On Biodiversity and its Valuation

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1 THE BIODIVERSITY ISSUE

Biodiversity[1] has existed and evolved since the emergence of the first life forms on earth over 3,500 million years ago. The natural processes of speciation and extinction caused many new species to appear and others to become extinct. This resulted in the biodiversity which human beings found on their appearance on earth, some 200,000 years ago. The subsequent development of mankind and the spread of human beings over the world's continents was able to take place thanks to the direct exploitation, i.e. the collection and more or less immediate use on a local scale, of the amply available biological resources[2]. Later on, the use of tools and domesticated plants and animals allowed mankind to exploit biological resources more efficiently, and on a larger though still local scale, leading to the development of agriculture and of the first cities some 10,000 years ago. During the 19th and 20th centuries, the industrial revolution and modern agriculture (which can be seen as an industrialized way of exploiting biological resources) led in the so-called 'developed' countries to a situation in which biological resources and the products derived from them are acquired, processed and distributed using a high (fossil) energy input and worldwide economic market mechanisms. This indirect exploitation of biological resources on a global scale is in sharp contrast to the situation in the so-called 'developing' countries where the majority of the population continues to depend largely on the direct use of locally available biological resources.

Thanks to the ever-increasing use of biological resources and improving health care, mankind has grown over the last few centuries to unprecedented numbers. Simultaneously there has been a sharp reduction in biodiversity (Soulé 1991), suggesting an impact of the human population on biodiversity, and, consequently, a possible threat to mankind itself. Indeed, it has become clear that man exerts a devastating influence on biodiversity. Current extinction rates are estimated to be much higher than those occurring before the arrival of man (Wilson 1988), and red lists of species threatened with extinction are becoming longer each year in both the 'developed' and the 'developing' countries.

This has led to an international recognition of the need for the protection of nature and for the sustainable use of biodiversity on a global scale. In

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[1] Without further specification, we use the term 'biodiversity' as a synonym for 'nature'. The concept of biodiversity is further elaborated in section 2.

[2] Biological resources are those biological objects with actual or potential use or value for humanity.

fact, man's attitude towards nature has been changing since the 1940s, when the first international treaties aimed at the protection of biological resources were signed (e.g. on whaling in 1946 and on wetlands in 1971). The publication of 'The Limits to Growth', a report by the Club of Rome on the Predicament of Mankind (Meadows 1972), had a major impact on public and political awareness of the exhaustibility of the earth's natural resources. For the first time it was recognized that the increasing human population poses a threat to the future of many living species, including man himself. Also in 1972, the United Nations Conference on the Human Environment took place in Stockholm: the first UN conference on environmental matters. The global organization of nature protection took further shape with the UN World Charter for Nature (1982), the UN Conference on Environment and Development with the resulting Rio Declaration on Environment and Development and Agenda 21 (1992), the worldwide adoption of the Convention on Biological Diversity (CBD) in 1992-93, and with the publication of many other policy and scientific documents on international nature conservation (see Box 1).

Box 1 Some major publications on biodiversity conservation since1980.

World Conservation Strategy: Living Resource Conservation for Sustainable Development (IUCN, UNEP and WWF 1980)

Our Common Future (WCED 1987) (the so-called "Brundtland report")

Biodiversity (Wilson and Peter (eds.) 1988)

Conserving the World's Biological Diversity (McNeely *et al.* 1990)

Caring for the Earth: A Strategy for Sustainable Living (IUCN, UNEP and WWF 1991) (the follow-up to the 1980 *World Conservation Strategy*)

Global Biodiversity: Status of the Earth's living resources (WCMC 1992)

Global Biodiversity Strategy (WRI, IUCN and UNEP 1992)

Global Biodiversity Assessment (UNEP 1995)

Global Biodiversity: Earth's living resources in the 21st Century (WCMC 2000) (the follow-up to the 1992 document)

In particular, the adoption of the CBD was a milestone, because it was the first global[3] comprehensive agreement to address biodiversity at different

[3] At the time of writing, 182 countries are party to the CBD.

levels of biological organization (genes, species and ecosystems). The CBD considers the conservation of biological diversity to be a common concern of mankind and an integral part of development. The CBD's objectives are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (UNEP 1992). To that end, the contracting parties committed themselves to measures ranging from the development of national strategies, plans or programmes for conservation and sustainable use (Article 6), through specific articles on conservation, sustainable use, incentive measures, research and training, public outreach, impact assessment, access to genetic resources, access to and transfer of technology, exchange of information, and technical and scientific cooperation, to the handling of biotechnology and its benefits (Article 19, UNEP 1992). However, the CBD as a world convention also clearly has its limits: "as an international treaty, (the CBD) identifies a common problem, sets overall goals and policies and general obligations, and organizes technical and financial cooperation. However, the responsibility for achieving its goals rests largely with the countries themselves" (UNEP 1992). Execution of the CBD is largely in the hands of the contracting parties, which means that they are supposed to execute policies in line with – or at least not contrary to - the CBD. This means, in practice, that the politicians and administrators of these countries have to make all decisions regarding biodiversity and natural areas in such a way that CBD's objectives are served. This implies that many choices are to be made with regard to land use, planning and development of natural, agricultural and urban areas, infrastructure, industry, and so on. However, the CBD does not indicate how such choices and decisions are to be made.

So, we have a situation where there is a worldwide commitment to the protection and preservation of biodiversity and, simultaneously, continuing biodiversity loss at an increasing rate. Decision-making power with regard to biodiversity issues is in the hands of national governments, but apparently the right choices are not being made. In this paper, we examine how knowledge about biodiversity may be employed in order to arrive at better decision-making on biodiversity issues, how the pros and cons of decisions liable to affect biodiversity can be assessed, and how tools can be developed to that end.

