Biodiversity and Poverty Reduction;

The importance of biodiversity for ecosystem services.

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Purpose of this Report

This report reviews existing scientific knowledge regarding the links between biodiversity and the sustainable provision of ecosystem services, and considers the implications of these links for development policy. It does not set out to assess the value of ecosystem services to the poor, on which there is a growing understanding presented in other reports and publications, and so does not present the economic valuation of biodiversity or ecosystem services. The report considers biodiversity in the broadest sense, to include variety at the genetic, species and ecosystem levels, and interactions between components of biodiversity, and is therefore not restricted to a consideration of species diversity alone. The links between biodiversity and ecosystem services presented in this report underpin the relationship between the environment and development, and as such contribute towards an understanding of the most effective national, bilateral, and international efforts to achieve the Millennium Development Goals, and towards an improved understanding of the true values of biodiversity.

Importance of Biodiversity for the supply of Ecosystem Services

Biodiversity underpins the ecosystem services that all people ultimately depend on at all scales, from the individual to the global, rich and poor alike. Important ecosystem services on which poor people are particularly dependent, include:

- varied diet (including flavourings and micronutrients), famine foods and food security - provided directly by components of biodiversity that are consumed, and through a wide range of biodiversity that is crucial for food production, including that involved in the services of pollination, pest and disease control, and soil fertility.
- water quality and availability (including regulation of flooding events), and erosion control - affected variously by vegetative cover at local and landscape scales
- medicines and health, both through the supply of natural medicines, and through the regulation of infections and emerging diseases.
- cultural values, closely tied in many societies to components of biodiversity, typically at the species or landscape level.

Current levels of scientific understanding of the links between biodiversity and ecosystem services have established that:

- Interactions between components of biodiversity (such as pollination, decomposition, and interactions between plants and soil organisms) are fundamental to the functioning of ecosystems, and to supporting the continued supply of ecosystem services.
- Diversity at genetic and species levels is important for maintaining the adaptability of ecosystems to changing environmental conditions, for example increasing climate variability and predicted changes in global and regional climate, and for maintaining the capacity of ecosystems to supply the combinations of a variety of services.
- Many of the substitutes for ecosystem goods and services, where available, have significant collateral costs – for example, use of pesticides has important human health implications; use of fossil fuels has climate change and often aerosol pollution implications; use of fertilisers has water quality implications. Sometimes these costs may be born by the users of the substitutes (eg. implications for farmer health of on-farm use of pesticides), but they are often externalised (eg. downstream problems of water quality caused by runoff from farms with high fertiliser input).
- Threshold effects in declining biodiversity are important in many instances. These are manifested when reduction in biodiversity to a certain level causes a sudden collapse in a system's ability to deliver particular services. These have most clearly been demonstrated in aquatic ecosystems, for example where increasing nutrient loading has led to dramatic reduction in oxygen levels and the emergence of so-called "dead zones" in lake and coastal waters, and where the persistent

overharvesting of fish stocks has caused sudden, apparently irreversible collapse in those stocks. Threshold effects caused by reductions in biodiversity on land are less well documented, but have been demonstrated in a range of habitat types.

And so it is clear that some level of biodiversity is absolutely necessary for human existence, rich and poor people alike. However, there is no simple answer to the questions "how much biodiversity do we need?" or "how much biodiversity can we afford to loose?" This is for a number of reasons:

- Biodiversity is a complicated concept with many dimensions. There is no single measure or metric that can adequately describe it. Similarly, ecosystem services are themselves multidimensional. These questions will therefore have a different answer in different contexts and at different scales.
- There is considerable scientific uncertainty, and vigorous debate, about the exact role of diversity in ecosystems and the relationship between the amount of any particular component of biodiversity in an ecosystem and the way that ecosystem functions. Three main approaches have been used to examine such relationships: theoretical, experimental and observational. Each can provide valuable insights, although each is also heavily compromised.
- Although capabilities for predicting some thresholds are improving, and increased *risks* of change can be determined, for most thresholds in most ecosystems, current understanding is unable to predict the thresholds where change will be encountered.
- Many ecosystem services may at some scales be substituted for by non-biodiversity alternatives, derived from technology, inorganic materials (of which petrochemicals are a special case) and human labour. In some instances, and at local scales, ecosystem services may be brought in from outside

Implications for the World's Poor

The limited purchasing power of poor people leaves them less capable of buying-in substitutes for local ecosystem services from outside. They are therefore highly dependent on the integrity of their local environment, for example for the supply of wild foods during times of famine, insecurity or conflict. Maintenance of a heterogeneous local environment provides the widest possible range of ecosystem services, reduces the exposure of local people to risk and lessens their dependence on the vagaries of global markets or on development assistance. When considered from the perspective of poor people it is this *local* level of biodiversity that is important: the distribution and abundance of wild species, the range of crop plants and livestock and the diversity of ecosystem types directly available to them. Not only are poor people generally not in a position to buy in substitutes for ecosystem goods and services, they are often forced to bear the externalised costs of other people's use of substitutes for ecosystem goods and services – for example, they may live in places that suffer the effects of pollution and eutrophication, or are displaced by hydroelectric projects, or conversion of natural or semi-natural forests to high intensity agriculture.

Implications for Development Policy

Recognition of the role that biodiversity plays in underpinning the ecosystem services has development policy implications at all levels from the international to the local or community.

International policy implications

Partnerships between development agencies and other government departments are essential to ensure coherent and consistent policies regarding biodiversity and poverty in all policy arenas. This includes including those concerned primarily with trade and finance, as well as those with a focus on environment and development.

Development agencies are well-placed to encourage appropriate strategies to meet development and environmental targets and indicators at national and international level, for example under in the Millennium Development Goals. MDG 7 'ensuring environmental sustainability' underpins all the other goals, as without it elimination of poverty will only be at best temporary and at worst illusory.

The incorporation of the CBD's 2010 biodiversity target into MDG7 has already contributed to this objective, and to ensuring policy coherence between biodiversity and poverty sectors, although in many instances, MDG7 is not considered or addressed by development agencies to the extent of other goals.

Influencing policies and institutions at the national level
Development agencies could further encourage governments to harmonise their various strategies and action plans, including sectoral plans, poverty reduction strategies, national strategies for sustainable development and national environmental and biodiversity strategies and action plans. Of particular importance in this regard are:

- adoption of participatory bottom-up planning approaches
- adoption of a people-centred ecosystem approach as agreed under the CBD
- promotion of systems of tenure and access to resources that are equitable and that promote sustainable use of natural resources through long-term management
- adoption of legal frameworks that allow for the integrated planning and management of resources at the landscape level
- information sharing within and between governments, including that arising from environmental assessment processes, and government-funded science.

Influencing policies and planning at the regional level
Development agencies could encourage management and planning practices that maintain or restore environmental heterogeneity at the landscape level. This is the simplest way to ensure that poor people have access to the range of ecosystem services that they need while at the same time allowing individuals or families to manage their own resources in ways that most suit them. Experience to date has shown that it is possible to develop multi-stakeholder plans and information sharing mechanisms successfully at the landscape level (particularly in coastal zones through integrated coastal zone management approaches), but that it is often then difficult to establish legal frameworks for the implementation of these plans. Hence the importance of encouraging national-level legal reform, as indicated above.

Influencing activities at the community, farm or individual level
The adoption of low-impact management practices should be encouraged in production systems where these can be shown to deliver significant on-site benefits. Two important examples are the use of integrated pest management techniques and commercial production of environmentally-friendly goods. In both cases barriers to adoption by poorer people can be relatively easily overcome with external assistance.

Where the livelihoods of poor people depend on or involve harvest of wild resources, at minimum efforts should be made to ensure that the harvest of these specific resources is sustainable. Although it is in principle not difficult to design sustainable harvest regimes, it has proven difficult to find successful mechanisms for their implementation. Development agencies could play a useful role here in widely disseminating best practice in natural resources management.

1 Introduction to study

1.1 Purpose and focus of report

This document provides an overview of the state of science relating to the role of biodiversity in the supply of "ecosystem services" (the benefits that people derive from ecosystems), highlighting what is known about how changes in biodiversity affect ecosystem services. It then presents the implications of these connections for development policy. It does not set out to assess the value of ecosystem services to the poor – it is assumed that the reader already has an understanding of the importance of agricultural production, waste processing, natural medicines, regulation of water quality and quantity, and other ecosystem services, information on which is widely available in a range of other reports, such as the range of Millennium Ecosystem Assessment technical and synthesis reports (available from www.MAweb.org). Where information is available, an emphasis is placed on demonstrating thresholds and the consequences of abrupt or non-linear changes to biodiversity.

Biodiversity is considered here in a broad sense, including variety at the genetic, species and ecosystem levels, and is therefore not restricted to a consideration of species diversity alone. This report presents the state of knowledge regarding how much biodiversity is needed for the sustainable supply of ecosystem services in the present, and into the future (see Figure 1). The report also reviews the level of understanding of the reliance of ecosystem services on various aspects of biodiversity, such as *variety* (e.g. number of species (species richness), genetic variability), *abundance* (e.g. number of individuals or populations in a given location), *level of organisation* (e.g. genetic, population, species, or ecosystem diversity or abundance), and *biological interactions* (e.g. between pollinator species and plants, and between predators and prey).

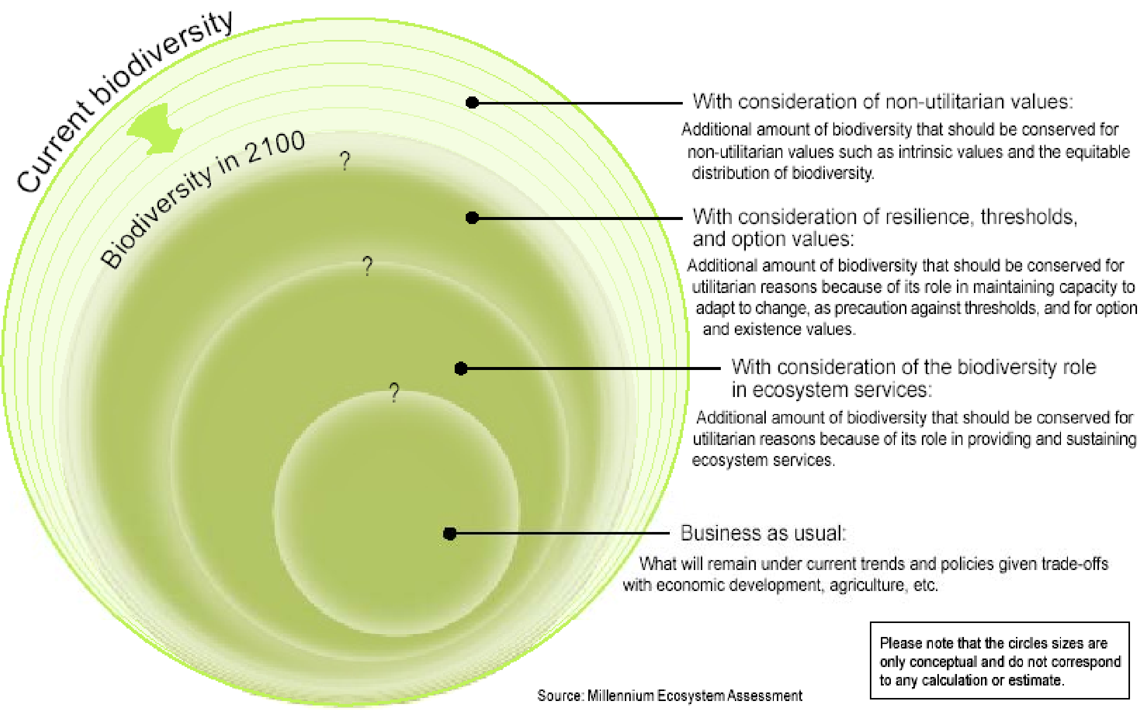

Figure 1. Conservation of biodiversity under different value frameworks – How much biodiversity might we need in the future? This report assesses the current state of knowledge regarding the sizes of these various circles, considering the importance of various attributes of biodiversity for the supply of ecosystem services, both now and into the future. There is little doubt that there will be less biodiversity in the future than at present, but note that the sizes of circles in this graphic are conceptual. Source: Millennium Ecosystem Assessment.

Biodiversity provides benefits to both the rural and urban poor. Although the majority of the world's poor currently live in rural areas, where they are most directly dependent on ecosystem services for their well-being, the rapidly-growing proportion that live in urban and peri-urban areas are also ultimately dependent on ecosystem services, both locally and from a distance. Ecosystem services particularly important to the growing number of urban poor include waste processing and detoxification, regulation of water and air quality, and services supporting small-scale agricultural production.

The issues considered in this report underpin the relationship between the environment and development at all scales, and as such relevant information is contributed here for national, bilateral, and international efforts to sustainably achieve the United Nations Millennium Development Goals and other poverty reduction strategies. The report lends support to, and builds on, previous publications and strategies on biodiversity and development.

1.2 Biodiversity and Ecosystem Services in the International Context

This report comes at a time of rapidly increasing awareness of the importance of biodiversity and ecosystem services. The Millennium Ecosystem Assessment (MA)[1] provided a baseline assessment of the condition of the world's ecosystems in providing benefits to people. It concluded that many of the benefits that people derive from ecosystems are being degraded, largely because their values are not captured in current economic systems. This finding is supported by other recent studies, such as that commissioned by UK Defra, and produced by EFTEC in 2005 on *the Economic, Social and Ecological Value of Ecosystem Services*, and reports of UNDP, the World Bank and others, such as *World Resources 2005; The Wealth of the Poor*.

The role and value of biodiversity and ecosystem services has been recognised at the centre of international efforts to reduce poverty and promote sustainable development, through the framework of the Millennium Development Goals. MDG 7, on environmental sustainability, calls for governments to *reverse the loss of environmental resources*, and although the indicators for monitoring progress towards this goal are not well developed, or comprehensive, the recent incorporation of the "2010 biodiversity target" (see below) into MDG7 has made the connection between biodiversity and the MDGs explicit. The Convention on Biological Diversity (CBD), signed by over 180 governments, manifestly recognises the important role of biodiversity in development, through its overarching objectives of conservation and sustainable use of biodiversity, and the equitable sharing of benefits arising from its use. Government Parties to the CBD, including the UK, have adopted a target, endorsed by the World Summit on Sustainable Development, to *achieve, by 2010, a significant reduction of the current rate of biodiversity loss at global, regional, and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth*. Despite this, there has been a tendency at the national level, and at the international level with development donor agencies, to move away from an explicit focus on biodiversity and ecosystem services in recent years. This may in part be due to a focus on short-term gains for some development targets, many of which come at the expense of environmental considerations, and longer-term sustainable development strategies. It may also be partly a result of the incorporation of environmental issues into national programmes of work without providing appropriate support for their effective implementation. The move by bilateral and international donors towards direct budgetary support of governments without the appropriate environmental considerations in place is likely to further exacerbate the situation.

