefore we contradict the view that developing nations are using natural resources more intensively due to a higher proportion of rural population and the requirements of subsistence needs (compare Khan 2009).

EPUs with a high Human Footprint Index show comparably high cultivation intensity, high deforestation rates coupled with high population densities (Figure B5). In those areas nature is overexploited in various ways. Nonetheless these regions are also characterized by high species endemism richness and high vegetation density, highlighting that most species, endemic and non-endemic, live in the most threatened regions of the world where ecological integrity has already diminished a substantial amount. Carbon storage on the other hand, shows the opposite trend and is highest in the less impacted areas supporting the previous results. Although nature has been overexploited in a substantial way in areas with high Human Footprint, human development is comparably low. This indicates that exploitation of nature has not always increased human development in the past.

Trends, tendencies and dependencies

Looking at the interdependencies of different variables we focused on the correlations between vascular plant species richness, carbon storage, the Human Development Index and the Human Footprint Index (Figure B6). First we looked at the correlations for two groups of EPUs according to the vascular plant species richness represented by these areas. For species rich areas we can find a positive correlation while the trend is negative for units with low vascular plant species richness. On the contrary there is not much difference between the correlation coefficients for human development and human footprint when looking at units with high and low carbon storage. There is also a general negative correlation between vascular plant species richness and carbon storage especially in high developed regions as well as in low human footprint regions. Conclusively, we can see a correlation between human development and the deterioration of nature but only for units with high vascular plant species richness. This can be explained by the unequal distribution of species richness and human development. Low species richness units, which are mainly located in the northern hemisphere, are showing the opposite trend. High species richness units are mostly located around the equator and in the southern hemisphere, with mostly lower Human Development Index values while species poor regions are mostly located in the northern hemisphere where most developed countries are located. Furthermore, we can again see that vascular plant species richness and carbon storage are negatively correlated indicating a non-congruent distribution.

Analysing the correlation between the Human Development Index and the Ecological Footprint of Consumption it can be observed that increasing development is exponentially fueling resource needs (here indicated by the Ecological Footprint of Consumption Index) (Figure B7a). Higher developed countries require unproportionally more resources than less developed countries. The Human Footprint, on the contrary, shows that higher human development does not necessarily imply a higher impact on the ecosystems in the same region. The correlation between the Human Footprint Index and the Human Development Index is even slightly negative indicating an externalization of environmental costs. Figure B7b shows how the capacity of an area to serve as an ecological reserve relates to the import and export of agricultural products. In areas, that are still comprising ecological reserves, we can find by tendency lower import-export ratios. Furthermore we can also see that areas with higher agricultural export than import rates are characterized by higher deforestation loss indicating that high export rates are somehow correlate with deforestation rates in many parts of the world (Figure B7c).

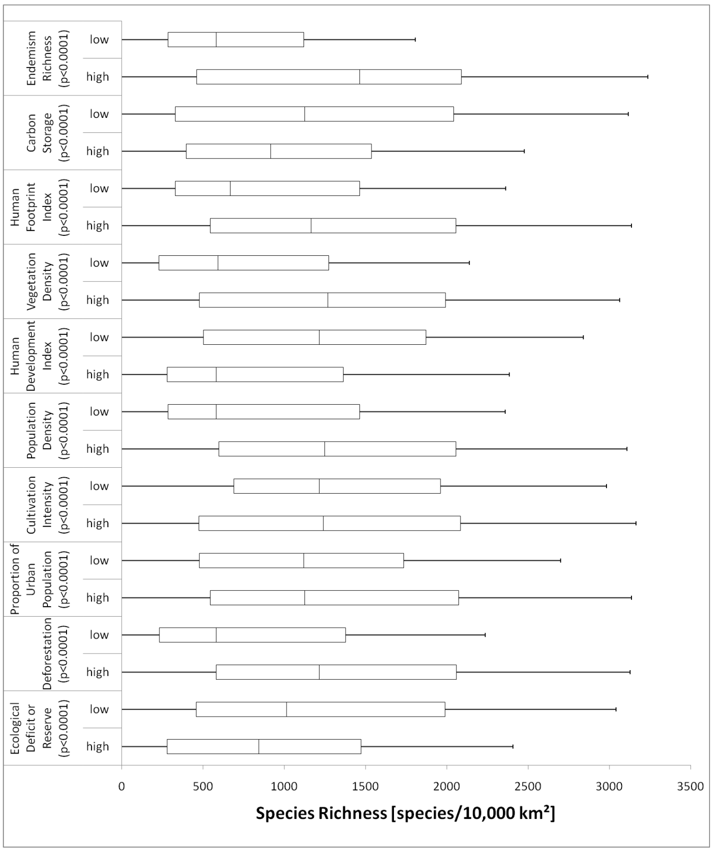

FIGURE B2: Comparison of vascular plant species richness for high and low ranking Ecopolitical Units regarding key variables (lower than and equal to the median and higher than the median); p values indicate differences (Mann-Whitney U-test) between both groups. Middle lines indicate the mean value, boxes indicate second and third quartiles and whiskers indicate the standard deviation.

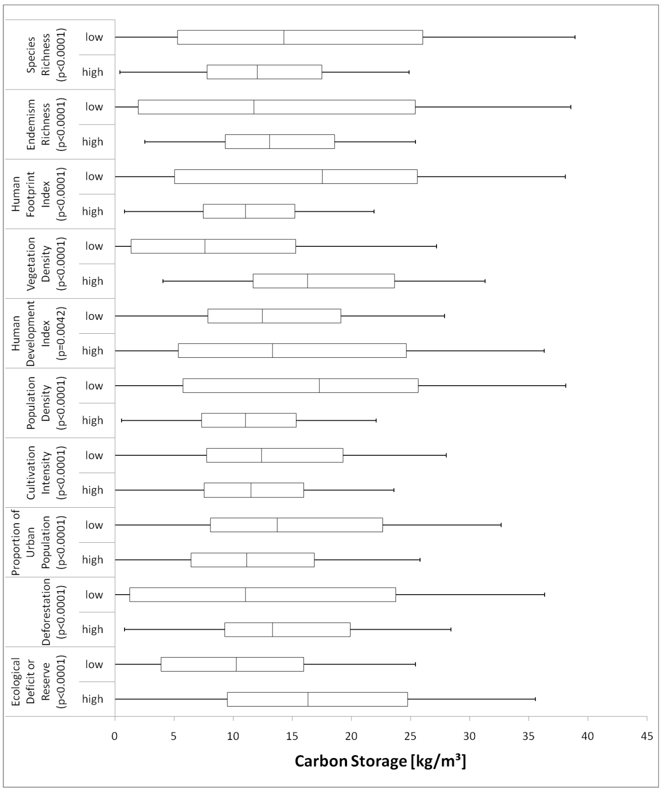

FIGURE B3: Comparison of carbon storage for high and low ranking Ecopolitical Units regarding key variables (lower than and equal to the median and higher than the median); p values indicate differences (Mann-Whitney U-test) between both groups. Middle lines indicate the mean value, boxes indicate second and third quartiles and whiskers indicate the standard deviation.

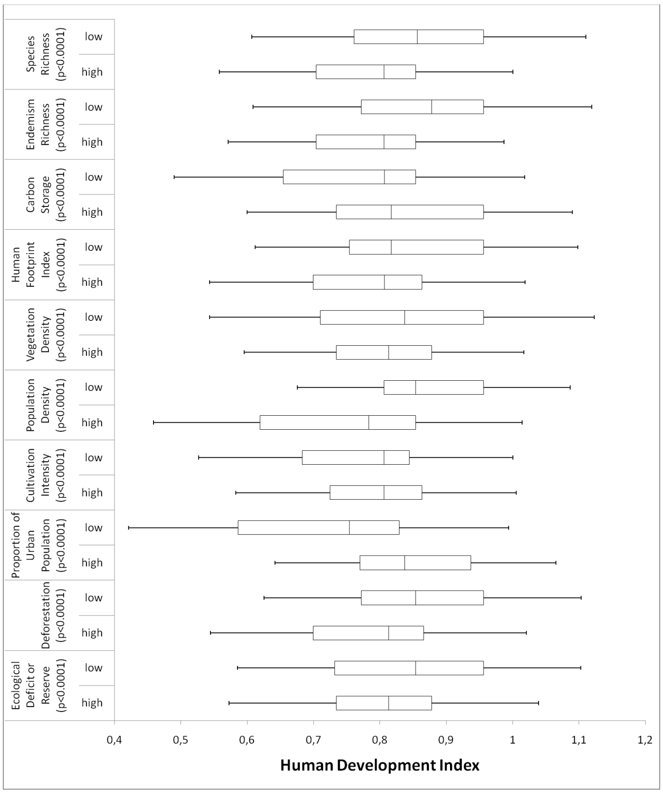

FIGURE B4: Comparison of Human Development Index for high and low ranking Ecopolitical Units regarding key variables (lower than and equal to the median and higher than the median); p values indicate differences (Mann-Whitney U-test) between both groups. Middle lines indicate the mean value, boxes indicate second and third quartiles and whiskers indicate the standard deviation.

