Selecting indicators for the management of biodiversity

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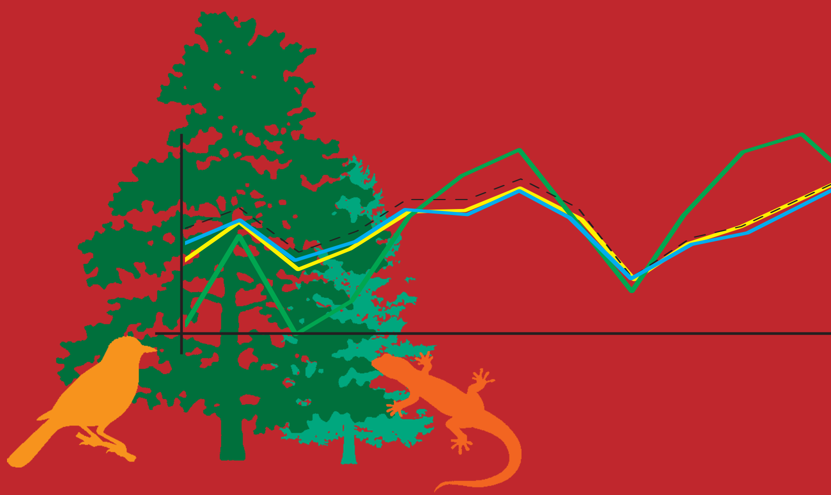

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Indicator indicator

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Preface

Denis Couvet
Professor, Director of the CERSP laboratory of the Museum National d'Histoire Naturelle

Jacques Weber
Director, Institut Français de la Biodiversité

Although climate change is admittedly a complex phenomenon, it can be explained in terms of a few variables: greenhouse gases, the average temperature of the earth, the average level of the oceans. Globally a single regulatory factor has been identified - the tonne of carbon emitted in the form of CO2.

It is harder to define the variables in the realm of biodiversity. Are they legacy variables, such as the number of species, total genetic variability, diversity of ecosystems - each one of these variables itself being hard to define? And if so, should each species, whether invasive, keystone, charismatic, or "ordinary", be taken account of in the same way?

Or should we rather be focusing on functional variables, such as the characteristics of trophic networks or the efficacy or resilience of ecosystem services?

And what does "average" temperature, or "average" ocean level, mean? Paul Krugman has pointed out that if Bill Gates were to enter a room with thirty homeless people, they would immediately all become billionaires "on average".

These are the key questions about the components of indicators - the data, averages, combinations of dimensions which allow us to grasp, monitor and compare across space and time phenomena such as climate change and biodiversity which are in themselves too complex to allow for direct measurement. Scientists need direct measurements whenever possible, as well as reliable indicators. Research administrations have to submit their reports to parliaments or to the European Commission, and to do so they need indicators. These administrations are also permanently threatened with criticism of their activities by the rest of society, especially NGOs. They thus need to have instruments available to them which are accepted by all the parties concerned, otherwise known as "mediation" indicators.

If climate change or changes in biodiversity are difficult to measure, what to say about interactions between human practices and natural processes of change? These interactions can be approached only via indicators, often very indirect ones. While the determinants of the carbon cycle, and thus the role played by humans, are quite well identified and quantified, the same is not true for the major factors determining the dynamics of biological diversity. The analysis of the relations between human beings and nature is far from solidly grounded scientifically, and is more often affected by value judgements, for example with regard to the relations between human beings and the diversity of ecosystems. A system of quantification in the form of indicators should contribute to improving the quality of this scientific analysis.

Economist Harold Levrel possesses a doctorate from the Ecole des Hautes Etudes en Sciences Sociales. He has carried out a sound analysis of the difficulties and the questions relating to the definition of indicators of biological diversity, and the interactions between humans and nature, in the light of the problems addressed by the disciplines concerned, in both the natural and social sciences.

We have asked him to excerpt this work from his thesis in order to respond to the desperate need for information about and methodological clarification of indicators. This thesis was written in the Museum's CERSP laboratory, which uses the "common bird indicator" as an indicator of changes in human practices and land use and of developments in the rural habitat; it seeks to elucidate the various types of mechanisms, not only human in origin, which affect the dynamics of this indicator. The author, as well as being an excellent economist, has a way with words. His style is clear and readable, and we are convinced that this work will soon find a place on the bookshelves of all the managers of the natural world, whether they work in research, administration, the management of natural areas, organisations or businesses.

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Introduction

In 2010, nations around the world will have to assess the state of their progress in preserving biodiversity, within the framework of the Convention on Biological Diversity adopted in Rio in 1992. To do so, they will need to make use of monitoring mechanisms. The indicators of biodiversity, as multi-purpose instruments appropriate for addressing hybrid questions (that is, those which concern both the scientific and the political arenas), have rapidly emerged as the best means for monitoring this progress.

According to Alain Desrosières (2003, p. 61), the advantage of the indicators compared to other assessment tools is that they are uniquely able to "distinguish the signifier from the signified". They function in a sense as "convenient fictions" and make it possible to perform indirect assessments where direct measurement is too costly. Faced with the multiform, complex and controversial concept of biodiversity, we are very lucky that approximate indicators are available which can nourish public debate on this topic. These indicators provide an opportunity to build bridges between the world of the expert and that of the lay person, the worlds of science and politics, by facilitating the emergence of a common language for discussing the subject of biodiversity.*

This book has two goals. We seek first of all to report briefly on the status of the existing indicators and to see in what way they enable us to better describe, understand and manage the dynamics which underlie biodiversity. Our second goal is to address new methods for the construction of indicators of biodiversity and new criteria for evaluation of the indicators thus produced.

>>> *In Section One we present the existing biodiversity indicators, addressing especially the institutional conditions from which they have emerged and the technical questions that they raise.*

>>> *In Section Two we address the indicators which seek to describe interactions between the dynamics of biodiversity and socio-economic dynamics.*

>>> *The third and last section explores new ways to develop indicators which can help stimulate the emergence of the adaptive co-management of biodiversity, by focusing on the needs and perceptions of the potential users of these instruments.*

* Direct measurement of sustainable development and biodiversity is impossible, but indicators of sustainable development and biodiversity are acknowledged to exist. The indicators thus allow for areas of uncertainty which measurement does not..

Section 1:
Indicators of biodiversity

The rate of extinction of biodiversity

It is essential to begin by defining what we mean by "biodiversity". The concept of biodiversity, introduced by Walter Rozen in 1985, has been much discussed ever since 1992, the year of the Rio Conference and the ratification of the Convention on Biological Diversity[3]. Biodiversity is traditionally understood in its literal sense - the diversity of the living world. It is considered to cover everything from the molecular level to that of the biosphere, although ecologists are interested more particularly in populations, communities and ecosystems (Krebs, 2001, p. 10).

Biodiversity is in fact one of the major subject areas within ecology. This discipline measures the diversity of the living world within the three functional areas we have just mentioned, in terms of genetic variability, species diversity and the complexity of trophic networks. However, as Robert Barbault and Bernard Chevassus-au-Louis stress (2004), the concept of biodiversity extends beyond the simple description of the diversity of the living world, no matter how exhaustive that description might be. In effect, biodiversity refers to the interactions[4] within each functional area, both internally among the functional levels and also with human societies.

The principal threat to biodiversity studied by biologists is the extinction of species. Every species has a limited life-span, on the order of five to ten million years. Using life expectancy and the number of species, a *global rate of extinction* can be calculated (Teyssèdre, 2004). This corresponds to the proportion of species which disappear during a given period of time. It is primarily dependent, in a "natural" situation, on the number of individuals in a species. Thus, the fewer individuals there are in a species, the greater the danger that it will disappear, due to its reduced capacity to adapt to environmental change. During the last 65 million years, the average rate of extinction was in the range of one extinction per year per million species. Today, this rate may be between "50 and 560 times greater than the rate of extinction required for stable biodiversity" (Teyssèdre, 2004, p. 27), but many people claim that this rate may in fact be 100 times greater and that it continues to increase. All this points toward the hypothesis of a sixth extinction crisis (Figure 1). The Earth has in fact undergone several major extinction crises[5], the most recent of which is related to the appearance of *Homo sapiens sapiens* and its remarkable expansion.

The human origins of this sixth extinction crisis are to be found in:

- The destruction or degradation of ecosystems (deforestation, soil and water pollution, habitat fragmentation, etc.).
- Non-sustainable exploitation of biodiversity (hunting, poaching, fishing, gathering, etc.).
- Invasions by non-native species (such as certain algae or invasive cultivated species, etc.[6]...).
- Global warming, which upsets biogeochemical cycles.

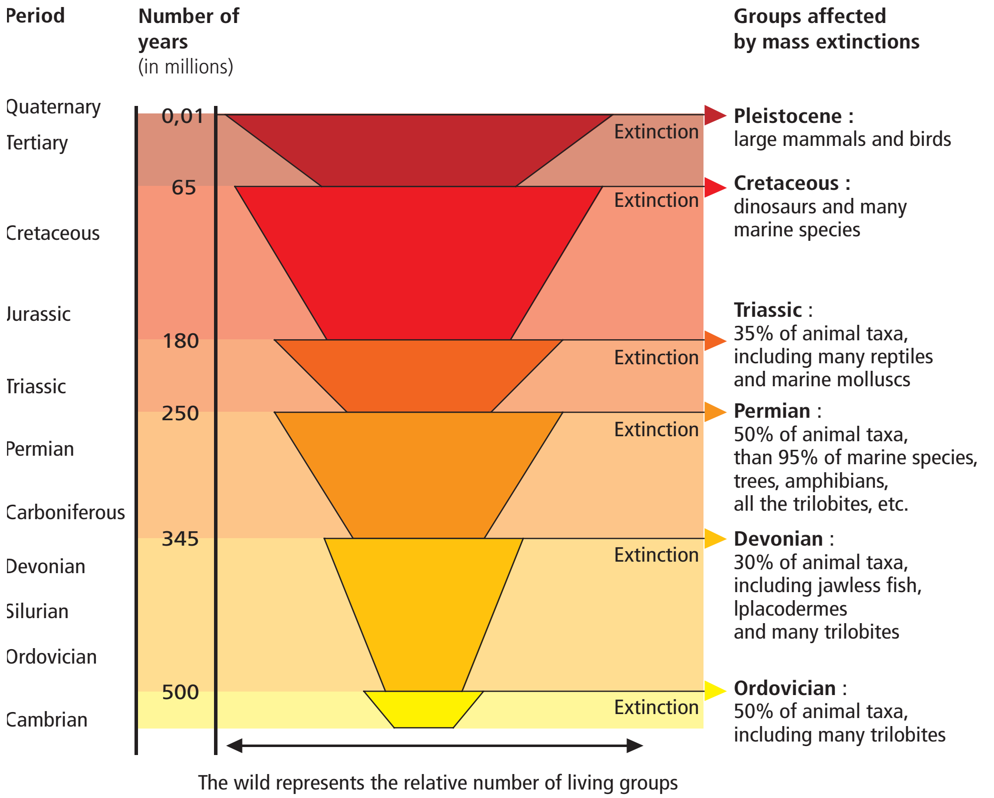
3 See http://www.biodiv.org/doc/legal/cbd-un-fr.pdf.

4 The concept of interaction in biology designates the process by which two or more elements are mutually determined via a reciprocal relation. The interactions generate simultaneous changes, which can be direct or indirect, and we speak accordingly of direct or indirect interactions. An example of direct interaction is the relation of prey and predator which two populations, A and B, will exhibit. An example of indirect interaction is the relation of competition between population A and population B relative to a resource C on which they both depend.

5 In the previous crises, the mechanism of evolution enabled these massive extinctions to be counterbalanced, so that after several tens of millions of years the total number of taxa on Earth increased. Thus the loss of diversity resulting from mass extinction leads to a loss of evolutionary potential but "only" for 10 to 15 million years, the time it took for reorganisation to take place.

6 It may be emphasised that while the impact of invasive species on biodiversity is significant, migration – here called invasion – is one of the components that drives evolution (Teyssèdre, 2004). Species always have a local origin, and how they spread will depend on their adaptive capabilities, the species with which they begin to interact, the ecological niches available to them, etc.

Figure 1: The major extinction crises



Source: Barbault, 2000, p.43

These various forces interact with one another (Teyssèdre, 2004). Thus, the overexploitation of species located at the end of the food chain can open the way for invasive species to establish themselves. These invasive species generally will have an impact on habitat quality and will indirectly cause an increased loss of biodiversity. Habitat disappearance also favours the exploitation of wild animals, which become concentrated in smaller areas, and thus makes ecosystems more vulnerable to invasive species.

Two of the factors which threaten biodiversity will see a substantial increase during the next fifty years, according to the Millennium Ecosystem Assessment (MEA, 2005): agricultural activities and climate change. These two phenomena are in fact already the principal sources of biodiversity loss.

To assess current rates of extinction, models must be used in which the forces affecting biodiversity are represented. These models tend to show that species richness will decline sharply in future years. The MEA (2005) speaks of the disappearance of 12% of the birds, 25% of the mammals and 32% of the amphibians between the present and the year 2100. The report adds that 20% of coral reefs and 35% of mangrove swamps have recently disappeared. According to other studies, two-thirds of all species living on earth are likely to die out within a hundred years, due simply to habitat destruction (Raven, 2002). If we add in the recent work on the possible extinction of 15% to 37% of the planet's species between now and 2050 due to global warming (Thomas et al., 2004), we can conclude that, even if all this research is still subject to debate, we are indeed living in a period of massive extinction.

It was on the basis of this awareness that the international community began to be mobilised, starting in the early 1990s, in order to better describe, understand and manage the problem of mass extinction.

A short institutional history of the indicators of biodiversity

Programmes for establishing indicators of biodiversity have been developed by many organisations since the 1992 Rio Conference, which gave prominence to this concept. These programmes can be divided into two categories. The first includes those whose primary concern is biodiversity and which seek to develop the best indicators to monitor the progress of its preservation. The second includes programmes for monitoring biodiversity which form part of larger initiatives, especially those relating to sustainable development. Our interest here is in the first of these categories.

Two goals co-exist with respect to policies for the preservation of biodiversity. On the one hand, the European Union (EU) wants to end biodiversity loss in Europe by 2010. This goal has also been adopted by France. On the other hand, the CBD wants simply to slow it dow7 (http://www.biodiv.org). We shall review the key stages which led to the adoption of these goals.

The first important date is of course that of the Rio Conference, during which the Convention on Biological Diversity was adopted (CBD, 1992). It was not until the 2002 Johannesburg Conference that a goal and a timetable were set: to reduce the rate of biodiversity loss significantly by 2010. To make sure that this commitment was followed through, the efforts implemented by each country needed to be tracked and measured. For this purpose the first CBD indicators were established in February 2004, at the seventh Conference of the Parties to the Convention which took place in Kuala Lumpur (http://www.biodiv.org; see Table 1).

Indicators adopted by the CBD in 2004 in order to evaluate progress towards the goal of biological diversity set for 2010.

Priority Areas	Indicators to be adopted immediately	Indicators possibly to be tested
Overall status: key components of biological diversity	Land use	State of preservation of endangered species (Red List Index)
	Abundance and diversity of groups of species	Genetic diversity of domesticated animals, cultivated plants, farmed fish
	Coverage of protected areas	
Sustainable use		Areas of forest, farm and aquaculture ecosystems under sustainable management
Reduction of human use pressure	Nitrogen deposition	Number and cost of biological invasions by alien species
Integrity of the ecosystem and of the goods and services it provides	Marine trophic index	Connectivity/fragmentation of ecosystems
	Water quality of aquatic ecosystems	
Status of traditional knowledge, innovations and practices	Linguistic diversity, number of speakers of indigenous languages	
National investment in the preservation of biodiversity	Financial support for the CBD	

Source: http://www.biodiv.org/2010-target/indicators.aspx

7 This difference is explained by the fact that the primary threats to biodiversity today are located in the South and that it is impractical to seek to stop the decline in biodiversity in these countries on such a short timetable.

At the same time, the European Commission launched a discussion of the indicators of biodiversity (2002-2004). It led to the Malahide Conference (Ireland) in May 2004, the first conference on biodiversity at which all the members of the EU were represented with the attendance of senior officials in departments of the environment and agriculture. One of the meeting's principal recommendations was "*To develop, test and evaluate indicators and harmonise habitat and landscape classifications, to deliver policy-relevant information on the status and trends in biodiversity, the drivers of biodiversity change and the success of policies designed to halt the loss of biodiversity by 2010, and to progress towards the targets of the EC Biodiversity Strategy*" (European Commission, 2004, p. 42). Politically, the outcome of the conference was the serious acknowledgement of the issue of biodiversity. Consequently, in June 2004 the EU ministers for the environment confirmed the goals set by the conference which had taken place a month earlier. This created real pressure to establish indicators of biodiversity. In France, a National Strategy for Biodiversity was adopted, also in 2004 (the Ministry for Ecology and Sustainable Development, 2004), and its first goal was set as the establishment of indicators of biodiversity, making it possible to monitor progress in the area of conservation policy by 2010 (Table 2).

Table 2: Biodiversity indicators of the French National Strategy for Biodiversity (sources in parentheses)

Genetic Diversity	Number of plant varieties and animal breeds registered and certified for commercial use, in the principal categories of cultivated plants and farmed animals (MAAPAR).
Species Diversity	Index of species diversity in common birds (MNHN).
	Species richness of fish (MNHN).
	Status of the species on the national red lists (MNHN).
Habitat Diversity	State of preservation of habitats of interest to the EU from the Natura 2000 sites (MNHN).
Ecological framework	Map of the diversity of types of land use which are not extensively commercialised at the local level (IFEN, Corine Landcover).
	Predominance of areas which are not extensively commercialised in the countryside (IFEN, Corine Landcover).
Ecosystem functioning	Tree defoliation (Département de la Santé des Forêts, MAAPAR).
	Global biological index of waterways (Réseau National des Données sur l'Eau).

Source: Medd, 2004

The goals set at the time of the Johannesburg Conference, the options taken up by the CBD and the initiatives implemented by the European Commission thus made it possible to pursue the consideration of biodiversity indicators which had begun a few years earlier within international organisations.

One institution which has been actively committed to the production of biodiversity indicators is the European Topic Centre on Biological Diversity (ETCBD) of the European Environment Agency[8] (AEE). It was created in 1995, one year after the founding of the EEA. It is one of the five topic centres designated by the agency to help with its task of collecting, analysing, evaluating and synthesising information to support the implementation of Community and national policies for the environment and sustainable development. The Centre began by providing information on biodiversity to the AEE for the production of reports - *The Dobris Assessment* in 1995 *and Europe's Environment: The Second Assessment* in 1998. The agency began to request biodiversity indicators in 1999. These were initially instruments seen as complementary to the reports, but their production was soon to become one of the EEA's chief goals. The EEA realised

8 There is in effect no institutional equivalent at the international level. Due to lack of time, the OECD has decided to stop addressing the question of biodiversity within its environmental division, and Eurostat is not directly concerned with the subject. We should also note that the Institut Français de l'Environnement (IFEN) is the focus of the EEA in France. The following details have been collected during interviews with individuals working in the topic centre.

that it needed synthesised information in order to communicate with the decision-making authorities of the European Union. To accomplish this, the agency established some "core indicators" relevant to major subjects such as water, air, waste and biodiversity. This poses a problem for the ETCBD, which is supposed to produce biodiversity indicators, because there is far less data on this subject than on waste, water or air.

However, we do not seem to lack for indicators of biodiversity. A report from the CBD identifies 236 of them (United Nations Environment Programme, 2001). The EEA counted 382 potential indicators of biodiversity in 2002 (European Environment Agency, 2002), of which 280 are classified as "in use". Surprisingly, a few years later the French Ministry for Ecology and Sustainable Development (MEDD) declared that it was able to draw on only one or two indicators for the monitoring of biodiversity in France[9] This difference is explained as a matter of scale: the indicators identified by the EEA and UNEP could be considered "in use" no matter what scale they were applied on. However, local ecological monitoring, which relies on the methods of ecological engineering and "traditional" monitoring by biologists, was in fact extensive. Monitoring on a regional level was relatively substantial, and indicators of biodiversity used to address very specific problems were also numerous. However, monitoring on a large scale, addressing biodiversity in a more general way and implemented using standardised data sets, was almost non-existent. Another problem is that the majority of biodiversity indicators change at a tempo which is unrelated to a short-term decision-making time-scale. This is why so much theoretical work has had to be undertaken in recent years in connection with the indicators of biodiversity (Balmford et al., 2003, 2005).

A recurring problem relative to the production of biodiversity indicators - and more generally of indicators of sustainable development - is the lack of coherence among the programmes which co-exist at various levels (local, regional, national, European, Pan-European and international). In this context, we can identify several scenarios for the development of the production of indicators related to sustainable development, in an institutional context (Ayong Le Kama et al., 2004). In the first scenario, current trends will continue, with a proliferation of extremely heterogeneous indicators defined within programmes which are just as heterogeneous. In the second, national biodiversity indicators will predominate, their main goal being to justify their progress with reference to the CBD. In the third, coherence will be introduced on each decision level - nature parks, local communities, national administrations, etc. - in response to a growing political demand for it on these various levels. In the fourth, private initiatives using a variety of proposed indicators will dominate, and only those which respond best to societal demands will survive (the Ecological Footprint or eco-certification indicators, for example). The final scenario is the achievement of coherence within and across different levels, thanks to efforts implemented jointly.