Additionally, at the national level within governments, and internationally through the various institutions and agreements, biodiversity-related policies are most frequently developed in isolation

[1] The Millennium Ecosystem Assessment (MA) was the largest ever assessment of the condition of the world's ecosystems to provide benefits to people, and of associated environment and development policy responses. Over 1600 scientists contributed to its findings. The MA was endorsed by the Convention on Biological Diversity, the Convention to Combat Desertification and the Ramsar Convention on Wetlands. Further information. The findings of the MA were launched in March 2005, and are available at: www.MAweb.org

between development, forestry, agriculture, fisheries, water, trade, and biodiversity sectors, resulting in unintended consequences for other sectors or for ecosystem services. Although not explicitly recognised, it is clear that many national and international processes, treaties, policies and negotiations in non-environmental or development sectors relate directly to ecosystem services and biodiversity. Typically, for example, natural resource commodities such as timber and genetic resources, and trade in agricultural products, are considered in isolation from their roots as the services of ecosystems. As a result, the value of the ecosystem in their supply is seldom recognised. In particular, the global trade agenda, and ongoing discussions under bodies such as the World Trade Organisation are in practice affected greatly by the changing capacity of biodiversity and ecosystems to provide services, and decisions taken from the international level through to the individual in all areas of society have the potential to impact on biodiversity and ecosystems, and thereby on the services from which people benefit.

2 Biodiversity and ecosystem services: Concepts and approaches

2.1 Definitions and patterns of biodiversity

Biodiversity is the variability of life, and encompasses diversity at all scales and levels of organisation from the genetic through populations, species, ecosystems and landscapes. However, it is most clearly manifested in the variety of different kinds of organisms and habitats in the world. It is the variety of organisms, interacting with the physical landscape, that creates the range and diversity of ecosystems. At global level, biodiversity is very unevenly distributed: that is, some parts of the world are far more biologically diverse than others. The pattern is complex but by no means random. The most important overall trend, manifest in terrestrial, freshwater and shallow water marine systems, is for species diversity to increase from the polar regions to the equator. This is because in general, warmer areas are more diverse than colder areas. On land there is also a general trend for areas with more rainfall to be more diverse than drier ones. Geographical variations in diversity are very marked – there are, for example, differences of two or three orders of magnitude in the diversity of, for example, tree species in forests between arctic latitudes and equatorial ones.

People have, of course, radically altered biodiversity at a global scale. Most dramatically, on land large areas of natural habitat have been replaced with agricultural systems. In the great majority of cases (though not all), agricultural systems are lower in diversity than the habitats that they replaced. They are also generally dominated by exotic, or non-native, species. In many areas the diversity of natural or semi-natural systems has been reduced through local and global extinction of species. Through accidentally or deliberately transporting large numbers of species across the world patterns of diversity have been further altered: in many cases (for example on some islands such as the Galapagos, and at the continental scale on most continents) we have actually increased species diversity by introducing new species, but in many others, and particularly at smaller scales, we have reduced diversity as introduced species have led to the local extinction of native ones.

2.2 Ecosystem processes and services

Ecosystem processes – those that define living systems – can be seen as flows of matter and energy. Fundamental to these is photosynthesis, whereby energy from sunlight is used to turn carbon dioxide and water into oxygen and biomass. Respiration then releases energy, breaking down organic matter back into, essentially, carbon dioxide and water. Other aspects of ecosystem processes that are also extremely important include the incorporation of elements from inorganic sources into living systems, notably including the incorporation of nitrogen from the atmosphere by various kinds of bacteria (also increasingly carried out through industrial processes) and the decomposition of waste matter so that it re-enters the various nutrient and mineral cycles. At a planetary level these are the ecosystem services on which continued human existence is absolutely dependent. More locally, people derive a whole range of other benefits from ecosystems, such as regulation of water flows and water quality, local regulation of climate, and stabilisation of land through vegetation reducing soil erosion.

The range and variety of benefits that people derive from ecosystems have been categorised into: *provisioning services* – the products (or goods) obtained from ecosystems; *regulating services* – the benefits obtained from the regulation of ecosystem processes; *cultural and amenity services* – the nonmaterial benefits obtained from ecosystems; and *supporting services* – those necessary for the production of all other ecosystem services. Examples of the various categories of ecosystem services, and the diverse linkages between ecosystem services and human well-being are illustrated in Figure 2.

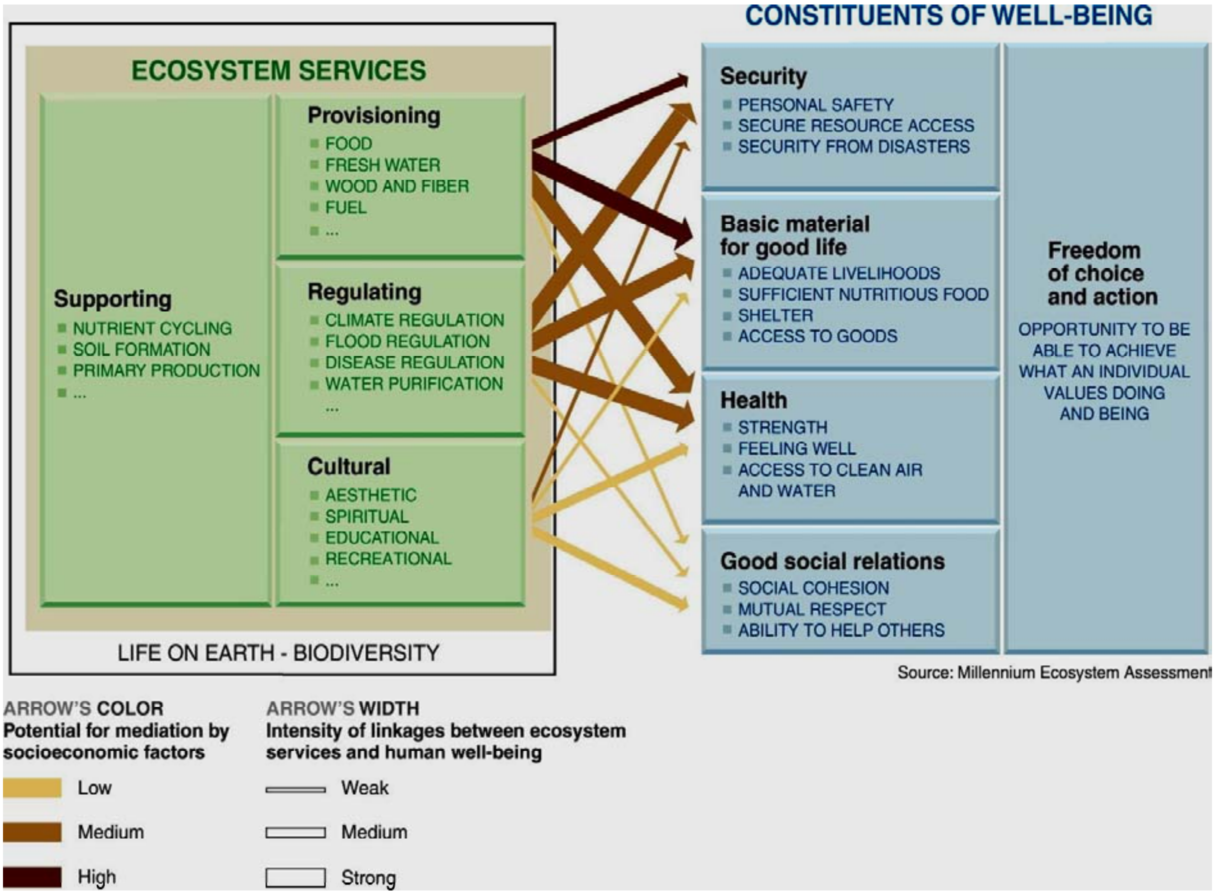

Figure 2. Classification of ecosystem services, and illustration of the linkages between ecosystem services and human well-being. The strength of the linkages and potential for mediation (for example through substitution) differ in different ecosystem sand regions. In addition to the influence of ecosystem services on human well-being, other factors also influence human well-being, such as economic, social, technological and cultural factors. Source: Millennium Ecosystem Assessment

2.3 Sources of information – theory and evidence

The great range and diversity of ecosystems found across the planet are a reflection of the range of different organisms that carry out the functions and processes sketched out above. However, the precise nature of the relationship between the diversity of organisms and the attributes of ecosystems and ecosystem processes is only now beginning to be understood, and research into the specific links between biodiversity and ecosystem services has only really emerged in the last decade (see Figure 3). Although there is no shortage of hypotheses, there is still not a single convincing explanation for the patterns of biological diversity that we observe in the world. Without this, any attempts to establish generally applicable quantitative and causal links between diversity and ecosystem attributes are likely to be compromised, although again a number of hypothesis are available (see Figure 4).

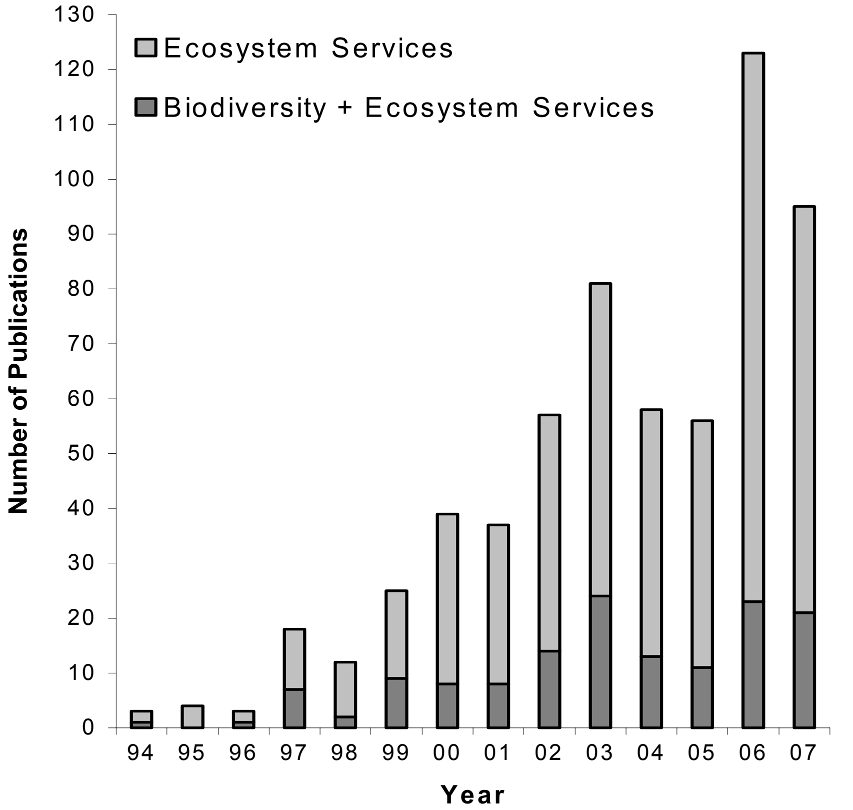

Figure 3. Emerging research on biodiversity and ecosystem services. Results represent number of publications between 1991 and 2007 that included either 'ecosystem services', or 'biodiversity' and 'ecosystem services' in their titles and abstracts. It's only for just over a decade that scientific research has focussed explicitly on the links between biodiversity and ecosystem services. Figure constructed with data from the BIOSIS literature database.

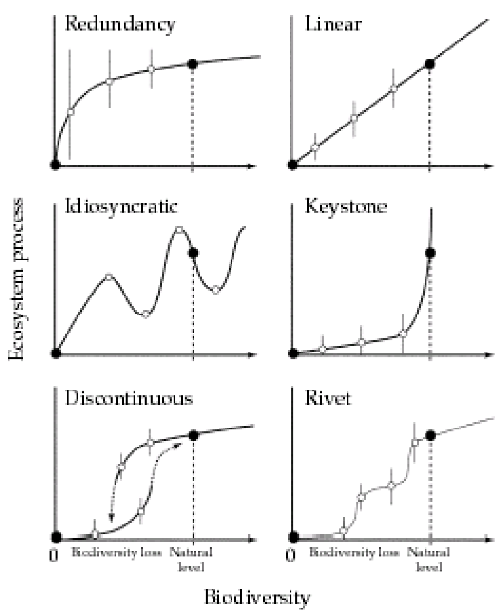

Figure 4. Examples of theoretical hypothesis describing the relationship between ecosystem processes, and changes in biodiversity from the natural level. Although none of these hypotheses are thought to accurately describe the true relationship between the amount of biodiversity and the functioning of ecosystems, they nonetheless describe the general concepts. In cases where there is no biodiversity, there are no ecosystem processes and functions. At a natural level of biodiversity, the processes and functions are largely predictable. However, the consequences of declining (or increasing) biodiversity from such natural levels is not well understood for most systems, in large part due to a lack of empirical and theoretical information, and due to the widely varying individual properties of ecosystems, and their components. Source: Loreau M, Naeem S, Inchausti P, 2002. *Biodiversity and Ecosystem Functioning: Synthesis and Perspectives*. Oxford University Press

This report draws on a variety of synthesized and primary scientific literature. The Millennium Ecosystem Assessment provides a basis for the conceptual approach to the links between biodiversity and ecosystem services (see Figure 5). Information from case studies is presented where appropriate, to highlight key points where larger-scale analysis has not been conducted.