Further, we note that the meaning of the term 'biodiversity' varies according to the context in which it is used. For example, it is often used as a kind of flagship term with an emotional load (the 'biodiversity problem' sketched above). In other more scientific contexts, the term is used to refer strictly to the variation in and among genes, species and ecosystems. This ambiguity hampers the development of clear lines of thought about biodiversity and needs clarification if biodiversity issues are to be dealt with in a proper way.

In the next section, we examine the current use of the term ‘biodiversity’, point out some ambiguities, and propose a univocal way to use it. We then provide more information on biodiversity: how it developed in evolutionary time, what we know of the causes of its actual decline, and what it means in an ecological and evolutionary sense. Finally, we examine ways in which biodiversity is important to human beings and discuss valuation as a tool for decision-making on biodiversity issues.

2 USE OF THE TERM ‘BIODIVERSITY’

The term ‘biodiversity’, a contraction of the terms ‘biological’ and ‘diversity’, emerged in the 1980s as a general catchword for “the whole variety of life on earth” (Gaston 1996). Indeed, since ‘diversity’ means ‘variety’, ‘biodiversity’ stands for biological (or biotic) variety[4].

In biology, “life on earth” is generally considered to be composed of a great number of biological objects that are hierarchically organized into many different levels. One usually distinguishes the following organizational levels and corresponding biological objects: alleles, genes, chromosomes, genotypes, individuals, populations, species, communities, ecosystems, landscapes, ecoregions, biomes and, finally, the biosphere as a whole. However, some of these concepts and the hierarchy among them are themselves contested. For example, the concept of ‘species’ is rather controversial.

In the vast literature on biodiversity, the term is usually used to denote the variety of biological objects at each and every level of organization. However, it has become fairly standard to consider biodiversity at three major levels, namely:

- *genetic diversity*, i.e. variation in the genetic make-up of organisms, either within or across species, which may occur at the levels of alleles

[4] Several other terms are used more or less synonymously with ‘diversity’ or ‘variety’, such as ‘variation’, ‘variability’ and ‘heterogeneity’. Although these terms are not equivalent, the concept of biodiversity seems to include all aspects of biological variety, variation, variability and heterogeneity.

(or, on a still lower level, nucleotides in DNA molecules) up to genotypes;

- *species diversity*, which is generally taken to be species richness, i.e. the number of species occurring in a particular area (or in a community or ecosystem), or a combination of species richness and equitability, which is the degree of evenness in the species' relative abundances;
- *ecosystem diversity*, i.e. the variety of (types of) ecosystems on the planet (such as tundra, temperate forest or tropical savannah).

In this terminology we recognize several ambiguities:

1. If the term 'biodiversity' is used to indicate "the whole variety of life on earth", then the variety at the three standard levels mentioned above is, indeed, a component, a part or a subset of 'biodiversity' thus defined. So, the term 'biodiversity' is used for both the variety among all organizational levels together and for the variety at each single level, and this makes it ambiguous. If somebody says that 'biodiversity has decreased', it is unclear as to whether this results from the loss of an allele in a population, from the extinction of a species, or from the destruction of an ecosystem. And since these processes also occur on different time-scales, the confusion becomes even greater.
2. In addition to the different organizational levels, 'biodiversity' can be considered on different spatial scales, e.g. that of a given area, a country, a continent or even the whole world. Using the term 'biodiversity' without indicating the spatial scale on which it is being considered, therefore, leads to confusion.
3. Another ambiguity in the use of the term 'biodiversity' is that it is used not only for (some measure of) *variety* within a particular set of biological objects (on any of the levels and scales discussed above), but also for *that set of objects itself*. This means that on a global scale, 'biodiversity' not only denotes "the whole variety of life on earth", but is also considered as a "synonym of life on earth" (WCMC 1992), that is, the total set of living organisms on earth (at some point in time). As such, the term 'biodiversity' can be considered as a synonym for the term 'nature' with the biological objects referred to as "elements of life" (Reid and Miller 1989), "units" and "components" (UNEP 1995), or "elements" (Perlman and Adelson 1997) "of biodiversity".
4. Using the term 'ecosystem diversity' as an expression of 'biodiversity' is strictly speaking not correct, because ecosystems comprise both biotic and abiotic components. 'Ecosystem diversity'

therefore has an even wider meaning than ‘biodiversity’, and, as such, we do not use it in this paper.

Commonly used terms such as ‘biodiversity decline’ or ‘biodiversity loss’ can thus have quite different meanings, especially if they combine several of the ambiguities cited above. They may, for example, refer not only to the disappearance of an individual species from an area, the disappearance of a certain community, or even the disappearance of a whole ecosystem, but also to the consequences, namely the decrease in variety at the corresponding organizational level or spatial scale.

Summarizing, we have a situation where the term ‘biodiversity’ may refer to any set of biological objects, at any level of organization, and on any spatial scale, as well as to any measure of variety within any of those sets. This makes the concept of ‘biodiversity’ difficult to define. Indeed, Perlman and Adelson (1997) state that the term ‘biodiversity’ represents a complex concept that should be explained and not defined. According to these authors, the meaning that one gives to the term biodiversity depends on one’s conception of reality. Different people use different principles or beliefs in assessing the world and, according to one’s (personal or professional) background, one will perceive, interpret and ascribe meaning or value to biodiversity. For example, the ‘biodiversity’ of a particular forest will mean different things to a biologist (who may value its species’ assemblage), to an economist (who may value its useful species or the products it can provide, such as timber), to a politician (who may recognize its value for recreation), or to a citizen (who just wants to air his dog).