It is to encourage the emergence of this final scenario and to keep political decision-makers - ministries, administrations, organisations of all kinds - from being overwhelmed by the proliferation of indicators at the European level that a harmonisation project was launched, based on the work performed within the framework of the CBD and that performed by the EEA. This project, entitled SEBI (Streamlining European 2010 Biodiversity Indicators) was launched in 2004[10] and led to the identification of 26 biodiversity indicators for Europe[11] by January 2007 (Table 3). Today, the indicators of biodiversity in France have to be brought into alignment with the results of the SEBI. This means completely redefining the indicators of the National strategy for biodiversity.

9 Remarks by Olivier Laroussinie (MEDD) on the occasion of the seminar on "Indicators of biodiversity and sustainable development" held in the Auditorium of the Grande Galerie de l'Évolution of the Muséum National d'Histoire Naturelle, 5 January 2006.

10 http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995/F1101800700/1090246068.

11 http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995/F1101800700/fol341646.

Table 3: The SEBI biodiversity indicators

Major topics of the CBD	EEA key indicators	Indicators proposed by the SEBI for 2010
Current status and changes in the components of biological diversity	Change in the abundance and distribution of some selected species	1-a) Pan-European Index of common birds
		1-b) European butterflies
	Alteration in the situation of threatened and/or protected species	2) The IUCN Red List Index for European species
		3) Change in the status of species of particular interest to Europe
	Change in some selected biomes, ecosystems and habitats	4) Change in the size and make-up of some selected European ecosystems
		5) Change in the status of habitats of particular interest to Europe
	Trends in the genetic diversity of domesticated animals	6) Number of breeds in each country
	Size of protected areas	7) Trends in the creation of protected areas
		8) Sites classified in accordance with the Habitats and Birds directives
Threats to biological diversity	Nitrogen deposition	9) Exceeding critical levels of nitrogen
	Populations and costs of alien invasive species	10) Total number of invasive species in Europe
	Effects of climate change on biodiversity	11) Indicators of species abundance
Integrity of the ecosystem and the goods and services it provides	Marine trophic index	12) Marine trophic index in European seas
	Connectivity/fragmentation of ecosystems	13) Change in forest canopies and in the distribution of natural areas
		14) Status of and trends in river fragmentation
	Water quality and quality of aquatic ecosystems	15) Organic substances in transitional, coastal and marine waters
		16) Freshwater quality
Sustainable use	Zones of forestation, agriculture, fishing and fish-farming managed sustainably	17) Increase in stocks
		18) Deadwood
		19) Nitrogen balance
		20) Agricultural systems managed sustainably
		21) Number of fisheries below the threshold of biological renewal
		22) Quality of effluent water
	Ecological Footprint of the countries of Europe	23) Ecological Footprint of the countries of Europe
Access to and sharing of benefits	Percentage of European patents based on genetic resources	24) Percentage of European patents based on genetic resources
Resource transfer and use	Funds for biodiversity	25) Financial support for biodiversity
Public opinion	Public awareness and participation	26) Number of visits to nature reserves and parks

Source: Pan-European Biological and Landscape Diversity Strategy (2006, p. 8)

Biodiversity indicators: from single-parameter indicators to composite indicators

The issue of biodiversity is above all an issue of integration, since it involves the simultaneous consideration of genetic variability within populations, the diversity of species within communities and the functional diversity of ecosystems.

Genetic variability enables us to measure the health of a population. In effect, a low level of genetic diversity within a population soon generates problems of inbreeding and reduced life expectancy of individuals, populations and species. Inversely, the good demographic health of a population reflects satisfactory genetic renewal and thus functions as a good indicator of genetic variation. Genetic variability is directly related to the size of the population: the smaller the population, the poorer the genetic variability.

Species richness along with an equal distribution of the abundance of species, which is traditionally referred to as species diversity, enables us to measure the health of a community. Unlike genetic variability, both species richness and abundance of individuals within a community are a function of many variables, which makes the assessment of biodiversity much more complex. Among these variables we may list habitat heterogeneity, geographical latitude, biogeochemical cycles, resilience of the ecosystems and so on, but above all the history of the community, which is unique in each case (Krebs, 2001).

The functional diversity of an ecosystem corresponds to the capacity for response which that ecosystem can draw upon to deal with disruption by external elements. It is bound up with several factors, such as the diversity of the functional groups, the structure and intensity of the interactions, the functional redundancy of the species, but also quite simply species diversity (McNaughton, 1985; McCann, 2000; Loreau et al., 2001). The combination of all these factors is what makes it possible to guarantee that the ecosystem can respond in the best way to the disruptions it will encounter and can sustain a high degree of resilience (Holling, 1973). Here too, the issue of assessment is very tricky.

The first category of indicators by means of which biodiversity can be measured is the single-parameter indicator. A single-parameter indicator establishes the value of a magnitude - in this case that of biodiversity - on the basis of a single unit of measurement. This unit might be the species, the individual, the gene or the interaction. In reality, genetic variability is very rarely investigated directly, since that would involve substantial manipulation of data; the same is true for the diversity of interactions, which requires a more precise knowledge of the operation of ecosystems than is now available. In actual fact, only species abundance and individual abundance are utilised.

The single-parameter indicator most often used to measure biodiversity is species richness, which equates to the number of species present in an ecosystem, a country or the biosphere. The problem is that ecologists today agree that the indicators of species richness do not provide very much information about the overall dynamics which drive ecosystems and the biosphere (Balmford et al., 2005; Dobson, 2005).

This is due firstly to the fact that thus far only a minority of species has been described - perhaps ten percent (Barbault, 2000). In all, 1.7 million species have been described, including 1.3 million in the animal kingdom and 350,000 in the plant kingdom. The number of species present on planet Earth is estimated to be between 10 and 30 million. "Thus only a million species of insects are known out of 8 to 15 million in all, 70,000 mushroom species out of perhaps two million, and 80,000 species of algae and protists out of nearly a million" (Teyssèdre, 2004, p. 26). In contrast, 95% of vertebrates and 85% of vascular plants have been described.

Each year 10,000 additional species are identified. At the rate of current discovery, we will know of five million species by 2300, i.e. between half and one-sixth of the totality of species. If the rate of discovery goes up to 20,000 species per annum, the figure of five million will be reached by 2170 (Chevassus-au-Louis, 2005). The problem is that before we can come to know the totality of the species which make up the biosphere, they will probably have disappeared.

Another factor which supports the view that species richness is not a good indicator of biodiversity is that the taxa which compose this biodiversity can respond in very different ways to similar environmental changes (Dudley et al., 2005; Gosselin and Laroussinie, 2004, pp. 221-224). What is pressure on certain species can be a source of opportunity for others[12]. There is no correlation between the development of species richness in different taxa, and we cannot conclude that change in biodiversity is positive overall simply because change in the species richness of some well-known and well-researched taxa is positive. This makes species richness an ambiguous indicator for assessing the health of biodiversity.

Furthermore, the extinction of species is not the best means of measuring the dangers which threaten genetic variability and functional diversity. "In short, rare species and isolated populations have low genetic diversity and a short life-span, and they do not contribute significantly to the ecological services performed by ecosystems. Thus, the genetic diversity and ecological impact of the thousand to two thousand endemic species of insular birds which disappeared due to gradual human colonisation of Polynesia were comparable to those of only ten or so related continental populations or species, containing the same number of individuals" (Teyssèdre, 2004, p. 29).

Finally, species richness is an index that is not very sensitive to short-term variation, in particular when viewed on a large scale, because the extinction of a species takes a long time, due to its resilience in the face of changes introduced from outside (Balmford et al., 2003). Thus, for example, species richness is correlated positively with the degree of fragmentation and disturbance of habitats: this may seem counter-intuitive, but it is explained by the fact that there is a positive differential between the appearance of generalist species and the disappearance of specialist species (Devictor et al., 2007). The extinctions observable today are thus dependent on processes which began decades or even centuries ago. This is why the rate of extinction tells us more about past populations' decline than it does about current dynamics (Teyssèdre, 2004); and even if species richness is an indicator which corresponds well to the public's understanding of biodiversity, it is a really poor indicator for monitoring its dynamics. In order to address the threats to biodiversity, a more operational concept than the rate of extinction of biodiversity is available: the erosion of biodiversity. The *erosion of biodiversity* is concerned with the variation in abundance within species (Balmford et al., 2003, 2005).

The advantage of an indicator of abundance is that it is sensitive to short-term dynamics and that it sends an unambiguous message to the layperson and the media. In addition, it makes it possible to propose indicators based on a list of indicator species which corresponds to a list of the phenomena to be assessed (Krebs, 2001; Lindenmayer et al., 2000). Some species are particularly informative and monitoring their abundance can provide a suitable indicator for assessing the well-being of an ecosystem.

Engineer species rebuild the natural environment in which they develop: for example, earthworms turn over a great quantity of soil, thus benefiting plants. The "quality" of the habitat and the proper functioning of the biogeochemical cycles within an ecosystem are therefore dependent on an abundance of this type of species. To assess the health of an ecosystem it is also possible to monitor *umbrella species*, which need wide ranges of territory. Their development can disclose the state of health both of the ecosystem and of all the species which comprise it.

The North American grizzly and the Indian tiger are two examples of these species. It is also possible to monitor the abundance of a *keystone species*, one which is located at the hub of many relationships between species, for example starfish, large predators or species on the first step of a trophic chain. A large predator has only to disappear for species previously kept in check by it to become invasive and upset the workings of the ecosystem. In the same way, if the species at the base of the trophic networks disappear (such as algae, micro-organisms or herbaceous plants), the whole of the trophic chain will be disrupted. We may also make use of *indicator species*, which do not themselves

12 We may think, for example, of the overgrowing of abandoned farmland, which has a negative impact on species dependent on open areas but a positive one on species dependent on wooded habitats.

determine the relations between species but are indirectly sensitive to the major interactions which drive the ecosystem, for example salmon in European rivers, the meadowlark in French agricultural habitats, or the great bittern, whose well-being is extremely sensitive to that of the reed-beds which form its preferred habitat.

Three criteria can be adopted to identify these species: how much existing knowledge there is of their history, biology and functioning; how easy it is to monitor them; and how well they can define precise structural phenomena (Krebs, 2001, p. 399).

Before going any further, we should note that the primary engineer species is also the primary keystone species: that is, humans. It is humans who transform and adapt the Earth's habitats most extensively. Humans also form the Earth's primary predators. The abundance of *Homo sapiens sapiens* might therefore be supposed to be a good indicator of the state of biodiversity; this, however, is not in fact the case (Lebras, 1994). In reality, both lesser and greater abundance of a human population[13] can be an indicator of threat to ecosystems, which suggests that there exists a U-curve relationship between these two phenomena (Locatelli, 2000).

In any case, the use of indicator species poses several problems. First of all, an indicator species always possesses an ambiguous character. Population explosion in the case of keystone species, engineer species, or umbrella species is often difficult to interpret: does this mean that the ecosystem is functioning well?

In fact, what all these indicator species have in common is a search for balance. Their abrupt development in one direction or another represents an imbalance and a regulatory problem in the ecosystem's functioning, but generally the cause of the problem cannot be identified precisely. An indicator species can serve as an alarm signal, but nothing more.

This raises a second problem. The development of indicator species can always be affected by random events, which biases the approximation of the phenomenon that they are supposed to be representing. Thus, if an indicator species collapses as the result of the introduction of a virus into the species, this represents not the defective functioning of the ecosystem but simply the accidental outbreak of a disease. The alarm signal will thus not work reliably.

In addition, the indicator species are always associated with a specific functional context which often makes it impossible to make comparisons between different regions. What constitutes an indicator species may in fact vary depending on the context, and changes in their populations may not mean the same thing.

Lastly, it is hard to imagine that those concerned with biodiversity will agree to assess its status on the basis of an indicator which considers the abundance of only one species - even if it is an "emblematic" species.

This is why, instead of focusing on the abundance of any particular species, it may be more helpful to make use of a simple indicator of total abundance. Indeed, since genetic variability is directly associated with abundance, the latter can provide an adequate indicator with which to assess the biosphere's future adaptive capacities when faced with large-scale change (Teyssèdre, 2004). However, even if this indicator is a relatively valuable one from an informational perspective, it is still problematic in that it does not match most concerned groups and individuals' idea of biodiversity, which is largely dominated by the concept of species diversity.

Thus, the problem which single-parameter indicators - whether species or individual - run up against is that they cannot readily exhibit "double sensitivity" - that is, both with respect to the dynamics of the biodiversity they seek to approximate and with respect to the ideas of the concerned groups and individuals whom they seek to affect.

We must therefore redirect our attention towards composite indicators. A composite indicator is the exact opposite of a single-parameter indicator, since it involves the use of at least two units of reference. At the level of information currently available, the possible units of reference are the number of species and the abundance of each species. The combination of these two units makes it possible to calculate the species diversity, which can be approximated using the indices proposed by Shannon and Simpson[14] (Krebs, 2001).

13 Low density favours non-sustainable practices such as slash-and-burn agriculture, which has a serious impact on biodiversity

14 We have not gone into the details of the calculation of these indices, since this is not particularly germane to our discussion here.

The advantage of the composite indicator is that it can claim to be fairly exhaustive, thus gaining substantial legitimacy. This also enables it to average out the effect of statistically random events.

Composite indicators are faced with two recurrent research questions (Couvet et al., 2007):

- how to group together populations or species, and the criteria for assessing these groups;
- what methods to use to weight the importance of species or groups.

In the case of *taxonomic groupings*, these must be guided by a definite goal of integration, which requires the development of indicators (Balmford et al., 2005; Table 4) that enable the approximation of:

1 - The size of the populations and threat of extinction.

2 - Changes in habitats.

3 - Ecosystem services provided to humanity.

4 - The forces at the origin of the erosion of biodiversity.

5 - The effectiveness of conservation measures.

Table 4: Some examples of indicators of functional biodiversity

Phenomena to be assessed	Examples of indicators
Genetic variability within an ecosystem	Variation in the size of the populations which make up the ecosystem
Species diversity within an ecosystem	Variation in the number of species, weighted according to their relative abundance
Well-being of a habitat	Variation in the abundance of populations dependent on this type of habitat
Originality of an ecosystem	Variation in the size of the populations of "specialist" and "generalist" groups
Cultural services	Variation in the abundance of populations with cultural-emblematic significance or value for recreational activities
Regulatory services	Variation in abundance within functional groups and trophic levels
Provisioning services	Variation in the abundance of populations of species used for human nourishment, health care, heating, etc.
Pressure on biodiversity	Variation in the abundance of populations sensitive to the primary drivers of change (climate, agriculture, habitat destruction, etc.)
Efficacy of conservation measures	Variation in the abundance of populations targeted by conservation measures

These indicators must also apply equally to "natural" areas and to areas under human use, and take domesticated species into account.

The problem is that even when an indicator is constructed on the basis of a single taxonomic grouping, contradictory developments can be observed within the various units which make it up. Thus species richness can increase while total abundance declines. This is why we have to be able to disaggregate a composite indicator and to view it as a "headline" indicator which must be split up into the single-parameter indicators of which it consists in order to get a clear reading of changes in biodiversity. A composite taxonomic indicator must therefore always be complemented by an indicator of species richness, an indicator of abundance and an indicator of the equal distribution of species, which can all be referred to when we seek to interpret the changes it undergoes (Buckland et al., 2005; Couvet et al., 2007).

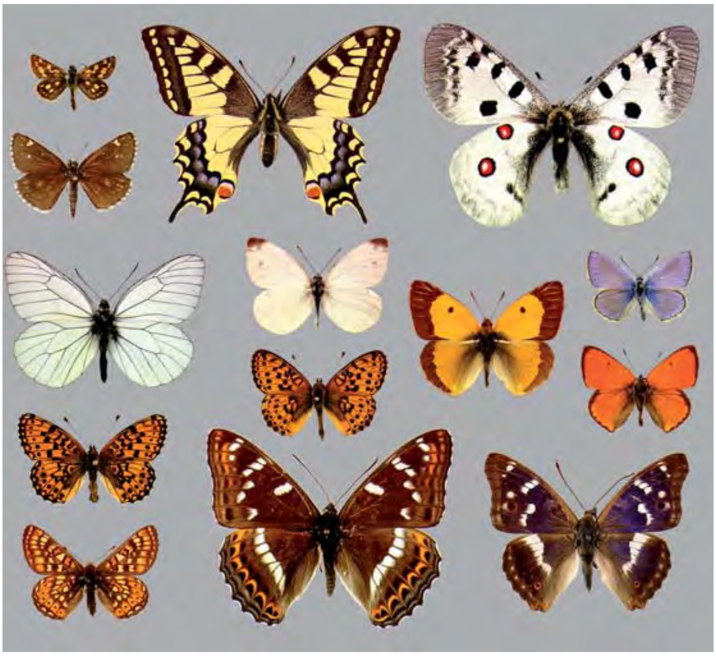
The *weighting of functional groups* is, like most of the questions relating to indicators, an issue at once scientific and political. It is particularly important in the case of highly aggregated indicators such as the Living Planet Index (LPI) which we will discuss in the next sub-section. These weightings can be a function of the extent of our knowledge, the quality of the data, the species richness exhibited by each subgroup, the importance of the species for the proper functioning of the biosphere, etc.

There are three possible choices with respect to weighting, which correspond to three different conceptions of conservation.

- In the first solution, the same weight is assigned to each species, the idea being that each species has the same value. This, however, raises the issue of the over-representation of species located on the first step of the trophic networks (in zones where there is significant monitoring of biodiversity) or conversely of species located at the end of the trophic chain (in zones where monitoring is poor)[15]. This also raises a major ethical question: can the value assigned to the panda or the African elephant can be the same as that assigned to an insect? From an ecological point of view perhaps, but from a societal point of view probably not. Another problem raised by a neutral weighting system is that it does not enable us to represent the various levels of an ecosystem's functional responses: in fact, it may seem logical to assign greater weight to a species for which there is no functional equivalent.
- A second approach with respect to the question of weighting can be called "conservationist". This approach stresses the importance of weighting species according to their scarcity, the degree to which they are threatened by extinction, or their emblematic significance. It might seem logical to make use of synthetic indicators of biodiversity which highlight the danger of extinction of certain bellwether species and the societal implications of their increasing scarcity (Butchart et al., 2005).
- A final approach, which we may call "ecological", assigns greater weight to those species which perform essential ecological tasks. Ecological tasks are mainly performed by the most abundant species; it would consequently be more worthwhile to weight the different species included in the indicator according to their relative abundance, especially in the case of those located on the first step of the trophic chain, on which the totality of the species in the ecosystem depends, and in the case of those located at the end of the trophic chain, which are indirectly sensitive to the totality of the changes which affect the ecosystem (Couvet et al., 2007).

Another major element to be taken into account when applying a composite indicator is how well it matches the symbolic levels and societal issues to which it relates.

Thus, decision-makers on a national level aim to show that the rate of erosion of biodiversity will be reduced in 2010, given the goals laid down by the CBD. Conversely, on a local level the biodiversity indicators preferred by managers will be different because their goals are different. What local decision-makers - managers and politicians - seek to demonstrate is the uniqueness of their terrains and the exceptional character of their ecosystems. And for those concerned with the general public, it is essential to make use of species that people feel strongly about (bears, wolves, deer, lynx, etc. in the case of forest biodiversity, for example) or which they can readily observe (common birds and butterflies, for example).



15 If there is a serious attempt at monitoring, small organisms, which are more numerous, will be very strongly represented. Conversely, if monitoring is not thorough, only those species which are easiest to detect will be properly described.

Composite indicators: the case of bird species

In the field of biodiversity, as we have explained, the chief threats are those related to the extinction of a species. The best-known indicators of biodiversity relevant to the risk of extinction are the red lists of the International Union for the Conservation of Nature. The red lists enable us to follow changes in the number of species which are "critically endangered", "endangered", or "vulnerable"[16]. These lists are drawn upon to characterise the state of health of the biodiversity of a country, a region, or an ecosystem[17] (Butchart et al., 2005).

Using these lists has led to the development of "status indicators" for species and, concomitantly, "knowledge indicators", "trend indicators", "pressure indicators" (which correspond to the causes of the decline of the species) and "response indicators" (which correspond to possible conservation measures).

The monitoring of biodiversity focuses on the change of status that species undergo. If a species goes from the status of "endangered" to that of "critically endangered", we can conclude that this represents a degradation of biodiversity.

According to these classifications, 12% of the Earth's bird species are in danger of dying out during the next hundred years, and 182 species are in a critical situation, with only a 50% chance of surviving beyond the next ten years (Heath and Rayment, 2001). 351 species of birds are critically endangered and 674 are endangered[18]. Among the endangered species, 235 are in the OECD countries. 170 species are threatened by changes in farming practices. France has 17 threatened species of birds (this category includes vulnerable, endangered and critically endangered species). We should note that parallel to the IUCN's classifications different categories have been established by other groups, which can be a source of confusion. In France, the Inventaire national du patrimoine naturel has counted 20 species "in danger", 52 "vulnerable" and 37 "rare" species[19].

A composite indicator exists based on the IUCN's red lists, calculated using the average of the conservation statuses of a group of species. This is the Red List Index (RLI). It can be computed for any group of species for which there are data sets from at least two different points in time. It is constructed using the number of species within each of the IUCN's categories and the number of species whose category has changed: this expresses improvement or decline in the state of biodiversity. With regard to the Earth's bird life, for example, the overall status has declined continually over the last 20 years, in every bio-geographic context (Butchart et al., 2005).

Although much of their bias has been corrected for, there is still a basic difficulty with these indicators: they change only over the long term (Balmford et al., 2003). They primarily address the irreversible disappearances of species and the changes of status which occur over relatively long time-scales. However, the goals of the CBD, the EU and France were established with reference to the year 2010, as we have already noted, which requires the use of indicators which change in the short term. Furthermore, these indicators share the limitations which we mentioned in connection with the indicators of species richness, in particular the small amount of information available on genetic variability and the functional diversity of ecosystems.