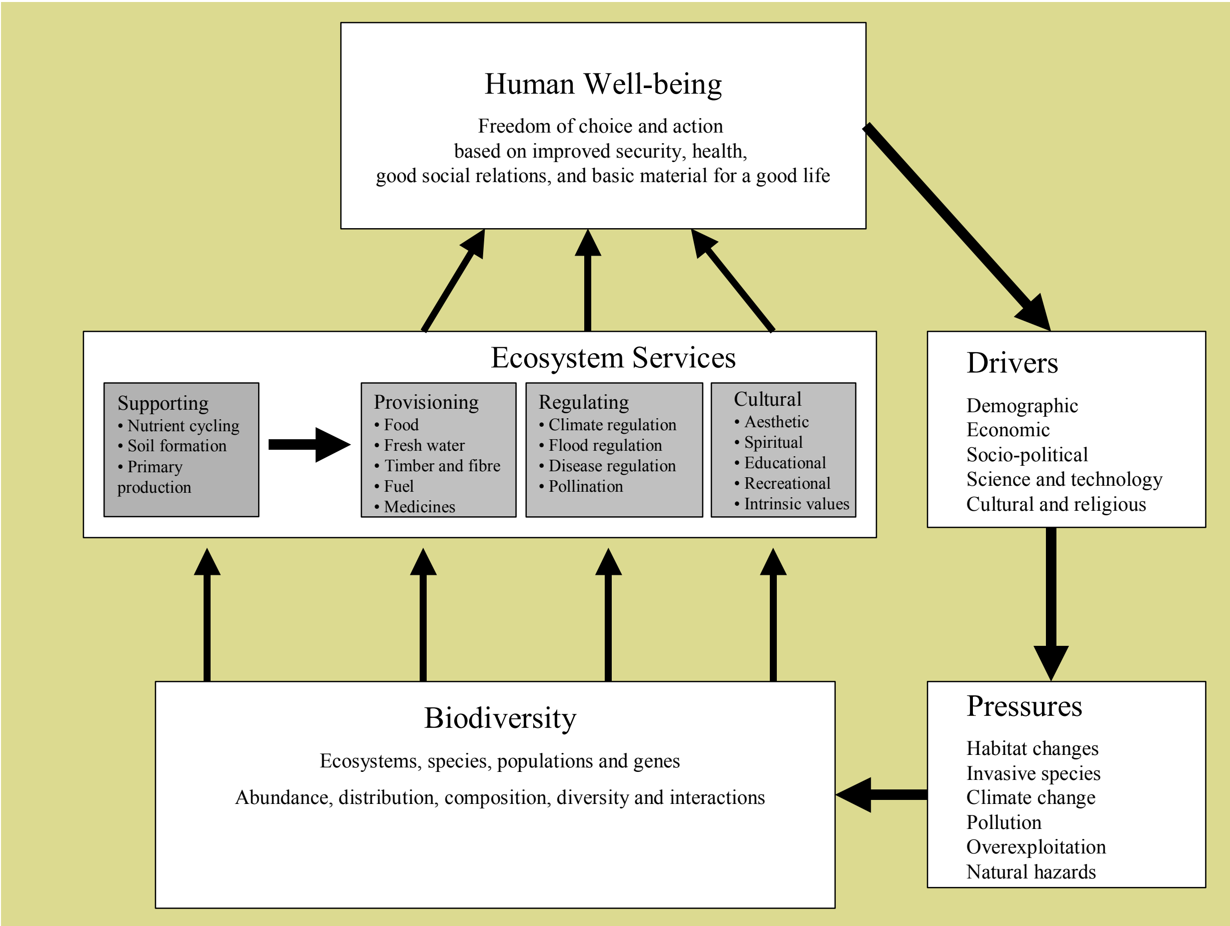

Figure 5. Conceptual approach to the relationship between biodiversity, ecosystem functioning, and ecosystem services. The links between biodiversity and ecosystem services form the focus of this report. Modified from the Millennium Ecosystem Assessment.

Three main approaches have been used to tease out relationships between biodiversity, ecosystem functions and attributes, and ecosystem services - namely theoretical, experimental and observational. Each can provide valuable insights, although each is also heavily compromised.[2] Nevertheless, it is possible to make some observations about the probable nature of links between diversity and ecosystem processes and attributes and, more importantly, show that diversity undoubtedly plays a

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[2] Theoretical models and experiments are both compromised by the need for simplifying assumptions, so that it is unclear to what extent any findings apply in more complex real-life situations. Most experiments either use very simplified model ecosystems in laboratories, or manipulations of simplified systems, usually temperate, low-diversity, grasslands in field situations. Even these often present statistical problems in interpretation. Dealing experimentally with more complex systems presents almost insurmountable problems of statistical analyses. Moreover, experiments are invariably carried out at very small scale and over timescales that are short in ecological terms and negligible in evolutionary ones. The use of observations of existing patterns of diversity and ecosystem processes and attributes is compromised by imperfect data and the fact that demonstrating correlations between different characteristics does not necessarily say anything about causality (are highly productive, highly diverse systems diverse because they are productive, or productive because they are diverse?).

vital role in the range of important ecosystem services. Examples of recent studies that have demonstrated links between changing diversity and various ecosystem functions are shown in Table 1.

Table 1. Examples of the demonstrated effects of increasing diversity on ecosystem functions.

Ecosystem	Effects of Increasing Diversity	Source/Authors
Artificial system of simplified communities of terrestrial plants, animals and single-celled organisms in a controlled chamber (Ecotron study)	Productivity increased	Naeem et al. 1995
Grassland	Drought resistance enhanced	Tilman et al. 1994
Fungi associated with plant roots (mycorrhizae)	Plant nutrient capture and productivity increased	van der Heijden et al. 1998
Experimental community of single-celled organisms (microbial mesocosm)	Ecosystem reliability (and insurance) enhanced	Naeem and Li 1997
Aquatic single-celled organisms	Less variable community and respiration	McGrady-Steed et al. 1997
Aquatic single-celled organisms	Increase in productivity and number of carbon and algae sources utilised	Naeem et al. 2000
Microscopic insects and other species in soil	Decomposition rate increased	Heneghan et al. 1999
Semi-natural grasslands	Productivity increased	Hector et al. 1999
Stream-dwelling organisms feeding on dead plant and animal matter (detritivores)	Increased litter decomposition	Jonsson and Malmqvist 2000; Jonsson et al. 2001
Wetland vegetation	Algal and total plant biomass increased, phosphate loss decreased	Englehardt and Ritchie 2001
Koa forests	Increase in non-timber ecosystem services	Pejchar and Press 2006
Mediterranean landscape (pine forests, oak woodland, managed olive groves)	Increased pollination service to wild flowers but also crops	Potts et al. 2006
Moorland	Decrease in pollution of aquatic systems	Marrs et al. 2007
Semi-arid rangelands	Increase in productivity and the diversity of ecosystem services available	O'Farrell et al. 2007
Native hardwood forests	Increased biomass accumulation and carbon sequestration	Thomas et al. 2007

Updated from: Giller, P., and G. O'Donovan, 2002. Biodiversity and Ecosystem Function: Do Species Matter? *Proceedings of the Royal Irish Academy.* 102B 3 129-139.

2.4 The importance of diversity

Clearly, some level of diversity is required to maintain ecosystem processes at all scales. No single organism can carry out all ecosystem functions, so even the simplest systems have more than one kind of organism. At larger scales, no single organism is adapted to the whole range of physical conditions occurring on the planet, and so the same functions need to be carried out by different organisms in different places. However, it is not clear that all existing diversity is strictly necessary in the functional sense. Certainly at global level there is undoubtedly what could be described as redundancy. This is because very similar physical and climatic conditions can be found in widely separated parts of the world, in each one of which is found a separate suite of species. There are no good theoretical reasons why the entire set of living organisms of a particular ecosystem in one part of the world could not replace the organisms of the same ecosystem type in another part of the world, with little if any change in observed ecosystem processes and attributes. In practice, of course, this is not a realistic possibility. Of much greater practical interest is the extent to which altering the diversity in a particular place alters ecosystem processes and attributes and thereby affects the ecosystem services provided. This is the focus of much of the rest of the report.

2.5 Thresholds in biodiversity and ecosystem services

Most of the time, changes in ecosystems and their services are gradual and incremental, and most of these changes are detectable and predictable, at least in principle. However, many examples exist of nonlinear and sometimes abrupt changes in ecosystems, including disease emergence due to changing environmental conditions, algal blooms and fish kills due to nutrient loading, fisheries collapses due to harvesting pressure, and species introductions and extinctions. In these cases, the ecosystem may change gradually until a particular pressure on it reaches a threshold, at which point changes occur relatively rapidly as the system shifts to a new condition. Some of these nonlinear changes can be very large in magnitude and have substantial impacts on the capacity of the ecosystem to provide ecosystem services, and therefore on human well-being. Capabilities for predicting some nonlinear changes are improving, but for most ecosystems and for most potential abrupt changes, while increased risks of change can be calculated, the exact threshold where the change will be encountered cannot easily be predicted. Where information on thresholds is available, it is included with the discussion of particular ecosystem services in section 3.

2.6 The dependence of the poor on ecosystem services

Many ecosystem services are partially substitutable. For instance, limited amounts of clean air and water can be obtained from mechanical filtration, and manufactured materials can be used in place of timber for housing construction. Declines in the supply of a service from a particular location, such as fisheries production, can be overcome through transferring demand to other areas where the service is still provided. However, access to substitutes, and availability of options for the supply of services, depends critically on socioeconomic status. Poor people, with restricted access to resources, and lower integration into the cash economy, are less able to substitute human and physical capital, and have less purchasing power, and are therefore particularly, and most directly, dependent on ecosystem services. Although poverty rates have been falling in all regions except Sub-Saharan Africa, more than 1.1 billion people remain in extreme poverty, and whilst the well-being of all people is dependent on ecosystem services, it is the dependence of the poor on ecosystem services that frames the discussion in this report.

Particularly important services on which poor people are dependent include the provision of food (both the components of biodiversity that are consumed, and the wide range of biodiversity that is crucial for food production); medicines and health (through both the supply of natural medicines, and through the regulation of infectious and emerging diseases); timber, fibres and fuel from forests and other sources; the regulation of fresh water quality and quantity; protection from (and regulation of) natural hazards; and cultural benefits of biodiversity. Supporting services on which these various benefits depend are also crucial, and in particular soil formation, pollination, nutrient cycling, and control of agricultural pests and diseases. Although the urban poor are buffered against changes in some ecosystem services, through access to alternatives such as improved water supplies, they are nonetheless also dependent on the full range of ecosystem services for their well-being. The links between biodiversity and these key ecosystem services are considered in the following section.

3 State of knowledge on the links between biodiversity and ecosystem services

This section presents available information on the links between biodiversity and ecosystem services. Key selected ecosystem services are addressed, in each case presenting the state of knowledge on how biodiversity contributes to the service, the consequences of changes in biodiversity for the sustainable supply of the service, and whether thresholds have been identified in the capacity of biodiversity to supply a particular service. Some sections, such as that on food production, focus largely on species and genetic level information, whereas others, such as on water quality and natural hazards, focus more on ecosystem and landscape scale diversity. Such differences reflect both the relative importance of the various attributes of biodiversity, but also the availability of information relating to the subject area. Key messages relating to each service are summarised in the opening paragraphs for each section.

3.1 Food Provision and Food Security

Although a relatively small number of the world's animal and plant species satisfies the vast majority of the world's basic nutritional needs, a much broader spectrum of agricultural and wild biodiversity remains of fundamental importance in food production systems. For poor people with limited capacity to buy in foods from outside, access to a diverse range of locally produced foodstuffs (including those that supply micronutrients and flavourings) is vital for maintaining a balanced and satisfying diet. Diversity within crops and livestock species (genetic or varietal diversity) is important in adaptations to particular local conditions, especially in marginal lands, for improving pathogen resistance and as insurance against future risks in the face of changing environmental conditions. Diverse farming systems, such as tropical agro-forestry (mixed) systems, maximise use of resources and are less prone to disease and pest infestations. Wild foods, especially those from inland water and inshore fisheries, but also a range of terrestrial resources (bushmeat, fungi, wild plants, invertebrates) are an extremely important resource for many poor people, either as a basic source of nutrition or as important dietary supplements, or as foods that play a particularly important role during crop failure and famine. "Wild" biodiversity also underpins many aspects of domestic food production systems, through maintaining soil structure and fertility, nitrogen fixation, pollination and natural pest control. Although some or all these functions can in theory be replaced by artificial, technologically-derived substitutes, these are often expensive and increase the dependency of poor people on industries and producers beyond their control.

The most direct role of biodiversity in food security is in the use of components of biodiversity as wild and cultivated foods. In addition, the supply of both cultivated and wild foods is variously dependent on a range of associated biodiversity, and in particular on the contribution of such biodiversity to the regulation of pests and diseases, pollination of crops, soil formation and soil fertility. This section includes an assessment of the state of knowledge of these links, and presents evidence of actual or predicted thresholds in the provision of food due to changes in biodiversity.

3.1.1 Diversity and availability of food resources

Of the approximately 270,000 known species of higher plants, 10,000-15,000 edible species are known, of which around 7,000 have been used in agriculture, although only a few hundred are deemed to be important at a national level. Thirty crop species alone provide an estimated 90% of the world population's calorific requirements, with wheat, rice, and maize providing about half the calories consumed globally. Although several hundred species of animals have been used for human food at one time or another, 14 species of livestock currently account for 90% of global livestock production.

Despite the relatively low species diversity in most agricultural systems, genetic diversity can be extremely high. Some crop species include many thousands of distinct varieties, and globally there are approximately 6,500 breeds of domesticated agricultural animals. However, there is a declining trend in the diversity of livestock breeds and crop varieties used by farmers, despite the increases in food productivity. Approximately 10–20% of current livestock breeds are no longer being used widely, and it is likely that breed loss will increase with further economic development. For major cereal crops, the varieties planted by farmers have shifted from locally adapted and developed populations (landraces) to more widely adapted varieties produced through formal breeding systems (modern varieties). Roughly 80% of the wheat area in the developing world is now sown to modern varieties, and over three quarters of all rice planted in Asia is planted to improved varieties.

Traditional, landrace-based farming systems tend to contain higher levels of crop genetic diversity than modernized systems, and although there is little evidence to suggest that the use of traditional landraces leads to higher yields or to improved overall food security, the adoption of modern varieties among the three major cereal crops—wheat, rice, and maize—has been less successful in marginal areas, where landraces are still widely cultivated and are often the main source of crop germplasm. Farmers continue, for example, to grow landrace varieties of rice in upland rain-fed areas of Southeast Asia, as well as in deep-water environments, and in parts of West Africa. Relative to wheat and rice, maize has a much higher proportion of area planted to landraces.

Box 1. The benefits of landraces

Farmers continue to use landraces in some areas rather than modern varieties for a range of different reasons. First, landraces provide a wider range of end uses and have distinct culinary purposes, which may also contribute to maintaining a balanced diet. Second, production factors and risk management provide additional motives for continued use of landraces. Different landraces are often used to match differences in soil water regimes, even within the same field, and varieties with different maturities may be used to spread labour requirements through the season. In addition, where weather patterns are uncertain or diseases are prevalent, planting several varieties spreads risk. Maintaining a diverse set of crop varieties to insure against production or market risks may be the most accessible means of insurance available to low-income households, and finally, in some unfavourable and heterogeneous environments, appropriate modern varieties have simply not been developed or are not available, so locally available varieties provide the only option for food production.

Even low diversity "monoculture" systems in much of the developing world often contain other dimensions of important agricultural biodiversity: intensive rice monocultures, for example, often support small areas of vegetable cultivation (on the dikes between paddies) as well as fish cultivation, and in some rice-growing areas in South and Southeast Asia, fish provide most of the local dietary protein. The true diversity on which poor farmers and consumers depend is therefore likely to be considerably higher than many of the global datasets, or available literature, suggest.