Be that as it may, we acknowledge - and accept - the widespread use of the term ‘biodiversity’ as a synonym of ‘nature’. A more specified use of the term requires an indication of *which* biodiversity is referred to: is it the variety of biological objects at some organizational level or spatial scale, or is it some set of biological objects, or are both of them referred to? For any of these meanings, we simply use the term ‘part of biodiversity’.

3 EVOLUTION, EXTINCTION, AND THE IMPACT OF MAN

Evolution and extinction of species

The fossil record represents biological history on earth over more than 3,500 million years. It shows that during the first 3,000 million years evolution took a slow pace and only led to unicellular and some very simple multicellular organisms. For unknown reasons, however, some 590 million years ago an explosive diversification of multicellular animals took place. Most of the major phyla we know today were formed and the numbers of species increased dramatically (Raup 1988). Around 450 million years ago, plants and animals invaded the land and began their pattern of terrestrial diversification (Lawton and May 1995). Since then, the fossil record suggests a gradual increase of biodiversity as attested by increasing animal family diversity and by increasing plant species diversity in the northern hemisphere (WCMC 2000). This increase took place despite the extinctions that occurred simultaneously. A rough estimate of the extinction rate in the fossil record over the last 600 millions years is one species per year (all fossil groups taken together). This natural ‘background’ extinction is considered to account for more than 90% of all extinctions (Raup 1992, Lawton and May 1995). However, like evolution, extinction does not occur in a regular rhythm. During the last 440 million years, at least five periods are notable for their extremely high extinction rates, when up to 95% of all species then living became extinct in a relatively short time, due to causes such as cooling and/or warming, meteor impact and volcanism (WCMC 2000). The last of these mass extinctions took place around 65 million years ago when the dinosaurs disappeared, together with a species loss of over 50% in groups such as land plants and planktonic micro organisms (Raup 1994).

Man’s impact on species evolution and extinction

Over many thousands of years up to today, man has contributed to the evolutionary development of species, and thus to an increase in biodiversity, through domestication and breeding of plants and animals. However, man’s role in species’ extinctions, recorded from prehistorical, historical and recent times, is probably far more important. During and after the colonization by humans of Australia (between 100,000 and 40,000 years ago) and of North and South America (between 35,000 and 11,500 years ago), more than 70% of the genera of megafaune disappeared. There is strong evidence that these extinctions were mainly due to overhunting and destruction of habitat by humans (Leakey and

Lewin 1995, WCMC 2000). In more recent times, as from 2,000 years ago, the disappearance of the megafaune following human colonization has also occurred in Madagascar, New Zealand and the Caribbean islands.

Since 1600, over 1,000 cases of man-induced extinction of plant and animal species have been documented (Diamond and Case 1986, Smith *et al*. 1993, WCMC 2000). Most occurred on oceanic islands, where population numbers are often low and the effects of human intrusion, and of the species that came with man such as dogs, cats, goats and rats, are severe. With respect to the total number of living species (see Box 2), this number of recorded extinctions may seem low, but there is more at stake. Because the extinction of small and inconspicuous species is not easy to document or even notice, the known extinctions are those of mainly large and easily recognizable species such as mammals, birds and higher plants. Given our limited knowledge of the world's species, and knowing that only a minute proportion of them are being actively monitored, the real number of man-induced extinctions is probably much higher.

Box 2 Species richness: the most common measure of biodiversity.

Species richness (or the number of species living in a particular area at a particular time) is often used to measure biodiversity: it is well-applicable to conspicious organisms such as terrestrial vertebrates and birds. However, within other groups of organisms such as bacteria, species are less easily to distinguish. In addition, there are different species concepts applying to different groups of organisms and leading to different classification systems. As a result, there is a considerable uncertainty as to the exact number of species in each taxonomic group. Furthermore, many species of insects, fungi and bacteria have sofar remained undescribed because they are small, difficult to collect, obscure or of no particular interest for humans. All this makes it difficult to establish the approximate number of species presently living on Earth: estimates vary between 7 and 20 million, with a current working estimate of 14 million (WCMC 2000), although some authors take into account the possibility of there being as much as 100 million species.

In all, around 1.75 million species have been described and classified scientifically (WCMC 2000). The taxonomic description and classification of most species concentrates on their anatomical and morphological characters and their way of reproduction. In general, only scant information is available on the ecology of the described species (for example, the environmental conditions required for survival, the role in the ecosystems they are part of, etc.). The ecology of the undescribed species is virtually unknown.

Resuming, an estimated 12.5% of all living species are actually described, including most large and conspicious species. In general, little is known about the ecology of the described species. So, our knowledge on overall biodiversity is very limited.

Additionally, the number of species threatened with extinction is very high. In all, 30,827 species of plants and 3,314 animal species are actually regarded as under threat. These figures include 1,096 mammal species (24% of the total number of 4,630) and 1,107 bird species (11% of the total number of 9,946) (WCMC 2000).

Furthermore, actual extinction rates are estimated to be higher than they would be in the absence of man. Wilson (1988) estimates that both the per-species rate and the absolute loss in numbers of species due to the destruction of rain forests (setting aside extinction due to the disturbance of other habitats) are about 1,000 to 10,000 times greater than they were before human intervention. The current extinction of mammals and birds is estimated at a rate of between 10 and 200 times the background extinction rates of respectively one and two species every 1,000 years (WCMC 2000). It is clear that these (and other) estimates suffer from large uncertainty ranges due to our limited knowledge of current species richness (see Box 2). But even the most conservative estimates of current extinction rates are much higher than the background rate deduced from the geological record, although for the moment they remain far from the high rates observed during the big mass extinctions.