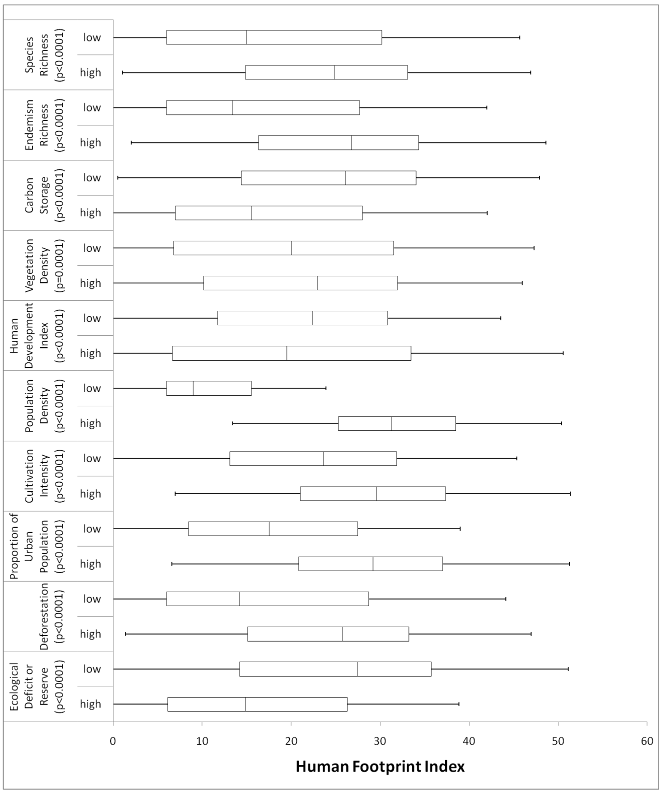

FIGURE B5: Comparison of Human Footprint Index for high and low ranking Ecopolitical Units regarding key variables (lower than and equal to the median and higher than the median); p values indicate differences (Mann-Whitney U-test) between both groups. Middle lines indicate the mean value, boxes indicate second and third quartiles and whiskers indicate the standard deviation.

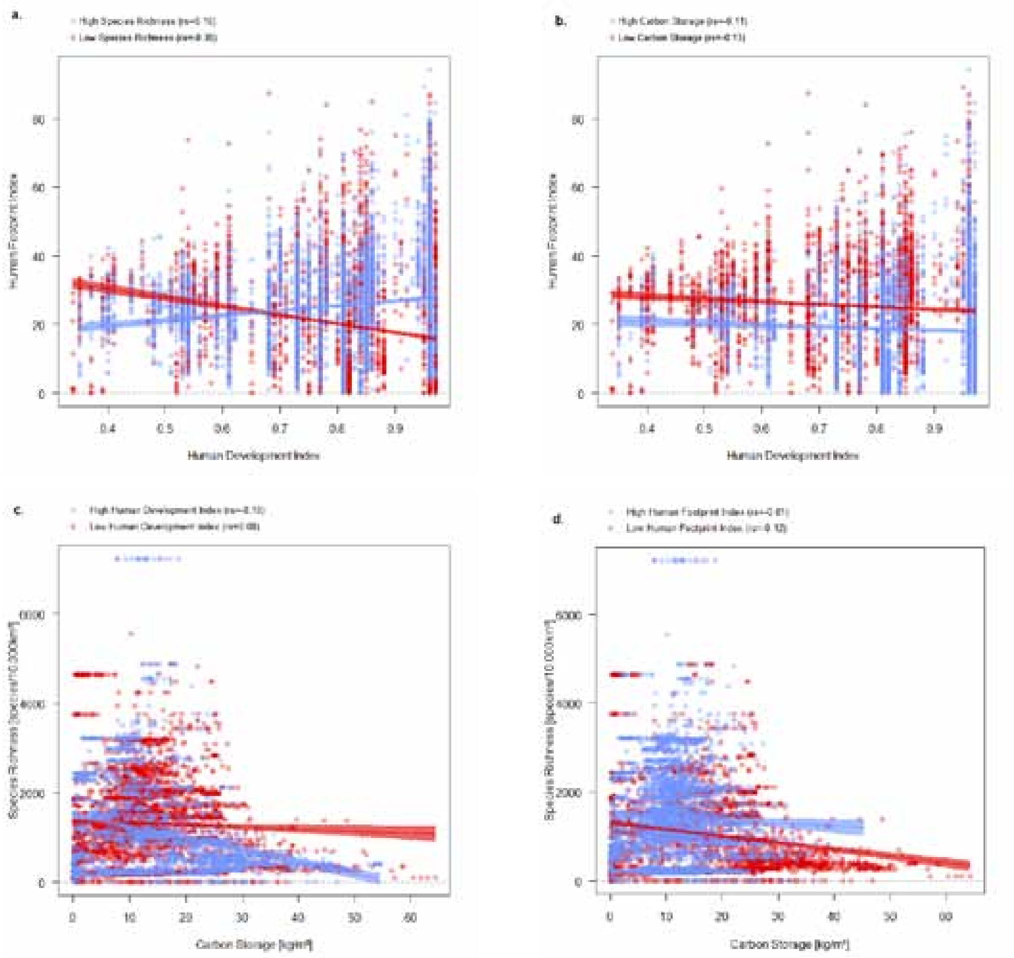

FIGURE B6: Correlation analysis for key variables for Ecopolitical Units with units grouping based on vascular plant species richness, carbon storage, Human Development Index and Human Footprint Index in high and low ranking units (lower than and equal to the median); rs values indicate spearman rank correlation coefficient and dashed lines 95% confidence intervals. a. Human Development Index vs. Human Footprint Index grouped by vascular plant species richness; b. Human Development Index vs. Human Footprint Index grouped by carbon storage; c. carbon storage vs. vascular plant species richness grouped by Human Development Index and d. carbon storage vs. vascular plant species richness grouped by Human Footprint Index.

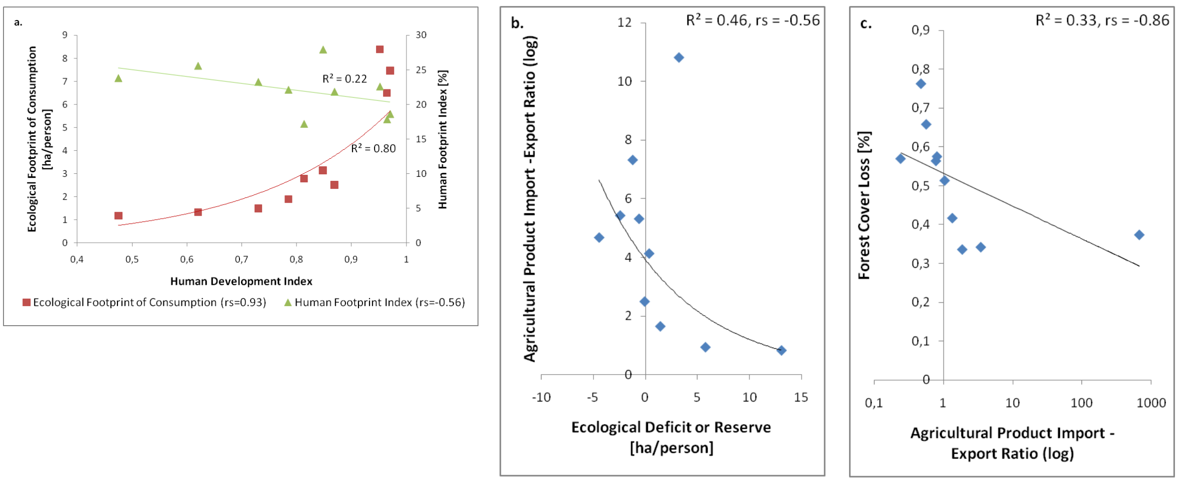

FIGURE B7: Correlation analysis for key variables for Ecopolitical Units with units grouping based on x-axis variable in 10% quantiles and associated mean value of y-axis variable. rs values indicate spearman rank correlation coefficient and R^2 values indicate regression coefficient of values after grouping of EPUs. a. Human Development Index vs. Ecological Footprint of Consumption and Human Footprint Index, b. ecological deficit or reserve vs. agricultural product import/export ratio and c. agricultural product import/export ratio vs. forest cover loss.

C. TABLES

TABLE C1: Complete set of analyzed variables, the original source, description of the measured parameter as well as processing details. Categories of indicators according to the DPSIR framework illustrated in Fig. 1 of the main text, including a. Driving Forces, b. Pressures c. State of the ecological system, d. State of the socio-economic system, e. Impacts and f. responses.