Wild foods

Many types of wild food also remain important for the poor and landless, especially during times of famine and insecurity or conflict, when normal food supply mechanisms are disrupted and local or displaced populations have limited access to other forms of nutrition. Even in normal times, these wild land-based foods, from plants, animals and fungi, are often important in complementing staple foods to provide a balanced diet, and in providing a source of cash income, from trade. Freshwater and marine fisheries are particularly significant sources of wild food for the poor globally, and it is speculated that 1 billion people rely on fish as their main source of protein, although the per capita consumption of fish (including crustaceans and molluscs) has declined slightly over the last two decades.

Fish population collapses have been commonly encountered in both freshwater and marine fisheries. Fish populations are generally able to withstand some level of catch with a relatively small impact on their overall population size. As the catch increases, however, a threshold is reached after which too few adults remain to produce enough offspring to support that level of harvest, and the population may drop abruptly to a much smaller size. The most famous such example is that of the Atlantic cod stocks of the east coast of Newfoundland, which collapsed in 1992, forcing the closure of the fishery after hundreds of years of exploitation. Most importantly, it appears that the collapse of a particular stock maybe accompanied by significant ecosystem shifts, sufficient that the stock in question may not recover or may take many years to recover, even if harvesting is reduced or eliminated entirely.

3.1.2 Biodiversity supporting food production

The wider biodiversity of agricultural systems often plays an essential role in supporting crop production. Soil animals and microbes, together with plant root systems, contribute to maintaining soil structure, and facilitate nutrient cycling – particularly important in marginal agricultural lands which are poor in nutrients. Pests and diseases are kept in check by parasites, predators, and disease control organisms, as well as by genetic resistances in crop plants themselves. Insect pollinators are often essential for fertilization of crop species. It is not only the organisms that directly provide such services that are important, but also the associated food webs, such as alternative forage plants for pollinators (including those in small patches of wild lands within agricultural landscapes) and alternative prey for natural enemies of agricultural pests. Agricultural ecosystems vary in the extent to which this biological support to production is replaced by external (human) inputs. In industrial-type agricultural systems, they have been replaced to quite a significant extent by inorganic fertilizers and chemical pesticides; but in many areas, particularly in the tropics, agricultural biodiversity provides the primary forces governing nutrient availability and pest pressure. The following sections provide further discussion on soil biodiversity, pest control and pollination.

Soil Formation and Plant Productivity

Soil is a complex mixture of inorganic material, dead and decaying organic material, water, and air, interspersed with living organisms, whose composition varies tremendously with location. Soil is essential for the growth of virtually all terrestrial vegetation, and agricultural production around the world. In addition, soil organic matter is the major global storage reservoir for carbon. The most important soil organisms in terms of numbers and biomass are the microbial organisms - bacteria and fungi, which in many soils constitute more than 90% of the total biomass. Soil formation is usually a lengthy process, and climatic conditions are likely to have the most important influences on soil formation regionally. However, biological populations and processes influence soil composition, structure and fertility, and are probably a more important determinant of soil formation at a local level, through the formation and decomposition of soil organic matter (affecting soil fertility and nutrient uptake by plants, soil acidity and soil water-holding capacity), the regulation of soil structure and soil water flow (including infiltration and run-off, thereby affecting erosion), and the retention and availability of soil nutrients, including nitrogen obtained through fixation (affecting soil health and the efficiency of nutrient cycles).

Of the soil microbes, mycorrhizal fungi play a particularly critical role in enhancing the availability of soil nutrients and water to plants, and improving plant growth and survival (increased resistance to disease, drought and extreme temperatures, toxic metals, adverse pH and transplant shock) through a symbiotic relationship between the fungi and plants. It is estimated that 80% of terrestrial plant species have a symbiotic relationship with such fungi. Both plant productivity and plant diversity have been shown to increase with increasing diversity of mycorrhizal fungi and vice versa, particularly in nutrient poor habitats. Other important groups include the nitrogen-fixing bacteria, such as associated with legumes, and cyanobacteria that mineralise atmospheric nitrogen, thus replenishing soil nitrogen lost through leaching and run-off. Interactions between plant root systems and bacteria have a particularly profound effect on soil quality, and crop health and yield, and this symbiotic relationship is the basis of intercropping in many semi-natural pasture and agro-forestry ecosystems.

Soil macrofauna such as termites, arthropods and particularly earthworms are important in enhancing soil structure, chemistry and productivity by mixing the upper soil, which redistributes nutrients, aerates the soil, increases surface water infiltration, promotes organic matter decomposition and enhances plant productivity. Above-ground vegetation also has a profound effect on soil formation and quality, affecting the extent of cover (influencing water runoff and erosion), the type and amount of organic matter accumulation on the soil (influencing soil pH and nutrient supply). This vegetation also provides the food source for most soil microorganisms and hence exerts a strong influence on soil microbial populations.

Although soil communities are by far the most species-rich components of terrestrial ecosystems, and species diversity may be several orders of magnitude higher than above ground diversity, soil communities remain poorly investigated and there has been very little research on thresholds for ecosystem change in soil systems. Tropical soil biota are particularly poorly documented and understood. However, field and small-scale experimental evidence suggests that the link between soil species richness and soil formation or properties is fairly weak, largely due to the high diversity of soil organisms, and associated high degree of functional redundancy in soils, whereby a broad range of organisms transfer materials, energy and nutrients through the soil food web. Soil properties are affected more by the traits of dominant species and by the complexity of biotic interactions that occur between soil food webs, than by species richness per se. Individual aspects of soil formation and function can be affected differentially by biodiversity loss, for instance in some cases with reduced biodiversity resulting in decreased nitrification and increased decomposition. In addition, even if high species richness does not always play a significant role in maintaining soil ecosystem processes under normal environmental conditions, it may confer resilience in the face of further environmental stresses.

Box 2. Biodiversity and productivity

The precise relationship between diversity and productivity is not well understood. Experiments, mostly in temperate grasslands, indicate that reducing diversity within narrow experimental limits has a negative impact on plant productivity. The two main reasons for this are likely to be that a range of plants can between them make more efficient use of available resources (sunlight, carbon dioxide, water, minerals) than one or two plant species, and that different plants are better adapted to the different micro-habitats that exist in even the most apparently homogenous expanse of habitat. This might imply that there is a straightforward connection between diversity and plant productivity, with greater diversity leading to greater productivity. However, wider observation does not seem to support this. In fact, very high levels of productivity seem usually to be associated with, relatively speaking, low levels of diversity. Nutrient enrichment of systems, usually through applications of nitrogen- or phosphate-containing fertiliser, or both, is usually associated with an at least temporary increase in productivity and a decrease in diversity. This seems to take place because the relatively small number of species that are adapted to high-nutrient environments can rapidly outcompete or displace other species. However maintenance of a high-nutrient, high-productivity, low-diversity system requires continuous external input – this is the logic that drives most modern forms of agriculture, where major inputs of nutrients and other factors (tilling, weeding or, usually, herbicides and insecticides) are needed to keep production at high levels. It seems likely, although quantitative data are scarce, that increasing diversity from these very low levels may help to maximise returns over the longer term.

Pest and Disease Control in Agricultural Systems

Natural pest and disease control benefits food security, rural household incomes, and national incomes of many developing countries, and is strongly dependent on components of biodiversity and their interactions. The productivity of agricultural systems with high crop genetic diversity or species richness tends to be more stable over time than that of low-diversity systems, in part due to improved pest and disease control. In many cases, increased crop genetic diversity and species richness at different trophic levels leads to more efficient natural control of pests and diseases in agricultural systems.

Available evidence suggests that conserving the genetic diversity of crops and crop relatives at a global scale, and deploying that diversity locally, will enhance natural pest control services. Although empirical evidence is limited, both theory and observation suggest that higher genetic diversity in planted crops reduces the chance of crop diseases. Fungal diseases are usually less severe in more diverse agricultural systems and the use of mixtures of different crop varieties has been shown to effectively retard the spread or evolution of fungal pathogens of grains. There is some evidence that these approaches may also be useful for the control of plant viruses.

Both the diversity of natural crop pest predators and the landscape diversity influence pest and disease control in agricultural systems. Yields of agricultural products may be reduced by attacks of herbivores above and below ground, fungal and microbial pathogens, and competition with weeds. Many insects, spiders, and other arthropods are natural predators of crop pests, and provide an especially valuable service either in the absence of, or as an alternative to, pesticides. In addition to the diversity of predators themselves, alternative food sources for the predators of crop pests can help stabilise their populations and therefore provide better pest control. There is some evidence of greater abundance of natural predators in spatially and temporally diverse landscapes, where asynchronous planting and patches of uncultivated land provide alternative food supplies for natural pest predators. Crop pest density in diverse agricultural systems is generally lower than in less diverse systems, and crops have considerably lower levels of herbivory and increased levels of productivity when planted adjacent to natural, diverse forests. Sometimes even growing a mixture of two crops is enough for broad pest control. There is also strong evidence that increasing crop species richness commonly decreases the severity of weed infestations, leaving fewer resources on which weeds can subsist.

Although natural pest control services are likely to be detrimentally affected by loss of species richness, in only a few cases has the role of species richness of crop pest predators been tested explicitly. Perhaps the most comprehensive understanding of the importance of predator species richness comes from spiders. There are indications of complementarity of function among spider species—that is, they catch prey using different methods, occupy different microhabitats, or are active at different times or seasons. Because of this, increasing spider species richness leads to higher and less variable predation rates and increased food web stability. Crop pest predators may also complement pesticide use. Because of the high population densities and short life cycles of crop pests, resistance to synthetic biocides typically evolves rapidly, necessitating continuing investments to develop and employ new synthetic biocides. The use of natural predators of crop pests can reduce the frequency with which biocides need to be applied and, hence, the selective pressure and rate at which resistance evolves.

Pollination
Pollination is the transfer of pollen between flowers, without which flowering plants (which make up by far the majority of plants, including all major food and medicinal plants, and hardwood timber trees) cannot reproduce. Although some plants are wind-pollinated (including some staple food crops), approximately 90% of flowering plants overall, and at least one third of agricultural crops (including three quarters of the world's principal crops), and are dependent on insects and other animals for their pollination.

Worldwide, the number of pollinator species is estimated to be about 300,000, including 25-30,000 bee species, which together with flies, wasps, beetles, butterflies and moths account for the vast majority of pollinators, although birds, bats and other mammals also play a role. Although some pollination systems are highly specialised, such as for Brazil nuts and fig trees, which rely on single pollinators, most pollination systems tend to be generalized and successful pollination can occur from a variety of pollinators. In such general systems, plants will rarely completely fail to produce seed or fruit when their most effective pollinator is removed, but rather the removal of key pollinators results in reduced quantity or viability of seeds and fruits.

At a local level there is a strong relationship between effective pollination and pollinator abundance and diversity. Larger individual fruit of a more uniform shape with better seed viability and production generally correlate with a greater number of visits from pollinators. Large fluctuations in insect populations are common, including those of important pollinators. In addition to raised yields, multiple species of pollinators stabilise pollinator services against variation in population sizes typical of single species. However, the relationship between pollinator diversity and successful pollination is likely to depend more on the identity of the dominant pollinator species than on species richness, and is also strongly affected by other factors, such as availability and connectedness of suitable pollinator habitat.

Many important wild pollinators are forest species, and several recent studies in Indonesia, Costa Rica and Brazil have shown that the diversity and abundance of a number of wild pollinators in agricultural landscapes decline significantly with increasing distance from forest habitats, leading to a decline in crop yields and fruit quality. This suggests that the most effective pollination services are likely to be derived from mosaic landscapes, comprised of mixed agricultural and natural vegetation.

3.2 Fresh Water Quality

Fresh water is a resource under increasing pressure with many, often competing uses. Nearly 20% of the world's population lack access to clean water supplies, leading to major problems of health and well-being. A large proportion of available freshwater is derived from land runoff. Often such water is of low quality owing to high sediment, mineral and nutrient loads as a result of land degradation and soil erosion within catchments. Catchments with well-managed natural forests almost always deliver higher quality water, with less sediment and fewer pollutants, than water from other catchments. Shallow water wetlands with emergent vegetation can improve the quality of water passing through them by trapping and retaining sediments and removing nitrogen, phosphorus and other nutrients.

Water quality is strongly affected by ecosystem structure and processes. Ecosystems vary greatly in their exposure to precipitation and hence as source areas for renewable runoff. Runoff from forest ecosystems provides some or all of the water for at least 4 billion people, or two thirds of the global population. Cultivated and urban ecosystems generate much less runoff but, because of their close proximity to human settlements, contribute to the supplies used by 4–5 billion people. Well-managed natural forests almost always provide higher quality water, with less sediment and fewer pollutants, than water from other catchments. Land degradation and soil erosion leads to poor water quality due to high sediment, mineral and nutrient loads that can impact not only drinking supplies but also the function of dams. It is widely perceived that forests control erosion and sediment processes and thus water quality (suspended materials). Riparian forests can form particularly effective barriers that intercept and absorb sediments, and store and transform excess nutrients and pollutants carried in runoff from adjacent lands. Undergrowth and forest litter, and at the local level soil depth, structure and degree of previous saturation are the most important factors influencing this. Forest soils serve in particular as effective filters that remove organic materials, matter and chemicals from water, contributing to its purification before it reaches streams and rivers.

Wetlands with emergent vegetation, such as Papyrus swamps, are probably the most efficient habitat type at trapping and retaining sediment, and can trap up to 80-90% of that from runoff. This function is particularly important in areas where alternative, artificial water filtering systems are unavailable. Wetlands can also perform important water purification functions by removing nitrogen and phosphorous from agricultural runoff. In addition to the removal of excessive nutrients, microbes and plants in wetlands can also remove or transform water-borne toxins.

3.3 Protection from Natural Hazards

Of the various kinds of natural hazards, floods and fires are the best characterised. Floods have an impact on more people than all other natural hazards combined. Regulation of water flow is a product of topography, soil, land-cover and precipitation regimes, all these factors interacting in complex ways. The capacity of soils to regulate water flow can be reduced by both mechanical factors (e.g. compaction) and biological ones (e.g. reduction in overall vegetative cover). However,

there are less clear-cut relationships between flood regimes and the kind of vegetative cover present in catchments. Cloud-forests are known to exert a strong regulatory influence on water flows. Elsewhere, forests and forest soil are capable of reducing water flows during small-scale rainwater events but may have relatively little impact on large-scale ones. Lowland wetlands (e.g. shallow lakes, swamps and marshes) can play a major role in mitigating impacts of flooding. Fires are a natural phenomenon and in some parts of the world the native biota are well adapted to regular fires. However the vast majority of fires are now caused by people. Changes in land management, particularly the replacement of fire-adapted systems with other forms of land-cover, can greatly increase the intensity and extent of fires when they do occur, increasing the hazard that they pose to people. Natural ecosystems can also play a role in mitigating other hazards, for example, natural forests on slopes appear to lessen the frequency of shallow landslides, and mangroves and other coastal vegetation features can lessen the severity of storm surges.