All this may indicate that we are now on the threshold of another massive, worldwide extinction, possibly of the same magnitude as the earlier mass extinctions. In contrast to the latter, which were caused by natural disasters, it is now a single species, *Homo sapiens sapiens*, that will be the cause. Today, roughly two-thirds of the earth's land surface is occupied by urban and agricultural areas which are rapidly expanding and are being used more and more intensively in both developing and developed countries. The remaining one-third (mainly tundras, cold and warm deserts and temperate and conifer forests) finds itself under growing human influence (Van Zoest 1998). This worldwide change in land-use is often considered to be the most important cause of current terrestrial biodiversity decline. Other underlying causes and more direct threats to biodiversity are given in Box 3. Both indirect and direct causes of biodiversity loss are effected through socio-economic and political mechanisms, shown in Box 4.

Box 3 Major underlying causes of biodiversity decline, and direct threats to biodiversity.

Major *underlying causes* of biodiversity decline are related to increasing human influence. They include social, economic, institutional and technological factors such as (after UNEP 1995, Tacconi 2000):

- increasing needs for new grounds for habitation, infrastructure, industry and agriculture;
- increasing demands for biological resources;
- human failure: greed, corruption, ignorance, war;
- causes related to the failure or non-existence of economic markets (see Box 4);
- causes related to insufficient (application of) political and institutional measures to regulate the use of biological resources (see Box 4);
- use of inappropriate technologies and practices.

As major *direct threats* to biodiversity can be mentioned (after McNeely 1988 and WCMC 2000):

- habitat fragmentation, modification or loss due to human expansion: the alteration and replacement of natural habitat, usually from ecosystems rich in biodiversity to (agro-eco)-systems poor in biodiversity;
- introduction of alien species into natural ecosystems;
- over-exploitation of biological resources, by taking off individuals at a higher rate than can be sustained by the natural reproductive capacity of the species involved;
- pollution of air, water, soil and ecological systems;
- climatic change, related to the results of human action such as changing regional vegetation patterns and global carbon dioxide build-up.

Box 4 Socio-economic and political mechanisms, leading to biodiversity decline (after McNeely 1988, Pearce *et al.* 1989, UNEP 1995, Pearce and Barbier 2000, Tacconi 2000).

Economy plays an important role in biodiversity decline. Current economic markets contribute to the over-exploitation and depletion of biological resources in various ways:

- Market prices do not take into account all values of biodiversity. For example, the value of the different services provided by forests (such as watershed protection, the production of clean water and air, or offering recreation possibilities) is not necessarily reflected in the price of the marketed products (such as timber), which are in fact underpriced. This applies especially to ecosystem functions and services and is also referred to as the absence of economic markets for such ecosystem assets. Since the latter cannot compete in the market place with types of use that deliver a direct economic benefit they are simply ignored in decision taking. *Non-existent* or *missing markets* are seen by some as the most common reason for environmental degradation.
- Market prices do not take into account all effects of the use and loss of biodiversity. These effects, the so-called 'externalities', are not (or only partly) reflected in the market prices of biological resources but are (partly) ignored, underestimated or transferred to others, to society as a whole or to future generations. This is referred to as *market failure*.
- Hence, cost-benefit analyses of biodiversity conservation are usually shortcoming and decisions to exploit are taken on the basis of incomplete economic information. Biological resources are often considered a "public good" of which the immediate benefits are gained by some, irrespectively of the (future) costs for many. This is referred to as *policy failure*.

In developing countries, bad governance and poor socio-economic circumstances may contribute to biodiversity decline through:

- Weak enforcement or misuse of property rights to biological resources by the government or private owners, leading to uncontrolled exploitation.
- Widespread individual use of biological resources, and large-scale sale at domestic and international markets, the latter facilitated by private companies, multinationals and developed countries which are thus co-responsible. Forest resources may be sold with large benefits for private owners or government leaders.
- National economies are often based on the unsustainable exploitation of biological resources, especially forests. In such countries, economic growth is founded on biodiversity depletion. This tends to remain obscure since conventional measures of national income such as per capita Gross National Product do not take into account the depletion of biological resources.

4 THE IMPORTANCE OF BIODIVERSITY

Now that we are confronted with sharp biodiversity decline, questions arise regarding the consequences this may have for the well-being of man, for the functioning of ecosystems, and – ultimately - for the biosphere. There is a growing concern that sharply reduced biodiversity may affect the functioning of ecosystems and even of the biosphere, leading to irreversible environmental change on a local, regional and global scale. However, the role of diminishing biodiversity in the regulation and functioning of ecosystems and of the biosphere is not at all clear, except for the obvious observation that, with severely reduced biodiversity, few ecosystems will survive and biosphere function will be impaired. Most probably, there are many ways in which biodiversity influences the functioning of ecosystems. Unravelling these relationships can only start by examining the role of specific aspects of biodiversity in particular aspects of ecosystem functioning. In section 4.1 we address the relationship between species richness and the functioning of ecosystems, and the consequences of reduced genetic diversity for the ecology and evolution of species. And in section 4.2, we evoke the many ways in which biodiversity is important to humans.

4.1 The ecological and evolutionary importance of biodiversity

Is species richness functional in an ecological sense?

There are indications that species richness is little related to ecosystem functioning. For example, a species-poor plantation forest may assure watershed regulation equally as well as a natural, species-rich forest. However, other indications point to a positive relationship: some species-rich ecosystems appear to be more stable than species-poor ecosystems, as expressed by a greater resistance to invasion by alien species or drought (Lovejoy 1994).