The IUCN's indicators, however, are often preferred by those who manage protected areas. First of all, these areas were often created to protect threatened or emblematic flora and fauna. Secondly, there are powerful financial and political incentives for national and international conservation programs to monitor and "produce" populations of endangered species.

The other type of indicator, which focuses on the erosion of biodiversity and not on levels of extinction, deals with the relative variation in animal or plant populations. Indicators dealing with populations of common birds in particular have been significantly developed in recent years.

16 http://www.iucnredlist.org/info/categories_criteria2001#definitions

17 These classifications are based on a number of criteria (Butchart et al., 2005): the size of a population, rate of erosion of the population, degree of reversibility of the causes of the erosion, the surface area of the territory it occupies, and a quantitative assessment of its viability.

18 http://www.iucnredlist.org/info/tables/table5

19 http://inpn.mnhn.fr/inpn/fr/inpn/esp_menacees.htm

The issue here is how to get quantitative data on the distribution and numerical change in the populations of the most common bird species (there are approximately 120 of these in France). These indicators are of interest in a number of ways for the monitoring of biodiversity (Heath and Rayment, 2001; Şekercioglu et al.,2004; Balmford et al., 2003, 2005; Gregory et al., 2005).

First of all, common birds are to be found in a wide range of ecosystems, including urban ecosystems. One advantage of the indicators is therefore that they can be constructed using an easily accessible source of information, distributed in a relatively homogeneous fashion across the terrain in question. This has enabled the development of a network of observers of common birds, who have generated a great deal of data (Levrel, 2006).

The populations which form part of "ordinary" biodiversity include large numbers of individuals, unlike the rare species, which are far less abundant; they thus contribute the most to the functioning and development of ecosystems. Indicators based on common birds therefore provide effective instruments for assessing ecosystem functioning.

Also, being positioned at a higher level within the food chain, populations of common birds are indirectly sensitive to the disruptions experienced by the totality of the species which make up the ecosystem. Changes among these populations thus provide an indicator through which ecosystem well-being can be measured. Moreover, any proposed interpretation of trends affecting these populations rests on a solid theoretical foundation - population and metapopulation biology (Couvet et al., 2007).

Lastly, the biology of common birds, their role in ecosystem functioning and the causes of their decrease are relatively well known, unlike the majority of the other components of biodiversity. Change in the common bird indicators is therefore relatively easy to interpret.

But the decisive advantage of these indicators is that they are derived from the monitoring of populations whose size is influenced significantly by short-term environmental changes. Indicators can thus be constructed whose changes from one year to the next have unambiguous significance, and which can therefore be effective instruments of policy assessment for measuring progress related to the 2010 goals.

From a "societal" point of view, common bird indicators have many advantages. Firstly, these are "neighbourhood fauna", often well-known to the public, with very familiar associations, as is shown by the traditional identifications of some birds as harmful (the crow and the magpie), as birds of ill omen (the albatross or the raven), or as parasitic (the cuckoo), not to mention all the expressions which use the names of common birds - "one swallow doesn't make a summer", "as the crow flies", or "swan song".

The variation in abundance of common birds thus means something concretely real for many people; the population has familiar associations and can be used as a jumping-off point for public discussion of biodiversity. This is all the more true because birds are extremely useful to the ecosystem, as most communities are well aware (Sekercioglu et al., 2004):

- Regulatory services, by preying on pest species.
- Provisioning services, in the case of birds which are hunted and eaten by humans (this is also a form of cultural services).
- Maintenance services, by the dispersal of seeds.
- Cultural services, via bird-watching.

What can the common bird indicators tell us?

The initial indicators which can be derived from common birds are traditional indicators of species diversity, through which we can follow changes in the biodiversity status of one ecosystem or one country. These changes are primarily characterised by variations in abundance, since species richness changes slowly.

In the case of variations in relative abundance on the national level - which corresponds to the average of the variation in abundance of common species - calculations show that between 1989 and 2001 the populations of common birds in France (where 89 species were counted) seem to have been reduced overall by 14%. These data show that 27 species are declining, 14 species require monitoring, 40 species are stable and 8 species are increasing[20].

To interpret and explain the decline more precisely, a number of explanatory parameters were statistically tested. It was found that neither hunting nor migration strategies nor the birds' body mass can explain the current decline (Julliard et al., 2004); these developments are in fact related to climate change and to changes in agricultural methods, that is, to the two principal threats to biodiversity today (MEA, 2005).

By using the common bird indicators we can assess the impact of global warming on biodiversity by measuring changes in the areas in which common birds are distributed (which is gradually moving northward) and the phenology of reproduction (the egg-laying period is earlier in the year). These provide extremely interesting approximations with respect to the reality of global warming, its effects on biodiversity and the functional responses that species can adopt (Julliard et al., 2004).

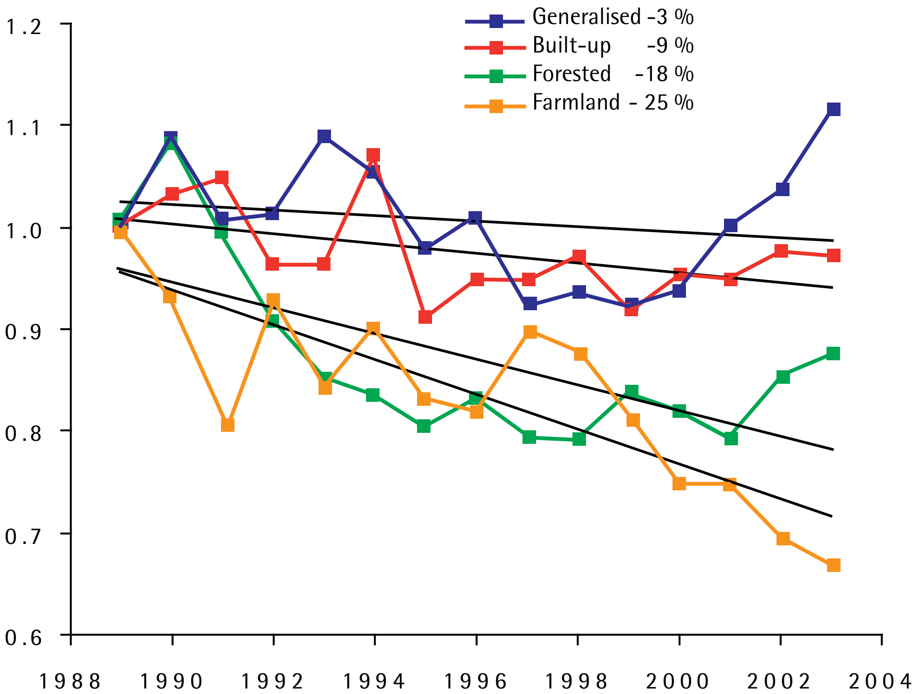
Common bird indicators have also been used to assess overall changes in habitat health (Julliard et al., 2006). To come up with these indicators, common species were grouped according to their degree of specialisation with respect to three habitats - forested, agricultural and built-up. By monitoring changes in abundance within these groups, we can measure the biodiversity response to the specific pressures which these various types of habitat are subject to. The relevance of these composite indicators depends on the way in which the specialist species which form them come to be selected. The level of specialisation is measured by the abundance of the various species in the various habitats. The criterion used to define a common species as "specialist" is that its abundance in a specific habitat is at least two times higher than its average abundance in other habitats. By contrast, generalist species are those whose abundance varies little from one habitat to another.

By using these indicators we can generate information on the reality of habitat change, the impact of this change on bird species and the vulnerability of certain species with respect to current or previous changes such as the growth of intensified farming (Heath and Rayment, 2001; Julliard et al., 2004). By precisely describing the current condition of a group of species located at the end of trophic chains and dependent on a particular environment, specialist species indicators provide information about the functional health of terrestrial ecosystems. Determining the current state of other trophic levels, following similar methods, would lead to a much more complete understanding of ecosystem functionality (Couvet et al., 2007). These indicators of specialisation also make it possible to remove bias related to the problem of invasive species: the appearance of an invasive population in an ecosystem might result in an increase in abundance, but we would not conclude that this is an improvement. Finally, the advantage of an approach which makes use of specialist and generalist species is that it is supported by a well-documented scientific theory of ecological niches: the greater the diversity of the environmental niches related to specific habitats, the greater the diversity of living things in general (Krebs, 2001).

The figures (Figure 2) for the period 1989-2003 show that specialist species are declining more than generalist species (which declined by only three percent between 1989 and 2003). These results highlight especially the decline of species in agricultural habitats (minus 25%) and forests (minus 18%) on the one hand, and the relative stability of specialist species in built-up environments (minus 9%) on the other.

20 These indicators can be consulted at http://www.mnhn.fr/mnhn/crbpo/index.html

Figure 2: Variation in the abundance of populations of specialist birds in France



Source: Couvet et al., 2004

The causes of the reduction in populations of farmland species can be traced to the intensified farming methods which the agricultural sector has adopted, the disappearance of non-specialised farming and of copses and hedgerows, the use of chemical inputs - pesticides, herbicides, fertiliser, etc. - and intensive irrigation (Krebs et al., 1999). We should also mention the abandonment of agriculture in regions where intensified farming has not been introduced, which leads to the loss of some farmed areas as a result of overgrowth and to the disappearance of species which depend on open farmland habitats (Bignal and McCracken, 1996).

The causes of the decline of species dependent on forested environments are less evident, more especially as forest areas have increased markedly in recent years and large animals dependent on this environment seem to be doing well (Gosselin and Laroussinie, 2004).

In order to investigate more fully the topic of the overall changes affecting habitats, a Community Specialisation Index (CSI) has been developed (Devictor et al., 2007). We can use it to connect changes in the level of specialisation within common-bird communities with the level of fragmentation and disruption of their habitats. It produces a ratio between the number of individuals belonging to species identified as specialist and the number of individuals belonging to species identified as generalist. If this ratio decreases, it probably means that functional homogenisation of the community is occurring (Olden et al., 2004), which can have a major impact on biodiversity as a whole, on the functions it performs in the major biogeochemical cycles and on ecosystem services in general. Statistical tests demonstrate that there is indeed a trend in this direction (Devictor et al., 2007).

At a higher level of aggregation there exists a composite indicator which groups together all the common species of vertebrates. This is the living planet index (LPI). The LPI was created in 1997 in conjunction with a program of the World Wildlife Fund (WWF). It was set up to measure changes in the totality of the Earth's biodiversity. It is based on a group of 3,000 vertebrate animal populations representing more than 1,100 species (Loh et al., 2005) living on land, in fresh water or in the ocean.

Birds and mammals are over-represented by comparison to other taxa, as are temperate-zone species by comparison to tropical species. In this indicator, however, common and threatened species are almost equally represented.

Each year new data, new populations and new species are added to the indicator. There are two methods for constructing it, both leading to roughly the same findings (Loh et al., 2005): a decline in population size of one quarter between 1970 and 2000.

The indicator is used to compare trends in different eco-areas (Australo-Asian, Afro-tropical, Indo-Malaysian, Neo-Arctic, Neo-tropical, Paleo-Arctic) and by category - terrestrial, marine, or freshwater species.

One of the striking findings is the difference in erosion between the Paleo-Arctic zone, which saw a loss of one percent of its terrestrial biodiversity between 1970 and 2000, and the Afro-tropical zone, which lost 60% of its terrestrial biodiversity.

A problem that has been discovered with this indicator is its limited usefulness, for two reasons: the monitored populations are selected arbitrarily, using a basically pragmatic approach, and the number of species in each environment and functional group is low (Couvet et al., 2007).

An example of biodiversity indicators used in connection with the sustainable management of forests in France

The French law of July 2001 on forestry planning states that a policy of sustainable and multi-functional forest management must be developed, and that protection of the forest ecosystems must also be strengthened. Assessing progress in this area requires the use of monitoring instruments, among which biodiversity indicators play a major role.

We propose here to examine the biodiversity indicators derived from the indicators of sustainable management of French forests compared to those derived from the national strategy for biodiversity, so as to identify the former's characteristics and to draw some lessons from them.

The specificity of biodiversity indicators in a forest environment

The indicators of forest biodiversity belong under the fourth criterion of the indicators of sustainable management of French forests (Table 5) - "Maintenance, conservation and appropriate improvement of biological diversity in forest ecosystems"[21].

The national strategy for biodiversity which was adopted in France in 2004 (Ministère de l'écologie et du développement durable, 2004) lists a number of indicators to be monitored to assess progress achieved in the realm of the conservation of biodiversity (Table 2).

With respect to these mechanisms, we can identify three characteristics of the indicators of forest biodiversity.

1) Characteristics relevant to an institutional perspective

The first characteristic has to do with the institutional process from which biodiversity indicators have emerged. One of the advantages of biodiversity indicators for sustainable management of forests is that they were conceived at a Europe-wide level and as a result are consistent with other indicators developed at national levels. It was the absence of planned consistency of this sort in the realm of biodiversity indicators which led to the launching of the SEBI programme mentioned above.

Another institutional characteristic is the very visible presence of the Inventaire Forestier National (IFN) among the information sources used to develop biodiversity indicators for the sustainable management of forests in France (12 indicators out of 15).

21 There are five additional criteria for the sustainable management of forests: "Conservation and appropriate improvement of forest resources and their contribution to the world-wide carbon cycle"; "Maintenance of the health and vitality of forest ecosystems"; "Maintenance and encouragement of forest production functions (wood and other products)"; "Maintenance and appropriate improvement of protective functions in forest management (notably of soil and water)";"Maintenance of other socio-economic benefits and conditions".

Table 5: Biodiversity indicators in France and the rest of Europe for the sustainable development of forests (specifically French indicators are shown in italics, sources are in parentheses)

Tree species composition	Surface area of forests and other woodlands, categorised by the number of tree species present and by type of forest (IFN);
	Purity at ground level of the tree population by principal species (IFN).
Regeneration	Surface area in a state of regeneration in forest tree populations of the same age and of differing ages, categorised by type of regeneration (IFN).
Natural character	Surface area of forests and other woodlands, categorised as "undisturbed by humans", "semi-natural", or "plantations", and then by type of forest (IFN); surface area of very old regular forests constituting specific habitats (IFN).
Introduced species	Surface area of forests and other woodlands composed chiefly of introduced species (IFN).
Deadwood	Amount of standing and fallen deadwood in forests and other woodlands, categorised by type of forest (IFN).
Genetic resources	Surface area managed for the conservation and use of forest genetic resources (genetic conservation in situ and ex situ) and surface area managed for the production of forest species seeds (CEMAGREF).
Landscape organisation	Spatial organisation of the forest canopy from the landscape perspective (IFN); *Length of the forest edge per hectare* (IFN); Length per hectare by type of IFN national population (IFN); cutting back and clear-cutting (IFN).
Threatened forest species	Proportion of threatened forest species, categorised in accordance with the IUCN Red List categories (MNHN).
Protected forests	Surface area of forests and other woodlands protected to preserve biodiversity, landscapes or other specific natural features, in accordance with the recommendations of the CMPFE inventory (IFN); density of deer populations per 100 hectares (ONCFS).

2) Characteristics relevant to a technical perspective

One characteristic of the IFN's indicators is the influence of landscape ecology in the selection of biodiversity indicators. This school of thought assumes that it is the spatial organisation of habitats which largely determines the dynamics of biodiversity (Burel and Baudry, 1999). Here the habitat is the forest, and its structure can be described on the basis of indicators of tree species composition (mixtures, purity, the presence of alien species), the quantity of deadwood, length of the forest edge, the presence of clear-cutting, areas undergoing regeneration, or degree of naturalness of the forests (semi-natural or exploited). Even the composition of the tree species, which could be regarded as a species richness indicator, appears here rather as a structural indicator, in the sense that it can be used to define a habitat as favourable overall to biodiversity. In a more general sense, we can say that some structural indicators also relate to the institutional environment (the surface area of protected forests).

This approach, based on the "structural" or "indirect" indicators (see box), has the advantage of being supported by a solid consensus, including from within the scientific community. It is noteworthy that when proposals for biodiversity indicators for forest environments are put forward in the scientific literature, they always relate to the structural dimension, exhibiting for example the inclusion of ponds, caves, rock falls and clearings (Deconchat and Balent, 2004), the use of generic indicators relative to the heterogeneity, complexity and interconnectedness of forest habitats (Lindenmayer et al., 2000) and even, quite simply, sustainably managed forest areas (Dudley et al., 2005). The indicators of forest management which have to do with biodiversity are thus largely dominated by the habitat aspect. The indicators known as "taxonomic" or "direct" (see box), such as the indicator species or the composite indicators derived from the grouping together of species are almost completely absent[22].

22 And those which are retained are not very informative. Thus, the "proportion of threatened forest species" is not a short-term indicator (even though the geographical comparisons that it makes possible provide invaluable information). The "density of deer populations" is ambiguous: is this an indicator that biodiversity is doing well, or doing badly, or is it a sign that pressure is being exerted on biodiversity?

Structural (indirect) versus taxonomic (direct) indicators

Structural (or indirect) indicators: Structural biodiversity indicators are related to the notion that certain landscape structures - biological, physical and social - have an important effect on biodiversity and thus can give us indirect information about its state of health. This is why we can also call them indirect indicators.

Taxonomic (or direct) indicators: Taxonomic biodiversity indicators are those which are focused on the monitoring of taxa - plants, birds, insects, mammals, etc. They are supposed to inform us directly about the state of health of biodiversity by addressing various living beings. This is why we can also call them direct indicators.

This position is supported by three arguments which we have already summarised (Lindenmayer et al., 2000; Dudley et al., 2005). Firstly, the use of indicator species is difficult, because their development can be due to random phenomena independent of those which the indicator is supposed to inform us about; this raises a problem of interpretation. Next, the composite indicators which make use of samples of several species are problematic, because these species do not respond in a homogeneous way to environmental changes; this creates yet other problems of interpretation. Finally, it seems to be more useful to have access to indicators directly connected with management practices. This point underlies the third characteristic of biodiversity indicators in a forest environment.

3) Characteristics relevant to a decision-making perspective

A final characteristic of biodiversity indicators in a forest environment is that they are intended for the use of managers. In effect, all the structural indicators mentioned thus far are supposed to send clear signals to forest exploitation managers. This is a major and permanent characteristic of the biodiversity indicators developed for agriculture, and silviculture is no exception to this rule. For this reason (and assuming the adoption of the pressure-state-response categorisation which we will spell out in the next section p. 44), forest biodiversity indicators tend to provide indicators of pressures and responses, and the respective goals of the latter indicators are to highlight threats and to propose standards of "good management", rather than to function as indicators of the state of biodiversity in the strict sense of the term. This particular situation is related to the history of the European forests, which have been managed for several centuries and whose well-being reflects sound use. This approach is also quite logical within an institutional context in which 74% of forests belong to private owners, who have to be provided with simple and graphic indicators, adapted to their methods of exploiting their resources.

Leaving aside the first, institutional, set of characteristics, it is worth emphasising that the principal characteristic of the forest biodiversity indicators is that they focus on the landscape parameters which "speak" most eloquently to managers. In what follows, we hope to highlight why it is important to expand forest biodiversity indicators to include taxonomic indicators, and also why it is important to target other categories of forest users.

Why supplement the forest biodiversity indicators?

While the use of structural indicators to monitor biodiversity in forest environments has many advantages, it still seems worthwhile to supplement them with taxonomic indicators. A simple illustration shows why this is the case.

The first impression produced by reading the report on the indicators of sustainable management of forests is that biodiversity seems to be doing rather well (IFN, 2005). The only indicator which appears to be truly negative is the fragmentation indicator[23]. Otherwise, single-species populations have tended to decrease and be replaced by mixed populations over the last twenty years; semi-natural forests benefit the most from forest expansion (more than plantations); the stability of very old regular forests has been documented; the growth rate on surface areas occupied by acclimatised species is faster than that of indigenous species, but the latter continue to increase in absolute terms and largely dominate forests in France (with 93.7% of the tree population); exotic species account for only one percent of forests and this ratio is stable; the quantity of deadwood is increasing rapidly, as is the surface area of protected zones.

However, it seems that some taxonomic indicators which are also relevant to the whole of France, but are not taken into consideration among forest biodiversity indicators, may reveal less positive trends. The populations of common birds dependent on forest environments declined by 18% between 1989 and 2003 (Couvet et al., 2004, 2007). This trend is especially surprising in that the rate is higher than the overall decline in the populations of common birds (14%), which would lead to the conclusion that what we have here is a "habitat effect"[24].

This item of information highlights the fact that, even if the structural biodiversity indicators exhibit a positive trend, this trend is not necessarily correlated with changes in the taxonomic indicators. This would amount to accepting that the decline in common bird populations dependent on forest environments is due purely to the fragmentation of this type of habitat - which would mean that this explanatory parameter outweighs all the others.

Admittedly, this observation relates to one single taxon and thus needs to be pursued in more depth. But it does expose one point: that there are many uncertainties with respect to the true relationships between direct and indirect indicators. This uncertainty is confirmed by the literature (Balmford et al., 2005; Dudley et al., 2005; Gosselin and Laroussinie, 2004; Redford, 1992). Even an indicator as generally accepted as deadwood abundance appears in the literature as a debatable structural feature, since excessive abundance of deadwood can become the underlying cause of new pressures due to the increased frequency of forest fires, especially in Mediterranean environments (Thompson et al., 2007).

Beyond this technical issue, other arguments support taking direct indicators into consideration.

The first argument is that in using only structural indicators to monitor the state of biodiversity, the relationship between ends and means in the field of conservation is reversed. Indirect indicators can thus contribute to a standardisation of forest management practices even though there are major areas of uncertainty about the real effect of these practices on biodiversity. The exclusive use of structural indicators can result in the substitution of the experts' opinions for the preferences of the managers - who have their own intuitions about good criteria of sustainable management (Trannoy and Van Der Straeten, 2001), criteria which can seem just as valid in specific ecological and societal contexts that local managers are familiar with.