A. DRIVING FORCES

Variable	Source	Description and data processing details
GDP-Growth Rate	(International Monetary Fund 2009)	The average gross domestic product growth rate of the years 2000 to 2007 was calculated using the function "Average" within Excel. The data were available per country and assigned to all EPUs belonging to the same national state territory.
Population Growth Rate	(United Nations Department of Economic and Social Affairs (Population Division) 2009)	Proportional estimate of mean annual population growth rate between 2005 and 2010. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Population Density	(Center for International Earth Science Information Network (CIESIN) & and Centro Internacional de Agricultura Tropical (CIAT). 2005)	Population density grids (per square km) 2.5 arc-minute grid cells and associated datasets dated circa 2000. The exchange file was converted to a grid file using the Converting tool "Import from exchange file". This grid file was resampled to a higher resolution of 0.0041666667 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. A statistic was calculated for this buffered EPU using the same tool.
Human Development Index (HDI)	(United Nations Development Programme 2009)	Composed from data on Life expectancy, Education and per-capita GDP (as an indicator of Standard of living) collected at the national level. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Change Rate Of Directly On Ecosystem Services Depending Population	(Food & Agriculture Organization of the United Nations (FAO) 2006a)	Calculated from the time-series of directly on ecosystem services depending population. The average of changing of directly on ecosystem services depending population was calculated as followed: $change\ rate = \left(\frac{1995-97}{1990-92} * 100 - 100 + \frac{2003-05}{1995-97} * 100 - 100\right) \div 2$ The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Date of most recent significant territorial modification	Various different resources	The year of the last significant territorial modification was taken. If no modification have taken place till today the year of independency was used for the analysis. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Change in Temperature	(British Atmospheric Data Centre 2006)	The projected temperature increase is given as the difference between the reference period from 1961 to 1990 and the projected time period between 2041 and 2050 (British Atmospheric Data Centre 2006). These data were generated according to A2 emission scenario and by using the Hadley Centre Model. Firstly the spaces between the values of each row were substituted by one tab space each. The decimal separating points were replaced by commas and the row numbers were added. The modified text file was loaded into ArcGIS, projected by the x and y data and exported to a grid file of the same resolution using the Conversation tool "Point to Raster". The resulting grid file was resampled to a higher resolution of 0.004 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Change in Precipitation	(British Atmospheric Data Centre 2006)	The projected precipitation change is given as the difference between the reference period from 1961 to 1990 and the projected time period between 2041 and 2050 (British Atmospheric Data Centre 2006). These data were generated according to A2 emission scenario and by using the Hadley Centre Model. The spaces between the values of each row were substituted by one tab space each. The decimal separating points were replaced by commas and the row numbers were added. The modified text file was loaded into ArcGIS, projected by the x and y data and exported to a grid file of the same resolution using the Conversation tool "Point to Raster". The resulting grid file was resampled to a higher resolution of 0.004 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.

B. PRESSURES

Variable	Source	Description and data processing details
Agricultural Production Index	(Food & Agriculture Organization of the United Nations (FAO) 2006b)	Reflects the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 1999-2001; disposable production for any use covering crops and livestock products except as seed and feed; index value is calculated by the Laspeyres formula. The average agricultural production index of the years 2000 to 2007 was calculated using the function "Average" within Excel.
Per-Capita Agricultural Irrigated Land	(Siebert et al. 2007)	Refers to the area that is artificially supplied with water. The ASCII file gmia_v4_0_1_pct.asc was loaded using the Conversation tool "ASCII to raster". The resulting grid file was resampled to a higher resolution of 0.00416666665 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this prepared grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The mean value per EPU was calculated for this buffered EPU using the same tool.
Fertilizer Consumption	(World Bank. World Development Indicators Database 2008)	Fertilizer consumption refers to the application of nutrients in terms of nitrogen (N), phosphate (P2O5), and potash (K2O) consumed in agriculture by a country. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Cultivation Intensity	(Reid 2005)	Originally available as grid file with proportional estimates of the agricultural intensity; modification of the original classification assigning the following percentage values to each cultivation category: cropland (1) 100%, pasture (2) 90%, cropland7 pasture (3) 80%, agriculture with forest (4) 70%, Agriculture with other vegetation (5) 70%, Agriculture/Forest mosaic (6) 50%, Agriculture/Other mosaic (7) 50%, forest with agriculture (8) 30%, other vegetation with agriculture (9) 30%, agriculture/ 2 other landcover types (10) 30% (values in brackets symbolize the original category identification number). The grid file was resampled to a higher resolution of 0.0041666667 using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. A statistic was calculated for this buffered EPU using the same tool.
Cultivated Area Extent	(Reid 2005)	Proportion of the area per EPU that is cultivated. The grid file of cultivation extent was converted to a polygon shape file using the Conversation tool "Raster to Polygon". The polygon shape file of EPU was clipped by the resulting polygon shape file of forest cover using the Analysis tool "Clip". The spherical area of forest cover was calculated for every EPU using the Graphics and Shapes tool "Calculate Geometry" (Jenness 2008).
Calorie Supply Per Capita	(Food & Agriculture Organization of the United Nations (FAO) 2006d)	Refers to the amount of available food for consumption, expressed in kilocalories per person per day. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Household Final Consumption Expenditure	(World Bank 2009a)	Household final consumption expenditure (formerly private consumption) is the market value of all goods and services, including durable products (such as cars, washing machines, and home computers), purchased by households. It excludes purchases of dwellings but includes imputed rent for owner-occupied dwellings. It also includes payments and fees to governments to obtain permits and licenses. Here, household consumption expenditure includes the expenditures of nonprofit institutions serving households, even when reported separately by the country. Data are in constant 2000 US$. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Ecological Footprint Of Consumption	(Ewing et al. 2009)	A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes, and to absorb the waste it generates using prevailing technology and resource management practices. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Human Appropriation Of Net Primary Productivity (HANPP) As A Percentage Of Net Primary Productivity (NPP)	(Imhoff et al. 2004)	To construct the HANPP map (the amount of carbon required to derive food and fiber products consumed by humans—including organic matter that is lost during harvesting and processing), the authors utilized data from the Food and Agriculture Organization of the United Nations (FAO) on products consumed in 1995 for 230 countries in seven categories: vegetal foods, meat, milk, eggs, wood, paper, and fiber. All calculations use the "domestic supply" quantity for all FAOSTAT country-level sums (i.e., production in country + imports – exports). This constrains the country-level estimate of NPP required to only those products that are consumed within a country's boundaries. To these data they applied harvest, processing, and efficiency multipliers, as well as estimates of below-ground production, to reconstruct the total amount of NPP required to derive final products. They then calculated the per capita HANPP of each country and applied these values to SEDAC's Gridded Population of the World v.2 (GPW) resampled to correspond to the quarter-degree spatial resolution of the NPP data. In the first step a grid file was created from the ASC file using the Conversation tool "ASCII to Raster". The resulting grid file was resampled to a higher resolution of 0.0041666666666667 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this prepared grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The mean value per EPU was calculated for this buffered EPU using the same tool.

Variable	Source	Description and data processing details
Travel Time To Major Cities	(Nelson 2008)	Accessibility is defined as the travel time to a location of interest using land (road/off road) or water (navigable river, lake and ocean) based travel. This accessibility is computed using a cost-distance algorithm which computes the "cost" of travelling between two locations on a regular raster grid. Generally this cost is measured in units of time. The values of travel time were extracted from the TIF file using the Spatial Analyst tool "Extract by Attributes". The resulting grid file was resampled to a higher resolution of 0.00416666665 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool. In the end the minutes of travel time per EPU were calculated.
Water footprints of nations	(Hoekstra & Chapagain 2008)	The water footprint of a nation is defined as the total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation. The data from 1997 to 2001 were available per country and the same value was assigned to all EPUs belonging to the same national state territory.