Three hypotheses concern the relationship between species richness and ecosystem functioning (after Lawton 1997):
- the *redundant species hypothesis*: ecosystem functioning is mainly regulated by a few dominant species, most co-occurring species are redundant;
- the *rivet hypothesis*: every species is of (almost) equal importance for the functioning of the ecosystem they live in;
- the *idiosyncratic hypothesis*: leaving several interpretations open.

A major obstacle in the verification of these hypotheses is the difficulty in assessing ecosystem functioning, for which there is no overall measure.

Indicators of ecosystem functioning include productivity[5], carbon storage and cycling of energy or mineral nutrients, and stability[6]. Furthermore, the relationship between ecosystem functioning and species richness depends on the type of ecosystem, and there are also problems of scale (Waide *et al.* 1999).

To identify the role of individual species in a food web[7], Paine (1966) performed so-called ‘removal experiments’, in which a species (Starfish *Pisaster ochraceus*) was removed for a long period from its habitat (a strip of seashore). The removal turned out to have large consequences for local species richness which was reduced by 50%. Apparently, the presence of Starfish determines the presence of many other species of the local food web. As such, the species is considered a keystone species[8] with an important function for species richness and the stability of the food web. But if we go one step further, to the relationship between species richness and food web stability, research has not, so far, yielded conclusive results. The same applies to the relationship between species richness and ecosystem functioning, which is still more complicated to establish because ecosystems comprise both the food web(s) and the non-living environment. Though there is no straightforward relationship between species richness and food web stability, we know that the re-establishment of a more species-rich food web or ecosystem after a disturbance is more difficult than that of a species-poor system, simply because there are more interacting species involved (McCann 2000).

With the current limited knowledge of the role of individual species in ecological communities we are unable to answer questions such as: “How many species may be removed from an ecosystem (in the case of, for example, over-exploitation or local extinction) without irreversibly disturbing it?” or “What is the ‘minimum structure’ (Pickett *et al.* 1989) necessary for an ecosystem to remain stable?”. Even the relationship between just a few species is not easy to unravel, and so is the role of species diversity in sustaining the assembly and functioning of

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[5] Ecosystem productivity is the amount of biomass produced per unit of area and per unit of time.

[6] Ecosystem stability is considered to have two components: ‘resistance’ (the ability to resist change) and ‘resilience’ (the ability to recover from disturbance).

[7] A food web consists of a number of interconnected food chains. A food chain is a series of organisms linked by their feeding relationships. Both a food web and a food chain may be considered as a subset of an ecosystem.

[8] A keystone species is a species upon which many other species in an ecosystem depend.

ecosystems in landscapes subject to increasingly intensive land use (Loreau *et al.* 2001).

If the function(s) of a single or a few species within an ecosystem are hard to assess, this is all the more so for the function(s) of a whole set of species. This means that we are still far from assessing the relationship between species richness and ecosystem functioning. Most evidence found so far supports the redundant species hypothesis. Keystone species occur widely and can be found among all kinds of organisms such as plants, herbivores, predators and parasites (Wardle *et al*. 1999), and, indeed, it is rarely found that the maintenance of ecosystem processes depends on a broad array of species.

Is genetic diversity functional in an ecological or evolutionary sense?

As mentioned in section 3, reduction of habitat is a major cause of biodiversity decline. If habitats are reduced in size, the (plant and animal) populations they harbour are also reduced in size and, often, fragmented. Such populations generally show a decline in genetic variety called 'genetic erosion'[9] (Young *et al*. 1996). Questions similar to those regarding declining species richness can then be raised: "What are the consequences of genetic erosion for the ecological functioning of species?" and "How much genetic variety is necessary to guarantee the future evolution of species?" Neither question is easy to answer. The ecological consequences of genetic erosion are hard to recognize. Plants, for example, are able to adapt themselves to a wide array of environmental conditions through phenotypic[10] adaptation, that is, without genotypic change. But phenotypic adaptation may also occur in the case of genetic change or genetic erosion. The evolutionary consequences of genetic erosion are also not easy to assess. Indeed, small populations with reduced genetic variety may have low reproductive success and become extinct. However, such populations may also experience the opposite, that is, increased speciation through adaptive radiation[11].

Furthermore, the relationship between genetic diversity and fitness (and thus, survival rate) of plant populations is complicated. There appears to

[9] The term 'genetic erosion' suggests a risk of lower survival chances as a result of a loss of genetic variation. This, however, is not always the case.
[10] The phenotype is the physical constitution of an organism as determined by the interaction of its genetic constitution (that is, its genotype) and the environment.
[11] Adaptive radiation is the evolution of an array of descendant species from a single ancestral species, often with reduced genetic variety.

be no general relationship, although low genetic diversity may induce increased inbreeding and thus reduced fitness (Booy *et al.* 2000). With regard to animals, the negative effects of inbreeding on population size are well documented for captive animals, but scarcely dealt with in wild populations (Madsen *et al.*1999). The latter have shown that the introduction of new genes from a different population into a severely inbred and isolated population of Adder (*Vipera berus*) in Sweden, halted its precipitous decline towards extinction and expanded the population dramatically, along with an increase in genetic variation. So, in this case, an (artificial) increase in genetic diversity resulted in population growth, although the mechanisms through which this growth is effected remain to be unveiled.

Environmental conditions also play a role in the relationship between genetic diversity and population stability. Experiments with fruit flies show that, under optimal environmental conditions, populations with poor genetic diversity may remain stable whereas, if environmental conditions become sub-optimal, they decline. Therefore, populations with low genetic diversity are more vulnerable to disturbance (Bijlsma *et al*. 1999).