23 However, there are many arguments over the correct way to calculate it: it may represent an increase in heterogeneity in a landscape that favours a kind of biodiversity that is dependent either on open spaces or on those requiring a heterogeneous habitat.

24 This seems to be confirmed by the literature (Julliard et al., 2004).

The second argument is that it is not possible to direct the indicators of biodiversity to only one sector of the public (in this instance forest managers). The issue of biodiversity in forest environments is a societal question which many other people are concerned with. These people too must have access to the indicators which enable them to take part in public debates. Biodiversity indicators must therefore be meaningful for all the actively concerned communities with an interest in this question, not merely for the managers.

How should we supplement the forest biodiversity indicators?

A first point that must be clarified in order to address the issue of biodiversity indicators in forest environments is: which biodiversity do we mean? As we stressed in the introduction, this plural, polymorphic and much-debated concept covers a wide range of conservation goals pursued by a wide range of people (Aubertin and Vivien, 1998; Barbault and Chevassus-au-Louis, 2004; Bouamrane, 2006). To preserve biodiversity can mean many things. To introduce indicators relative to ecosystem resilience, species richness, genetic variability or the amount of ecosystem services is to set conservation goals which may not be mutually compatible. We therefore need to connect the biodiversity indicators with the specific components whose conservation is desired - if possible, by prioritising them (Failing and Gregory, 2003). This perspective should lead to the construction of indicators through which we can both monitor developments in each component of biodiversity and expose any contradictions between one measurement of conservation and another. Viewed from this angle, the indicators must help to clarify the issues involved in the conservation of biodiversity in forest environments and also foster debate on the subject.

Another important point is the need to reframe the scope of the indicators of biodiversity. We cannot assume that monitoring biodiversity can be confined to a limited number of either taxonomic indicators (common birds, for example) or structural ones (the composition of tree species, for example) whose primary virtue is that they are easy to document. It is essential, as long as the number of taxa investigated remains limited, to take into account the opinions of both specialists and lay people to supplement the sources of quantifiable information. Experience and concrete knowledge "on the ground" can usefully supplement the indicators used to monitor biodiversity, if they are communicated within a transparent and collective framework that involves many active participants, following the principles of "technology democracy" to which we will return in Section Three (Callon et al., 2001).

Moreover, in this context where there still exists so much uncertainty we should be unassertive and cautious in our approach to conceiving and using indicators of biodiversity. These should be instruments of experimentation rather than of standardisation, in tune with a perspective in which knowledge and practice develop together in the adaptive management of biodiversity[25] (Arrow et al., 2000 ; Gunderson et Holling, 2002 ; Olsson et al., 2004 ; Weber, 1996). Management practices should remain heterogeneous and adapted to specific ecological and

25 We will return in more depth to this issue of adaptive management in Section Three.

institutional contexts, just as the indicators should. Thus, the same biodiversity indicator may provide two different results, representing positive or negative change, depending on the context (the density of deer populations, for example). It can also be counter-productive to seek to use exactly the same set of indicators for forests located in nature reserves and for private forests exploited for commercial purposes. Certainly the common indicators (such as those of the IFN) must allow us to make comparisons, but it is just as necessary to develop indicators adapted to specific contexts.

It thus seems that there are today two priorities in the field of the development of biodiversity indicators in forest environments.

First of all, it seems important to introduce direct, taxonomic biodiversity indicators, complementing the existing structural indicators, so as to limit the level of controversy and improve the quality of discussion about the management of biodiversity. As we emphasised above, significant progress has been made in the design of composite indicators by proposing groupings based on the functional characteristics of species and no longer merely on their membership in the same taxon (Julliard et al., 2006; Couvet et al., 2007). Through such groupings we can obtain unambiguous, targeted indicators in which the problems due to random phenomena are reduced by being averaged out. This, however, means that we have to pay particular attention to the methods for selecting the taxonomic groups to be monitored.

At the same time, we must assess more thoroughly the quality of the indirect indicators, by identifying the causal connections between the dynamics of forest landscape structures on the one hand and the dynamics of taxonomic groups on the other. Large-scale projects aiming at connecting structural indicators with taxonomic indicators have already produced interesting results in the case of agricultural environments, for example by defining the indicators resulting from the TERUTI database (on the structure of agricultural land use in France) and the STOC database (monitoring over time of common birds), and make it possible to connect conservation issues with regional planning issues (Devictor et al., 2007). This type of experiment ought to be multiplied to arrive at a better understanding of the connections between structural and functional changes in forest ecosystems.

Section 2:

Indicators of interactions between human society and nature

The indicators of interactions between human societies and nature to which we will devote some time in this section refer to what are traditionally understood as indicators of sustainable development. We prefer to stick to the term "indicators of interactions", because we are seeking to analyse their capacity to describe the interactions between the dynamics of biodiversity and socio-economic dynamics.

Some synthetic ecologically-focused indicators

One very active field of research related to biodiversity is the production of synthetic indicators. We have already described the Red List Index, the Community Specialisation Index and the Living Planet Index, whose purpose is to implement taxonomic regroupings that will enable a better description of changes in biodiversity and the dangers that threaten it. Another category of synthetic indicators has to do with the interactions between human societies and nature, their function being to promote a better understanding of the socio-economic dynamics at the origin of these dangers.

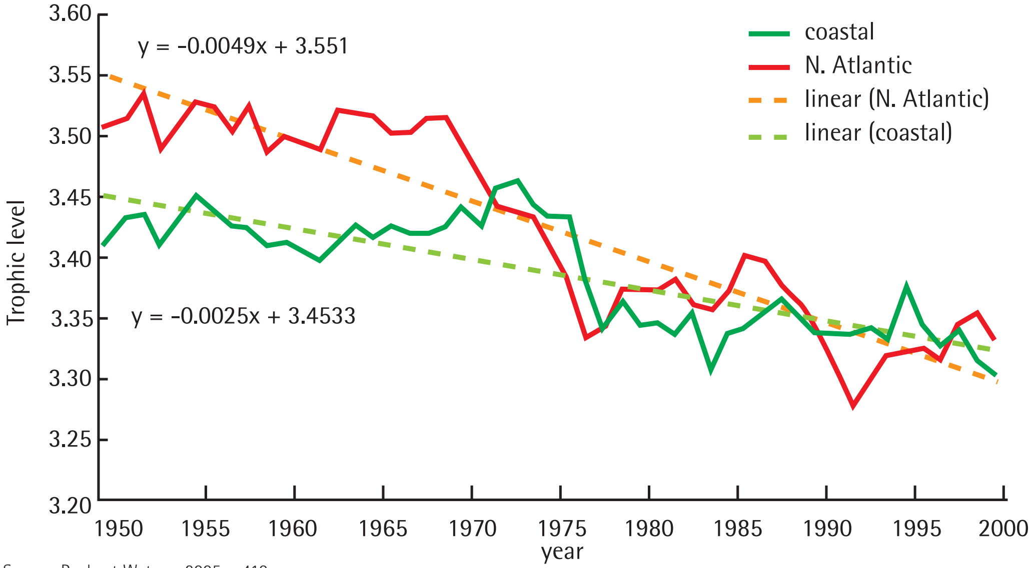
The marine trophic index

The first synthetic indicator we may cite is the marine trophic index of the United Nations Food and Agriculture Organisation (FAO). This is an indicator which has been developed since 1998 on the basis of data on fish catches since 1950.

This indicator is based on the trophic levels at which the catch is effected. Given that a trophic level corresponds to the rank occupied by a living being in the food chain, trophic levels can be classified very simply: "primary producers" (responsible for photosynthesis), "primary consumers" (micro-organisms, invertebrates), "secondary consumers" (small vertebrates), "large predators" (mammals), "super-predators" (humans) and "decomposers" (consumers of the waste products of the other levels). It is also possible to identify many far more minutely defined categories and subcategories, leading to the differentiation of a great many levels (Barbault, 2000). The higher up one is in the chain, the smaller the number of species.

The work of the FAO has encompassed more than 200 species or groups of species distributed by trophic level. Based on this information, an indicator of the average trophic level of fish catches has been calculated (Pauly and Watson, 2005). This average has declined throughout the second half of the twentieth century (Figure 3).

Figure 3: Changes in the marine trophic index (MTI) by fishery zone



Source: Pauly et Watson, 2005, p.419

This trend represents a decrease in catches at the higher trophic levels and the exhaustion of fisheries world-wide. This erosion affects all the world's oceans and seems to be characterised by a reduction at the higher levels - the most sought-after ones - which forces fishers to go after smaller fish. This interpretation is corroborated by results related to two other indicators - the depth at which fish are being caught, which is increasing, and the amount of trawler fishing, which is in decline (Couvet et al., 2007). One reason why the MTI is a legitimate indicator is that it is based on a sound ecological theory, that of the trophic networks (Krebs, 2001). From the point of view of biodiversity, the MTI can thus be considered as an indicator of the functionality of ecosystems and of the variation in ecosystem services. It enables us to follow indirectly the changes in the provisioning services provided by marine biodiversity.

To pursue the use of this indicator further: it would be interesting to calculate it on the basis of the countries of origin of the fishing vessels so as to bring out specific countries' responsibility for changes in the indicator[26], rather than calculating it simply by area of exploitation, as the MTI proposes at the moment..

The Ecological Footprint

The Ecological Footprint (EF) was invented by William Rees (Rees, 1992; *Ecological Economics*, 2000, vol. 32) to assess town planning policy. The NGO *Redefining Progress* (founded in 1994) developed it further and the WWF has made it one of its bellwether indicators. The EF is relevant only to renewable natural resources and thus to biodiversity (soil, forests, living species, etc.). It is designed to relate the flow of resources used by human beings to the capacity of those resources to regenerate, given a particular mode of consumption and a specific level of technology (Gadrey and Jany-Catrice, 2005). The calculation is based not on the regenerative capacity of the resources of a particular country, but on the basis of a unit of average world-wide capacity, called the global biologically productive hectare. The EF is constructed on the basis of a country's final consumption, and uses a conversion matrix for calculating the equivalent of the consumed renewable natural resources. The unit of equivalence adopted for this ratio is the hectare of ecosystem consumed by an individual[27], a city, a company, or a country. Five types of EF can be computed (Gadrey and Jany-Catrice, 2005, p. 73):

- The *cropland Footprint*, which includes surface areas used for the production of raw materials needed for food or industrial production.
- The *grazing land Footprint*, which supports animals grown for meat, leather, wool, milk, etc. To be included in this Footprint, the animals must occupy the land full-time and not be factory-farmed.
- The *forest Footprint*, which corresponds to forestry use through which needs for wood and non-wood forest products are met. Wood-based energy is not included.
- The *fishing ground Footprint*, which corresponds to a population's needs for fish and other seafood. Species diversity is taken into account so as to weight the fish biomass accurately.
- The *energy Footprint*, which corresponds to the surface needed to meet energy requirements. This Footprint is subdivided into four types: energy from fossil fuels, from the biomass, from nuclear power stations and from hydro-electric power stations.

The EF concept of regenerative capacity is close to the concept of load-bearing capacity, in that it enables us to determine whether humans are consuming more than nature can produce and thus to establish whether a debit or credit is being added in terms of the consumption of ecosystems.

We can use this indicator to tell how many planets would be needed if the whole of humanity were to consume in the same way as such and such a country, such and such an individual, etc.

26 We may note that introducing this indicator would be easy, since the data used by the MTI are organised by country (Pauly and Watson, 2005).

27 Calculation at the individual level is easy and can even be done on-line by answering a few simple questions (http://www.earthday.net/footprint/index.asp).

The power of the indicator is due to the fact that it is very graphic and that it allows for comparisons on various levels based on modes of consumption. The EF has established that, to stay in line with the biosphere's regenerative capacities, an individual should not consume more than 1.4 hectares of the earth's surface (assuming that the population remains stable). However, the average US American consumes 9.6 hectares, the average Canadian 7.2 and the average European 4.5. By contrast, the EF of an inhabitant of Pakistan or India is around 0.8 hectares. At the city level, we can take the example of London, which includes 12% of the population of the United Kingdom and covers 170,000 hectares, but consumes the equivalent of 21 million hectares (United Nations Programme for the Environment, 2002). The conclusion to be drawn from calculating the Ecological Footprint is that the modern mode of consumption is not sustainable.

Today the EF is the most symbolically powerful indicator of interactions between human society and nature, and the most visible in the media. It was the subject of a prime-time programme on the France 2 TV channel, on which various TV celebrities had to calculate their Footprints. This programme, ClimAction (shown 3 June 2003), was structured around 43 questions which the guests answered one after the other in order to gradually calculate their EF. Combined with comments from scientists and explanations of the impact of human activity on the environment, this programme is only one example of the use of an indicator in an educational context on a very large scale. The EF was also the only indicator mentioned by Jacques Chirac during his speech at the 2002 Johannesburg summit (Gadrey and Jany-Catrice, 2005, p. 69).





However, the Ecological Footprint has several major flaws

First of all, the equivalencies it establishes for the energy Footprint are highly debatable (Gadrey and Jany-Catrice, 2005, p. 73). The fossil fuels Footprint is supposed to correspond to the forest surface area needed for the absorption of the carbon dioxide emitted by fossil fuels, and the biomass energy Footprint is supposed to correspond to the forest surface area needed for the production of biomass energy, but these two calculations are full of uncertainties.

The chief problem arises in the case of the nuclear power Footprint. It is calculated according to the same method as the fossil fuel energy Footprint, but this is based on a scientifically false premise: in fact, nuclear power produces less elevated greenhouse gas emissions than fossil fuels do. Choosing to equate them is undoubtedly motivated by the fact that it is difficult to integrate the issue of nuclear risk (in particular with regard to radioactive waste) into the EF, but the solution adopted seems problematic.

The debate over these established equivalencies raises problems exacerbated by the fact that 70% of the EF is taken up by the energy Footprint (Ayong Le Kama, 2006).

A second problem: while the EF can in theory be calculated for everything from the individual level right up to the international level, it turns out that in fact there are no data on final consumption at intermediate levels such as the region, county or department (Rousseau, 2006).

A third problem concerns the assumptions about the levels of technology and of population size used to calculate not only the ratio between quantities consumed and the biosphere's capacity for regeneration, but also the load capacity of 1.4 hectares per capita. In reality, all of human history is characterised by an increase in population and in technological innovation, and by the many interdependencies between them (Lebras, 1994). The EF only proposes simulations matching different levels of consumption, but it would be just as interesting to perform the calculations based on varying levels of technological complexity and/or population size. To cite one example, the development of renewable energy, recycling and the "doubly green revolution" are all ways to de-link final consumption from consumption of renewable natural resources.

The real advantage of the EF as an indicator is its educational function. It can be used to make comparisons in an engaging way, by connecting everyday behaviour with global change. This key feature, which no other available indicators can match, has distracted attention from its major conceptual flaws.

The Natural Capital Index (NCI) and the Biodiversity Intactness Index (BII)

The NCI was developed in the Netherlands and the BII in South Africa. These two indicators are based on a very pragmatic approach whose goal is to assess the erosion of biodiversity as the result of the impact of human activities on natural habitats.

The NCI focuses on two aspects through which habitat change can be defined (RIVM, 2002): the quantitative and the qualitative. Quantitative habitat change relates to the conversion of "natural" areas into agricultural areas and to urbanisation. Qualitative change relates to pollution, global warming, the introduction of invasive species and habitat fragmentation resulting in the reduction in numbers of some key vertebrate and plant species.

Qualitative and quantitative change are calculated using an equation which represents change from a given historical reference point:

NCI = quantitative change in an ecosystem (in percentages) multiplied by qualitative change in the ecosystem (in percentages).

The results obtained for the Netherlands are 40% for quantitative change and 44% for qualitative change in natural ecosystems, compared to a pre-industrial reference point. Thus the NCI is calculated as 0.40 x 0.44 = 0.176 (17.6% compared to the initial reference point).

This same calculation can be performed for different types of habitats and on different geographical scales to show the distribution of human pressure on biodiversity.

Another biodiversity indicator, based on the same approach but much more scientifically successful, is the Biodiversity Intactness Index. This in fact is the only composite indicator of biodiversity, presented as such, which has been published in the prestigious journal Nature (Scholes and Biggs, 2005). The BII is an indirect indicator of the average abundance of all the organisms (vertebrates and plants) living in a given geographical area.

Its implied goals are to supplement the Living Planet Index, mentioned above, by enabling the assessment of changes in biodiversity in countries where there is insufficient information to calculate the relative abundance of populations. This indicator aims to approximate change in biodiversity resulting from the impact of human land use[28] on the animal and plant reference populations, and to generalise this impact to all the populations belonging to the same functional groups. Each taxon is thus divided into five to ten functional groups composed of species which respond in a similar way to the pressures exerted by human use activity. The functional groups are devised on the basis of three key criteria: organism body size, trophic niches occupied and reproduction strategies adopted.

The impact is estimated by drawing on expert opinion[29]. Specialists have to assess the impact of human activity on populations from different taxa broken out according to standard ecosystem types (forest, savannah, prairie, wetland and waste land). This reliance on expert opinion raises the problem of legitimacy, since experts have their own value-judgements which will be conveyed through the criteria of assessment and the equivalence conventions selected[30] (Couvet et al., 2007). This problem can be partly eliminated by drawing on several experts, as the authors suggest.

28 The land use levels in question are listed as: protected, moderate use, degraded, cultivated, plantation and urbanisation.

29 It is recommended that at least three specialists be used for each taxonomic group (plants, mammals, birds, reptiles and amphibians).

30 We go into the issue in more detail in Section Three.

The aggregation of the data obtained for each functional group is weighted by the surface area of each ecosystem included in the indicator and by the estimated species diversity of each type of ecosystem (Scholes and Biggs, 2005). The indicator is represented as a ratio, like the NCI. The findings obtained for South Africa are that the average abundance of the totality of species is 84% of the average abundance for the pre-modern period (71% in the case of mammals).

Using this indicator we can carry out monitoring on the basis of ecosystem levels, or of activities with an impact on habitats, or of functional groups. The BII retains the same meaning regardless of the scale it is used on. Thus for South Africa, the BII was applied on a national scale (1.2 x 106 km^2), a provincial scale (1.35 x 105 km^2) and a local administrative scale (4.6 x 104 km^2).

The results obtained from the BII were tested (in particular, using maps showing the distribution of mammals) and the robustness of this indicator has been confirmed.

The primary appeal of the NCI and the BII is that through them we can assess the absolute rate of erosion of biodiversity in Western countries and in developing countries, using the pre-industrial period as a common point of reference. These indicators provide an opportunity to emphasise that the Northern countries have been degrading the majority of their renewable natural resources for a long time[31].

The strength of the NCI and the BII is also their weakness. To adopt pre-industrial conditions as the point of reference, and thus implicitly to view them as "desirable", is socio-politically unacceptable. The inventors of the indicators defend this approach by claiming that it is not a question of desirable conditions but simply of a reference point which can be used to determine current conditions and to establish political objectives with reference to earlier conditions. But nonetheless this does make its adoption by potential users problematic.

Indicators of interactions used with reference to national accounting

There are two ways to approach the topic of the indicators dealing with interactions between human activities and biodiversity dynamics with reference to national accounting systems (Vanoli, 2002). The first option is to implement indicators which can be integrated into Systems of National Accounts (SNA) through the development of satellite accounts. The second option is to use national accounting aggregates and adjust them in order to produce indicators of sustainable development.

The goal of national accounting is to measure changes in the economic wealth (added value) created by various branches of activity within a country. The sum of these added values represents the GDP. The limits of the GDP as an indicator of development - and therefore of sustainable development - are manifold (Viveret, 2003; Gadrey and Jany-Catrice, 2005). Satellite accounts aim to compensate for these limits by providing measurable information on social and ecological phenomena which it is hard to take into consideration within the central framework of national accounting.

The development of satellite accounts for the environment was made possible through the implementation of the System of Economic and Environmental Accounting (SEEA) by the UN in 1994 (Vanoli, 2002, p. 434). They correspond to physical accounts which record stocks of natural resources at the start and end of a given period. The purpose of this accounting system is to represent the environmental costs of human activities, which are not included in the SNA.

Biodiversity appears clearly in the SEEA in the form of "non-produced natural assets". The costs associated with the depletion of renewable natural assets are calculated only when the extraction activities are out of line with the renewal rates of those resources. With regard to ground areas, land areas and ecosystems, these costs are related to soil erosion, to the introduction of cultivation, or to the destruction of non-cultivated ecosystems. These natural assets do not

31 This leads us to emphasise the hypocrisy of some international organisations who criticise the annual rates of biodiversity erosion in developing countries by using indicators such as Genuine Saving (GS), to which we will return in the following sub-section.

always lie within the territory of the country itself (fish stocks, for example) and they may also be human-produced resources (extraction from forest plantations, for example). Another interesting aspect of the system is that the depletion of natural assets can be calculated with reference to its origin, either internal or external - which is extremely important for developing countries, since a significant amount of biodiversity erosion in these countries can be laid at the feet of foreign companies. Another advantage of the SEEA is that it includes an accounting of the costs of restoration of natural assets to the community.

In order to construct equivalence matrices models must be used which can describe the impact of human activities on natural assets and then convert them into monetary equivalents. The models used are system dynamics (input-output) models which connect stocks (population abundance) with outflows (extraction of some number of individual entities). Once these stocks and outflows have been determined, the next step is to convert them to monetary form.