Of the various natural hazards, the impacts of floods (including coastal flooding) and fires are most directly influenced by changes in biodiversity, and the role of biodiversity in regulating the impact of these two hazards is better studied than for other natural hazards.

Floods
The capacity of soils to store water, facilitate its transfer to groundwater, and prevent or reduce flooding is largely dependent on soil texture, structure and depth. For instance, clay soils have a larger capacity to hold water than sandy soils, and it is widely recognized that the level of porosity or degradation of the soils rather than the presence or absence of tree or other vegetation roots is the most important factor in determining the overall discharge of water from forested areas. The regulation of water flow by soils is reduced by both mechanical factors, such as exposure of bare soil, soil compaction by machinery and overgrazing, and biological factors, such as declining activity of soil fauna, and reduced vegetative cover. However, the relationship between the water retentive capacity of soils and their species richness or composition is less clear, as is the relationship between the kind of vegetation cover in a catchment and downstream flood regimes.

The situation is most clear in cloud forest systems, where during prolonged dry periods, streamflow from forested areas is higher than that from adjacent pasture areas, and after heavy rain streamflow is lower in cloud forest streams than in streams flowing from pasture areas. The strong streamflow regulatory functions of cloud forests are also likely to reduce soil erosion and consequently sedimentation in downstream water resources. In other forested areas, recent studies show that forests and forests soils are capable of reducing runoff from small-scale rainfall events, but during a major rainfall event, especially after prolonged periods of preceding rainfall, the threshold of the forest's capacity to regulate the flow of water is often exceeded, forest soils become saturated and water runs off along the soil surface. In such situations, flooding is unlikely to be prevented by forest cover, but peak streamflow is likely to be less than that which would occur in the absence, or through a reduction, of forest cover.

It is clear that both soils and forests play a key role in reducing the flow of water to river systems. However, the varied mechanisms by which trees and other vegetation intercept, use and transpire water increase the complexity of the relationship between forest cover and streamflow regulation. Evidence suggests that conversion of natural to managed forest produces a slight decrease in available freshwater flow and a decrease in temporal reliability (lower long-term groundwater recharge) in most temperate and warm humid forests, although this is largely dependent on the dominant tree species. Various studies have shown that water yields from catchments increase following deforestation, but that there is a fairly rapid return to pre-clearing levels as plant cover regenerates. In tropical woodland, recovery times of less than five years have been recorded. However, conversion of forest to agricultural land or pasture can result in permanent increases in stream-flows as short vegetation reduces capacity to intercept and evaporate rainfall, and to extract water from deeper soil layers during periods of drought.

The role of wetlands in storing water and regulating streamflow is well documented, and is both a function of their vegetative composition and their characteristically gentle slopes. Lakes and marshes attenuate floods by retaining water or storing it in the soil and therefore reducing the need for engineered flood control infrastructure, and the conversion of wetlands is known to be a major cause for increased streamflow after heavy rainfall, particularly in the lower reaches of floodplains.

Fires

Fire regimes are determined by a number of different variables, including climate, land cover (particularly the amount of combustible biomass), and land use. Regions with climates that present distinct dry and wet seasons have potentially more fires, as a result of vegetation growth during the wet season increasing fuel load and consequent flammable conditions during the dry season can lead to more frequent or more intense fires. Land cover and land use are important because they can affect fuel load, flammability, number of ignition events, and the conditions under which fires spread. For example, forests with deep root systems (and therefore access to lower-lying water resources) may take longer to become flammable during dry periods than vegetation with shallow roots, such as savanna species. Changes in land use and land cover, including clearance for agriculture and grazing, housing development, logging and reforestation, land management and habitat fragmentation, can change fuel load, flammability, number of ignition events, and fire-spread conditions, reducing fuel loads if biomass is removed or increasing fuel loads when biomass debris is left.

The altered distribution of biodiversity has affected the capacity of ecosystems to regulate fire regimes. Native species, particularly plants, in areas that are naturally fire-prone are usually fire-adapted so that ecosystems and ecosystem services are generally not disrupted by fire events. Fires in such situations are usually relatively limited in extent, short-lived and not very intense, and are less likely to pose an important hazard. When non-native species become established, either as invasives or because natural systems are replaced, for example by plantations, fire regimes are likely to be altered. Fires may become less frequent but much more intense and extensive, posing severe hazards.

Hurricanes and storm surges

Although there have been very few studies that compare the effects of hurricanes across sites differing in biodiversity, evidence of differences in hurricane resistance between intensively cultivated and less intensive agricultural systems is available, chiefly from farms in Nicaragua after Hurricane Mitch, in 1998. On average, plots on less intensive farms had more topsoil, higher field moisture, more vegetation, less erosion and lower economic losses after the hurricane than control plots on more intensive farms. The differences in favour of such plots tended to increase with increasing levels of storm intensity, increasing slope and years of low intensity practices, though the patterns of resistance suggested complex interactions and thresholds.

In coastal areas, mangroves especially have been shown to provide shoreline stability, reducing erosion, trapping sediments, toxins and nutrients, and acting as wind breaks to buffer against storms. Following the Indian Ocean tsunami of December 2004, initial reports suggested that communities living behind intact mangrove forests suffered less destruction than those in places with no natural protection from the sea. However, it is likely that the magnitude of tsunamis is often such that mangroves are able to offer limited protection in places receiving the maximum force of the waves, and other shoreline characteristics are likely to have played a critical role in mitigating the impact of this particular event in many places. Three factors appear to undermine the ability of mangroves to protect coastal villages from storm surges and associated flooding: complete clearance, insufficient re-growth following a previous clearing, and infusion of non-mangrove vegetation. Indeed where mangroves were present around the Indian Ocean, the key feature of the forests that were most severely damaged during the tsunami appeared to be a prominence of vegetation not typically found in natural mangrove forests. Clearly the deeper the mangrove forest from the coast, the more protection that it is able to offer, and it has been suggested that effective protection against the actions of waves requires at least 100m depth of forest from the shoreline. The extent to which mangroves contribute to protecting coastal areas against tidal waves and storm surges also depends on other factors such as wave height and velocity, and coastline topography and orientation. Functioning coral reefs and populations of coastal trees and shrubs also help minimize wave energy, although there is little evidence to suggest that coral reef degradation contributed to an increased damage on land following the Indian Ocean tsunami in 2004.

Landslides
The frequency of shallow landslides appears to be strongly related to vegetation cover. Tree and other vegetation roots play an important role in slope stability and can give the soil mechanical support at shallow depths. The type of vegetation cover is particularly important. For example, evidence from field studies following Hurricane Mitch in Central America, showed that conventional cross-slope barriers of grass did little to prevent landslide generation, but deep-rooted trees from the original forest were more effective. Conversely, deep-seated landslides, with a minimum depth of three metres, are not noticeably influenced by the presence or absence of well-developed vegetation cover, but most influenced by geological, topographical and climatic factors.

3.4 Regulation of Infectious Diseases

Although many of the generalities are unknown, there is an increasing body of evidence to suggest that human health, particularly exposure risk to infectious diseases, depends on the condition of biodiversity in ecosystems to which people are exposed. The equilibrium among predators and prey, hosts, vectors, and parasites in an ecosystem provides mechanisms for controlling the emergence and spread of infectious diseases, and changes to such biodiversity have altered the incidence of many infectious diseases. There is also strong evidence to suggest that natural systems with intact structure and characteristics generally resist the introduction of invasive human and animal pathogens brought by human migration and settlement.

There is an increasing body of evidence to suggest that human health, particularly risk of exposure to many infectious diseases, depends on the condition of biodiversity in ecosystems to which people are exposed. Over 60% of human pathogens are naturally transmitted from animals to people, many by insect and other vectors, suggesting that greater wildlife species diversity sustains greater pathogen diversity. However, evidence is accumulating that greater species richness at the local scale may in fact decrease the spread of pathogens to people. Although the actual effect of biodiversity on disease risk is expected to depend on the nature of interactions between the wildlife host and vector species, such data are lacking for most such diseases. The following diseases are both significant for poor people globally, and are highly sensitive to ecological change:

- malaria (across most ecological systems);
- schistosomiasis, lymphatic filariasis, and Japanese encephalitis (particularly in cultivated and inland water systems in the tropics);
- dengue fever (particularly in tropical urban centers);
- leishmaniasis and Chagas disease (in forest and dryland systems);
- meningitis (in the Sahel);
- cholera (in coastal, freshwater, and urban systems).

Risks of other infectious diseases might also depend on the condition of biodiversity, although data to fully understand such links are sparse and inconsistent. The equilibrium among predators and prey, hosts, vectors, and parasites in an ecosystem provides mechanisms for controlling the emergence and spread of infectious diseases, and changes to such biodiversity have altered the incidence of many infectious diseases. Rabies transmission to people for example has increased in parts of the Amazon basin following declines in wild vertebrate populations that led to increased vampire bat attacks on people.

Spread of one disease for which there is considerable data, Lyme disease, seems to be decreased by the maintenance of natural ecosystems. Although it is not one of the most important diseases amongst poor people in developing countries, Lyme disease is considered epidemiologically representative of emerging diseases in general, and can be used as a model system to illustrate some of the effects of biodiversity change on infectious disease transmission. Lyme disease is the most common vector-transmitted disease of people in North America, and thousands of cases occur annually in Europe and Asia. Studies indicate that the ticks that transmit the disease primarily acquire the pathogen from the white-footed mouse. A greater number of other small mammal species could reduce the number of ticks feeding on mice either by reducing mouse abundance through competition, or by attracting ticks that would otherwise have fed on mice. Indeed areas inhabited by more species of small mammals have fewer reported cases of Lyme disease per capita. Lyme disease risk is also greater in forest fragments than in larger forest areas that typically harbour a greater number of mammal species, and also appears to be related to other variables correlated with mammal species richness, such as climate, geographic location, and the presence and abundance of specific mammal species.

Human contact with natural ecosystems containing infectious diseases increases the risk of human infections. However, there is strong evidence to suggest that natural systems with intact structure and characteristics generally resist the introduction of invasive human and animal pathogens brought by human migration and settlement. This appears to be the case for a number of disease organisms, such as cholera, kala-azar, and schistosomiasis, which have not become established in the Amazonian forest ecosystem.

Different types of ecosystems may contain a unique set of infectious diseases (such as kala-azar or plague in drylands, dengue fever in urban systems, and cutaneous leishmaniasis in forest systems), but some major diseases are ubiquitous, occurring across many ecosystems (such as malaria and yellow fever). Areas of transition between different systems are frequently sites for the transfer of pathogens and vectors to susceptible human populations such as urban-forest borders (malaria and yellow fever) and agricultural-forest boundaries (hemorrhagic fevers, such as hantavirus).

*3.5 **Regulation of Climate and Air Quality***

The role of biodiversity in climate regulation is most important at the regional and global scale. Ecosystems exert a strong influence on climate and air quality as sources and sinks of chemicals, including carbon, and due to the physical properties of vegetation, affect heat and water exchange. Changes in the relative abundance of different vegetation types, and particularly their structural diversity, can have significant local effects on wind turbulence and water availability at the more local scale.

Certain attributes of vegetation, such the characteristics of the dominant species and the distribution of vegetation in the landscape, influence the capacity of terrestrial ecosystems to regulate climate at the local, regional, and global scales. Changes in the relative abundance of different plant types (such as needle-leaved versus deciduous trees, shrubs versus grasses) may have substantial impacts on sources and sinks of greenhouse gases and on other ecosystem properties, and the structural complexity of plant canopies also influence water and energy exchange through their effects on albedo. Complex canopies trap more reflected radiation, thereby reducing albedo. In dense vegetation, albedo is determined by the properties of the dominant plant types, with albedo decreasing from grasses to deciduous shrubs and trees to conifers. In open-canopied ecosystems, which account for the majority of vegetation, all individuals contribute to albedo, and more biodiverse (and hence more structurally complex) communities have lower albedo.

Large-scale changes in the diversity of vegetation patches in a landscape can have significant effects on regional climate. Patches that have lower albedo and higher surface temperature than neighbouring patches create cells of rising warm air above the patch (convection); this air is replaced by cooler moister air that flows laterally from adjacent patches (advection). Climate models suggest that these landscape effects substantially modify local-to-regional climate.

Carbon sequestration is affected primarily by species traits, particularly traits related to growth (which governs carbon inputs) and woodiness, a key determinant of carbon turnover rate within the plant.

Species diversity can enhance plant productivity through making the most of available resources, and through increasing the probability of including productive species in the community. Woodiness is particularly important in enhancing carbon sequestration because woody plants tend to contain more carbon, live longer, and decompose more slowly than smaller herbaceous plants. However, they also tend to grow more slowly, and so there is a trade-off among traits of plant species that promote short-term carbon accumulation versus long-term carbon storage. Plant traits also influence the probability of disturbances such as fire, wind-throw, and human harvest, which temporarily change forests from accumulating carbon to releasing it.

The major importance of marine biodiversity in climate regulation appears to be via its effect on biogeochemical cycling and carbon sequestration. Marine organisms strongly influence the effectiveness of the biological pump that moves carbon from the surface ocean and sequesters it in deep waters and sediments. Some of the carbon that is absorbed by marine photosynthesis and transferred through food webs to grazers, sinks to the deep ocean as fecal pellets and dead cells. The efficiency of this transfer and therefore the extent of carbon sequestration is sensitive to the species richness and composition of the plankton community.

3.6 Waste Processing and Detoxification

The processing and detoxification of untreated waste is a particularly important service for the urban poor. Although very little is known about how many species are necessary to provide detoxification services or how changes in species composition affect detoxification processes and rates, these services are likely to critically depend on a small number of specialised species. Plants and microbes in inland water systems are particularly important. There are clear, although largely unpredictable, limits to the capacity of ecosystems to undertake detoxification, and these have frequently been exceeded at the local scale with increasing loads of domestic sewage or industrial effluent.

The production of wastes is a normal function of all living organisms. Individuals, groups of organisms, and societies depend on the capacity of ecosystems to detoxify such wastes. Some waste contaminants (including heavy metals and salts) cannot be converted to harmless materials and will remain in the environment permanently, but many other contaminants (such as organic chemicals and pathogens) can be degraded to harmless components, at varying rates.