C. STATE OF THE ECOLOGICAL SYSTEM

Variable	Source	Description and data processing details
Vascular plant species richness	(Kier et al. 2005)	Range equivalents of vascular plant species standardized for 10,000km². Data are available per ecoregion; assignment of the same value to all EPUs belonging to one ecoregion.
Plant Endemism Richness	(Kier et al. 2009)	A combination of endemism and species richness of range equivalents per 10,000 km² of vascular plants.
Vertebrate Endemism Richness	(Kier et al. 2009)	A combination of endemism and species richness of range equivalents per 10,000 km² of vertebrates.
Endemism Richness	(Kier et al. 2009)	A combination of endemism and species richness of range equivalents per 10,000 km². Weighted for 50% plant and vertebrate endemism richness each.
Carbon Storage	(Gumpenberger et al. 2010)	Carbon storage of vegetation, litter and soil down to 1.5 m for the reference period 1991 to 2000 in kg Carbon/qm; Calculation of the mean carbon storage value per EPU. Firstly the row numbers of the text file and a headline with headings were added, the spaces between the values of each row were substituted by one tab space each and the decimal separating points were replaced by commas. The modified text file was loaded into ArcGIS, projected by the x and y data and exported to a grid file of the same resolution. The resulting grid file was resampled to a higher resolution of 0.004 using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Human Footprint Index	(Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN) 2005)	A percentage value of the relative human influence in each terrestrial biome; values range from zero to 100, with a value of zero representing the least influenced and a value of 100 representing the most influenced part of the biome. The mean value per EPU was calculated. The coordinate system of the grid file was transformed from GCS_Clarke_1866 to GCS_WGS_1984 using the function "Export data". This grid file was resampled to a higher resolution of 0.004166665 using the Spatial Analyst tool "Resample". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Global Humidity Index	(Deichmann & Eklundh Lars 1991)	Index describing the mean annual potential moisture availability for the period 1951-1980 based on a ratio of annual precipitation and potential evapotranspiration; classified into four aridity zones and one humid zone, defined in this data set as follows: Hyper-Arid Zone P/PET < 0.05 Arid Zone 0.05 <= P/PET < 0.20 Semi-Arid Zone 0.20 <= P/PET < 0.50 Dry-Subhumid Zone 0.50 <= P/PET < 0.65 Humid Zone 0.65 <= P/PET, Calculation of the mean Global Humidity Index value per EPU.
Global Burnt Area Index	(Grgoire et al. 2002)	Area of the globally burnt area for the year 2000, using the medium resolution (1 km) satellite imagery provided by the SPOT-Vegetation system, Calculation of the burnt area per EPU. Transformation of the ASCII file to grid format with "ASCII to raster"; resampling to higher resolution of 0.004 decimal degrees with Spatial Analyst tool "Resample"; buffering of small polygons with the Analysis tool "Buffer" with a distance of 0.004 decimal degrees; calculation of mean value per EPU.
Precipitation	(Mitchell & Jones 2005)	Average precipitation in mm for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean precipitation value per EPU. Conversion of grid file to polygon shape file using the Conversation tool "Raster to Polygon". The text file with all climate parameters' means was joined to the resulting polygon shape file and exported to a polygon shape file with all attributes. The mean per EPU was calculated using the Analysis tool "Spatial Join".
Mean Temperature	(Mitchell & Jones 2005)	Average temperature in C° for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean temperature value per EPU. For processing details see precipitation.
Maximum Temperature	(Mitchell & Jones 2005)	Average maximum temperature in C° for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean temperature value per EPU. For processing details see precipitation.
Minimum Temperature	(Mitchell & Jones 2005)	Average minimum temperature in C° for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean temperature value per EPU. For processing details see precipitation.
Diurnal Temperature Change	(Mitchell & Jones 2005)	Average temperature change in C° for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean temperature value per EPU. For processing details see precipitation.
Vapor Pressure	(Mitchell & Jones 2005)	Average vapor pressure in hPa for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean vapor pressure value per EPU. For processing details see precipitation.
Cloud Cover	(Mitchell & Jones 2005)	Average cloud coverage in % for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean cloud cover value per EPU. For processing details see precipitation.
Wet Day Frequency	(Mitchell & Jones 2005)	Average number of wet days per year for the years 1973 to 2002 available as 0.5° raster file, Calculation of the mean days per EPU. For processing details see precipitation.

Variable	Source	Description and data processing details
Frost Day Frequency	(Mitchell & Jones 2005)	Average number of frost days per year for the years 1973 to 2002 available as 0.5° raster file; Calculation of the mean days per EPU. For processing details see precipitation.
Forest Coverage	(Olson J. S. 2000)	The percentage of forest cover calculated from Olson landcover data considering all forest types (category values according to Olson landcover legend 3 to 6, 13, 18, 19, 20 to 29, 32 to 34, 48, 55 to 57, 60 to 63, 77 to 79, 89 to 90 and 95 to 96) as forested area, Calculation of the percentage of area covered by forest per EPU. The ASCII file olson.txt was loaded using the Conversation tool "ASCII to Raster". A grid file with forest types was created from this imported grid file using the Spatial Analyst tool "Extract by Attributes". The resulting grid file of forest cover was converted to a polygon shape file using the Conversation tool "Raster to Polygon". The polygon shape file of Ecopolitical Units was clipped by the resulting polygon shape file of forests cover using the Analysis tool "Clip". The spherical area of forest cover was calculated for every EPU using the Graphics and Shapes tool "Calculate Geometry" (Jenness 2008). Forest area coverage was calculated by dividing total forested area by the total polygon size of each EPU.
Vegetation Density	(Hansen et al. 2003).	Proportional estimates for vegetative cover types (woody vegetation, herbaceous vegetation, and bare ground); Calculation of the mean vegetation density value per EPU. A grid file of the same resolution and geographical coordinate system of the original data with the full extent of the world and the value 0 for all grids was created using the Data Management tool "Create Random Raster". The created grid file was overlaid with all tiles of the vegetation density using the Data Management tool "Mosaic To New Raster" with the same resolution and geographical coordinate system and with the Mosaic Method MAXIMUM. The value 254 (fill) was changed to 0 using the Spatial Analyst tool "Reclass by Table". A statistic of this prepared grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Normalized Difference Vegetation Index (NDVI)	(Tucker et al. 2004)	Maximum value of the NDVI for each pixel measured in 2006; Calculation of the mean NDVI value per EPU. Firstly a grid file of the 2006 maximum value of NDVI was calculated using the Spatial Analyst tool "Single Output Map Algebra" with the expression MAX. Secondly all no data values -10000 were excluded using the Spatial Analyst tool "Extract by Attributes". A statistic of this grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. A statistic was calculated for this buffered EPU using the same tool.
Tree Coverage	(DeFries et al. 2000)	Proportional estimates for tree cover; Calculation of the mean vegetation density value per EPU. The treecoverlatlong.img file was renamed to treecoverlatlong.bsq. A header file was created to load the data. The content of the header file was taken from the file gl-latlong-treecover.glcf. The value 254 (non-vegetated) was changed to 0 and the value 255 (tree cover less than 10%) was changed to 5 using the Spatial Analyst tool "Reclass by Table". The modified grid file was resampled to a higher resolution of 0.00416666665 decimal degrees using the Spatial Analyst tool "Resample". The mean tree cover of each EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. A statistic was calculated for this buffered EPU using the same tool.
Vegetation Height Heterogeneity	(Simard & Pinto 2008)	Number of different vegetation height classes (classification by equal breaks for classes 1 to 10) per EPU. The values of the vegetation height TIF file were extracted to a grid file using the Spatial Analyst tool "Extract by Attributes". A grid file of the same resolution and geographical coordinate system with the full extent of the world and the value 0 for all grids was created using the Data Management tool "Create Random Raster". This created grid file was overlaid with the grid file of vegetation height using the Data Management tool "Mosaic To New Raster" with the same resolution and geographical coordinate system and with the Mosaic Method MAXIMUM. This grid file was resampled to a higher resolution of 0.004166665 decimal degrees using the Spatial Analyst tool "Resample". The resulting grid file was clipped by the EPU polygon shape file using Hawth's Tools "Clip Raster By Polygons II (with autodetect)" with the polygon buffer method "Buffer Polygon" with the distance of 0.004 decimal degrees. The number of vegetation height classes was counted using a VBA script which counted the number of rows of the attribute table of every clipping output grid file.
Elevation Heterogeneity	(ESRI® Data & Maps 2008)	Number of different elevation height classes (classification by equal breaks for classes 1 to 10) per EPU. The grid file was reclassified to 500m classes using the Spatial Analyst tool "Reclass by Table". A grid file of the same resolution and geographical coordinate system with the full extent of the world and the value 0 for all grids was created using the Data Management tool "Create Random Raster". This created grid file was overlaid with the grid file of elevation height classes using the Data Management tool "Mosaic To New Raster" with the same resolution and geographical coordinate system and with the Mosaic Method MAXIMUM. This grid file was resampled to a higher resolution of 0.004166665 decimal degrees using the Spatial Analyst tool "Resample". The resulting grid file was clipped by the EPU polygon shape file using Hawth's Tools "Clip Raster By Polygons II (with autodetect)" with the polygon buffer method "Buffer Polygon" with the distance of 0.004 decimal degrees. The number of elevation height classes was counted using a VBA script which counted the number of rows of the attribute table of every clipping output grid file

Variable	Source	Description and data processing details
Net Primary Production (NPP)	(Prince & Small 2003)	Average Net Primary Production derived from the Advanced Very High Resolution Radiometer (AVHRR) images at an 8km resolution from the AVHRR Pathfinder Project for the year 2000. Calculation of the mean NPP value per EPU In the first step the TIF file was resampled to a higher resolution of 0.004 decimal degrees using the Spatial Analyst tool "Resample". The mean global production efficiency of each EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Biocapacity	(Ewing et al. 2009)	The capacity of ecosystems to produce useful biological materials and to absorb waste materials generated by humans, using current management schemes and extraction technologies. "Useful biological materials" are defined as those used by the human economy, hence what is considered "useful" can change from year to year (e.g. use of corn (maize) stover for cellulosic ethanol production would result in corn stover becoming a useful material, and so increase the biocapacity of maize cropland). The biocapacity of an area is calculated by multiplying the actual physical area by the yield factor and the appropriate equivalence factor. Biocapacity is usually expressed in units of global hectares. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.