The first problem raised by the construction of these models on a national scale is that it is essential to have data on the interactions between human activities and the dynamics of natural assets. However, the standardised systems for monitoring these interactions are still few in numbe[32]. In addition, monetary conversion poses many problems of a technical and ethical nature (O' Connor and Spash, 1999; Vanoli, 2002). Finally, we should add that satellite accounts are not really used in public discussions, because anything that does not form part of the central framework of national accounting is quickly forgotten by decision-makers (Gadrey and Jany-Catrice, 2005).

This is why a different approach has been developed, working directly on the aggregates of the central framework of the SNA. The adjustment of the national accounting aggregates aims to create a kind of "green GDP" through which we can measure more accurately the progress made by different countries in the realm of sustainable development (Vanoli, 2002). Several indicators claim the title of "green GDP" today: the Index of Sustainable Economic Welfare (ISEW), the Genuine Progress Indicator (GPI) and Genuine Saving (GS).

The ISEW was created by the Friends of the Earth NGO in association with the New Economic Foundation (a think-tank) and the Centre for Environmental Strategy at the University of Surrey (Cobb and Cobb, 1994). It is calculated as follows (Gadrey and Jany-Catrice, 2005, pp. 62-64): ISEW = household consumer expenditure + services from domestic labour + public expenditure other than on defence - defensive private expenditure - cost of environmental pollution - depreciation of natural capital + formation of productive capital.

The costs related to biodiversity erosion may appear under defensive private expenditure, cost of environmental pollution, or depreciation of natural capital.

Defensive private expenditure means the expenditure undertaken to compensate for the loss of well-being related to environmental pollution. In the ISEW, this expenditure is associated with private expenditure on health and education and with the cost of commuting to work. There is no question of biodiversity or natural environment at this level.

32 The only sector for which the SEEA has a good account of outflows is forestry.

The costs of environmental pollution are defined as the costs of water pollution calculated using data on the levels of river pollution; costs of air pollution estimated using data on carbon monoxide, carbon dioxide, and nitrous oxide emissions; costs of noise pollution resulting from motor vehicle traffic. Biodiversity is not taken into consideration here either, except perhaps very indirectly in the form of pollution levels which create pressure on it.

Depreciation of natural capital is calculated as follows: wetlands lost through drainage; arable land lost through urbanisation or a non-natural reduction in the quality of the soil; replacement costs of non-renewable energy resources; an environmental debt related to energy consumption (in equivalent barrels of oil); use cost of chlorofluorocarbons. Biodiversity is still not taken into consideration, except perhaps indirectly in the form of wetland loss.

In short, it is hard to see the ISEW as a useful indicator for approximating the interactions between development dynamics and biodiversity dynamics.

The GPI was constructed by the Redefining Progress NGO, which also participated in the development of the EF (Lawn, 2003). Like the ISEW, the GPI is calculated on the basis of household consumption. This consumption is then adjusted (Gadrey and Jany-Catrice, 2005, pp. 66-68) using a large number of variables (24 in all). These adjustments involve economic, societal and environmental data. In the realm of the environment, we find exactly the same parameters as those which appear under the costs of environmental pollution and depreciation of natural capital for the ISEW, to which are added the costs of reducing household pollution and the costs related to the destruction of old forests. The conclusions are thus the same as those reached by the ISEW.

The GS was developed by the World Bank and by US researchers during the 1990s (Atkinson and Pearce, 1993; The World Bank, 1997; Dasgupta, 2001). This indicator is, by far, the most well-known of the three "green GDPs". It aims to assess changes in human, produced and natural capital of use to society[33] (Dasgupta, 2001).

Human capital is a function of a population's levels of education, health and vocational training. Produced capital corresponds to the means of production of goods and services that a country possesses. Natural capital refers in general to natural resources. The sum of these three is called genuine wealth. Assessing change in a nation's genuine wealth is done by measuring change in the GS. According to the World Bank, it presents "a nation's genuine savings rate after taking into account the depreciation of produced assets, the depletion of natural resources, investments in human capital and the value of global harm resulting from carbon emissions" (The World Bank, 1997, pp. 1-2, quoted by Vanoli, 2002, p. 431).

It is computed as follows (Boulanger, 2004; Gadrey and Jany-Catrice, 2005): GS = Gross fixed capital formation (GFCF) + expenditure on education + expenditure on health - foreign debt - depreciation of produced capital - depletion of energy resources - depletion of mineral resources - depletion of forests - harm resulting from CO_2 emissions.

The monetary assessment of resource depletion is calculated on the basis of the "rent" of the resources, i.e. the difference between the selling price after extraction and the cost of exploitation (prospecting, development and extraction) of these resources (Vanoli, 2002). In the case of forests, the calculation relates only to those levels of exploitation which exceed the dynamic renewal of the forests. The value of environmental damage is limited to carbon dioxide emissions (effects on the climate) on the basis of the marginal cost of treatment of one emitted tonne.

No estimate can be produced for the ecosystem services related to biodiversity. The impoverishment of the soil, the value of water or the depletion of fish stocks were also not included in the calculation.

Beyond the inadequate recognition of biodiversity, the results produced by this indicator pose major problems of interpretation (The World Bank, 2000). According to the World Bank's calculations, it is mainly the developing countries (Brazil, India, Mexico, South Africa and Turkey) who are responsible for the erosion of the world's renewable natural resources, because their per capita GS rate is negative (respectively - $157; - $24; - $89; - $172 and - $115), while the Northern countries seem to be managing their resources carefully: + $156 for the United

33 Social capital (Putman et al., 1993; Pretty, 2003) has not been included in this indicator since it is not a form of capital in the strict sense understood by this approach (Dasgupta and Serageldin, 1999).

States; + $2166 for the United Kingdom; + $2939 for France; + $4224 for the Netherlands; + $4333 for Germany. These results are at once statistically trivial and not really explanatory of the dynamics in process. First of all, as the BII and the NCI show, Western countries have been wasting their natural capital for a long time, and this is why their current rates of erosion are low. Next, this indicator neglects the international economic and political context. In reality, if the developing countries are using their renewable natural resources non-sustainably it is because in most cases they are totally dependent on a primary sector which has seen prices fall on international markets for the last 50 years, and also because of commercial regulations which do not adequately take account of issues of development and conservation on an international scale (Levrel, 2003).

Another problem is that genuine saving is an indicator of *inter*-generational equity, since the underlying assumption is that capital which is consumed today cannot be consumed tomorrow. But the issue of *intra*-generational equity - which brings up the question of the allocation of resources - is just as essential for assessing the sustainability of development and for understanding the causes of erosion of renewable natural resources.

Another limitation of this indicator is that it permits complete substitutability among the three forms of capital (Boulanger, 2004). The World Bank's position is problematic in this respect, since its indicator justifies policies based on *weak sustainability* (Atkinson and Pierce, 1993). Development would in effect be considered sustainable if a reduction in natural capital was entirely compensated with an increase in produced capital. Air-conditioning would thus make it possible to produce cooling that the tree no longer produces because it has been cut down, and the water treatment plant would continue to produce drinking water even if the groundwater was completely polluted by surrounding industries.

Critical Natural Capital (CNC) was developed to provide an alternative to the economic indicators which assume the criterion of weak sustainability (*Ecological Economics*, 2003, vol. 44, issues 2-3). The concept of CNC is based on a principle of *strong sustainability*, which presupposes that a natural entity is not substitutable by produced capital (Ekins, 2003). CNC thus refers to the totality of the ecological functions essential to the development and maintenance of quality of life on Earth. The underlying idea is that the disappearance of this CNC would generate ecological imbalances which would in turn lead to virtually irreversible social and economic crises. The critical character of this capital can thus be connected to the concept of resilience (Holling, 1973). The critical level of natural capital is reached when the use of one additional unit of renewable natural resource causes the erosion of the ecosystem's resilience.

The three criteria which define CNC are the absence of substitutes, the vital or strategic importance for human activities and the danger that a resource or ecosystem will disappear (IFEN, 2001b). From the perspective of economics the first route, pursued but quickly abandoned, was to assess ecosystem functions in monetary terms in order to prioritise them and thus determine

which were the most important functions (Heal, 1998; Ekins, 2003). The problems raised by the economic assessment of ecological functions (O'Connor and Spash, 1999) led researchers working on this issue to adopt a more pragmatic approach, by approaching CNC from the perspective of the utility of the ecosystems for human health (physical and psychological), the danger levels which affect functional changes related to human activities, and the principles of economic sustainability which must be followed in all activities (Ekins, 2003). To do this they had to identify the functions of the ecosystems; the direct or indirect benefits these ecosystems provide for human well-being; the socio-economic pressures which this natural capital is subject to; the standards of sustainability to be followed; and the socio-economic consequences of the sustainable development policies adopted.

A problem for CNC is that strictly speaking it is a method rather than an indicator[34]. This makes it interesting from a scientific and decision-making point of view, but it means that it does not provide a tool for effective communication. This is why it has not been very successful.

The ecosystem services approach has borrowed significantly from the key ideas of CNC (Daily, 1997; MEA, 2003, 2005). However, rather surprisingly, economists who have worked on CNC are not well represented in the Millennium Ecosystem Assessment, and are even absent from its editorial board, though it is clear that these are the people best prepared to address the topic of ecosystem services and their contributions to human well-being. In any event, ecosystem services have stolen the limelight from CNC because of a powerful push in their favour at the institutional level and because their conceptual framework is much clearer.

Ecosystem services and the Millennium Ecosystem Assessment

To illustrate the complexity of the ecosystem services approach and to distinguish it from a simplistic understanding of natural capital, Gretchen Daily (1997) begins with a story. Let us imagine that there is a breathable atmosphere on the moon and that humans could settle there. Which species should we take with us for food, health care, clothing, etc.? Daily concludes that we would need between 100 and 10,000 species to support human life on the moon. But then a problem arises: we would also need to bring along the species which support these useful species. However, while we know quite well which several thousand species are directly useful for us, the same is not true for the species on which these useful species depend, nor for the interactions between them. We would therefore probably be unable to recreate the ecological conditions necessary to our survival on the moon. The failure of the "Biosphere 2" experiment, whose purpose was similar[35], a permis de faire comprendre deux choses essentielles à l'homme: il est pour l'instant incapable de recréer la complexité des interactions écosystémiques qui sont à la base de la dynamique du vivant ; l'hypothèse de substituabilité parfaite entre le capital naturel et le capital physique, défendue par certains économistes, est intenable.

Consequently, rather than seeking to create artificial ecosystems, it would be better to try to understand how real ones function and how they are interdependent with human well-being. Even if we have plenty of experience of humanitarian crises originating in ecosystem dynamics,

34 We may however mention the attempt by IFEN, which proposed a list of variables corresponding to CNC for France (IFEN, 2001a, p.26): the variation in the number of individuals in threatened species / the variation in the expenditures directly committed for the conservation of these species; the variation in the number of endemic species; the variation in the number of cultivars; the variation in the number of livestock; changes in the budget for promoting the conservation of species; the variation in surface areas of significant size / the variation in the expenditure allocated for their management and conservation; the mapping of the diversity of landscapes and its development; changes in single-species forests / mixed forests; changes in the agronomic quality of the soil (erosion) / changes in the expenditure allocated to protecting this resource; changes in the water quality index (map) / changes in the expenditure allocated to protecting this resource.

35 Biosphere 2 was a giant greenhouse built at the end of the 1980s, whose purpose was to reproduce in miniature a biosphere featuring the principal ecosystem types: tropical rainforest, ocean, desert, semi-desert, marshland and savannah. By controlling ecological interactions, Biosphere 2 was supposed to create self-sufficiency by producing internally all the ecosystem services needed by a small human community: water, food and air. In September 1991, it was announced that a team of eight researchers had been voluntarily locked in the greenhouse and would stay for a period of four years. However, after two years a consistent decrease in the oxygen rate was observed which ended up becoming dangerous for the scientists, and they had to leave. A new experiment took place in 1994, but the result was even worse. After only six months, the oxygen rate broke down and carbon dioxide concentrations rose to a level of 571 ppm. At the same time, the disappearance of the majority of the species was observed (most of the insects and 19 of the 25 vertebrate species). The ants, cockroaches and grasshoppers became invasive species and today are spread throughout all the biomes of Biosphere 2.

we find it extremely difficult to anticipate these crises, even when we ourselves have caused them. We are usually satisfied with the adoption of a reactive strategy after having acknowledged the existence of an ecological and societal crisis.

An interesting example is that of the Aral Sea (Barbault, 2000, p. 249; *Courrier international* n° 782, 2005, p. 28). The Aral Sea, the second-largest fresh-water lake in the world, is located in the middle of the arid regions of Central Asia, astride the borders of Kazakhstan and Uzbekistan. It is fed by two rivers, the Amur Darya and the Syr Darya. During the Soviet period, the planners in Moscow wanted to turn this zone into the cotton belt of the USSR. Since growing cotton requires a lot of water, several dams were built and a powerful irrigation system was installed to divert water from the rivers to support this new intensive cultivation. This was accompanied by a massive use of chemical inputs needed for the production of cotton in the region. This twofold technical innovation, typical of the green revolutions implemented around the world at that time, produced one of the greatest human-created ecological catastrophes; the resulting feedback produced one of the greatest human catastrophes resulting from pollution of the natural environment.

Before 1960, the two rivers poured 55 billion cubic metres of water per annum into the Aral Sea. By 1980, this had fallen to 7 billion (Barbault, 2000, p. 249). This change upset the ecological and human dynamics of the Aral Sea. As it lost three-quarters of its surface area and 90% of its volume, the number of species of nesting birds went from 173 to 38, the number of fish species from 24 to 4 and the salinity of the water from 10g/l to 30g/l. Concomitantly, potable water disappeared, as did fishing, which had produced 50,000 tonnes of fish per annum and employed 60,000 people. Traditional agriculture could not be sustained, fishing villages were abandoned and the whole society associated with them vanished. At the human level, the catastrophe was just as impressive. The infant mortality rate became the highest in the world and 9% of the surviving infants suffered from mental health problems. In the most polluted regions, nearly 80% of the population had stomach cancer. It is easy to see how in this example biodiversity, ecosystem services and human well-being were extinguished in sync.

The Soviet authorities had focused all their innovations on increased productivity, and therefore on extraction, while neglecting all the other services, which in the long term resulted in the collapse of the human society-nature system. Today, in an irony of history, the petrodollars generated by the increase in the price of oil have enabled Kazakhstan to undertake the largest ever reconstruction of an ecosystem at a cost of 120 million dollars (*Courrier international*, n° 782, p. 28)

It was to improve the understanding of these interdependencies that the Millennium Ecosystem Assessment was launched by Kofi Annan in June 2001. Lasting for a period of four years, with 1360 scientists from 95 countries and an independent board of 80 people responsible for verifying the results of the research programme, its goal was to inform governments, NGOs, scientists and the general public about ecosystem changes and their effect on human well-being (MEA, 2003; Figure 4). This makes it the first large-scale program whose goal is the integration of the economic, ecological and societal issues involved in the conservation of biodiversity.

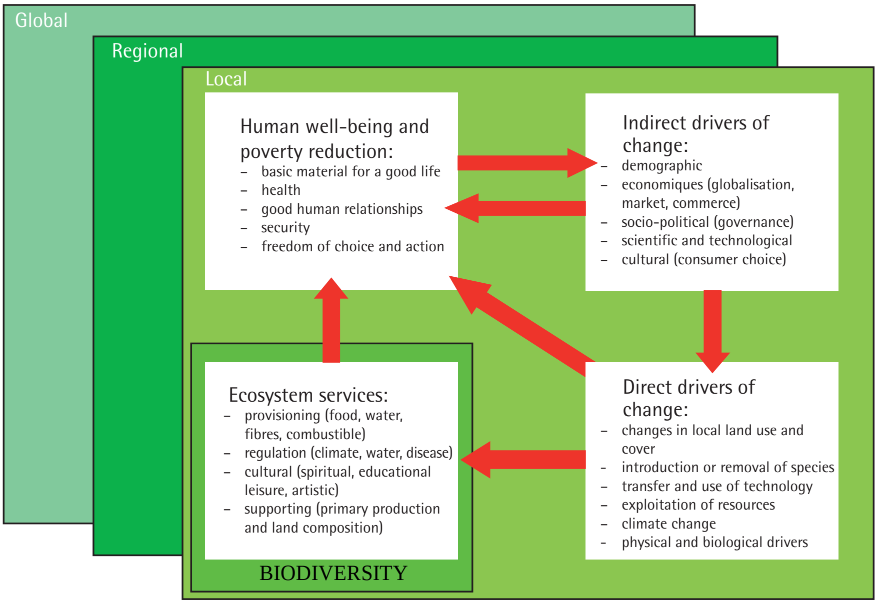
To perform this integrated assessment, the MEA analysed developments in ecological services over the last fifty years. The only services which increased were the provisioning services.

Between 1960 and 2000, world population doubled, going from three to six billion people. To cope with this explosion in human needs, major artificial components were introduced into ecosystems in order to adapt them to intensive extraction of food, fresh water, energy, wood, fibres, and other needs. These efforts were crowned with success: during the period 1960-2000, food production for the planet as a whole doubled; wood logged for the production of pulp and paper tripled; hydro-electric capacity doubled; the production of construction timber increased by more than 50%; the use of water doubled (MEA, 2005).

As a result, the average number of calories consumed per person per day for the world as a whole went from 2290 in 1962 to 2805 in 2002 (http://faostat.fao.org/faostat/); life expectancy went from 46 in 1955 to 65 in 2005; the infant mortality rate went from 157 children per thousand to 57 per thousand (http://esa.un.org/unpp/index.asp).

However, the benefits of this intensified use of resources were distributed very unevenly[36] and were accompanied by major depletion of 15 out of the 24 services inventoried by the MEA (Table 6).

Figure 4: Relations between biodiversity, ecological services, change factors and well-being



Source : MEA, 2005, pp.13-14

Table 6: Change in ecosystem services

Type of service	Services	Direction of change
Provisioning services	Agriculture	+
	Livestock	+
	Fishing	-
	Aquaculture	+
	Food gathered in the wild	-
	Construction timber	+/-
	Cotton, jute, silk	+/-
	Firewood	-
	Genetic resources	-
	Biochemical products, natural medicines, pharmaceutical products	-
	Fresh water	-
Regulatory services	Regulation of water quality	-
	Regulation of world climate	+
	Regulation of regional and local climate	-
	Regulation of the water cycle	+/-
	Regulation of erosion	-
	Water purification and waste treatment	-
	Regulation of disease	+/-
	Regulation of parasites	-
	Pollination	-
	Regulation of natural dangers	-
Cultural services	Spiritual and religious values	-
	Cultural values	-
	Recreation and eco-tourism	+/-

Source : MEA, 2005, p.46

36 The number of calories consumed per day in Africa is 2100 compared to 3400 in Europe (FAO); 800 million of the world's people still suffer from hunger (MEA); life expectation in Africa has gone from 51.5 years in 1985 to 49 years today (WPP); a child born in sub-Saharan Africa is 20 times more likely to die before the age of five than a child born in an industrialised country (MEA).

The 2005 report emphasises that 60% of ecosystem services are deteriorating. Among these, the renewal of fishery stocks and the production of fresh water seem to be the most threatened. This erosion has been more substantial during the last fifty years than in all of human history, and it will be even more substantial in the next fifty years. The inhabitants of the developing countries are directly affected by the threats resulting from the erosion of ecosystem services, and they bear most of the burden[37].

Based on its assessment, the MEA has developed a table showing the dangers expected over the next hundred years in the form of four scenarios. These scenarios were constructed using both the pooled opinions of experts on the "possible futures" of ecosystems, ecological services and human well-being, and global models which include the principal forces for change that impact ecosystem services[38].

The four types of scenario are as follows:

- "Order from Strength", which assumes that in a world of increasing risk, the solution will focus on security and protectionism. On this assumption, a fragmented world is organised into large regions split by conflicts of many kinds. Environmental problems are addressed reactively, in response to crises. Human and ecological risks increase globally. Economic growth is the weakest of all four scenarios, while population growth is the greatest.
- "Global Orchestration", which envisages an increase in the liberalisation of trade, as well as stronger global interconnections and the emergence of a world governance which will pursue a more effective war on poverty. The approach to the management of environmental crises is still a reactive one, resulting in serious risk from natural disasters for a large proportion of the population. This scenario leads to the strongest economic growth and the weakest population growth, with an increase in environmental risks to human populations.
- "Adapting Mosaic", which refers to a vision of the world in which governance moves not towards the global but towards the local level. A great diversity of local styles of ecosystem management will co-exist. Extremely strong emphasis is put on education and health. These dynamics correlate with local and diversified processes of "learning by doing", with varying degrees of success. The preferred political and economic decision level is the ecosystem and the large watershed. Out of these local experiences networks are formed to improve overall ecosystem management. However, there is no global-level governance. Economic growth is relatively weak at the beginning but increases after some time. Population growth is substantial.
- "TechnoGarden", which gives pride of place to ecological engineering and the integration of ecosystem services into the commercial sphere, in an approach that uses revolutionary technological change to reduce the use of physical resources and reach optimal management of ecological functions. Agriculture becomes multifunctional. Massive reliance on new technologies is instituted. Economic growth is considerable and population growth is average.

It should be noted that none of the scenarios results in economic decline or even in stasis. In contrast, all the MEA's scenarios, even the Adapting Mosaic, which envisages an increase in all the ecosystem services, predict the erosion of species diversity. There is thus no direct connection between change in ecological functioning and change in biodiversity as traditionally understood.

Three of the scenarios - Global Orchestration, Adapting Mosaic and TechnoGarden - conclude that at least one of the four types of ecosystem services will increase between 2000 and 2050. These three scenarios involve societal responses which require major innovations for the institution of sustainable development policies.

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37 As Carl Folke observes (2003, p.233), "In rich regions the resulting crises have led to spasmodic lurches of learning with expensive actions directed to reverse the worst consequences of past mistakes. In poor regions the result has been dislocation of people, increasing uncertainty, impoverishment and a poverty trap".