In summary, we are only just beginning to identify the ecological and evolutionary functions of species and genetic diversity, and are still far from a complete understanding of the importance of biodiversity in this respect. Species with little function today may be very important tomorrow, for instance, under other environmental conditions. All we can say for now is that species loss means a loss of ecological potential and that loss of genetic diversity implies a loss of evolutionary potential. The biological and social consequences of this are simply impossible to foresee.

4.2 The importance of biodiversity to man

Traditional use of biodiversity

Throughout man's evolution and history up to today, biological resources have provided him with all sorts of goods and services. Apart from food (meat, fish, fruits, nuts, leaves, roots), clothing (skins, furs, plant fibres), shelter (construction materials), energy (firewood) and medicines, plants and animals have supplied mankind with an enormous range of useful materials and substances such as tools, paper and ink, oils, waxes, pigments and so on. The traditional modes of exploitation of the natural environment are hunting, gathering, fishing, herding and small-scale cultivation. Even today, more than 250 million people in developing

countries depend on such activities to fulfil their basic requirements for food and fuel (Cotton 1996). A severe reduction in biodiversity will probably have serious consequences for them.
Today, biodiversity contributes to human welfare in many of the same ways as described above, in both developing and developed countries. Perhaps the most outstanding ways are still by providing food and by assuring health, although now often in a more sophisticated way, but further, by providing a basic biological, biochemical and biophysical infrastructure on which human life thrives, and finally, by contributing to human religion, culture and mental health. We highlight these issues below.

Biodiversity and agriculture

The development of agriculture started with the domestication of certain plant and animal species some 10,000 years ago. The improving supply of food and animal power allowed for a progressive sedentarization, the emergence of the first cities and the further development of human civilization. Since then, more than 7,000 wild plant species have been used for food (Ehrlich and Wilson 1991), and around 200 have been domesticated. Today, only 30 species provide 95% of the world's nutrition (Cockburn 1991), of which about 50% is provided by just four species (i.e. wheat, maize, rice and potato). In contrast, there are some 30,000 wild plant species with edible parts that might still be brought into cultivation (Nebel and Wright 2000). This is an enormous potential for future food production in both favourable and adverse environments. Furthermore, for food production, there is a risk in depending on just a few species cultivated in extended monocultures. Diseases and pests may have disastrous effects, as for example in Ireland, where in 1845-47 the potato crop was wrecked by a parasite. This resulted in a famine in which nearly a million people starved and another million emigrated to escape the same fate (Nebel and Wright 2000).

In traditional agriculture, it is common practice to cultivate low yielding varieties of staple crops alongside those capable of higher yields, on account of particular functional characteristics such as drought resistance, storage properties, or the ability to exploit a range of micro-environments (Wilkes 1989). In this way, the genetic diversity of traditional crop species - which results from millennia of experimentation and selection by local farmer-breeders - provides food security where environmental conditions are variable and unpredictable. In South America, for example, several thousands of varieties of potato are still being cultivated. Indeed, traditional farmers spread risk by cultivating both several varieties of staple crops and a number of different crop species (Cotton 1996). Van Noordwijk *et al.* (1994) show, on a theoretical basis, that the cultivation of mixed crops, rather than monocultures of high yielding varieties, can be considered a risk-spreading strategy.

Modern agriculture also benefits greatly from the genetic diversity within wild, ancestral varieties of crop species. These still have resistance to pests, diseases and adverse environmental conditions which the cultivars lack. Introducing such traits into the cultivar (through crossbreeding or genetic engineering) may prevent harvest failure and lead to higher productivity. For example, in the 1970s the USA corn crop was saved from blight by genes from a wild strain of maize (Nebel and Wright 2000).

In summary, biodiversity has an important reservoir function for species and varieties of (terrestrial and aquatic) plants and animals with high instrumental value for food security and productivity. This is not limited to agriculture but also includes forestry, animal husbandry, cattle raising, aquaculture, fisheries etc. For this reason, from a utilitarian viewpoint, natural biota are often referred to as a genetic bank where the gene pools of all (potentially) useful species are deposited. In addition, they contain an unknown number of natural enemies of pests.

Biodiversity and medicine

An estimated 10 to 20,000 plant species are being used medicinally (WCMC 2000). Indeed, biodiversity plays an essential role in providing mankind with medicines, a role that is recognized at three levels:

- in developing countries, the majority of the population (and thus the majority of the world’s population) still largely depend on medicinal plants for their health care needs (Farnsworth 1994, Cotton 1996);
- in the industrialized countries, traditional medicines constitute an increasingly important market to compensate for costly modern medicine;
- amongst the top 150 most prescribed drugs in the USA, 56% contain compounds attributable to animals or plants (Grifo *et al.* 1997), representing an economic value of at least $8 billion per year in the USA alone (Artuso 1997).

So, the conservation of present biodiversity and its further exploration for medical application appears of utmost importance for man both in developing and developed countries.

The ecosystem services of biodiversity

Biodiversity delivers many so-called ‘ecosystem services’ (see Ehrlich 1995, Leakey and Lewin 1995), which refer to the value of biodiversity in providing us with many of life’s essentials, such as agreeable places to live, clean air and water, and - through the natural biogeochemical cycles - a fairly stable biotic and abiotic environment. All these features are taken for granted but only exist thanks to properly functioning ecosystems. In section 4.1, we evoked the opaque relationship between species richness and ecosystem functioning.