D. STATE OF THE SOCIO-ECONOMIC SYSTEM

Variable	Source	Description and data processing details
Per-Capita GDP	(International Monetary Fund 2009)	The average gross domestic product growth rate per capita of the years 2000 to 2007 was calculated using the function "Average" within Excel. The data were available per country and assigned to all EPUs belonging to the same national state territory.
Failed States Index	(The Fund for Peace 2009)	Failed States Index Scores based on 12 social, economic and political indicators ranging from 18 to 115 and recorded on national scale. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Directly On Ecosystem Services Depending Population	(Food & Agriculture Organization of the United Nations (FAO) 2006a)	Refers to agricultural population defined as all persons depending for their livelihood on agriculture, hunting, fishing or forestry. This estimate comprises all persons actively engaged in agriculture and their non-working dependants. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Military Expenditures	(World Bank 2009b)	Military expenditures data from SIPRI are derived from the NATO definition, which includes all current and capital expenditures on the armed forces, including peacekeeping forces; defense ministries and other government agencies engaged in defense projects; paramilitary forces, if these are judged to be trained and equipped for military operations; and military space activities. Such expenditures include military and civil personnel, including retirement pensions of military personnel and social services for personnel; operation and maintenance; procurement; military research and development; and military aid (in the military expenditures of the donor country). Excluded are civil defense and current expenditures for previous military activities, such as for veterans' benefits, demobilization, conversion, and destruction of weapons. This definition cannot be applied for all countries, however, since that would require much more detailed information than is available about what is included in military budgets and off-budget military expenditure items. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Rural Population	(Vorosmarty et al. 2000)	Global population fields were constructed for the year using country-level demographic statistics from the World Resources Institute (WRI) Earth Trends database (http://earthtrends.wri.org/). The urban and rural population data sets were developed by spatially distributing the WRI 2000 country level population data among DMSP-OLS nighttime stable-lights imagery (Elvidge 1997a) and ESRI Digital Chart of the World populated places points (ESRI 1993). Rural population was spatially distributed equally among the DCW populated places points falling outside of the DMSP-OLS city lights extent. Total population is simply the sum of urban and rural population data sets. The grid file was transformed to a floating point grid file using the Spatial Analyst tool "Single Output Map Algebra" with the map algebra expression "Float". This floating point grid file was resampled to a higher resolution of 0.004 decimal degrees using the Spatial Analyst tool "Resample". A statistic of each EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Urban Population	(Vorosmarty et al. 2000)	Global population fields were constructed for the year using country-level demographic statistics from the World Resources Institute (WRI) Earth Trends database (http://earthtrends.wri.org/). Country-level urban population was evenly distributed among the DMSP-OLS city lights data set at 1-kilometer grid cell resolution with detectable lights in at least 10 per cent of the cloud free observations. Where available, the spatial extents of major city locations with known demographic data were superimposed in the DMSP-OLS city lights data set to enhance the accuracy of the urban population distribution. For processing details see Rural Population.
Rural-Urban Population Ratio	(Vorosmarty et al. 2000)	The ratio between the number of rural and urban inhabitants was calculated by dividing the number of rural and urban population of the original data.
Number of Official Languages	(Lewis 2009)	This dataset is following the ISO 639-3 for defining a language in relation to varieties which may be considered dialects. The criteria are: a) Two related varieties are normally considered varieties of the same language if speakers of each variety have inherent understanding of the other variety at a functional level (that is, can understand based on knowledge of their own variety without needing to learn the other variety). b) Where spoken intelligibility between varieties is marginal, the existence of a common literature or of a common ethnolinguistic identity with a central variety that both understand can be a strong indicator that they should nevertheless be considered varieties of the same language. And c) Where there is enough intelligibility between varieties to enable communication, the existence of well-established distinct ethnolinguistic identities can be a strong indicator that they should nevertheless be considered to be different languages. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Language Diversity	(Lewis 2009)	Calculated from the number of official languages and standardized per 10,000 km^2. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.

E. IMPACTS

Variable	Source	Description and data processing details
Date of most recent significant territorial modification	Various different resources	The year of the last significant territorial modification was taken. If no modification have taken place till today the year of independency was used for the analysis. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Change In extent Of Forest	(Food and Agriculture Organization of the United Nations 2006)	The recent annual net deforestation data are given as annual change rates of deforestation in each country between 2000 and 2005. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Mean Per-Capita Deforestation	(Food and Agriculture Organization of the United Nations 2006)	The change in extent of forest per capita was calculated by dividing the value of change in extent of forest by the value of total population derived from population density data. The data were available per country and assigned to all EPUs belonging to the same national state territory.
Ecological Deficit Or Reserve	(Ewing et al. 2009)	Measures the difference between the biocapacity and Ecological Footprint of a region or country. An ecological deficit occurs when the Footprint of a population exceeds the biocapacity of the area available to that population. Conversely, an ecological reserve exists when the biocapacity of a region exceeds its population's Footprint. If there is a regional or national ecological deficit, it means that the region is importing biocapacity through trade or liquidating regional ecological assets. In contrast, the global ecological deficit cannot be compensated through trade, and is therefore equal to overshoot. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Human Induced Soil Degradation (GLASOD)	(Oldeman et al. 1991)	This parameter reflects the overall severity by which the polygon is affected by soil degradation. This item takes the degree and extent of both types into account. For the classification from 1 (low) to 4 (very high), a look-up table created by ISRIC was used.
Forest Cover Loss	(Hansen et al. 2010)	This dataset represents 2000-2005 gross forest cover loss. A separate regression estimator (i.e. separate regression models and parameter estimates allowed for each stratum) and post-stratification were employed to estimate Landsat-calibrated forest cover loss area. For sample blocks with intensive change, a simple linear regression model was applied using the proportion of area within the sample block classified as MODIS-derived forest loss as the auxiliary variable. For low-change blocks post-stratification based on VCF tree canopy cover was implemented to partition blocks into areas of nearly zero change and areas of some change. The forest cover loss area estimates were then constructed from the sample mean Landsat-derived clearing within post-strata. The TIF file with a sinusoidal projection was transformed to a grid file with the geographical coordinate system GCS_WGS_1984. The resulting grid file was resampled to a higher resolution of 0.0041666665 decimal degrees using the Spatial Analyst tool "Resample". A statistic of this prepared grid file for every EPU was calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.
Mean annual relative water stress index	(Vorosmarty et al. 2000)	The relative water stress index is representing the proportion of renewable water resources that are being withdrawn for human use. Gridded fields of water stress indicators are based on the ratio of human water use (sum of domestic, industrial and agricultural = DIA, in km3 per year) to renewable water resources (Q) for 1995 (in km3 per year) at 30 minute (latitude by longitude) resolution. The original grid file was transformed from the geographical coordinate system GCS_Clarke_1866 to GCS_WGS_1984 using the function "Export data". This grid file was resampled to a higher resolution of 0.004166665 decimal degrees using the Spatial Analyst tool "Resample". The mean opportunity costs of each EPU were calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The statistic was calculated for this buffered EPU using the same tool.