38 These scenarios were constructed in relation to the topics of globalisation and ecosystem management. Two different assumptions were used for each topic. With respect to globalisation, dynamics would be either regional or global. With respect to management, management would be either proactive or reactive. In all the scenarios, human pressure on ecosystems will increase for at least the first fifty years. The forces of change taken into account are: habitat change (changes in land use, physical alteration of rivers or extraction of water from rivers); over-exploitation; invasive species; pollution; climate change.

Global Orchestration envisages a "liberal" revolution in which agricultural subsidies are abolished. It incorporates an active commitment to the war on poverty. This leads to sustainable development from the societal point of view, but not necessarily from the ecological one. In Adapting Mosaic, the majority of countries substantially increase the share of their gross national product (GNP) devoted to education (from 3.5% of GDP in 2000 to 13% in 2050). In addition, there is a proliferation of institutions designed to support exchanges of knowledge and information about ecosystem management. In the TechnoGarden, technological and economic measures give rise to improvements in ecological engineering and the remuneration of individuals and companies who provide and maintain ecological services.

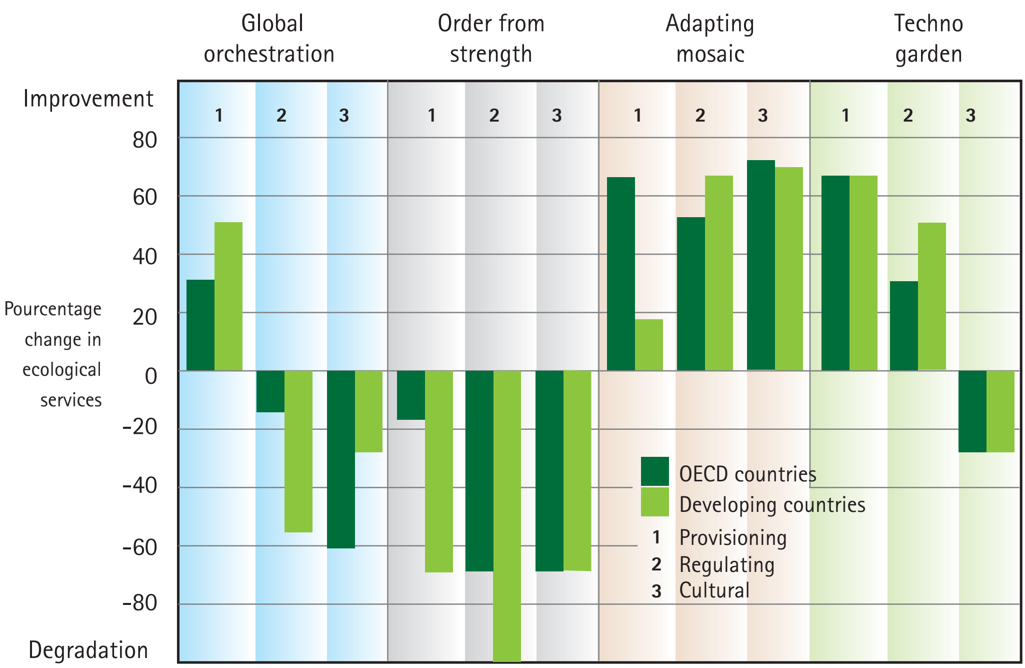
Thus, in MEA's view there are not one but three models of sustainable development (Table 7) and one truly non-sustainable model ("Order from Strength").

We can conclude by highlighting the principal strengths and weaknesses of the MEA.

The strengths are as follows (Levrel et al., 2007):

- An integrated framework for analysis which represents compromise reached by many scientists and provides benchmarks for analysing the interactions between issues of conservation and development.
- A description of society-nature interactions based on the concept of ecosystem services which is directed equally to the social sciences and to the biological sciences.
- A clarification of the meaning of the term "ecosystem service" and the production of an exact list of ecosystem services organised into four categories.
- An original approach using scenarios, through which interdependencies between political choices and global changes can be highlighted (even if these scenarios seem rather limited in both form and content).
- The initiation of shared research programmes on an international scale (for example, the launching of several "Ecosystem Assessments" in European countries since the publication of the MEA reports).

Table 7: Change in ecological services according to the four scenarios



Source : MEA, 2005, p.139

However, the MEA's experience shows us that the results reported in 2005 fall far short of the goals formulated in 2001, for several reasons:

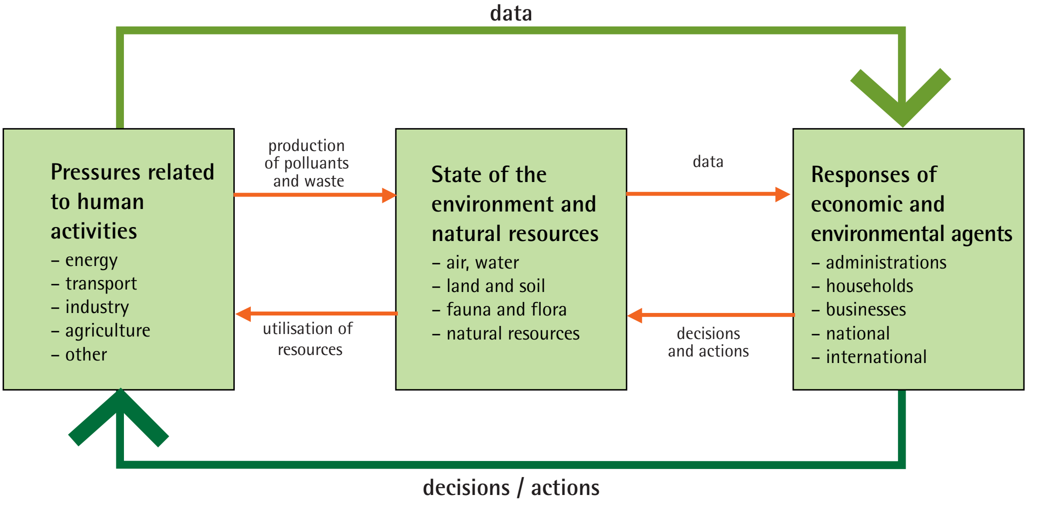
- The inactivity of the majority of the sub-global programmes, which simply failed to turn in their reports, thus preventing comparative analysis; this has forced the MEA to present results almost exclusively on a global level (although it calls for a multi-level perspective).
- The lack of standardised longitudinal data on the interactions, which led the MEA to adopt an approach focused on ecosystem services (without establishing a link with the three other components of the conceptual framework) and to draw on expert opinion to identify the connections between the direct drivers of change and change in ecosystem services.
- The weakness of the five volumes of the report on the "well-being" dimension, and the lack of consideration of the interactions between the four types of capital (produced, natural, human and social) which form the sources of human development.
- A conceptual framework that is adapted to identifying the interdependence between well-being and the state of renewable natural resources in developing countries (where the populations depend directly on the surrounding ecosystem services) but is less relevant for the OECD countries.

Indicators for the management of society-nature interactions

Pressure-State-Response Indicators

Pressure-State-Response indicators enable us to assess the pressures which human activities exert on biodiversity and to identify the societal responses which can compensate for the negative effects of these pressures[39] (figure 5).

Figure 5: PSR indicators



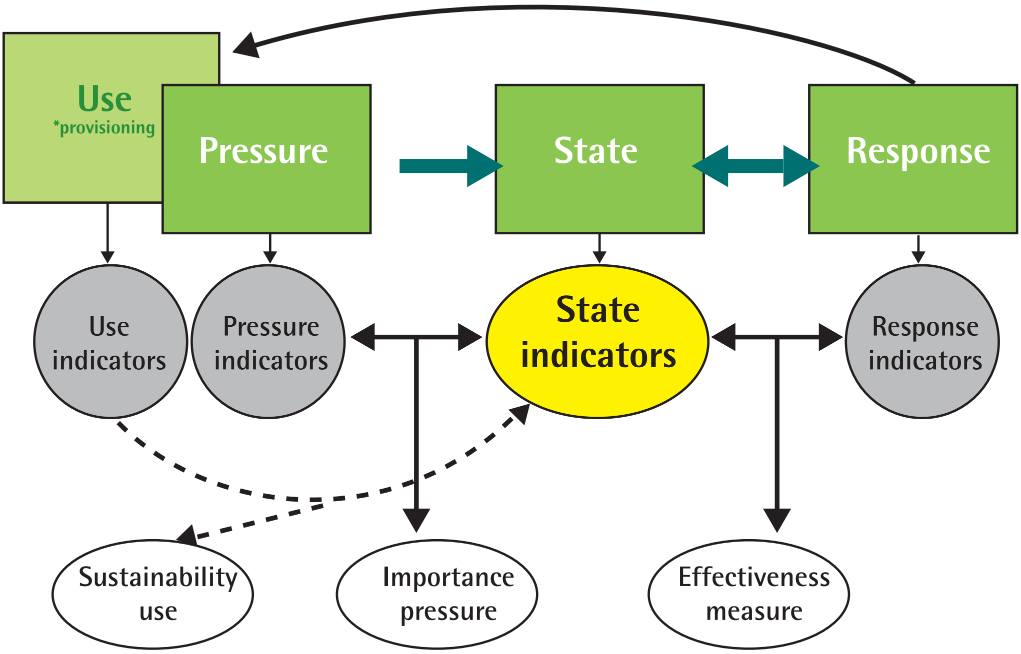
Source : OCDE (2001)

39 "The pressure-state-response framework is based on a concept of causality: human activities exert pressure on the environment and change its quality and the quantity of natural resources (the "state" box). Society responds to these changes through environmental, general economic and sectoral policies" (the "societal responses") (OECD, 1994, p.10).

These indicators were created by the Organisation for Economic Co-operation and Development during the 1990s (OECD, 1994; Lehtonen, 2002). Today PSR indicators play a key role in the field of indicators of interactions. They inspired the driving forces-pressure-state-impact-response indicators of the European Environment Agency (EEA, 2003), the driving forces-state-response indicators of the Commission on Sustainable Development (CSD, 2001) and the use-pressure-state-response indicators of the Convention on Biological Diversity (UNEP, 2003; Figure 6). These indicators represent the dominant frame of reference for illustrating society-nature interactions.

The intuitive character of this analytical framework has helped it become very well known, in particular among economists and ecologists, who see it as a relatively effective instrument for teaching purposes. The OECD recognises, however, that this analytical framework is flawed in that it suggests that relations between human activities and the state of biodiversity are linear, and thus understates the complexity of the interactions[40].

Figure 6 : The CBD Use-Pressure-State-Response indicators



Source : UNEP, 2003, p.34

In particular, in this framework biodiversity has to be characterised with reference to a "State", in which ecological interactions are not taken into account. Only humans act as a source of change within this framework, through the pressures that they generate and the responses they provide.

This model is also a source of several ambiguities (Couvet et al., 2007). Firstly, the response indicators focus on the measures society can take to slow down the erosion of biodiversity and not on the adaptive responses that biodiversity adopts to deal with human pressures. Nature is not dynamic in this information system.

40 "While the PSR framework has the advantage of highlighting these links – pressures and responses –, it tends to suggest linear relationships in the human activity-environment interactions. This should not obstruct the view of more complex relationships in ecosystems and environment-economy interactions" (OECD, 1994, p.10).

Another ambiguity affects the PSR classification. To take an example, overgrowth of open land by weeds as a result of the abandonment of agriculture, which affects "traditionally" open farmland, is considered by some a source of pressure on biodiversity and by others a state of biodiversity. The same applies to the density of deer populations in forest environments. Those involved do not use the same criteria to assess a "good state" of biodiversity or identify what counts as pressure. But the approach recommended by the PSR indicators does not leave room for this diversity of perspective.

The issue of the response indicators raises a second fundamental problem. If these indicators incorporate the best responses from the experts' point of view, then we are dealing with a normative instrument which effectively substitutes specialist opinion for citizen preference. However, the societal response indicators proposed by conservation organisations have never been put to the test of public discussion, and when one questions local people concerned with this issue it turns out that the responses they adopt to counteract the erosion of biodiversity vary considerably (Levrel et al., 2006).

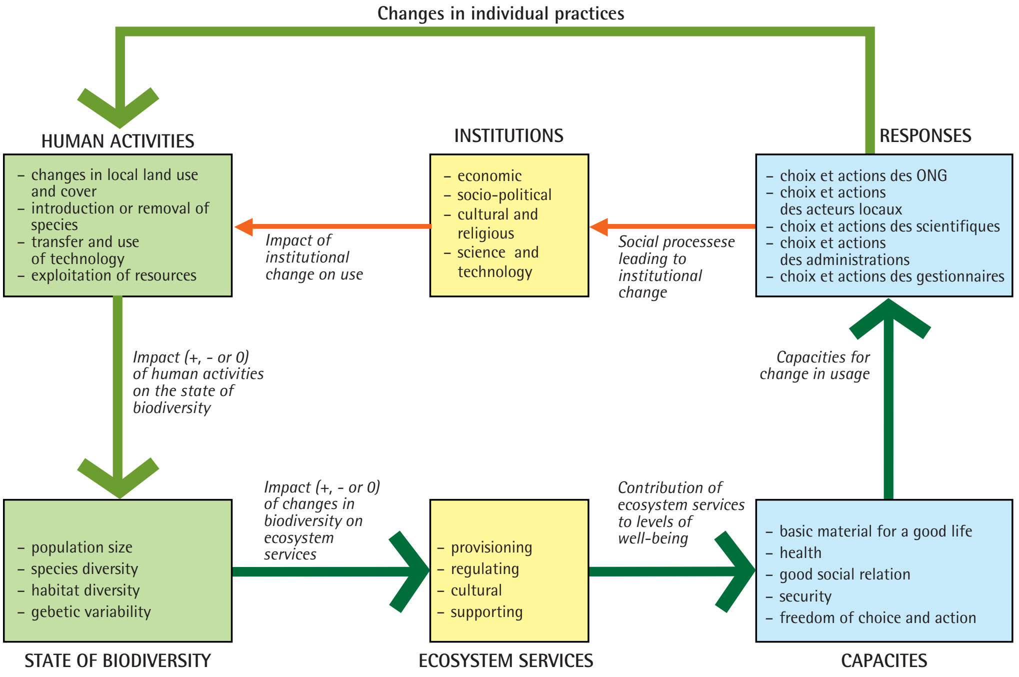
This diversity of responses allows us to highlight the political character of this category of indicators. The response indicators can only be of use to managers if they connect with other indicators which inform us about individual and collective capacities for response and also about the effectiveness of these responses. Capacities for individual response are significantly related to the degree of dependence of populations on the resources which they use. Capacities for collective response include the institutional and organisational capacities which enable local populations to take charge of managing the resources they depend on. Finally, the effectiveness of the responses will be largely a function of the legitimacy of the process which led to the adoption of the responses. These various elements depend on a great number of parameters, both economic (financial, human, technical and organisational resources) and societal (positive political will, the nature of local social relations, conflicting interests, status of the parties involved, institutions providing access, existing usage), which make it extremely difficult to identify response indicators.

Moreover, the tools for discussion and negotiation offered by the PSR indicators seem to be rather inadequate. This is due in particular to the fact that identifying pressures and responses leads to seeing some agents as responsible for the pressures and to adopting measures to implement the responses, to the disadvantage of the local people involved. Admittedly, these diagnoses are acknowledged to be necessary by the local people, but PSR indicators would distort rather than explain the reality of society-nature interactions at this level (Levrel et al., 2006). Thus, for example, in order to get local populations to change their behaviour, it seems just as important to emphasise the use of resources which are favourable to biodiversity or the capacities available to the local populations.

Another major problem with the PSR indicators is that they fail to provide a genuinely integrated instrument, because they exist in their own separate sector (CSD, 2001). The PSR model does not allow for the emphasising of interdependence between levels of well-being and the state of biodiversity; but it is by highlighting this interdependence that we can reach out to a great many people who are directly or indirectly dependent on biodiversity (Levrel et al., 2006).

On the basis of these various criticisms, we can propose a framework for identifying indicators of interactions which takes into account both the PSR indicators and the MEA framework (Figure 7).

Figure 7 : An alternative framework for identifying indicators of interactions



The eco-efficiency indicator

Another very successful indicator at present is eco-efficiency (OECD, 1998), which draws on the "energy" approach of Georgescu-Roegen (1979). This indicator aims to measure the intensity of matter consumed (in energy equivalent) per unit of service or goods produced (in economic equivalent). It depends on input-output eco-energy models (Beaumais, 2002), through which the effectiveness with which ecological resources are used to produce goods and services can be measured. Eco-efficiency expresses the ratio of the monetary value of resources used compared to the weight of these resources, and produces the formula EE = V/RC where EE is eco-efficiency, V the value produced and RC the natural resources consumed. This indicator relies on two concepts: the level of entropy of a system and the load capacity of the system (Hukkinen, 2003).

Concretely, through the application of EE calculations can be performed at the societal or nation-wide level, notably via a GDP that is de-linked from energy consumption. This should make it possible to compare alternative products, procedures or technologies based on a Life Cycle Analysis which assesses their respective impacts on the natural environment (CENECO, 1995). In the realm of biodiversity, ecological engineering ought to be a major source of eco-efficiency in the future.

The supporters of this approach argue that a reduction in the quantity of matter and energy that is consumed in production will make it possible to sustain dynamic growth without harming the natural environment. All that needs to be done is to introduce innovations which will replace technologies that consume a great deal of matter and energy by non-polluting technologies, and GDP growth will become sustainable. The eco-efficiency indicator thus expresses great faith in the capacity of technological progress and development to provide answers to the new demands of sustainability.

One problem, however, is that the goal of eco-efficiency is a reduction in the intensity of the quantities of energy and matter consumed in production, but not necessarily a reduction in the absolute quantity of energy and materials extracted.

A relative decline in consumption can in fact result in a total increase in raw materials consumed (Hukkinen, 2003). Then the positive effects of the decrease in pollution and extraction per unit are wiped out by the increase in the number of units produced. This phenomenon is called the rebound effect. This objection is confirmed by the facts: although technologies developed in the last twenty years definitely consume less energy, that has not prevented an absolute increase in the overall consumption of energy (MEDD, 2003).

Moreover, an improvement in eco-efficiency does not necessarily mean an improvement in traditional methods of production so as to make them less energy-intensive. Eco-efficiency can improve simply because new, less "material" sectors emerge, as for example in the case of the new information technologies.

Finally, the issue of entropy does not reflect the qualitative dimensions of system change - the diversity of the living world, for example - and this indicator provides a very limited model of interactions between society and nature, viewing them via a linear input-output graph (Hukkinen, 2003).

A technical problem also arises. Measuring eco-efficiency is often complex: If we want to know about the eco-efficiency of the production of a cheese, should we take into account the energy consumption related to the use of the manure which made it possible to produce the grass eaten by the cow? Moreover, converting units of input into their energy equivalent is not necessarily an easy task.

Principles, criteria and indicators

One of the most frequently used models of management indicators in the realm of interactions between human activities and biodiversity dynamics is the principles, criteria and indicators model (PCI) (Buttoud and Karsenty, 2001). The "principles" enable the establishing of broad management objectives. The "criteria" translate these objectives into terms of states and dynamics relevant to the system that is to be managed. The "indicators", finally, allow us to measure concretely the progress achieved. These PCI have been used especially in the domain of the sustainable management of forests (Centre for International Forestry Research, 2000; Inventaire National Forestier, 2005).

Table 8: The three major PCI systems

	Regionally based PCI systems		Global PCI system
	Boreal and temperate forest	**Tropical forest**	**All forests**
Ecology	Health and vitality of the forest ecosystem. Maintenance of protective functions	Maintenance of the primary ecological functions of the forest	Environmental impact Plantations
Production	A forest that is productive of goods and services	The forest is sustainably developed with the goal of providing goods and services	Benefits provided by the forests Management programme Monitoring and assessment
Socio-economics	Maintenance of other socio-economic functions	Forest management must contribute, for all those involved, to the improvement of the well-being of present and future generations	Community relations and workers' rights
Institutional aspects		Sustainable use of the forest and the maintenance of its multiple functions are a high political priority	Respect for the law Rights of indigenous peoples Security of tenure, rights to land use and responsibilities
Biodiversity	Conservation of biological diversity		Maintenance of forests with high conservation value

Source : Lescuyer, 2002, p.109

The goal of the PCI is to connect management practices with instruments for assessment of the impact of these practices. These instruments are thus intended for eco-certification managers and programmes. For example, one of the major current questions in the timber industry is how to justify ethical practices which promote sustainable management. In the case of biodiversity, the principles must establish broad conservation goals which relate to specific criteria such as the maintenance of diversity of certain tree species or the preservation of fauna which depend on forest habitats. Indicators are then associated with these criteria, so as to enable the measurement of progress achieved. The goal is to standardise practices and to develop indicators which make this process transparent. This standardisation aims at connecting basic ecological and societal standards with the practices of forestry development.

An initial problem is that of the legitimacy of the sources of PCIs and the meaning of "sustainable forest management" (Dudley et al., 2005). There are three groups of PCIs (Lescuyer, 2002), corresponding to three approaches to sustainability. The first relates to boreal and temperate forests. It seriously attends to the issue of conservation of biodiversity. The second relates to tropical forests, and its primary goal is to strengthen the institutional dimension of forest management in the developing countries, especially by taking into consideration the local inhabitants who are largely dependent on forest resources. Finally, a global PCI system seeks to create a degree of co-ordination between the Northern and Southern PCIs. This system has strong support from the NGO and industrial sectors because it would ensure consistency at the level of international markets (Table 8).