Religious, cultural and mental importance of biodiversity

Most of the world’s religions recognize the importance of biodiversity and consider the world and all its inhabitants as a creation of God. As such, living organisms may be used for the benefit of man but should always be treated with respect. This belief is also widespread in animist communities for whom biodiversity and specific biological objects often have high spiritual and cultural value. In addition, (non-religious) people may attach aesthetic and moral values to biodiversity and often find that biodiversity makes life more enjoyable and worthwhile. Indeed, recreation activities take often place in natural settings and many psychologists consider nature to be important for mental health, especially in children (McKinney and Schoch 1998).

5 BIODIVERSITY VALUATION: A TOOL FOR DECISION-MAKING?

As pointed out in section 3, we are currently living in a situation where sharp biodiversity decline is occurring on a worldwide scale. Both the underlying causes and the direct causes of this decline find their origin in the increasing human impact on the natural environment (Box 3). At the same time, we are starting to recognize the many ways in which biodiversity is important for the well-being of mankind and for the functioning of the biosphere (section 4). We realize that we may run into huge difficulties if nothing is done about the ‘biodiversity problem’.

What humans do with their natural environment, in addition to social, ecological and economic issues, also raises moral and ethical questions. What rights and obligations are involved here? For example, there is a problem with intergenerational equity: current irreversible destruction of biodiversity by man deprives future generations of the very (part of) biodiversity that is destroyed. We cannot discuss these issues in depth in this paper but below we note some of the major ethical views (after Ehrenfeld (1988), Swanson (1997) and Nebel and Wright (2000)):

- All biological objects have equal, intrinsic value that resides in their being an inherent part of life. Their long-established existence as a result of the evolutionary process and their unique set of biological characteristics carry with them a right to continued existence. Of course this principle is not without problems in the case of pathogens or parasites, where a moral justification can be raised for driving them to extinction.
- Since humans are capable of moral considerations, they have a special responsibility towards the natural world, which includes a concern for other species.
- Biodiversity is a one-time, non-renewable endowment to mankind from the evolutionary process, which man has no right to deplete or destroy. Indeed, both the biological objects and the diversity among them can be considered as non-renewable.

Altogether, this makes a strong argument for the preservation of *all* biodiversity actually existing on the planet. It is however clear that, in the context of today's ongoing human expansion, such a total preservation strategy is not a realistic option. The second best objective would then be to save the *maximum* of today's existing biodiversity. Indeed, "a consensus exists around the imperative of safeguarding as much biodiversity as possible" (OECD 2002, p.18). In that case, there are choices to be made and decisions to be taken on *which* biodiversity to save and where, and which not. Such decision-making requires sound scientific information on the importance of (parts of) biodiversity as described in section 4. It also requires information on the status of existing biodiversity: is a given ecosystem or wild species more or less important, or is it rare or particular on a national or global scale? Traditionally, biologists and ecologists provide this information.

However, this decision-making demands that the interests of biodiversity preservation have to be counter-balanced with other interests. Such trade-offs cannot be avoided - only the objective of 'saving *all* biodiversity' would allow us to ignore or neglect other interests that can only be realized at the cost of some degree of biodiversity decline. Therefore weighed comparisons have to be made between biodiversity preservation, on the one hand, and activities that have a negative impact on biodiversity (but which serve other interests), on the other. Such comparisons can only be made if the importance, or value, of the alternatives can be assessed.

At this point, *valuation* of (parts of) biodiversity comes into play as a tool for decision-making. In a general way, valuation, i.e. the attribution of values, enables us to weigh the importance we assign to something and to compare it with the importance we attach to other things so as to come to a trade-off and to a choice between the alternatives. Several authors insist on the necessity of valuation for proper decision-making with regard to biodiversity. Such decisions result in alternative environmental futures, and, "if they are to have a rational basis, (they) must involve identification and assessment of the values affected or created by each alternative" (Lockwood 1999). As Costanza *et al.* (1997) put it, "the decisions we make as a society about ecosystems imply valuations (although not necessarily expressed in monetary terms)". It is even argued that valuation of biodiversity is unavoidable: "to say that we should not do valuation of ecosystems is to simply deny the reality that we already do, always have and cannot avoid doing so in the future" (Costanza *et al.* 1998).

In our view, rational and well-informed decision-making on biodiversity issues cannot be done without valuation of (parts of) biodiversity. It seems to us that entirely value-free methods that allow weighing the advantages and disadvantages of human actions liable to affect biodiversity are not readily available. Since the outcome of any decision-making process regarding biodiversity is necessarily value-laden, it seems unlikely that the decision-making process itself can remain value-free. Up to now, biodiversity valuation has often been denounced as being morally repugnant, either for ethical reasons such as those cited above or because the value of biodiversity is considered to go beyond any other value and should thus not be compared to, let alone traded-off with, the values attached to other things (see for example, Ehrenfeld 1988). This claim may be right in itself but, according to Randall (1991), it is also without content because it depends on a first-principle or pre-eminent value status for biodiversity, and such status is unlikely to survive scrutiny given the powerful appeal of the value of many other things. Just as the preservation of *all* biodiversity is considered not realistic (and hence the adoption of a second best, pragmatic approach of saving the maximum of biodiversity), so too it seems that the moral claim of placing biodiversity's value above all others cannot hold in practice and again we have to opt for a more pragmatic approach. The latter implies the comparison of the value(s) of (parts of) biodiversity with the value(s) of other, competing, things as a basis for deciding between the alternatives. This means that biologists and ecologists, and conservationists in general, have to provide information on the value(s) of (parts of) biodiversity. Strange as it may seem, this has so far hardly been done at all.

About a decade ago, the field of *ecological economics* was described as “a new transdisciplinary field of study that addresses the relationships between ecosystems and economic systems in the broadest sense” (Costanza *et al.* 1991). Today we see that interdisciplinarity has mainly been developed from the economic side. For example, theory and practice of environmental valuation are important subjects in this domain and, so far, (biodiversity) valuation approaches have mainly been developed by economists. Recent work may illustrate that more input from biologists and ecologists is needed.