Although there are thousands of types of materials in wastes, there are two main types of ecosystem processes that act to reduce the concentrations or impacts of wastes in an environment: processes that act to change wastes into less toxic forms (i.e. detoxification) and processes that move and transport wastes (reducing concentrations of waste by diluting them into larger areas or larger volumes of water). The breakdown of organic chemicals, and loss of their toxicity, is mostly conducted by microbes (primarily bacteria and fungi) and depends on the type and number of microbes in the total community that are capable of degrading a particular waste, which in turn depends on prior exposure to the waste. Some groups of organic chemicals (particularly those not consumed as a food source by microbes) are especially slow to break down in the environment. For many of these, e.g. Persistent Organic Pollutants, their resistance to microbial degradation results from the presence of chlorine or bromine, and breakdown can take years and decades.

Some habitats and species groups play a particularly important role in detoxification and waste removal. Wetlands are especially important for aquatic waste removal. Wetland plants slow down, trap and retain suspended sediments and can remove high levels of nutrients, especially phosphorus and nitrogen commonly associated with agricultural runoff, which could otherwise result in eutrophication of ground, surface and coastal waters. For example, vegetation along the edge of Lake Victoria, East Africa, was found to have phosphorus retention of 60–92%. Inland water systems can also export nutrients. Experimental increases of the species richness of submerged aquatic plant communities have resulted in higher algal and total plant biomass, enabling more sediment to be trapped, as well as greater capture of phosphorus. Experimental work in grasslands also suggests that greater plant species richness leads to more efficient uptake of nutrients and greater productivity, thereby reducing runoff loads into neighbouring water courses. The relationship between species richness, species composition and detoxification can be complex, and less common, less competitive species may play a significant ‘facilitation’ role to other species involved with detoxification processes.

The capacity of wetlands to remove pollutants from chemical or industrial discharges is being increasingly used as a passive treatment process. For instance, the floating water hyacinth and various reed species have been used to treat effluents from mining areas that contain high concentrations of heavy metals. In West Bengal, India, water hyacinth is used to remove heavy metals, while other aquatic plants remove grease and oil, enabling viable fisheries from ponds that receive significant pollutants from both industrial and domestic sources.

There are clear limits to the capacity of systems to undertake detoxification, which are largely dependent on contaminant load. For instance, although metals and persistent organic chemicals can build up to high enough concentrations to have detrimental effects on the wetland functions, moderate waste loadings can generally be tolerated by wetlands without loss of services. Moderate loadings of plant nutrients leads to enrichment (analogous to fertilization of crops), while severe loadings will lead to a major loss in wetland productivity, structure, and function through eutrophication. The threshold after which increased loadings significantly damage the capacity of wetlands to detoxify wastes is not easily determined and depends on the specific conditions in each wetland.

3.7 Nutrient Cycling

Nutrient cycles – the flow of nitrogen, phosphorus, sulphur, potassium and a range of other elements – within the biosphere are an essential part of living processes. These cycles are mediated by a range of different organisms, including those that extract nutrients from inorganic sources, such as nitrogen-fixing bacteria, and decomposers, that recycle nutrients from dead organisms or waste products, incorporating them into other living systems or returning them to inorganic form. Many nutrient cycles have been heavily modified by people, usually through large increases in the supply of nutrients (e.g. by industrial fixation of nitrogen and the application of agricultural fertilizers). While this has greatly increased primary productivity in many areas, as nutrients are required for plant growth, it has created widespread and major problems through increasing nutrient load in downstream systems beyond the capacity of these systems to cope effectively. This can lead to a deterioration or complete loss of ecosystem services, such as collapse of inshore or inland water fisheries, which may be of particular value to local communities.

Nutrients, such as nitrogen, phosphorous, sulphur and potassium are essential for organisms to grow and develop, and an adequate and balanced supply of nutrients underpins all other ecosystem services. Ecosystems regulate the flow of nutrients through a number of different processes, which allow these elements to be extracted from water, air and soil, or recycled from dead organisms. This service is supported by a diversity of different species. Human activity, largely agricultural use of fertilizers and other industrial processes, has resulted in a doubling of the rate of creation of available nitrogen on the land surfaces of Earth. While in some areas (notably parts of sub-Saharan Africa) shortage of nitrogen still limits agricultural productivity, in much of the rest of the world its use is inefficient, with excess often applied. This increase in nitrogen on land and in surface waters has resulted in increasing food production in some countries, but at the cost of frequent deterioration in freshwater and coastal ecosystem services, such as water quality, fisheries and amenity values.

Eutrophication (inadvertent nutrient enrichment) has commonly resulted in thresholds of change in surface waters, with widespread algal blooms and anoxic zones – regions where the level of dissolved oxygen is too low to support most or all oxygen-breathing organisms. Phosphorus, the use of which tripled between 1960 and 1990, has similar impacts. Although agricultural fertilizers are the main cause of nutrient loading, human and animal waste are also important causes of nutrient enrichment in inland and coastal waters. Untreated sewage not only causes eutrophication, but is also a major health hazard because of the likely presence of various kinds of pathogens.

Although the diversity of plants and soil invertebrates may influence nutrient cycling and regulate nutrient flow between ecosystems, the generality of this process has not yet been demonstrated, and the underlying mechanisms have not been clearly identified. However, experimental studies have shown with high certainty that a decline in species richness results in more variable soil nitrogen levels, and it is clear that the presence of certain functional groups of species is the most important factor in determining biodiversity effects on nutrient cycling. For example, decomposers play a strong role in moving nutrients from organic matter into the soil and water, and mycorrhizal fungi play a particularly critical role in enhancing the availability of soil and water nutrients to plants.

Whilst nitrogen is transferred through cycles at a global scale, returning to the land via atmospheric pathways from the ocean, phosphorous typically flows from terrestrial to marine systems, only returning to land over geological timeframes through ocean sedimentation. However, at a very local scale some animals play a key role in returning both nitrogen and phosphorous from marine to terrestrial and freshwater systems. Sea birds, and some marine mammals and fish move nutrients from food sources in the sea to the land and into inland waters via excretory processes, and mortality, either in coastal areas, or further inland as a result of migration pathways.

3.8 Medicines

The widespread reliance of the poor on natural medicines is met largely through the use of locally harvested plant extracts. Other species groups are used infrequently. In addition to the direct benefit from medicinal plants, medicinal benefits from manufactured drugs have historically been largely dependent on extracted biodiversity. Such benefits have largely derived from high diversity ecosystems, although active ingredients have also been sourced from low diversity systems, where they have often arisen as a response to harsh environmental conditions.

Traditional medical systems are important globally, and particularly for the world's poor, who have restricted access to formal medical care. Natural medicines are often the only source of medicine accessible by poor people, and can help alleviate the national costs of supplying medical provisions in many developing countries. An estimated 2000 tonnes of herbs are used annually in India, and the ratio of traditional healers to western-trained doctors reaches 150:1 in some African countries. Many countries, such as Thailand, Sri Lanka, Mexico, and China and India, have integrated traditional medicine into their national health care systems. There is also a very large and expanding commercial trade in medicinal plants, involving an estimated 2,500 species. In addition to the direct harvest for traditional medicines, biodiversity also provides both information and raw materials that underpin medicinal and health care systems worldwide in the formal sector. More than half the world's modern drugs are derived from biological resources.

About 85% of traditional medicine involves the use of plant extracts. Although the number of plant species that have been used for medicinal purposes is not known accurately, it is estimated that current use exceeds 50,000 species, including almost 20% of the Chinese flora, around 7,000 species in India, and some 10% of Indonesia's flora. The use of other groups in traditional medicine is infrequent, and poorly documented. Estimates of the number of marine species used for medicinal purposes ranges from a few hundred to a few thousand, the use of which is mainly confined to Asia.

As a result of their relatively high biodiversity and the knowledge of this held by traditional cultures, forests, particularly tropical rainforests, have provided many important medicinal drugs used in the developed world. This is despite the fact that only 5 –15% of higher plant species have been investigated for the presence of bioactive compounds. Some low biodiversity habitats, such as drylands, produce very valuable medicinal and aromatic plants, where the active ingredient(s) is often a chemical response to living under harsh environmental conditions (e.g. chemicals which provide some tolerance to drought, high-salinity soils, extreme temperatures, etc).

The future ability of poor people to benefit from natural medicines is likely to be threatened by the loss of local populations of species. Supplies of wild plants in general are increasingly limited by over-harvesting and loss of forest cover. In Eastern Amazonia, for example, where native plants provide most of the medicines used locally, logging of trees that supply medicinal leaves, fruits, bark, or oils has critically diminished the supply of medicines required by both the rural and the urban poor. However, while forest loss or degradation tends to reduce the availability of medicinal resources, not all species are affected in the same way by harvesting pressures, and a few useful species thrive in the secondary growth that follows timber extraction.

The number of medicinal and related species currently in formal cultivation for commercial production does not exceed a few hundred world-wide, although many more species, especially the aromatic herbs, are cultivated on a small-scale in home gardens. Globally, about 75% of all botanical species in trade continue to be sourced from the wild. Increasing disease resistance to some medicinal compounds is likely to result in alternative sources of plant-derived medicines becoming increasingly important.

3.9 ***Timber, Fibres and Fuel***

The availability of timber, natural fibres and woodfuel on which poor people depend is largely determined by the distribution and abundance of particular forest and woodland species. Some such species require intact forest habitats in order to thrive, whilst others grow outside of wooded areas, and some are widely cultivated. Limited available evidence suggests that the productivity of timber, fibres and fuel from wooded areas is enhanced with increasing species diversity, particularly on marginal land.

For timber and fibre production, the presence of specific species and combinations of species, rather than the diversity of the forest area or agricultural area per se, is the most important factor at any particular locality. The timbers of individual tree species, for example, possess different properties that render them suitable for different purposes. Production of woodfuel from natural areas is less species-dependent, although there are certainly preferred species that generate more heat or better quality charcoal. Most studies of the relationship between timber, woodfuel or fibre production and species diversity have centred on commercial plantations or compared plantations of varying species richness with neighbouring natural forest. In general, forests of two species are more productive than single species stands, but they are not necessarily more productive than the best monoculture. Inhibitory and enhancing effects of particular species and combinations of species are common.

Few studies have compared primary production of forests over a wide range of species richness. Studied forests in the US and in the western Mediterranean show a positive correlation between tree species richness and stand productivity, some of which has been explained due to greater leaf litter production in mixed forests, a key process in nutrient cycling. However, positive effects beyond two-species mixtures largely depend on the species and functional identity of the dominant tree species. The enhanced timber and woodfuel production from more diverse forests has also been attributed to several factors including: lower levels of pest damage and stem rot; higher resistance to invasive species; species differences in height (rather than diameter) growth, form, and shade tolerance; more efficient nutrient use (due to species differences in rooting patterns, mycorrhizal associations and nutrient demands); and 'nurse' species providing structure beneficial to primary crop species, e.g. training, shade, or protection from frost or drought. Overall, although the lack of long-term monitoring of diverse sites limits the ability to assess the relative importance of composition versus number of tree species on timber, woodfuel and fibre productivity, diverse forests tend to outperform monocultures on poor sites, but pure stands of a highly productive species can have higher merchantable yields on high quality sites.

Despite the importance of forest patches for the local supply of timber, fuel and other services to poor people, rates of deforestation during the last four decades has been highest in tropical forests in Africa, Southeast Asia, and South America. In addition to changes in land use, habitat fragmentation has a significant impact on forest structure and species composition, including those important for the supply of timber, fuel and fibre. Forest fragments are ecologically different from intact areas, and are also influenced by “edge effects” – ecological changes associated with the artificial abrupt margins of habitat fragments. New plants growing near forest edges tend to be small disturbance-tolerant pioneer and secondary species rather than old-growth, forest-interior species. Large canopy and emergent trees, which contain a large proportion of forest biomass are particularly vulnerable to fragmentation.

3.10 Cultural Services

Cultural, amenity and spiritual services provided by ecosystems are highly valued by the poor, and play a key role in medium to long-term sustainable development strategies. Indeed cultural diversity itself has been affected by the distribution of biodiversity. Cultural ecosystem services generally depend on the importance of particular cultural relationships with various features of the landscape, such as particular stands of forests, and with specific components of biodiversity, such as particular revered species. The vast majority of formal religions and belief systems have clear links to the natural world, although the impact of the loss of particular attributes of biodiversity on many cultural services is not clear.

There is a tendency to dismiss, or at least attach little importance to, the non-material services provided by biodiversity when addressing the needs of the poor. And yet these aspects – cultural, amenity and spiritual –are evidently highly valued by many of the non-poor. This is manifested in the environments that the latter usually choose to live in when given the opportunity – rich in gardens, parks and other green spaces. Such environments undoubtedly increase the quality of life of the people who inhabit them. Not only is there every reason to assume that they would do the same for poorer people if they had the opportunity to experience them, but recent studies at the local level have in fact demonstrated the importance of cultural services to poor people[3]. Although when poverty reduction is dealing with extreme levels of absolute poverty there are likely to be other short-term priorities, when development is dealing with longer-term goals, the cultural benefits that are derived from biodiversity should be a major factor to be considered.

The varied distribution of biodiversity has contributed directly to cultural diversity itself, and *visa versa* - cultural practices have significantly shaped the patterns of biodiversity distribution at local and regional scales. The various cultural and amenity services provided by ecosystems include: cultural identity (that is, the current cultural linkage between people and their environment); heritage values (‘‘memories’’ in the landscape from past cultural ties); spiritual services (sacred, religious, or other forms of spiritual inspiration derived from ecosystems); inspiration (the use of natural motives or artefacts in arts, folklore, and so on); aesthetic appreciation of natural and cultivated landscapes; and recreation and tourism. The capacity of an ecosystem to supply cultural and amenity services is partly determined by the physical and biotic environment (such as the presence of landscape features with scenic, inspirational, or sacred values), and partly by culture. Thus similar environmental features (particular species, forests, soil, waterfalls, landscapes, and so on) will be perceived, experienced and valued differently by different societies, depending on the cultural background and the way societies have shaped their environment during the course of their development. Cultural and amenity services are of direct importance to human well-being in terms of improved physical and mental health and well-being, and can represent a considerable economic resource, for example in the case of tourism.

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[3] See the Millennium Ecosystem Assessment sub-global assessments, information on which is available from www.MAweb.org

Cultural identity, including different knowledge and value systems, is integral to most people's lives, even if not consciously recognised, and maintenance of cultural heritage is an important service of many semi-natural and cultivated ecosystems and landscapes. At the global level, initiatives have emerged to conserve culturally important landscapes directly - through, for example, UNESCO's Man and Biosphere Reserves and World Heritage Sites, FAO's Globally Important Ingenious Agricultural Heritage Systems, and WWF 'Sacred Gifts to the Earth' initiative.