Another problem is that standardisation creates a risk of uniformity of usage, which could lead to the homogenisation of biodiversity in a context where there still exists a great deal of uncertainty about the real effects of management practices on the biodiversity of forest environments (Dudley et al., 2005; Gosselin and Laroussinie, 2004; Lindenmayer et al., 2000).

Moreover, standardisation is primarily driven by demand from consumers in the West. This is why the implementation of these PCIs can be a source of danger for developing countries. They are threatened by a dual exclusion from the timber markets of the West (Lescuyer, 2002). The first form of exclusion affects the tropical forests (which are more threatened), which the large timber businesses may abandon in favour of the boreal and temperate forests. The second affects the companies in developing countries who do not have the means to pay for the external audits which lead to the development of a PCI. This in turn gives a decisive advantage to the multinational timber companies, who are the only ones capable of assuming this substantial fixed cost with a view to deriving comparative advantage from it in the medium and long term.

Results indicators

Another category of management indicators is the results indicator. These indicators are much influenced by the business world and its audit systems. They are supposed to provide information on the good governance of protected areas. The primary function of results indicators is to verify whether planned objectives have in fact been achieved and whether it is possible to move on to a subsequent stage. The development of the implementation of a plan is thus related to the validation of these results indicators. These indicators are mainly used by funders to oversee a programme's progress.

The idea is that projects can be funded in stages, depending on the progress of these results indicators. Managers must thus fulfil goals for the production of species, ecosystems or ecological functions: in short, they must be effective.

It has become quite clear that the protected natural areas created around the world have not always fulfilled their conservation functions very well, generally for lack of means to do so. The top priority for conservation organisations is therefore to secure these protected areas by implementing the effective management of biodiversity.

It was with this in mind that the World Bank/WWF Alliance for Forest Conservation and Sustainable Use was created. The goal of this "alliance" is to address the problem of continuing erosion of forest biodiversity and of the renewable natural resources needed for the sustainable development of Southern countries. It is in this context that the WWF and the World Bank (2003) have introduced results indicators for evaluating the management of natural areas.

These indicators are based on an analytical framework produced by the World Commission on Protected Areas (Hockings et al., 2000), whose goal is to standardise the systems for evaluating the management of protected areas. This analytical framework is based on the notion that good management of protected areas must proceed through a series of required stages: a local diag-

nosis, which should lead to a sound understanding of the context; the introduction of a management plan; the allocation of financial, human and organisational resources to implement this plan; the performance of conservation activities; the eventual production of goods and services; the evaluation of the results with respect to the management plan.

To evaluate these various stages concretely with the use of simple indicators, the World Bank and the WWF introduced indicators to monitor the effectiveness of the management modes (the Management Effectiveness Tracking Tool). The guiding concern in the development of these indicators was simplicity and comprehensibility: they had to be filled out very quickly by non-specialists. There was no plan to make geographical comparisons, because these organisations believed that the diversity of the contexts (in the resources available, infrastructure, political situation, etc.) would render comparisons impracticable.

These indicators are divided into two groups. The first group serves to contextualise the protected areas, with indicators providing key information on the site (size of the area, threats, priority conservation goals, the authority responsible for management, etc.). The second relates to the actual evaluation of the management of the protected areas. We focus here only on the second group.

The indicators draw on 30 simple questions about the management of the protected zone. The indicators correspond to the points which can be awarded in answer to the questions. The scores go from 0 (poor) to 3 (excellent). Each individual point corresponds to a particular description of a situation. Comments can also be added, so as to incorporate the managers' opinions and any explanations needed. The points are added up to obtain a final score (Table 9). The final score must then be weighted according to the number of answers given.

The great - and only - advantage of these indicators is that they are extremely simple and quick to use, thanks to the scoring system.

Their major problem is that the surveys are filled in by the managers themselves (often by only one person), which is contrary to proper auditing principles. It is thus impossible to assume that the scores are objective, especially as the organisations which finance the surveys represent major funders of protected areas. It would be much better if they were filled in by one person, or one group of people, who could go from reserve to reserve and thus perform a true external audit. Indeed, since these indicators are extremely subjective, the only way to standardise them is to have the same people doing the evaluations - people who, needless to say, are impartial with respect to the management issues concerned. This approach is being adopted more and more by the majority of funders to evaluate results at the termination of funded programmes. The problem is that the evaluators in question generally have a very poor knowledge of the contexts and thus are limited to assessments based on a list of multiple choices which are often difficult to select following a standardised system.

Another problem with the results indicators in the realm of biodiversity is that conservation programmes often seek to protect emblematic species such as the large mammals, which is why they base their results indicators on the abundance of these species. However, to suppose that the results of a conservation programme lasting only a few years can be evaluated using indicators of changes in populations of large mammals is unrealistic: these populations cannot respond to conservation policies in such a short time-frame. This point is often taken into account insufficiently, if at all.

Table 9 : An example of questions, multiple-choice answers and points used to monitor the efficacy of styles of management of protected areas

Questions	Multiple choice	Points
Managers' ability to apply the regulations for access and use (question 3)	Managers are unable to apply regulations for access and use	0
	Managers lack the resources to apply regulations for access and use	1
	Managers are able to apply regulations for access and use but there are deficiencies	2
	Managers have the needed capacity to apply regulations for access and use	3
Existence and implementation of a management plan (question 7)	There is no management plan	0
	A management plan is being prepared or already exists but has not been implemented	1
	There is a management plan but it is only partly implemented due to a lack of means to do so	2
	There is a management plan that is being implemented	3

Source: World Bank/WWF, 2003

Section 3:

Technology democracy and the development of indicators for the adaptive co-management of biodiversity

Evaluating indicator quality: the issue of trade-offs

The criteria selected by the OECD (the organisation which has done the most work on indicators) to evaluate indicator quality are political relevance, analytic robustness and quantifiability. These headings can be expanded using the six criteria officially accepted by the Statistical Programme Committee[41] (Desrosières, 2003a):

1) *Relevance*, meaning a good fit between the instrument and the needs of the user.
2) *Precision*, which demands a close relation between estimated values and actual values.
3) *Currency* and *punctuality*, which relate to decision-making schedules.
4) *Accessibility* of the statistical data and clearness of the forms for the use of decision-makers.
5) *Comparability* of the data.
6) *Consistency*, which relates to the method of standardisation of the data and to the interpretations that these data lead to.

This approach is the one we find in the majority of institutional reports; it makes it possible to standardise the instruments that the indicators represent. The problem is that there are many conflicts between these evaluation criteria. Let us take one example from the social sciences.

Constructing an indicator of international scope requires that the criteria of quality be adhered to at the international level. This is what the World Bank's extreme poverty indicator seeks to do (this is the proportion of the population living on less than $1 PP[42] per day). This indicator responds to a frequent request from international development organisations, who need an indicator to assess the results of their war on poverty programmes and to compare the situations in various developing countries. However, while it answers the need for a realistic picture on a global scale, it produces a completely unrealistic picture on a local scale, whether because of unavailability of data or problems with the chosen criteria of equivalence (the principle of economic poverty is not very relevant for characterising poverty in regions where monetary exchange is infrequent). It appears that there is a real conflict between different levels of realistic representation, which in turn implies that the criteria of quality of the indicators will vary depending on whether the scope is national, international or local. This explains why the majority of the indicators fail to take context into account and why these indicators are often (rightly) perceived to be not very useful as technical-administrative instruments.

This problem of scale also concerns the time-frame of decisions. Decision-makers do not all operate with the same time periods. Some need indicators to convey their message, others need them to manage events over various periods of time, meaning that they work under different temporal constraints. This time-frame problem expands when a multidimensional approach to a complex phenomenon is called for. In the case of poverty, moving from a purely economic description to a multidimensional approach, as proposed by the United Nations Development Programme (UNDP), led the UNDP to produce a Human Development Indicator (HDI) in which change is difficult to interpret. The HDI is composed of life expectancy, the GDP per inhabitant and the illiteracy rate (UNDP, 1990). However, change in life expectancy within one country can be assessed only on a generational scale, whereas change in the GDP can be very rapid. Change in the HDI is thus difficult to interpret, due to the incompatibility of the normal time-frames of the three variables which it comprises. It is also very tempting to initiate development policies which affect short-term variables, so as to show quick results in the reduction of poverty, even if the policies in question do not solve the problems of those parameters which change over the medium or long term. The same problems arise in the case of many of the composite biodiversity indicators. For example, the Living Planet Index (LPI) tracks changes in the size of 3000 populations of vertebrates whose life-cycles are very different. From a political point of view, it

41 The Statistical Programme Committee consists of the Directors-General of the National Statistical Institutes of the EU countries and the Director-General of Eurostat.

42 Purchasing Power Parity.

can make sense to give priority to protecting those populations whose life-cycles are shortest, so as to see rapid improvement in the indicator.

To sum up, the conflicts between the criteria of quality of indicators can be defined as follows:

– A first source of conflict is the level at which the indicator is realistic and hence applicable. The real character of a phenomenon varies depending on its scale, as we have just emphasised. With respect to biodiversity, the real situation is different on a local or global level, in the short run or long run, for an ecologist or a hunter. So to try to develop a realistic, applicable indicator of biodiversity on the level of the biosphere and for the use of international organisations means accepting that this indicator will probably be unrealistic on a local level, since it will not be representative of local biodiversity nor sensitive to its changes nor in harmony with the experience of the local people involved. Conversely, an indicator adapted to a local reality will not be easily scalable to a global level. But an indicator always refers both to a *universal dimension* through which it can compare various situations - geographical, temporal or symbolic - and to a *contextual dimension*, due to the fact that it has been devised with reference to some specific geographical, temporal or symbolic level.

– A second source of conflict is that indicators always have both a *political and scientific dimension*. The political dimension means that an indicator must be comprehensible by a large audience; that is, it must be possible to derive simple information from a simple indicator. The scientific dimension means that the indicator in question must be able to provide an instrument of verification and that the interpretation of the information transmitted by the indicators must be carried out cautiously. This is accomplished especially via the use of meta-data through which we can see which conventions the indicator is based on and how these conventions have been selected. But if its users really pay attention to the scientific issues, this limits the simplicity and the effectiveness of what can be said about the indicator to a general audience. This is why indicators' "scientific" flaws are often quickly forgotten.

– The last source of conflict arises from the conventional (or subjective) versus the real (or objective) character of the indicators (Desrosières, 2003b). Indicators are approximate instruments, which makes them partial (in both senses of the term) tools of information. This is why they are often sharply criticised, in particular by scientists. However, indicators also provide intermediate or boundary objects[43] which allow people from extremely different communities of practice to discuss a given subject together[44]. To deprive ourselves of them would be to deprive ourselves of tools which foster public debate. To question them is useful, but to overemphasise their arbitrary character would risk destroying all confidence in them and eventually the loss of a useful tool for debate. As Paul Valéry once said, "whatever is simple is false and whatever is complicated is unusable"[45].

This is why constructing an indicator requires above all accepting trade-offs between these inherent conflicts.

These trade-offs have to do with three aspects of an indicator:

- The *functional* aspect: like any other instrument, an indicator has a primary function, associated with its specific use. The statistical data generated when a phenomenon is monitored become an indicator only if they are used. An indicator provides synthetic information about a precise object in verbal and/or visual form, in order to represent, act upon, or convey information about some phenomenon. These three functions are always present in an indicator even if one of them takes priority over the others. The

43 "Boundary objects are objects which 'inhabit' several communities of practice and satisfy the information needs of all of them. They are thus sufficiently flexible to adapt to local needs and to the constraints of the various users, but also robust enough to retain a consistent identity across locations. With respect to their shared use they are weakly structured, but they become strongly structured when they are used at a specific location. They can be both abstract and concrete" (Bowker and Star, 1999, p.297, quoted by Desrosières, 2003b, p.6).

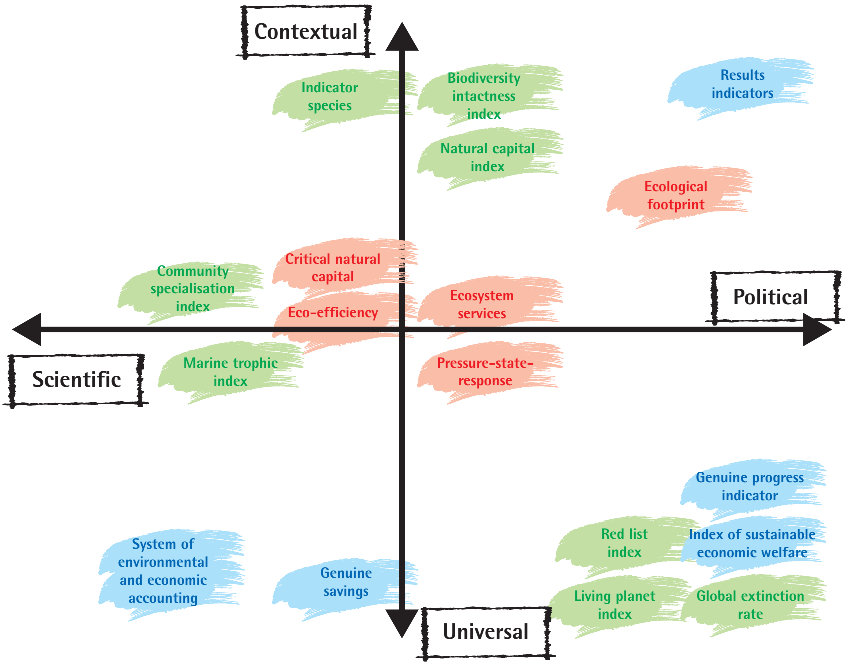
44 For example, indicators of unemployment, in spite of their flaws, provide essential tools for initiating and stimulating public debate on the issue of employment. They provide a common language for talking about the issue.

45 I would like to thank Laurent Mermet for this quotation, which I think sums up very well the constraints which anyone who constructs indicators has to deal with.

future use and users of the indicator must be specified before it begins to be constructed. The indicator's function is related to the identification of certain needs, and the trade-offs which will structure its design must be guided by the expression of these needs[46]. Thus an indicator whose primary function is to communicate information on some short-term topic at an international level will not be required to comply with the same restrictions as an indicator whose primary function is to provide an instrument for the long-term management of an ecosystem.

- The *instrumental aspect*: an indicator is an instrument composed of two things - a mechanism of synthesis (aggregation, averaging, weighting, etc.) through which a great deal of information can be summarised, and an interface (with charts, different colours, etc.) in which verbal and visual signals convey the synthesised information. The mechanism needs to be as precise and the interface needs to be as understandable as possible. The signals must be appropriate to the modes of understanding of future users, so as to be easily grasped by them. The indicator is thus an instrument which can take on a variety of forms. To be effective, its form must be adapted to its function, like any tool. It must be adjusted to the capacities of the potential users, so that the synthesised information can be easily extracted.
- The *constructivist aspect*: an indicator is a tool constructed using a particular method which requires a division of labour (data collectors, biodiversity experts, statisticians, etc.) and a decision-making process (negotiation, mediation, dialogue, validation, etc.). It is the combination of these two features which leads to the adoption of conventions for the indicator (units of measurement, geographical level of reference, mechanism of synthesis).

Figure 8: The positioning of indicators of interactions with respect to the conflicts between the scientific/political aspects on the one hand and the universal/contextual aspects on the other



46 The same is true for the construction of any tool. The process starts with identifying the needs of the tool's potential users in order to define the precise functions it must fulfil. Trade-offs are made between the conflicting properties required so as to fulfil the expectations of the users - lightness vs. solidity, precision vs. ease of use, variety of functions vs. suitability for some specific functions, etc

The criteria of quality of indicators must therefore pay attention to the way in which the trade-offs are made

These trade-offs must be guided by a desire for consistency. To establish a "good" indicator means first and foremost that the function, the form and the method of construction share some degree of consistency. It is especially crucial to adapt the indicator's equivalence levels and interface to the level of reality where the users' needs are located. To clarify, let us take an example. The most emblematic and most discussed biodiversity indicator today is the global rate of extinction of the Earth's species (Balmford et al., 2003; Thomas et al., 2004). This indicator is a very imperfect way to monitor or manage biodiversity, as we emphasised in Section One, but it makes a good indicator for communicating the threats to biodiversity today. It answered a specific need: to sound the alarm about changes in the state of biodiversity. Its purpose was not to provide an effective tool for monitoring biodiversity but to energise public opinion. Its primary function is to inform a large audience about threats to biodiversity. The trade-offs affecting this indicator are thus weighted in favour of its universal, objective (extinction) and political aspects (Levrel, 2006). The form matches the function, since the rates and curves are easy to understand.

These trade-offs were adopted, more or less implicitly, by the inventors of the indicators of interactions which we mentioned in Section Two, as is shown (in simplified form) in Figure 8. In this figure, the green indicators represent an ecologically-focused approach, the blue ones an economics-focused approach and the red ones a more cross-disciplinary perspective.

What this sub-section has demonstrated is that the key to preserving an indicator's consistency is to start with its function. Doing this, as we explained above, requires first identifying the needs of the potential users.

Adapting the indicators to the users' needs brings us back to the relevance criterion established by the Statistical Programme Committee. In spite of the fuzziness of this criterion, some working groups are defining the criteria for assessing the relevance of the indicators of primarily socio-economic phenomena - poverty, unemployment, wealth, etc. The problem is that these European working groups are mainly composed of metrologists, in most cases statisticians, who have a narrow conception of the problems of relevance (Desrosières, 2003a). As a result, the debates on this subject generally turn on technical questions and reduce to discussions of the statistical conventions for aggregating, weighting, or acceptable margins of error.

More general questions about the relevance of indicators and information systems seem to attract little attention. In fact, no investigative work is being done to assess the fit between the tools produced and the needs of their users, whether political decision-makers or members of civil society (Desrosières, 2003a).

Constructing biodiversity and interaction indicators on the basis of needs

The subject of needs is often little discussed in the reports of organisations responsible for the production of biodiversity indicators.

Biodiversity indicators are often discussed by way of the "control panel" metaphor which imagines a "rational manager" piloting a society-nature system towards a desirable goal - sustainability. However, the reality is quite different.

If we go back to the example of the management of forests in France, brought up in Section One, we see that the number of entities who intervene in the decision-making process is substantial: the State as the owner of the national forests, communities in forested regions and the Fédération Nationale des Communes Forestières de France (FNCOFOR) which represents them, the Office National des Forêts (ONF) which manages state- and community-owned forests, forest landowners and tree-growers represented by their own national organisation (the chief representatives of private owners, who own 74% of forests in France), private managers working for these latter groups, co-operatives and their national union, hunters, environmental protection organisations, forestry experts, the Société Forestière de la Caisse des Dépôts et Consignation, local political leaders, the Fédération Nationale du Bois (FNB), the administrations of the MEDD and the MAP, to mention only the principal ones. Introducing the issue of the conservation of biodiversity in forest environments requires attending to the needs of all these concerned groups.

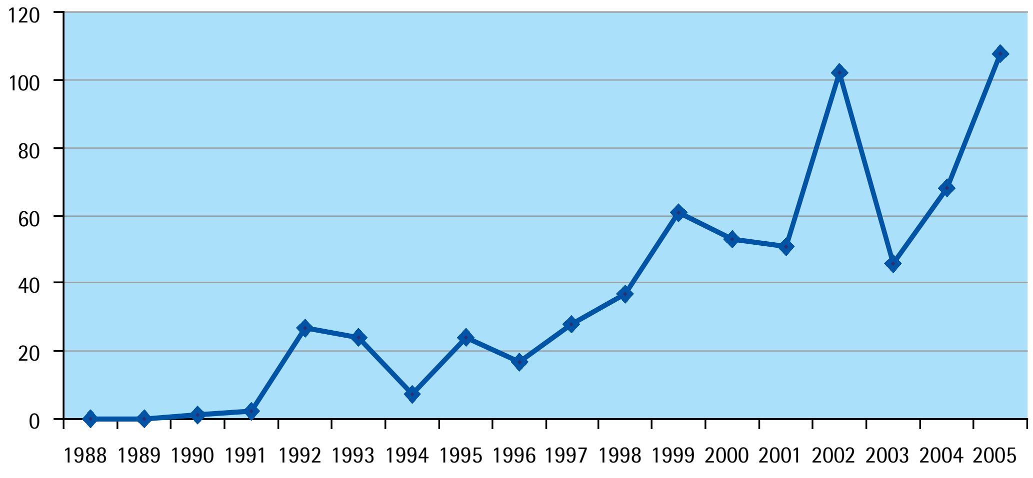
There thus exist many diverse entities who relate to each other in many ways - but rarely on an equal footing - and whose goals and available means for implementing these goals are very varied. This is still true when we consider only those goals which bear upon the issue of the conservation of biodiversity (Westley et al., 2002; Weber and Revéret, 1993). The first step in questioning the quality of the indicators from the point of view of users' needs is therefore to admit that there is no such thing as a rational planner who can direct a system of society-nature interactions along an optimal trajectory by using a set of indicators which have been scientifically validated and organised in the form of a "control panel".

The subject of needs must thus be rephrased in terms other than those adopted up until now. In fact, the demand for biodiversity indicators has emerged at the same time that this subject has become a societal concern (Boulanger, 2006; Dewey, 1927). A societal concern comes into existence when a public arena develops to address it. These public arenas are concerned, for example, with employment, the economy, immigration, culture, or the environment. Is there a public arena focused on biodiversity?

The concept of biodiversity is a recent one and refers to a complex reality. It developed between 1985, the date when Rozen proposed the term, and 1992, the date of the Rio Conference. It is complex because it refers, as we have said, to various inter-connected levels. Taking such a concept on board is not easy, and it is not obvious that there exists a "societal concern" around the concept of biodiversity.