For example, Nunes and Van den Bergh (2001) explore the economic valuation of biodiversity at four so-called ‘levels of biodiversity’: genetic, species, ecosystem and functional diversity. They conclude that monetary valuation of changes of biodiversity (at the distinguished levels) can make sense if a number of requirements are met: “that a clear life diversity level is chosen, that a concrete biodiversity change scenario is formulated, that a multidisciplinary approach (...) is used, and (...) that the change is well defined and not too large”. In our view, further development of this issue requires that the ambiguities in the use of the term ‘biodiversity’, as pointed out in section 2, are dealt with. Certainly, biodiversity has many functions (for a description see section 4 of this paper), but this diversity of functions is not the same as the variety among the biological objects that exert these functions, and therefore it cannot be considered as a ‘level of biodiversity’. Furthermore, a vocabulary should be developed that includes the ecological and biological terminology that is in current use and in which species qualifications are given in terms of, for example, rarity, endemism, distinguishing between native and alien species, and where ecosystem qualifications are expressed in terms of ‘naturalness’ and of resistance and resilience (see section 4).

Another example is the “Handbook of Biodiversity Valuation” published by OECD (2002), in which the principles and practices of biodiversity valuation are presented, though again, largely from an economic viewpoint. For instance, the handbook recognizes (p.24) that “Any discussion of the value of biodiversity requires an understanding of what exactly the object of value is”, and, to improve this understanding, a distinction is proposed between biological diversity and the biological resources that harbour diversity. In addition, as pointed out in section 2 of this paper, it is necessary to indicate ‘which’ biodiversity is under consideration.

Apart from input from biologists and ecologists, biodiversity valuation is in great need of philosophical work. Up to now, there has been no firm epistemological basis for valuation theory. It has long been debated whether value resides within the object of interest itself, independent of external observers (‘objective’ or ‘intrinsic value’), or whether value is conferred upon the object by the valuer (‘subjective value’) (see OECD 2002, p.47). Further, the term ‘intrinsic value’ is used in at least three different basic senses: as a synonym for ‘objective value’, as a synonym for ‘non-instrumental value’[12], and to refer to the value an object has solely by virtue of its ‘intrinsic properties’ (O'Neill 1992). Apart from these uncertainties, there are questions regarding the ethical and esthetical values of biodiversity, and the notion of ‘subjective value’ in general. Many such values of biodiversity may be recognized, based on the merits and functions described in section 4, and it seems likely that new values are still to be discovered, along with the development of (new) moral systems and scientific disciplines. Indeed, since any value that is assigned to something, originates from human perceptions and ideas (see section 2), those values may vary as widely as human knowledge and beliefs do, so that in fact an infinite number of values may be identified for whatever is valued.

Furthermore, in addition to value identification (or qualification), valuation in general also implies the assessment (or quantification) of values, which in turn supposes the expression of value in some currency (see Lockwood 1999). Again, at this point, we encounter pitfalls. If one is to balance the value of biodiversity against the value of other things, all values have to be expressed in the same currency (for example, money). However, it is not at all clear how this might be done. For example, religious, cultural and ethical values are often considered to be ‘priceless’, and intrinsic value is simply unmeasurable.

Another approach would be the development of different valuation systems, each emerging from the main disciplines or moral systems involved, and each with its own currency. When it comes to weighing the alternatives, the different systems would then be confronted with one another, which seems no less difficult than the conception of a common currency. So, although both approaches may account for the complexity of biodiversity, we are still far from conceiving a valuation system that covers all its dimensions.

[12] An object has instrumental value insofar as it is a means to some other end.

Apart from these problems, there are questions related to the spatial scale on which (parts of) biodiversity occur and the decision-making power with regard to biodiversity issues, which is currently at the national level. For instance, highly endangered 'red list species' have been identified but the range of these species is not necessarily confined to a single country. In such cases, it is not at all clear which country should do what to protect the same species. And, at the global level, several 'hotspots of biodiversity' have been identified as having great value from a biological point of view. Such hotspots may also be of great economic interest at the national level. How are such cases, where national interests confront global interests, to be dealt with? It seems necessary to define the spatial scale - and perhaps the temporal scale as well - on which biodiversity valuation is performed. Indeed, any "valuation study is partial and characterized by strict temporal and spatial boundaries" (Nunes *et al.* 2000).

Realization of the objectives of the CBD depends a great deal on proper decision-making, based on adequate knowledge in the main fields concerned: biology, socio-economy and philosophy. Many difficulties relate to the conceptual ambiguities surrounding the term 'biodiversity' and to the current state of the art in our knowledge of biodiversity. For the further development of biodiversity valuation as a tool for decision-making, contributions from biologists, ecologists and philosophers seem necessary, in addition to the efforts already made by economists. We recognize that even such an integrated approach would have shortcomings because not all values can be identified, and those that are cannot all be expressed in a currency. This means that, with the current state of knowledge, univocal valuation of biodiversity seems difficult to achieve. The best we can do in the meantime is to be as careful as possible, as advocated by the precautionary principle (see Myers 1993) and the safe minimum standard approach (Bishop 1993).

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Acronyms

CBD	Convention on Biological Diversity
IUCN	International Union for Conservation of Nature and Natural Resources (currently: World Conservation Union)
UNEP	United Nations Environment Programme
USA	United States of America
WCED	World Commission on Environment and Development
WCMC	World Conservation Monitoring Centre
WRI	World Resources Institute
WWF	World Wide Fund for Nature

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