Most people feel the need to understand their place in the universe, and they search for spiritual connections both to and through their environment, through personal reflection, and through more organized experiences (as part of religious rules, rituals, and traditional taboos, for example). This is reflected by spiritual values placed on certain ecosystems (such as ''holy'' forests), species (sacred plants and animals, for instance), and landscape features (such as mountains and waterfalls). The spiritual connections between people and the earth are often a reflection of traditional views on nature – they are also integral parts of ethnic identity, particularly among indigenous peoples, and the most common element of all religions throughout history has been the inspiration they have drawn from nature, leading to a belief in non-physical beings. The concept of the ''sacred grove'' that traditionally served as an area for religious rituals to appease nature-linked deities as well as a site of worship for ancestral spirits can be viewed as symbolic of the spiritual services derived from ecosystems and illustrates the long importance of components of biodiversity in humankind's cultural evolution. These sites can be very numerous – for instance, there are estimated to be between 100,000 and 150,000 sacred groves in India alone.

Sacred species, habitats and landscapes, often also have other values. Indeed most sacred groves are also sources of food, or fuel, e.g. the tembawang groves of the Dayak people in Kalimantan, Borneo are simultaneously burial sites and fruit gardens. In providing focal points for social and cultural celebrations and religious rituals, sacred natural sites also help establish and maintain social cohesion and solidarity within communities.

Natural and cultivated systems inspire an almost unlimited array of cultural and artistic expressions, from books, paintings and sculptures, to folklore, music and dance, and even architecture. Natural environments are also an important source of aesthetic pleasure for people all over the world, including the poor. A great number of studies in environmental aesthetics have shown that people display, in general, a strong preference for natural over built environments and this has been observed across all times and cultures. Numerous studies have demonstrated that contact with nature may enhance recovery from stress and increase physical and mental health and well-being, as well as conferring social benefits, such as decreased levels of aggression and criminality and increased social integration. In general, people prefer natural settings that are healthy, lush, and green. Verdant vegetation is preferred over arid landscapes.

The culture of many traditional societies is particularly based on extended associations with ecosystems, a reflection of which is a deep empirical knowledge about local natural resources, especially food and medicines, and a wealth of language for describing these items and associations. Indeed, language, knowledge, and the environment have been intimately related throughout human history and approximately two thirds of the world's languages are linked to forest-dwellers, with almost 50% of all languages spoken in tropical/sub-tropical moist broad-leaved forest biomes. The clearance of tropical forest regions has resulted in social breakdown and forced emigration of traditional groups (for example in Indonesia, Brazil and elsewhere), and reduced cultural diversity.

There are very few documented examples of the effects of decline or loss of biodiversity on cultural and amenity service provision. However, customs and beliefs that have long prevented problems of overexploitation of natural resources have softened, traditional knowledge systems have been lost, and numbers of sacred sites and populations of sacred species have declined globally. This has a particular impact in traditional societies, such as shifting agricultural societies in the tropics where there can be major economic as well as social consequences. The gradual change from direct and participative experience of nature (through all senses) to its virtual representation through the media is hard to describe, let alone quantify. The loss of particular ecosystem attributes (e.g. sacred species and forests), combined with social and economic changes, can sometimes weaken the spiritual benefits people obtain from ecosystems. On the other hand, under some circumstances, the loss of some attributes may enhance spiritual appreciation for what remains.

Invasive species are also becoming a major issue in the maintenance of cultural and amenity services in different parts of the world. Studies suggest that invasions by exotic species can have a strong impact on land transformations and land degradation and affect traditional livelihoods as well as cultural and spiritual well-being, particularly the poorer sections of rural society in the developing tropics.

4 Conclusions and Implications for Policy

The overarching focus of the current development agenda is enshrined in the Millennium Declaration, and embodied in the Millennium Development Goals, which establish a framework for progress towards the Millennium Declaration. Much of the work relating to biodiversity within the context of development agencies has been guided by three principles: the overriding priority of poverty elimination; sustainable development, and; the precautionary principle. The last of these has been defined by the UK Department for International Development as follows: 'Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.' Although in practice the precautionary principle has proved difficult to implement, considerable analysis of approaches and practices has been undertaken in recent years resulting in guidelines for its more effective implementation.

- ***Poverty elimination***

In considering the extent to which development agencies should concern themselves with biodiversity in all its various aspects it is important to distinguish between situations where the objective is the immediate and urgent relief of absolute levels of poverty (effectively disbursement of humanitarian aid) and those where the aim is longer-term, planned development to lift people permanently out of poverty and enable them to lead lives with a large degree of freedom and choice. In the former case environmental concerns are, understandably, likely to be accorded lower priority, although the effect of this will often be simply to defer problems associated with environmental management. Certainly where options are available, humanitarian interventions with the least impact on local and landscape-scale biodiversity are likely to lead to a stronger foundation for medium to longer-term development. In the latter case, where the majority of development agencies see the focus of their activities, ***there are compelling reasons why consideration of biodiversity at the landscape scale, and the benefits it provides in the form of ecosystem services should be fully incorporated into mainstream development planning.***

- ***Risk and local diversity***

The poor typically need to adopt short-term planning horizons. They by definition accumulate few reserves and are therefore vulnerable to both foreseeable and unpredictable changes in their situation. Such changes may be lead to shortages of basic goods and necessities, such as food, drinking water, shelter, clothing, medicines, fuel and sanitation. The rural poor in particular usually obtain these services locally, and may be heavily dependent on the diversity and integrity of the environment within the immediate landscape for a continued supply. ***Although the precise conditions vary enormously from place to place, the range of needs of the poor is most likely to be met through a diverse mosaic of more or less intensively managed systems, including agricultural lands, pasture, wood-lots or forests, and aquatic systems.***

However, use of resources from these systems is often not sustainable, or is threatened by external factors and forces leading to environmental degradation, deterioration in quality of life for those concerned, and increased exposure to risk. Traditional responses to this involve attempting to increase economic activity (often at national or regional level) from alternative livelihoods, with the intention that the poor will ultimately have more money at their disposal and will be more able to buy in substitutes from elsewhere for those resources that had previously been supplied locally. Increasing economic activity normally involves intensification of production associated with simplification of production systems, conversion of natural or semi-natural systems to artificial ones, higher inputs and increasing exposure to and dependence on global markets, both as a source of income through selling the commodities produced, and a source of goods to be bought.

It is very doubtful that these changes are always to the benefit of the poor in those places where they take place. One important reason for this is that they reduce the capacity of the local area to meet the needs of the local population, increasing dependency on the vagaries of markets, from regional to global in scale. With increasing globalisation, such markets are extremely vagile, always seeking the lowest-priced supply, so that producers in any given area are very vulnerable to being under-cut and losing market share. Because of this, producers often try to maximise short-term returns, usually leading to accelerated rates of environmental degradation, and eventually leaving local people in the position where they have neither the capacity to produce commodities for sale nor a local resource base to fall back on.

The medium and long-term interests of the poor are likely to be best served by the maintenance of a diverse resource base at the landscape (i.e. accessible) scale, at the very least as a vital risk-mitigation measure. This does not, of course, mean that all forms of intensification and adoption of new technologies should be avoided – far from it. Judicious application of new technologies and techniques, use of improved varieties (not necessarily excluding those developed with gene transfer technologies) in agriculture, and appropriate levels of inputs such as nitrogen and phosphate-based fertiliser, can increase productivity and help towards eliminating poverty. Increasing the efficiency of use of existing agricultural lands can actually reduce environmental degradation by reducing the incentive to convert marginal lands. The key is that such development should not be at the expense of the existing natural resource base and should be planned to ensure delivery of medium and long-term benefits, rather than maximising short-term gains. This suggests that the most successful long-term poverty elimination strategies would, for example, include supporting agroforestry and multicropping rather than monoculture commodity production, use of integrated pest management techniques rather than intensive blanket applications of pesticides, encouragement of sustainable fisheries practices and so forth.

Although various ecosystem services are often presented as discrete benefits, it is of course the multiple benefits that people derive from biodiversity that are important. Human well-being is dependent on benefits not just of individual services such as food, or clean water, or waste processing, but combinations, or "bundles" of services. The relative importance of services within such bundles depends on both attributes of the local environment (including climate, topography, and human population density), and wealth (ability to substitute various ecosystem services with technologies). In considering the dependence of ecosystem services on biodiversity, it is therefore necessary to consider the full range of ecosystem services from which people benefit. Typically for poorer people, this range is wider, both because of the restricted access to substitutes, and because of lack of security in terms of land tenure and access to resources, reliance on more marginal lands, and reduced protection from natural hazards.

- ***Global and local values of biodiversity***

Confusion exists between the different kinds of value that are attached to biodiversity and the different levels at which these are important. At global level, many people consider existence value important. This is a major impetus for conservation and is manifested most clearly in the attempt to prevent species going extinct and to preserve unique or representative habitats and ecosystems in Protected Areas. Poor people living in places where species are at risk of going extinct or where loss of habitats and ecosystems is proceeding most rapidly are generally less able to implement existence values (although it is not true to say that they attach no importance to such values, and in some circumstances they may value existence of particular aspects of biodiversity quite highly). It is widely argued that under these circumstances local people, usually poor, are expected to bear a disproportionate amount of the costs of conservation. This is undoubtedly often true (although a mechanism theoretically exists through the Global Environment Facility for this to be corrected). However, it is also often true that ***there may be strong convergence between the longer-term interests of the local poor and those whose concern is global, conservation benefits***. This is because the presence somewhere of a significant number of threatened species or rapidly disappearing habitats generally signals unsustainable use of a particular resource. A classic example is the small forest areas, high deforestation rates and large numbers of threatened species on many tropical islands. Reduction in deforestation rate and sustainable management of remaining forest areas is almost always in the longer-term interest of the local poor and of conservationists, even if for somewhat different reasons.

- ***International obligations***

A number of important multilateral environmental agreements are directly concerned with or have implications for biodiversity. The most important of these is the Convention on Biological diversity (CBD). Others include UN Framework Convention on Climate Change (UNFCCC), the UN Convention to Combat Desertification (UNCCD), the Ramsar Convention on Wetlands, the Convention on International Trade in Endangered Species (CITES) and the Convention on Migratory Species (CMS). Parties to these various conventions are bound by obligations under these agreements.

Box 3. The Convention on Biological Diversity (CBD): Implications for development policy

In the case of developed countries, obligations under the CBD fall into two main categories: domestic obligations – that is within-country implementation of the substantive Articles of the Convention, to ensure that the Convention's objectives are met at home; and provision of assistance to developing country Parties to enable them to meet the Convention's objectives. Such assistance is expected to take the form of co-operation, provision of new and additional financial resources and transfer of technology, including through the Global Environment Facility, which operates the financial mechanism under the CBD. Development agencies are well placed to assist developing country partners in their implementation of the CBD, through the multilateral GEF mechanism, bilaterally and through regional associations and partnerships.

Almost all the substantive Articles of the CBD are relevant to the work of development agencies and should be taken into account in policy implementation. Some of the most pertinent are:

- Mainstreaming of biodiversity (Article 6)
- Incorporation of biodiversity concerns into other sectors (Article 6)
- Respect, preserve and maintain knowledge, innovations and practices of local and indigenous communities (Article 8(j))
- Cooperate in providing financial and other support for in-situ conservation of biological diversity to developing countries (Article 8 (m))
- Ensuring that use of the components of biodiversity is sustainable (Article 10);
- Carrying out impact assessments for all activities to ensure that they do not have an adverse impact on biological diversity (Article 14)
- Provision to developing countries of the technology needed to implement the Convention under fair and most favourable terms (Article 16)
- Provision of new and additional financial resources to enable developing country Parties to meet their obligations under the CBD both through the GEF and by bilateral and other means (Article 20)

An important challenge for development agencies in this arena is to identify significant gaps in policy implementation by governments and to develop mechanisms for filling these gaps.

Parties to the CBD (of which there are 188) are bound by obligations under that Convention, whose objectives are: the conservation of biological diversity, the sustainable use of the components of biological diversity and the equitable sharing of the benefits arising from the use of genetic resources (see Box 3). Developed country Parties have agreed not merely to meet these objectives at home, but also to provide the additional resources necessary to enable developing countries to meet them. At the very least, therefore, ***it is incumbent on government agencies and departments to ensure that their activities do not conflict with the objectives of the CBD***. Similarly, Parties having ratified the Kyoto Protocol of the UN Framework Convention on Climate Change (UNFCCC), and undertaken to reduce their own greenhouse gas emissions, would be inconsistent to support or promote activities in other countries that would result in an increase in such emissions.

- ***International policy implications***

It is important that national development agencies continue to build on partnerships with other government departments to ensure that the governments present coherent and consistent policies regarding biodiversity and poverty in all policy arenas. This involves not merely developing a harmonised position in the different multilateral environmental agreements but also ensuring that obligations under these are reflected in other arenas, such as OECD and WTO. With regard to the latter, the relationship between the livelihoods of the poor, trade barriers and subsidies and incentives is not straightforward. For example, removal of trade barriers will not necessarily benefit the world's poorest people if it leads to a significant deterioration in the local ecosystem services on which they depend, even if it leads to some increase in national economic activity in the countries in which they live. In contrast, removal of perverse (environmentally and socially damaging) incentives is on the whole likely to benefit poor people. For example, reduction in subsidy to industrialised fisheries will generally be of great benefit to poor fishers, as it will lead both to increasing fish stocks and decreasing competition for those stocks. Pro-poor policies in these areas would benefit from taking more fully into account the ecosystem services on which poor people depend.

Ensuring environmental sustainability is one of the eight Millennium Development Goals. It does, additionally, underpin all the other goals – without it, elimination of poverty will only be at best temporary and at worst illusory. However, the central role that this goal plays in long-term poverty elimination is not well reflected in the current choice of targets or indicators for it, and there is considerable opportunity for the revision of these so that they more fully reflect the fundamental importance of this goal, including closer alignment of the indicators with those adopted in the CBD, in relation to the 2010 biodiversity target.

- ***Influencing policies and institutions at the national level***

Many development agencies are well-placed to help partner governments harmonise their various strategies and action plans, including sectoral plans, poverty reduction strategies, national strategies for sustainable development, national environmental action plans and national biodiversity strategies and action plans. This would help identify inconsistencies and gaps and ensure that they take into account the needs of the poor, reflecting the value of diverse ecosystem services, and would entail encouraging the adoption of participatory, bottom-up planning and of a people-centred ecosystem approach, as agreed under the CBD.