G. RESPONSES

Variable	Source	Description and data processing details
Agricultural Product Import	(Food & Agriculture Organization of the United Nations (FAO) 2009b)	Agricultural product import value measured in US$ as the sum of all vegetal and animal products for the year 2007. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Agricultural Product Export	(Food & Agriculture Organization of the United Nations (FAO) 2009a)	Agricultural product export value measured in US$ as the sum of all vegetal and animal products for the year 2007. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Agricultural Product Import-Export Ratio	(Food & Agriculture Organization of the United Nations (FAO) 2009a)	The data were calculated from agricultural product import value divided by agricultural product export value. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Food Import Value Index	(Food & Agriculture Organization of the United Nations (FAO) 2006c)	Import value indices represent the change in the current values of import c.i.f. (cost, insurance and freight) all expressed in US dollars. For countries which report import values on an f.o.b. (free on board) basis, these are adjusted to approximate c.i.f. values (by a standard factor of 112 percent). Trade indices of food products include commodities that are considered edible and contain nutrients, except for animal feed products and alcoholic beverages. Coffee and tea are also excluded because, although edible, they have practically no nutritive value. The data were available per country and the same value was assigned to all EPUs belonging to the same national state territory.
Opportunity Costs for Conservation	(Naidoo & Iwamura 2007)	Opportunity costs for conservation projects in US$ per ha based on spatial information on crop productivity, livestock density, and prices indicating the gross economic rents from agricultural lands. The original grid file was transformed from the geographical coordinate system GCS_Clarke_1866 to GCS_WGS_1984 using the function "Export data". This grid file was resampled to a higher resolution of 0.004166665 decimal degrees using the Spatial Analyst tool "Resample". The mean opportunity costs of each EPU were calculated using the Spatial Analyst tool "Zonal Statistics as Table". All small polygons which were excluded by this calculation were buffered using the Analysis tool "Buffer" with a distance of 0.004 decimal degrees. The mean value per EPU was calculated for this buffered EPU using the same tool.
Protected Area Coverage	(United Nations Department of Economic and Social Affairs (Population Division) 2008)	The proportional proportion of the current national coverage of protected terrestrial and marine areas derived from the World Database on Protected Areas of the UNEP World Conservation Monitoring Centre (WCMC). The WDPA applies the definition of a protected area as adopted by the IUCN for compilation of the database. From the global map of protected areas, compiled on the basis of the World Database on Protected Areas and including all IUCN categories, we calculated the national protected area coverage. Firstly the polygon shape file of Ecopolitical Units were clipped by protected areas polygon shape file of WDPA (2009) using the Analysis tool "Clip". Secondly the spherical area of the resulting polygon shape file excluding the protected areas was calculated by the tool "Calculate Geometry" (Jenness 2008).
Water savings and losses due to trade in agricultural products	(Hoekstra & Chapagain 2008)	A nation can preserve or sell its domestic freshwater resources by importing or exporting a water-intensive product instead of producing it domestically. This value is referred to as net water saving or loss. The data from 1997 to 2001 were available per country and the same value was assigned to all EPUs belonging to the same national state territory.

TABLE C2: Overseas territories with limited sovereignty, for which one or more parameter data were not available and the associated countries the territories were assigned to. In other cases, where no data were available, no value was assigned.

Country	Status	Assignment
American Samoa	US Territory	USA
Andorra	UN Member State	France
Anguilla	UK Territory	United Kingdom
Aruba	Netherlands	Netherlands
Baker I.	US Territory	USA
Bermuda	UK Territory	United Kingdom
Bouvet I.	Norwegian Territory	Norway
British Indian Ocean Territory	UK Territory	United Kingdom
British Virgin Is.	UK Territory	United Kingdom
Cayman Is.	UK Territory	United Kingdom
Christmas I.	Australian Territory	Australia
Cocos Is.	Australian Territory	Australia
Cook Is.	New Zealand	New Zealand
Dominica	UN Member State	Grenada
Falkland Is.	UK Territory	United Kingdom
Faroe Is.	Denmark	Denmark
French Guiana	France	France
French Polynesia	France	France
French Southern & Antarctic Lands	France	France
Gaza Strip	Occupied Territory	Israel
Gibraltar	UK Territory	United Kingdom
Glorioso Is.	France	France
Greenland	Denmark	Denmark
Guadeloupe	France	France
Guam	US Territory	USA
Guernsey	UK Territory	United Kingdom
Heard I. & McDonald Is.	Australian Territory	Australia
Howland I.	US Territory	USA
Isle of Man	UK Territory	United Kingdom
Jan Mayen	Norwegian Territory	Norway
Jarvis I.	US Territory	USA
Jersey	UK Territory	United Kingdom
Johnston Atoll	US Territory	USA
Juan De Nova I.	France	France
Kiribati	UN Member State	Micronesia
Liechtenstein	UN Member State	Switzerland

Country	Status	Assignment
Marshall Is.	UN Member State	Micronesia
Martinique	France	France
Mayotte	France	France
Midway Is.	US Territory	USA
Monaco	UN Member State	France
Montenegro	UN Member State	Serbia
Montserrat	UK Territory	United Kingdom
Nauru	UN Member State	Micronesia
Netherlands Antilles	Netherlands	Netherlands
New Caledonia	France	France
Niue	New Zealand	New Zealand
Norfolk I.	Australian Territory	Australia
Northern Mariana Is.	US Territory	USA
Palau	UN Member State	Indonesia
Pitcairn Is.	UK Territory	United Kingdom
Puerto Rico	US Territory	USA
Reunion	France	France
San Marino	UN Member State	Italy
South Georgia & the South Sandwich Is.	UK Territory	United Kingdom
St. Helena	UK Territory	United Kingdom
St. Kitts & Nevis	UN Member State	Grenada
St. Lucia	UN Member State	Grenada
St. Pierre & Miquelon	France	France
St. Vincent & the Grenadines	UN Member State	Grenada
Svalbard	Norwegian Territory	Norway
Tokelau	New Zealand	New Zealand
Tonga	UN Member State	Samoa
Turks & Caicos Is.	UK Territory	United Kingdom
Tuvalu	UN Member State	Micronesia
Vanuatu	UN Member State	Solomon Islands
Virgin Is.	US Territory	USA
Wake I.	US Territory	USA
Wallis & Futuna	France	France
West Bank	Occupied Territory	Israel
Western Sahara	Non-Self-Governing T.	Morocco

D. REFERENCES

MAIN TEXT AND APPENDIX

Anderson, B. J., P. R. Armsworth, F. Eigenbrod, C. D. Thomas, S. Gillings, A. Heinemeyer, D. B. Roy and K. J. Gaston. 2009. Spatial covariance between biodiversity and other ecosystem service priorities. Journal of Applied Ecology **46**:888–896.

Araujo, M. B. 2003. The coincidence of people and biodiversity in Europe. Global Ecology and Biogeography **12**:5–12.

Araujo, M. B., D. Nogues-Bravo, I. Reginster, M. Rounsevell and R. J. Whittaker. 2008. Exposure of European biodiversity to changes in human-induced pressures. Environmental Science & Policy **11**:38–45.

Bawa, K. S. and S. Dayanandan. 1997. Socioeconomic factors and tropical deforestation. Nature **386**:562–563.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS.

Bradshaw, C. J. A., X. Giam and N. S. Sodhi. 2010. Evaluating the relative environmental impact of countries. PLoS One **5**:e10440.

Brashares, J. S., P. Arcese and M. K. Sam. 2001. Human demography and reserve size predict wildlife extinction in West Africa. Proceedings of the Royal Society of London Series B-Biological Sciences **268**:2473–2478.

British Atmospheric Data Centre. 2006. HadCM3 Model Data. UK Meteorological Office Hadley Centre.

Cardillo, M., A. Purvis, W. Sechrest, J. L. Gittleman, J. Bielby and G. M. Mace. 2004. Human population density and extinction risk in the world's carnivores. PLoS Biology **2**:909–914.

Carr, D. L. 2004. Proximate population factors and deforestation in tropical agricultural frontiers. Populationa and Environment **25**:585–612.

Cash, D. W., W. N. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard and O. Young. 2006. Scale and cross-scale dynamics: Governance and information in a multilevel world. Ecology and Society **11**.

Caviglia-Harris, J. L., D. Chambers and J. R. Kahn. 2009. Taking the "U" out of Kuznets: a comprehensive analysis of the EKC and environmental degradation. Ecological Economics **68**:1149–1159.

Ceballos, G. and P. R. Ehrlich. 2002. Mammal population losses and the extinction crisis. Science **296**:904–907.

Center for International Earth Science Information Network (CIESIN), C. U. and and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World Version 3 (GPWv3): Population Density Grids, Palisades, NY, Socioeconomic Data and Applications Center (SEDAC), Columbia University.

Chown, S. L., B. J. van Rensburg, K. J. Gaston, A. S. Rodrigues and A. S. van Jaarsveld. 2003. Energy, species richness, and human population size: Conservation implications at a national scale. Ecological Applications **13**:1233–1241.

Cincotta, R. P., J. Wisnewski and R. Engelman. 2000. Human population in the biodiversity hotspots. Nature **404**:990–992.

Collard, I. F. and R. A. Foley. 2002. Latitudinal patterns and environmental determinants of recent human cultural diversity: do humans follow biogeographical rules? Evolutionary Ecology Research **4**:371–383.

Cornell, S., R. Costanza, S. Sörlin and S. van der Leeuw. 2010, in press. Developing a systematic "science of the past" to create our future. Global Environmental Change.

Cumming, G. S., D. H. Cumming and C. L. Redman. 2006. Scale mismatches in social-ecological systems: Causes, consequences, and solutions. Ecology and Society **11**.