As part of this, ***systems of tenure and access to resources are needed that are equitable and that promote the sustainable use of natural resources through long-term management***. Full environmental impact assessments for all projects, and the adoption of strategic environmental assessments for all plans and strategies would also contribute enormously to ensuring ecosystem services are more fully incorporated into development planning. Such assessments should address both global biodiversity concerns (e.g. impact on threatened or unique species or ecosystems) and the need to maintain provision of diverse environmental services for poor people. The sharing of information made available from environmental assessments and other processes with development practitioners and governments is much needed. ***Information sharing within and between governments, including***

that of government-funded science, would greatly assist in the development of appropriate development and environmental policies.

Box 4. Questions arising for consideration by development agencies in light of these policy implications

- Are effective mechanisms in place to ensure that all development activities are in conformity with national obligations under the CBD and other environmental agreements?
- Are effective mechanisms in place to ensure coordination and sharing of information at the national level within government on policies and practice related to ecosystem services and the poor?
- Do development agencies have effective mechanisms in place for assessing the extent to which programmes and policies of partner governments are in conformity with Millennium Development Goal 7 (ensuring environmental sustainability)? Are effective strategies in place for assisting governments to implement MDG7 fully?
- What are the implications of the important links between biodiversity and ecosystem services for budgetary support and other emerging aid instruments?
- How effectively do current environmental assessment processes (SEAs and EIAs) deal with biodiversity? Are suitable criteria developed and used to determine that programmes and projects at minimum do no harm?
- Are effective mechanisms in place for monitoring the impact of projects and programmes on ecosystem services, and assessing the effects of any impacts on livelihoods?
- How can the risks to the poor of biodiversity loss be appropriately assessed? Do such assessments take into account the full range of ecosystem services on which poor people depend?
- Are specific policies in place for promoting both integrated environmental management at the landscape level, and low-impact agricultural practices, including integrated pest management?
- Are effective mechanisms in place for disseminating best practice in natural resource management?

- ***Influencing policies and planning at the regional level***

Development agencies should encourage management and planning practices that maintain or restore environmental heterogeneity at the landscape level. This is the simplest way to ensure that poor people have access to the range of ecosystem services that they need while at the same time allowing individuals or families to manage their own resources (eg. farm-plots in agricultural systems) in the ways that most suit them. This approach is precautionary in that it does not call for a detailed understanding of the precise role that biodiversity plays in providing different services from the various ecosystems but simply recognises that a diverse array of systems is most likely to supply a diverse array of services. It should not impose excessive costs on individuals, as it does not expect them to maintain on their plots systems from which they cannot derive immediate benefit.

Although integrated landscape planning is the best way to ensure continuing provision of ecosystem services (and is reflected in the ecosystem approach of the CBD), operationally it is difficult to put into practice because governments are generally organised by sector. Experience in integrated coastal zone management, where such practices tend to be most advanced, indicate that multi-stakeholder plans and information sharing can be successfully developed (eg. in the Tanga region of Tanzania, and in Belize), but that it is then difficult to establish a legislative framework for implementation of plans and strategies. A key challenge for development agencies is to find ways of overcoming this obstacle.

- ***Influencing activities at the community, farm or individual level***

The adoption of low-impact management practices should be encouraged in production systems where these can be shown to deliver significant on-site benefits. Two important examples are the use of integrated pest management techniques and commercial production of environmentally-friendly goods. Integrated pest management has been shown to deliver both immediate economic benefits (lower input costs for the same or enhanced yields) and wider environmental and health benefits (eg. reduced water pollution, reduced adverse health impacts from exposure to pesticides). Barriers to adoption of such techniques are often to do with lack of knowledge and/or entrenched customary practices. Markets for value-added environmentally friendly goods are growing, chiefly in developed countries but also amongst wealthier consumers in developing countries. Poor producers, however, often have difficulties in accessing such markets, particularly where they are based on independent certification schemes. Development assistance can be very valuable in helping overcome such barriers, and in developing other innovative ways of benefiting from the global values of biodiversity through, for example, low impact tourism.

Where programmes are planned that encourage exploitation of previously unharvested resources, or increase levels of exploitation (for example through the opening up of outside markets) it is crucial that a thorough assessment is first made of the possible impacts on the resource. In this instance, a precautionary approach calls for an analysis of the possible collateral impacts on other ecosystem services of such exploitation.

Where the livelihoods of poor people already depend on or involve the harvest of wild resources (such as timber and non-timber forest products from natural or semi-natural forests, capture fisheries, or bushmeat), ***at a minimum efforts should be made to try to ensure that the harvest of resources is sustainable at the local level***. This may entail: assistance in the establishment of adequate and appropriate tenure regimes; development of monitoring regimes and setting and enforcement of harvest limits (eg. closed seasons, harvest quotas); and adoption of non-destructive or low-impact harvest techniques. Such approaches may also be viewed as precautionary as they do not require a complex understanding of the impacts of harvest on non-target populations and ecosystems to be justified. Although it is in principle not difficult to plan such approaches, developing effective intervention mechanisms has proven challenging. ***Development agencies could play an extremely useful role in widely disseminating best practice from their work in natural resource management.***

Annex – Glossary and acronyms

Advection: The transport of an atmospheric property (e.g., temperature) by the wind
Albedo: A measure of the degree to which a surface or object reflects solar radiation.
Anoxic zone: An environment devoid of oxygen
Benthic zone: The oceanic zone that encompasses the sea-floor and the organisms living in or on it.
Biocide: A chemical with the capacity to kill living organisms e.g. pesticides, herbicides.
Biodiversity (a contraction of biological diversity)**:** The variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. Biodiversity includes diversity within species, between species, and between ecosystems.
Biogeochemical cycling: A natural process in which elements are continuously cycled in various forms between different compartments of the environment (e.g., air, water, soil, organisms).
Biomass: The mass of tissues in living organisms in a population, ecosystem, or spatial unit.
Biota: All living organisms of an area.
Boreal forest: Forests of pine, spruce, fir, and larch stretching from the east coast of Canada westward to Alaska and continuing from Siberia across the entire extent of Russia to the European Plain.
Co-metabolite: An enzyme produced by microbiological metabolism that aids degradation of a contaminant
Carbon sequestration: The process of increasing the carbon content of a reservoir other than the atmosphere.
CBD: Convention on Biological Diverstiy
Decomposition: The ecological process carried out primarily by microbes that leads to a transformation of dead organic matter into inorganic mater.
Denitrification: The process by which nitrates are converted to ammonia and molecular nitrogen by denitrifying bacteria in the soil.
Ecolabelling: A voluntary method of certification of environmental quality (of a product) and/or environmental performance of a process based on lifecycle considerations and agreed sets of criteria and standards.
Ecosystem: A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit.
Ecosystem process: An intrinsic ecosystem characteristic whereby an ecosystem maintains its integrity. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy.
Ecosystem services: The benefits people obtain from ecosystems. These include *provisioning services* such as food and water; *regulating services* such as flood and disease control; *cultural services* such as spiritual, recreational, and cultural benefits; and *supporting services* such as nutrient cycling that maintain the conditions for life on Earth. The concept "ecosystem goods and services" is synonymous with ecosystem services.
Edge effects: ecological changes associated with the artificial abrupt margins of habitat fragments
Efficacy: a measure of the benefit resulting from an intervention for a given health problem under the ideal conditions of an investigation
EIA: Environmental Impact Assessment
Eutrophication: The increase in additions of nutrients to freshwater or marine systems, which leads to increases in plant growth and often to undesirable changes in ecosystem structure and function
Evapotranspiration: *see Transpiration*
Exotic (alien) species: Species introduced outside its normal distribution
FAO: Food and Agriculture Organisation (of the United Nations)
Food Web: The complex patterns of energy flow in an ecosystem, summarised by the known feeding relationships in a biological community. A food web illustrates how each type of organism in a community is typically consumed by or consumes more than one other type of organism, and that different types of organisms compete for the same food sources.
Fuel load: the amount of combustible material available for burning generally referring to dry herbaceous material or leaf litter (fine fuel).
Functional diversity: The value, range, and relative abundance of traits present in the organisms in an ecological community.
GEF: Global Environment Facility
Germplasm: The genetic material, especially its specific molecular and chemical constitution, that compromises the inherited qualities of an organism.
Herbivore: An animal that only eats live plant matter
Heterogeneity: the quality of being diverse and not comparable in kind *Genetic heterogeneity* refers to diseases, conditions or other characteristics that appear similar but whose genetic basis is different in different

populations or individuals. *Habitat heterogeneity:* the degree of variability and patchiness across a landscape at a given scale.

Heterotrophic: an organism, such as an animal or fungi, that cannot synthesize its own food and is dependent on complex organic substances for nutrition (antonym- autotrophic: an organism (green plant) that can make complex organic nutritive compounds from simple inorganic sources by photosynthesis)

Host a living organism that serves as a blood source for blood-feeding arthropods, or on which a parasite lives

In-situ conservation: The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.

Invasive species: A species whose establishment and spread modifies ecosystems, habitats, or species.

Landrace: Locally bred and adapted varieties of crops

Leaching: The loss of soluble material such as nutrients or toxins from the soil.

MA: Millennium Ecosystem Assessment (www.MAweb.org)

Macrofauna: an animal whose shortest dimension is greater than or equal to 0.5 mm

Mesocosm: A field-scale model utilized to understand the interactive relationship of microbial communities and the roles played by microbial populations within ecosystems. For example, a sediment sample contained in an opened vessel and placed on a riverbed or in a flow-through system in a laboratory (not temperature controlled as it should simulate outdoor temperatures).

Microbe: Microscopic organism, such as a bacteria, virus or protozoa

Microcosm: A laboratory-scale model used to understand the interactive relationships of microbial communities and the roles played by microbial populations within ecosystems.

Microhabitat: The individual faunal habitat or niche within a larger environment where environmental conditions differ from those in a surrounding area, e.g. under logs, in rock crevices.

Mimetics: Compounds that mimic the function of other molecules via their high degree of structural (conformational) similarity, and hence physio-chemical properties.

Mycorrhizae: fungi that grow underground on plant roots and have a mutual beneficial relationship with the plant; in exchange for sugars and simple carbohydrates, the mycorrhizal fungi absorb and pass on minerals and moisture required for the plant's growth

Native Species: Plants, animals, fungi, and micro-organisms that occur naturally in a given area or region.

Nitrification: Nitrification is a biological process involving the conversion of nitrogen-containing organic compounds into nitrates and nitrites. It is part of the nitrogen cycle and considered to be beneficial since it converts organic nitrogen compounds into nitrates that can be absorbed by green plants

Nitrogen fixation: The conversion of atmospheric nitrogen to biologically usable nitrates.

Non-linearity: A relationship or process in which a small change in the value of a driver (i.e., an independent variable) produces an disproportionate change in the outcome (i.e., the dependent variable). Relationships where there is a sudden discontinuity or change in rate are sometimes referred to as abrupt and often form the basis of thresholds. In loose terms, they may lead to unexpected outcomes or "surprises."

Non-timber forest products (NTFPs): all biological materials other than timber which are extracted from forests for human use including edible plant and animal products, fibre, medicinal products

Pelagic zone: One of the two basic subdivisions of the marine system consists of the open sea and ocean and its organisms, excluding the sea bottom (compare: B*enthic zone*)

pH: A measure of the acidity or alkalinity of a solution (**p**ower of **H**ydrogen); pH below 7 indicates an acid. pH above 7 indicates a base.

Phenology: The scientific study of or the relationship of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions.

Photosynthesis: The process by which chlorophyll-containing cells in green plants convert sunlight to chemical energy (for growth and repair) and synthesize organic compounds from inorganic compounds, accompanied by the release of oxygen

Phytoplankton: Microscopically small plants which float or swim weakly in fresh or salt water bodies

Pioneer species: A species that is an early occupant of newly created or disturbed areas. A member of the early stage communities in ecological succession.

Primary producer: Organism that occupies the first trophic level in a food chain. They harness energy from external environmental sources and convert it to stored energy that can be consumed by heterotrophic organisms.

Protozoa: A large group of single-celled animals, such as amoebae, that are bigger and more complex than bacteria and often cause disease.

Rattan: A vine-like palm native to Asia used for furniture, especially for caning and wicker because it is strong and easy to manipulate.

Resilience: The level of disturbance that an ecosystem can recover from without crossing a threshold to a situation with different structure or outputs. Resilience depends on ecological dynamics as well as the organizational and institutional capacity to understand, manage, and respond to these dynamics.
Resistance: The capacity of an ecosystem to withstand the impacts of drivers without displacement from its present state.
Respiration: The process of oxygen uptake and carbon dioxide release while breathing. In plant physiology, respiration refers to the cellular breakdown of sugar and other foods, accompanied by the release of energy
Rhizobia: Bacteria that form a symbiotic relationship with leguminous plants obtain and are responsible for fixing atmospheric nitrogen into a form that can be used by plants and animals..
Riparian: Something related to, living on, or located at the banks of a watercourse, usually a river or stream.
SEA: Strategic Environmental Assessment (or Appraisal)
Secondary species: Plant species that arrive in a recently created or disturbed area, often replacing pioneer species to form a shift in community composition.
Soil fertility: The potential of the soil to supply nutrient elements in the quantity, form, and proportion required to support optimum plant growth.
Species diversity: Biodiversity at the species level, often combining aspects of species richness, their relative abundance, and their dissimilarity.
Species richness: The number of species within a given sample, community, or area.
Symbiosis: Close and usually obligatory relationship between two organisms of different species, not necessarily to their mutual benefit.
Synergy: When the combined effect of several forces operating is greater than the sum of the separate effects of the forces.
Threshold: A point or level at which new properties emerge in an ecological, economic, or other system, invalidating predictions based on mathematical relationships that apply at lower levels. For example, species diversity of a landscape may decline steadily with increasing habitat degradation to a certain point, then fall sharply after a critical threshold of degradation is reached. Human behavior, especially at group levels, sometimes exhibits threshold effects. Thresholds at which irreversible changes occur are especially of concern to decision-makers. (Compare *Non-linearity*.)
Transpiration: The process by which water is drawn through plants and returned to the air as water vapor. Evapotranspiration is combined loss of water to the atmosphere via the processes of evaporation and transpiration.
Trophic level: The average level of an organism within a food web, with plants having a trophic level of 1, herbivores 2, first-order carnivores 3, and so on.
Turbid: Cloudy or opaque water due to the suspension of sediment
UNEP: United Nations Environment Programme
UNESCO: United Nations Educational Scientific and Cultural Organisation
Vector: An arthropod carrier of a disease producing organism.
WCMC: World Conservation Monitoring Centre (of UNEP)
WWF: World Wide Fund for Nature
WTO: World Trade Organisation
Zoonotic disease: A disease of animals that may be secondarily transmitted to man