Czech, B., P. R. Krausman and P. K. Devers. 2000. Economic associations among causes of species endangerment in the United States. Bioscience **50**:593–601.

DeFries, R. S., M. C. Hansen, J. R. G. Townshend, A. C. Janetos and T. R. Loveland. 2000. A new global 1-km dataset of percentage tree cover derived from remote sensing. Global Change Biology:247–254.

DeFries, R. S., T. Rudel, M. Uriarte and M. Hansen. 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience **3**:178–181.

Deichmann, U. and Eklundh Lars. 1991. Global digital data sets for land degradation studies: a GIS approach, Nairobi, Kenya. GRID Case Study Series:24–25.

Dias, R. A., C. R. Mattos and J. A. Balestieri. 2006. The limits of human development and the use of energy and natural resources. ENERGY POLICY **34**:1026–1031.

Diniz Filho, J. A. F., G. de Oliveira, F. Lobo, L. G. Ferreira, L. M. Bini and T. F. L. V. B. Rangel. 2009. Agriculture, habitat loss and spatial patterns of human occupation in a biodiversity hotspot. Scientia Agricola **66**:764–771

EEA Report. 1999. Environmental Indicators: Typology and Overview. Technical Report No. 25. Available from http://reports.eea.europa.eu/TEC25/en/tech_25_text.pdf.

Ehrlich, P. R. and R. M. Pringle. 2008. Where does biodiversity go from here? A grim business-as-usual forecast and a hopeful portfolio of partial solutions. Proceedings of the National Academy of Science of the United States of America **105**:11579–11586.

Ericksen, P. J. 2008. What is the vulnerability of a food system to global environmental change? Ecology and Society **13**:Art. 14.

ESRI Environmental Systems Research Institute. 2008. ArcGIS. 9.3.

ESRI® Data & Maps. 2008. Global Digital Elevation Model (ETOPO30).

Evans, K. L. and K. J. Gaston. 2005. People, energy and avian species richness. Global Ecology and Biogeography **14**:187–196.

Ewers, R. M. 2006. Interaction effects between economic development and forest cover determine deforestation rates. Global Environmental Change—Human and Policy Dimensions **16**:161–169.

Ewing, B., S. Goldfinger, A. Oursler, A. Reed, D. Moore and M. Wackernagel. 2009. The Ecological Footprint Atlas 2009, Oakland.

Folke, C. 2006. The economic perspective: Conservation against development versus conservation for development. Conservation Biology **20**:686–688.

Folke, C. 2007. Social-ecological systems and adaptive governance of the commons. Ecological Research **22**:14–15.

Folke, C., L. Pritchard, F. Berkes, J. Colding and U. Svedin. 2007. The problem of fit between ecosystems and institutions: Ten years later. Ecology and Society **12**.

Food & Agriculture Organization of the United Nations (FAO). 2006a. Agricultural Population, Rome. Available from http://www.fao.org/.

Food & Agriculture Organization of the United Nations (FAO). 2006b. Agricultural Production Indices. Food Production Per Capita Index. Available from http://www.fao.org/.

Food & Agriculture Organization of the United Nations (FAO). 2006c. Food Import Value Index (Excluding Fish Products), Rome. Available from http://www.fao.org/.

Food & Agriculture Organization of the United Nations (FAO). 2006d. Nutrition: Calorie Supply Per Capita, Rome. Available from http://www.fao.org/.

Food & Agriculture Organization of the United Nations (FAO). 2009 (Last Update)a. Agricultural Product Export Value. Available from http://www.fao.org/.

Food & Agriculture Organization of the United Nations (FAO). 2009 (Last Update)b. Agricultural Product Import Value. Available from http://www.fao.org/.

Food and Agriculture Organization of the United Nations. 2006. Global Forest Resources Assessment 2005: Progress towards sustainable forest management, Rome

Gaston, K. J. 2005. Biodiversity and extinction: species and people. Progress in Physical Geography **29**:239–247.

Geist, H. J. and E. F. Lambin. 2002. Proximate causes and underlying driving forces of tropical deforestation. Bioscience **52**:143–150.

Ghertner, D. A. and M. Fripp. 2007. Trading away damage: Quantifying environmental leakage through consumption-based, life-cycle analysis. Ecological Economics **63**:563–577.

Grégoire, J.-M., K. Tansey, I. Marengo, D. Stroppiana and S. Fritz. 2002. The Global Burnt Area 2000 initiative: GBA-2000. Mapping the areas burnt globally during the year 2000. Pulications of the European Commission **No. I.01.117**:Joint Research Centre, Ispra, Italy, January 2002, p. 40.

Gumpenberger, M., K. Vohland, U. Heyder, B. Poulter, K. Macey, A. Rammig, A. Popp and W. Cramer. 2010. Predicting pan-tropical climate change induced forest stock gains and losses-implications for REDD. Environmental Research Letters **5**.

Hammer, Ø., D. A. T. Harper and P. D. Ryan. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia. Electronica **4**:9.

Hansen, M., R. DeFries, J. R. Townshend, M. Carroll, C. Dimiceli and R. Sohlberg. 2003. Vegetation Continuous Fields MOD44B: 2001 Percent Tree Cover: Collection 3, College Park, Maryland. Available from http://www.landcover.org/data/vcf/.

Hansen, M. C., S. V. Stehman and P. V. Potapov. 2010. Quantification of global gross forest cover loss. Proceedings of the National Academy of Science of the United States of America **107**:8650–8655.

Hanson, T., T. M. Brooks, G. A. Da Fonseca, M. Hoffmann, J. F. Lamoreux, G. Machlis, C. G. Mittermeier, R. A. Mittermeier and D. P. John. 2009. Warfare in Biodiversity Hotspots. Conservation Biology **23**:578–587.

Hoekstra, A. Y. and A. K. Chapagain. 2008. Globalization of water. Sharing the planet's freshwater resources. Blackwell, Malden, Mass.

Hoekstra, J. M. and J. L. Molnar. 2010. The atlas of global conservation. Changes, challenges and opportunities to make a difference. University of California Press, Berkeley.

Holland, T. G., G. D. Peterson and A. Gonzalez. 2009. A cross-national analysis of how economic inequality predicts biodiversity loss. Conservation Biology **23**:1304–1313.

Imhoff, M. L., L. Bounoua, T. Ricketts, C. Loucks, R. Harriss and W. T. Lawrence. 2004. Human Appropriation of Net Primary Productivity (HANPP) as a Percentage of Net Primary Productivity (NPP). Available from http://sedac.ciesin.columbia.edu/es/hanpp.html.

International Monetary Fund. 2009. The World Economic Outlook Database.

Jenness, J. 2008. Tools for Graphics and Shapes: Extension for ArcGIS. Jenness Enterprises.

Jha, S. and K. S. Bawa. 2006. Population growth, human development, and deforestation in biodiversity hotspots. Conservation Biology **20**:906–912.

Katzner, T. E. 2005. Corruption—a double-edged sword for conservation? A response to Smith & Walpole. Oryx **39**:260–262.

Kessler, J. J., T. Rood, T. Tekelenburg and M. Bakkenes. 2007. Biodiversity and socioeconomic impacts of selected agro-commodity production systems. Journal of Environment & Development **16**:131–160.

Khan, S. R. 2009. Assessing poverty-deforestation links: evidence from Swat, Pakistan. Ecological Economics **68**:2607–2618.

Kier, G., H. Kreft, T. M. Lee, W. Jetz, P. L. Ibisch, C. Nowicki, J. Mutke and W. Barthlott. 2009. A global assessment of endemism and species richness across island and mainland regions. Proceedings of the National Academy of Science of the United States of America **106**:9322–9327.

Kier, G., J. Mutke, E. Dinerstein, T. H. Ricketts, W. Küper, H. Kreft and W. Barthlott. 2005. Global patterns of plant diversity and floristic knowledge. Journal of Biogeography **32**:1107–1116.

Kovach, W. L. 2000. A Multivariate Statistical Package (MVSP). Version 3.1. Kovach Computing Services, Pentraeth, Wales, UK.

Kramer, D. B., G. Urquhart and K. Schmitt. 2009. Globalization and the connection of remote communities: A review of household effects and their biodiversity implications. Ecological Economics **68**:2897–2909.

Kreft, H. and W. Jetz. 2007. Global patterns and determinants of vascular plant diversity. Proceedings of the National Academy of Science of the United States of America **104**:5925–5930.

Lee, T. M. and W. Jetz. 2008. Future battlegrounds for conservation under global change. Proceedings of the Royal Society of London Series B-Biological Sciences **275**:1261–1270.

Lenzen, M., A. Lane, A. Widmer-Cooper and M. Williams. 2009. Effects of Land Use on Threatened Species. Conservation Biology **23**:294–306.

Lewis, M. P., editor. 2009. Ethnologue: languages of the world: Sixteenth edition, Dallas.

Li, Q. and R. Reuveny. 2006. Democracy and environmental degradation. International Studies Quaterly **50**:935–956.

Luck, G. W. 2007. A review of the relationships between human population density and biodiversity. Biological Reviews **82**:607–645.

McDonald, R. I., R. T. T. Forman, P. Kareiva, R. Neugarten, D. Salzer and J. Fisher. 2009. Urban effects, distance, and protected areas in an urbanizing world. Landscape and Urban Planning **93**:63–75.

McDonald, R. I., P. Kareiva and R. T. Formana. 2008. The implications of current and future urbanization for global protected areas and biodiversity conservation. Biological Conservation **141**:1695–1703.

McKinney, M. L. 2001. Role of human population size in raising bird and mammal threat among nations. Animal Conservation **4**:45–57.

Microsoft. Office Excel. 2007.

Mills, J. H. and T. A. Waite. 2009. Economic prosperity, biodiversity conservation, and the environmental Kuznets curve. Ecological Economics **68**:2087–2095.

Mitchell, T. D. and P. D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology **25**:693–712.

Monticino, M., M. Acevedo, B. Callicott, T. Cogdill and C. Lindquist. 2007. Coupled human and natural systems: A multi-agent-based approach. Environmental Modelling & Software **22**:656–663.

Moore, J. L., L. Manne, T. Brooks, N. D. Burgess, R. Davies, C. Rahbek, P. Williams and A. Balmford. 2002. The distribution of cultural and biological diversity in Africa. Proceedings of the Royal Society of London Series B-Biological Sciences **269**:1645–1653.

Morse, S. 2006. Is corruption bad for environmental sustainability? A cross-national analysis. Ecology and Society **11**:Article No.: 22.

Muradian, R. and J. Martinez-Alier. 2001. Trade and the environment: from a 'Southern' perspective. Ecological Economics **36**:281–297.

Naidoo, R. and W. L. Adamowicz. 2001. Effects of economic prosperity on numbers of threatened species. Conservation Biology **15**:1021–1029.

Naidoo, R. and T. Iwamura. 2007. Global-scale mapping of economic benefits from agricultural lands: Implications for conservation priorities. Biological Conservation **140**:40–49.

Nelson, A. 2008. Travel time to major cities: A global map of Accessibility. Available from http://gem.jrc.ec.europa.eu/.

Oldekop, J. A., A. J. Bebbington, D. Brockington and R. F. Preziosi. 2010. Understanding the Lessons and Limitations of Conservation and Development. Conservation Biology **24**:461–469.

Oldeman, L. R., R. T. A. Hakkeling and W. G. Sombroek. 1991. World map of the status of human-induced soil degradation. An explanatory note. 2. rev. ed. Internat. Soil Reference and Inform. Centre, Wageningen.

Olson, D. M., et al. 2001. Terrestrial ecoregions of the worlds: A new map of life on Earth. Bioscience **51**:933–938.

Olson J. S. 2000. Global 1km Land Cover—Olson Global Ecosystem Legend. Version 2.0. U.S. Geological Survey (USGS), the University of Nebraska-Lincoln (UNL), and the European Commission's Joint Research Centre (JRC).

Orme, C. D., et al. 2005. Global hotspots of species richness are not congruent with endemism or threat. Nature **436**:1016–1019.

Polasky, S. 2008. Why conservation planning needs socioeconomic data. Proceedings of the National Academy of Science of the United States of America **105**:6505–6506.

Prince, S. and J. Small. 2003. Global Production Efficiency Model. Version 1.0, College Park, Maryland. Available from http://ftp.glcf.umd.edu/data/glopem/.

R Development Core Team. 2010. R: A Language and Environment for Statistical Computing. Version 2.11.1. R Foundation for Statistical Computing, Vienna.

Redman, C. L., J. M. Grove and L. H. Kuby. 2004. Integrating social science into the long-term ecological research (LTER) network: Social dimensions of ecological change and ecological dimensions of social change. Ecosystems **7**:161–171.

Reid, W. V. 2005. Ecosystems and human well-being. Synthesis ; a report of the Millennium Ecosystem Assessment. Island Press, Washington, DC.

Rockström, J., et al. 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society **14**:article 32.

Rodrigues, A. S. L., R. M. Ewers, L. Parry, C. Souza Junior, A. Verissimo and A. Balmford. 2009. Boom-and-bust development patterns across the Amazon deforestation frontier. Science **324**:1435–1437.

Sachs. J. D., et al. 2009. Biodiversity Conservation and the Millennium Development Goals. Science **325**: 1502–1503.

Sayre, N. F. 2005. Ecological and geographical scale: parallels and potential for integration. Progress in Human Geography **29**:276–290.

Siebert, S., P. Döll, S. Feick, J. Hoogeveen and K. Frenken. 2007. Global Map of Irrigation Areas. version 4.0.1. Johann Wolfgang Goethe University, Frankfurt am Main, Germany/Food and Agriculture Organization of the United Nations, Rome, Italy.

Silver, J. J. 2008. Weighing in on Scale: Synthesizing Disciplinary Approaches to Scale in the Context of Building Interdisciplinary Resource Management. Society & Natural Resources **21**:921–929.

Simard, M. and N. Pinto. 2008. Combining Lidar and Radar for Remote Sensing of Land Surfaces.

Smith, R. J., R. D. Muir, M. J. Walpole, A. Balmford and N. Leader-Williams. 2003. Governance and the loss of biodiversity. Nature **426**:67–70.

Smith, R. J. and M. J. Walpole. 2005. Should conservationists pay more attention to corruption? Oryx **39**:251–256.

Socioeconomic Data and Applications Center (SEDAC), C. U. Data Resources. Available from http://sedac.ciesin.columbia.edu/.

Sommer, J. H., H. Kreft, G. Kier, W. Jetz, J. Mutke and W. Barthlott. 2010 Projected impacts of climate change on regional capacities for global plant species richness. Proceedings of the Royal Society of London Series B-Biological Sciences **277**:2271–2280.

Strassburg, B. B. N., et al. 2010. Global congruence of carbon storage and biodiversity in terrestrial ecosystems. Conservation Letters **3:** http://dx.doi.org/10.1111/j.1755-263X.2009.00092.x.

Sunderlin, W. D., S. Dewi, A. Puntodewo, D. Muller, A. Angelsen and M. Epprecht. 2008. Why forests are important for global poverty alleviation: a spatial explanation. Ecology and Society **13**:Art. 24.

Sutherland, W. J. 2003. Parallel extinction risk and global distribution of languages and species. Nature **423**:276–279.

The Fund for Peace. 2009. Failed States Index.

Tucker, C. J., J. E. Pinzon and M. E. Brown. 2004. Global Inventory Modeling and Mapping Studies, College Park, Maryland. Available from http://www.landcover.org/data/gimms/.

Turner, W. R., T. Nakamura and M. Dinetti. 2004. Global urbanization and the separation of humans from nature. Bioscience **54**:585–590.

United Nations Department of Economic and Social Affairs (Population Division). 2008. Nationally designated protected areas data extracted from World Database on Protected Areas (WDPA): a joint project of UNEP and IUCN.

United Nations Department of Economic and Social Affairs (Population Division). 2009. World Population Prospects: The 2008 Revision. CD-ROM Edition. Available from http://unstats.un.org/unsd/demographic/products/socind/population.htm.

United Nations Development Programme. 2009. Overcoming barriers: Human mobility and development. Palgrave Macmillan, Houndmills **2009**.

United Nations Environmental Programme (UNEP). UNEP Grid Arendal. Globalis. Available from http://globalis.gvu.unu.edu.

Vazquez, L. B. and K. J. Gaston. 2006. People and mammals in Mexico: conservation conflicts at a national scale. Biodiversity and Conservation **15**:2397–2414.

Vorosmarty, C. J., P. Green, J. Salisbury and R. B. Lammers. 2000. Global water resources: vulnerability from climate change and population growth. Science (Washington) **289**:284–288.

Wildlife Conservation (WCS) and Center for International Earth Science Information Network (CIESIN). 2005. Last of the Wild Data Version 2: Global Human Footprint data set (HF). Available from http://sedac.ciesin.columbia.edu/wildareas/.

World Bank. 2009a. Household Final Consumption Expenditure—Total. Available from http://search.worldbank.org/.

World Bank. 2009b. Military Expenditures—Percent of GDP. Available from http://www.worldbank.org/data/.

World Bank. World Development Indicators Database. 2008. Fertilizer consumption (kilograms per hectare of arable land).

WWF. List of Ecoregions. Terrestrial Ecoregions. Available from http://wwf.panda.org/about_our_earth/ecoregions/ecoregion_list/.

York, R., E. A. Rosa and T. Dietz. 2003. Footprints on the earth: The environmental consequences of modernity. American Sociological Review **68**:279–300

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