To determine whether this is the case, we propose to show the development in the volume of publications dealing with biodiversity, in order to reach an estimate of changes in demand for written information on the subject, which can be regarded as the precondition for requests of a more formal and quantified nature. To do this, we have inventoried the number of articles published by the newspaper Le Monde during the period 1988-2005 in which the word "biodiversité" appears[47] (figure 9).

Figure 9: Number of articles appearing in Le Monde in which the word "biodiversité" appears

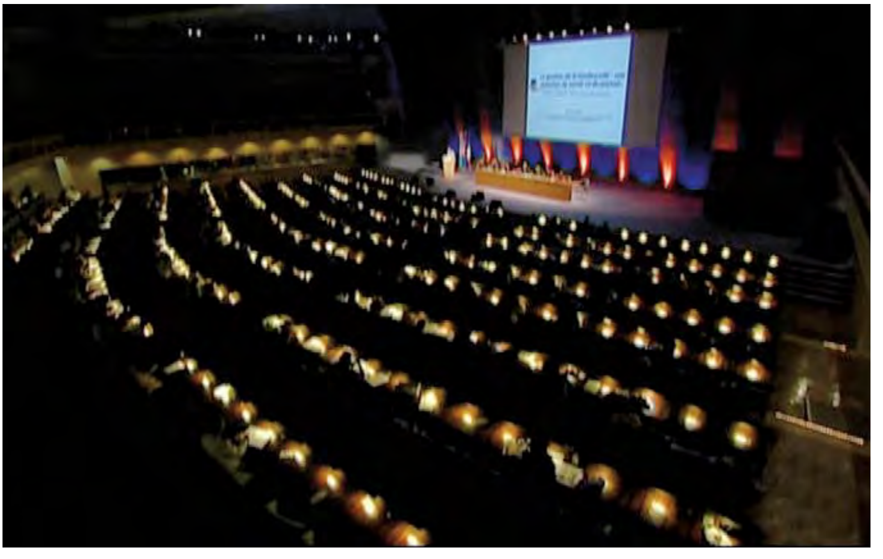


Source: http://www.lemonde.fr

47 http://www.lemonde.fr/web/recherche/1,13-0,1-0,0.html

The "societal concern barometer" that these numbers may indicate reveals several things. Firstly, this demand has really emerged since 1992 (27 publications in 1992 compared to one in 1990 and two in 1991), the date of the first conference on sustainable development, held in Rio, at which the concept of biodiversity played an important role. Demand increased in the following years and reached its peak in 2002 and 2005, with respectively 102 and 108 articles published in *Le Monde*. 2002 was the year of the second major UN summit on sustainable development, held in Johannesburg, and 2005 was the year when an international summit on biodiversity was held in Paris.

This change in the number of publications leads to the conclusion that the concept of biodiversity has been the object of media and political attention during the past fifteen years, implying in turn the presence of societal concern with the subject.



International Conference " Biodiversity, Science and Governance", Paris, January 2005

In becoming a societal concern, the concept of biodiversity has generated interest and gone through a series of changes resulting from the interplay of various alternative understandings of the concept and resulting in greater conceptual coherence. These stages can be described as follows (Seca, 2002):

- The complexity of the subject to be defined, and the multiplicity of perceptions it can give rise to, generated a *dispersal* of the interpretations and information relative to it. Ecologists, taxonomists, hunters, local naturalists, managers, geneticists, economists, etc. all have access to their own specific information and interpretation of biodiversity.
- Because of the impossibility of reaching a single exhaustive account of biodiversity, some of its emblematic features (as direct functions of the understandings of the people and groups concerned) were selected and emphasised: population, diversity, landscape, gene, abundance, taxon, species, interaction, or service, are emblematic features which relate to the concept of biodiversity.
- The need for action, communication and justification with respect to this complex subject created a "*pressure to define*" which gave rise to discussions, definitions, evaluations and processes of validation whose ultimate purpose was to reach a formal consensus on the content of the concept of biodiversity and the best way to define it. Species richness, red lists, population viability, landscape variety, size of the trophic network, genetic variability and ecological services could all thus be understood as indicators of biodiversity.

There are three key phases which work to define the formation of a public arena from a political perspective (Dewey, 1927): problematisation (discussion and the construction of a shared discourse), institutionalisation (reaching consensus on the major issues relating to this arena) and dissolution (disappearance of a public arena as it is replaced by new arenas).

Paul-Marie Boulanger (2006) proposes a theory of indicators drawing on these three phases. During the problematisation phase, many indicators co-exist and there is no clear justification for using one rather than another. During the institutionalisation phase, the use of a limited number of indicators by various political decision-makers is a major ingredient in the structuring of the arena. Finally, in the period of dissolution, the indicators are used as instruments to resist dissolution.

During the problematisation phase, the indicators function as instruments for the justification of differing perspectives and are often used in ways that we might call "activist". During this phase they provide the tools for processes of negotiation among various parties which will result in the dominance of a specific interpretation of the concept. In the case of the indicators of society-nature interactions, for example, competing indicators of sustainable development support either strong sustainability (Ecological Footprint) or weak sustainability (Genuine Saving). The vast majority of the population is unaware of the existence of these indicators and does not view them as important.

We may say that today biodiversity indicators belong to an arena which is still in the process of problematisation. We are in a phase when constructivist criticisms are generally dominant. Competition between the various biodiversity indicators reflects competition between various interpretations of the phenomenon of biodiversity, and thus helps to define its contours in an increasingly precise way.

This problematisation phase corresponds to the period of increasing conceptual coherence which results in the three stages that we have just defined: dispersal of information, focus on a limited number of parameters, pressure to define. During these successive stages, the indicators develop simultaneously with the interpretations and information available. Interpretations, information and indicators influence each other reciprocally as they construct a public arena for biodiversity.

It is when the "pressure to define" phase is over that we can say that a new phase appears, that of institutionalisation. During the institutionalisation phase, the interpretations and indicators related to the concept in the public arena are in harmony. The indicators have become tools of public policy, in that they provide benchmarks which help in decision-making and they enable the monitoring of the results of political measures, but also in that they validate results relating to the indicators. They are therefore utilised a great deal. They are subject to much scientific criticism, but they also become very widely known. Current examples include the indicators of unemployment and of GDP growth (Desrosières, 2003b). The process of institutionalisation can however take time, as Paul-Marie Boulanger (2006) emphasises. The unemployment rate took about sixty years to be accepted by politicians as a key indicator. It began to be elaborated in various forms during the 1880s and was not really used until 1946 in the United States, in conjunction with the Employment Act, which established political goals based on a reduction of the unemployment rate.

This example highlights an important point: it is perhaps too soon to introduce biodiversity indicators which will actually be utilised.

This hypothesis can be supported by reference to experiments undertaken in the field of sustainable development. The introduction of Indicators of Sustainable Development (ISD) in France, Belgium and Switzerland ended in failure (Boulanger, 2004; De Montmollin, 2006; IFEN, 2001a, 2003; Lavoux, 2006); they did not generate any public or political attention when they were introduced, online information about them is rarely if ever consulted, and their publication caused no interest in the media.

However, there is some evidence that things are changing. First of all, sustainable development has become a major social issue and has led in France to the initiation of the Stratégie Nationale pour le Développement Durable[48] (Medd, 2003a). This suggests that the institutional context can

48 We may even hope that a law on sustainable development may be passed, as one has been in Quebec, for example.

change very quickly and that the demand for monitoring tools for the policies which have been adopted is becoming more and more insistent. Thus, the Centre d'Analyse Stratégique (formerly called the Commissariat Général au Plan[49]) asked an interdepartmental working group (the "Equilibres" group) to analyse "the strategic role of the State vis-à-vis the issues posed by sustainable development". One of the group's priorities was to work on the ISDs (Ayong Le Kama et al., 2004). This work represents a real change in politicians' relationship to the question of the ISDs. The ISDs developed by the Institut Français de l'Environnement (IFEN) between 1996 and 2003 were in fact commissioned by the Ministry for Ecology and Sustainable Development in the context of the introduction of ISDs by the UN Commission on Sustainable Development. Today, the ISDs are commissioned within a much broader and more concrete context, thanks to the Stratégie Nationale pour le Développement Durable.

The same is true in the field of biodiversity. The initiation of a National Strategy for Biodiversity should make it possible to translate the goals of the CBD into concrete action, that is, to halt the erosion of biodiversity between now and 2010. However, to assess the progress achieved during this period requires above all that we have indicators for monitoring biodiversity (MEDD, 2004).

Further, we should note that even if the publication of these ISDs did not generate excitement, thematic indicators dealing with agriculture, biodiversity, or energy consumption have nonetheless been covered in the media (Lavoux, 2006). Each time, a "tangible" reality is present beneath the conceptual one. Admittedly, the scope of these realities is often debatable and difficult to determine, but all the same they "speak" to people. Thus in 2002 the publication by the Muséum National d'Histoire Naturelle of indicators of change in common bird populations in France was widely covered in the media (Levrel, 2006).

There is clearly also a demand for indicators during periods of crisis (Mirault et al., 2006). What concerns us in the context of biodiversity management is the extinction crisis which the Earth is facing today and which it is likely to go on facing tomorrow, with all the consequences that this might entail for the ecosystem services we use. The main thing is that the indicators enable us to recognise future crises as far as possible.

49 The task of the Commissariat Général au Plan was to identify the policy areas in which the State, as the protector of the general interest and the public good, will play a major role in the next 10 to 15 years.

Another essential element is that people use a wide variety of informal indicators to make decisions in daily life (Levrel et al., 2006). As a result, a demand for indicators can arise if these relate directly or indirectly to daily activities.

Finally, instead of waiting for the demand for biodiversity indicators to arise by itself, we can try to stimulate it by way of an interactive construction process involving scientists and communities of practice concerned with biodiversity management. It is by working and discussing collectively that needs are clarified and demands are formulated.

To grasp the needs of the users of biodiversity more accurately thus means taking account more fully of the complexity of collective decision-making processes with respect to society-nature interactions. This is what is proposed by the adaptive co-management of biodiversity.

Towards the adaptive co-management of biodiversity

One reason why development policies have often caused natural disasters (as in the example of the Aral Sea cited above) and why biodiversity conservation policies have often had only modest success is that scientists and decision-makers have failed to take uncertainty and complexity into consideration (Holling and Gunderson, 2002; Ludwig et al., 1993; Passet, 1996).

Refusing to take uncertainty into consideration is justified, from a scientific perspective, by the fact that the enormous complexity of the dynamics of change is not comprehensible and that it is therefore useless to adopt a systemic perspective (Kinzig et al., 2003). It is better to continue to develop partial but "true" knowledge than to seek to integrate many dynamic parameters which cannot be made fully explicit. Moreover, politicians want clear explanations, which are hard to provide when they have to be based on complex information.

This is why even today science is often reductionist, analytical, mechanistic and rationalistic, even though the subjects it investigates are polymorphic, systemic, complex and controversial (Passet, 1979; Morin, 1996; Benkirane, 2002):

- *Reductionism*, which seeks to establish strict boundaries between disciplines, comes out of a philosophical tradition in which science is viewed as objective and neutral, unlike the rest of society. A scientific approach here means a discipline-based approach.
- The *analytical method* consists of separating and isolating the parts of a whole in order to be able to study them more effectively. The underlying assumption is that the whole is the sum of the parts, so that aggregating micro-level dynamics leads to understanding macro-level dynamics.
- The *mechanistic* view of science derives from Newtonian physics, which assumes that a perfect understanding of dynamics can be achieved starting from a number of limited and known laws. From this perspective, the world functions like a clock and irreversibility does not exist.
- The *rationalistic* approach is based on the idea that all information about the state of the world is accessible and that all phenomena are subject to the laws of probability, which makes it possible to predict future events in order to adopt optimal societal responses (for economists this means using the criteria of the least cost or maximum utility).

In this paradigm, questions of global threat (which affect biodiversity in particular) are addressed via a process of risk assessment. This process requires identifying the sources of the threat, the probability of its occurrence and the causal connections it depends on, then assessing the possible consequences and the procedures for compensation or repair which those will entail (Gilbert, 2001, 2004), so as to approach threats in a rational way. However, each of these steps raises extremely complex problems in the field of biodiversity. While it is possible to calculate the degree of risk for some environmental threats, such as earthquakes, whose dynamic is quasi-linear, threats to biodiversity affect living systems containing an infinite number of non-linear interactions, which generate adaptive and complex dynamics at various levels of organisation.

These scientific methods underlie the "pathology of natural resource management" (Holling and Gunderson, 2002; Berkes et al., 2003), which is characterised by:

- The search for ever greater control of variable phenomena (the "command and control strategy") and a short-sighted approach to systems for managing renewable natural resources, focused especially on economic outputs and profit in general.
- The establishment of specialist agencies which are initially flexible but very quickly become short-sighted and rigid, with a strategy focused on their own survival. The acquisition of funds, resources and jobs often becomes the ultimate goal of this type of agency.
- The introduction of subsidies, which encourage increased production and make the users of renewable natural resources increasingly dependent on these "artificial" incomes. The effect is at once to ignore the costs of the erosion of biodiversity and to create a lobbying system whose only goal is the preservation of this system of revenues, so that the slightest suggestion of change is viewed as a crisis.
- Loss of resilience in ecosystems, which can result in the collapse of the society-nature system, as we saw in the section on ecosystem services in the case of the Aral Sea.
- The proliferation of crises and a general increase in the vulnerability of the populations which depend on biodiversity, accompanied by a general loss of confidence in existing systems of governance and management.

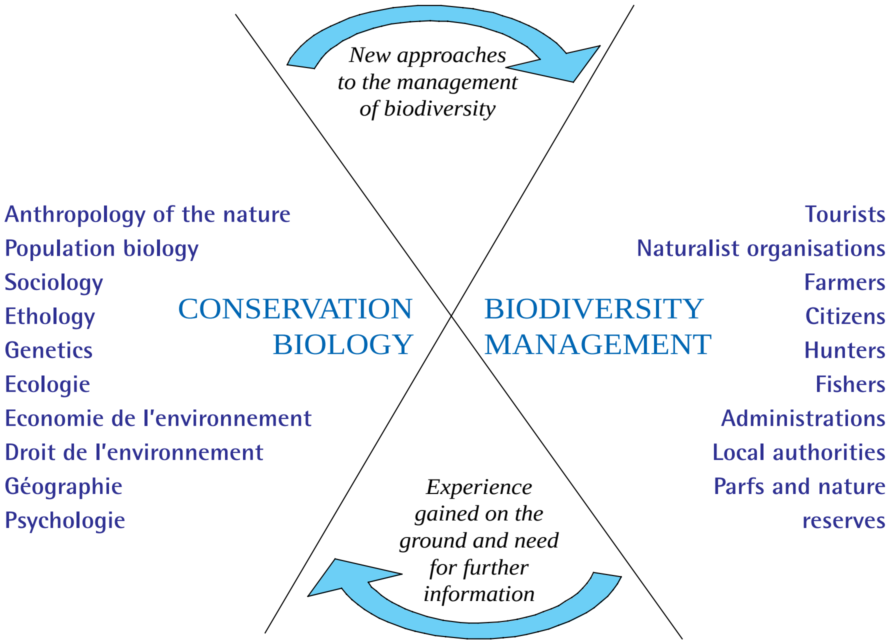
Recognising the inefficiency of traditional styles of management for managing renewable natural resources and the inability of science to grasp complex dynamics, many ecologists and economists have moved towards the *adaptive management* of renewable natural resources (Arrow et al., 2000; Dasgupta, 2001; Holling and Gunderson, 2002; Weber, 1996). Adaptive management is seen as a more operational approach than traditional "command and control" management, because at the core of its approach is the uncertainty caused by the management of complex ecosystems whose mechanisms remain little known. To deal with this uncertainty, adaptive management preaches a cautious approach which emphasises the process of learning about the interactions between societal and ecological dynamics (Olsson et al., 2004). It is an interactive form of management based on the idea that every management practice must be seen as part of an iterative, ongoing process of experimentation in which decision-makers and scientists must collaborate (Figure 10). This approach should make it possible to modify management practices in the short term, in accordance with the responses of the society-nature system to these practices, and to avoid large-scale ecological and societal crises like the Aral Sea case.

Adaptive management works in conjunction with a systemic scientific approach which allows for interactions, complexity and the uncertainty of the mechanisms involved (Passet, 1996, p. xvi). The systemic analysis "proposes a method for studying complexity based at once on the knowledge of the various elements of the system (the analytical approach) and on that of the connections between these elements" (CENECO, 1995, p. 12). It proposes moving away from mechanics towards a thermodynamics which allows for irreversibility, while rejecting the version of the thermodynamic approach, which sees evolution as simply a process of destruction and accepting the more biological version, which sees all these processes as tremendous movements of creative destruction. Instead of the reductionist and discipline-bound perspective, the systemic approach proposes a perspective that involves many disciplines addressing shared questions or subjects. Instead of an economics-centred concept of rationality, it proposes a concept of rationality that involves a minimum of coherence among the ends and as much coherence as possible between the ends and the means.

The initial assumption of the adaptive management of biodiversity is that scientists from various disciplines can work together to establish what might be called "conservation science" (or "conservation biology"). This joint work can be viewed from two angles: as multidisciplinary or as interdisciplinary (Morin, 1994).

In the first of these, scientists work on a shared topic - the conservation of biodiversity - but in their own field of competence. This is the avenue adopted by most of the books and research programs which propose "transversal" approaches to biodiversity (Kinzig et al., 2003). Scientists use their own concepts and methods without worrying about the perspectives of the other disciplines involved in the transversal program. Once their work is completed, they each present it to the collective of researchers engaged in the project. This is known as the *multidisciplinary perspective*. The research programme is divided up logically, discipline by discipline, subtopic by subtopic, and at the end of the program everything is combined so as to produce an overall

Figure 10: The adaptive management of biodiversity



Source: Barbault, 2000, 308

answer to the initial question. There is no real need for mutual understanding, since everyone stays within their own field of competence and works in parallel. Disciplinary boundaries are respected and the representatives of the various disciplines have no authority to intervene in those of their neighbours. There is no need to create a common language, since there are very few interactions among the participants.

There are very few transaction costs[50] entre les différentes parties prenantes puisque l'ensemble des disciplines – qui représentent autant de communautés de pratique – ne travaillent ensemble que lors des restitutions et n'entretiennent pas d'interactions entre elles. Il n'y a pas besoin dans ce cas de créer une communauté d'intérêt et le travail collectif est assez simple à réaliser.

This approach creates many difficulties. First of all, the specialists from the various disciplines are not really interested in the other research undertaken as part of the project, or only in a superficial way when it is relevant to their own research. This lack of interest is often related to a lack of knowledge of the other discipline, its vocabulary and methods, and especially to the accessibility of its research results. The more "arcane" and "verbose" the presentations from the other disciplines, the greater the lack of interest is likely to be, since the results reported will be not easily usable by the other disciplines.

A second problem with this approach is that it is often very difficult to synthesise the research in ways that decision-makers will find operationally useful. Often scientists prefer an exhaustive, bulky report, because it reflects the scope and richness of the work performed, but this tendency towards the encyclopaedic does not accommodate the decision-makers' need for simple communication. Finally, and perhaps most importantly, there is insufficient integration in this kind of project. The results of the research completed in the various disciplines are likely, unless they are co-ordinated coherently, to be a source of confusion for their users, because of the heterogeneous temporal, geographical and even symbolic (as in the units of equivalence and the key parameters) levels used in the reports. This can produce conflicts and even contradictions in the results, especially in large international organisations which split up their divisions and departments in order to rationalise their problem-solving methods. For example, in work done by the Inter-American Institute for Co-operation on Agriculture, it is noted in connection with the World Bank's recommendations (Reed, 1999, p. 19) that "while on the one hand incentives are introduced for the development of exports and the more intensive exploitation of natural resources, on the other hand new policies are advanced to encourage the conservation of the environment and of these same natural resources". This is simply due to an initial lack of attention to the consistency of the expertise applied in the development and environmental divisions of the organisation.

When these research projects are performed in parallel, they require a great deal of subsequent work to make them consistent with one another. In fact, this can sometimes be impossible, since the research is carried out on such different levels. The multidisciplinary approach thus offers a rather poor methodological tool for transversal projects which are supposed to be integrated, and does not succeed in reuniting dispersed knowledge.

Consequently, many scientists insist instead on the need for a theory of integration, or "inclusive theory" (Yorque et al., 2002). "Sustainability science" makes direct reference to this theory of integration. It renounces disciplinary ties in order to create a new field of study - sustainability.

The term "sustainability science"[51] was coined by the US National Research Council (1999) with the specific purpose of creating a space for thinking about the interactions between societal and ecological dynamics. It seeks to treat the impact of ecological dynamics on societal issues on a par with the impact of societal dynamics on ecological issues (Clark and Dickson, 2003).

To establish sustainability as a field means adopting an interdisciplinary approach. In this approach, scientists work together to solve shared problems. Interactions between representa-

50 Transaction costs are related to the diversity of value systems, the integration of dispersed kinds of knowledge, the initiation of agreements and control of their application, and the establishment of rights (North, 1999). These costs have to be "paid" in order to carry out collective work and make an organisation efficient, whether its goal is to make a profit, govern a country, or preserve shared biodiversity.

51 See http://sustainabilityscience.org.

tives of the various disciplines are obligatory, since they must collectively define the goals of the program, the levels of reference to be used, the protocols, the key parameters to be studied, the various stages to be followed, etc. A community of shared interest with respect to an issue or problem has to be developed in order to complete work of this kind; that is, the first step is to reduce the transaction costs for the participants. In that process, interpretations, interests and preferences will come into conflict and all the participants will have to agree to give up part of their freedom of action. To initiate truly interdisciplinary work which will produce integrated, synthesised and communicable information means that the participants must let go of their assumptions about what counts as scientific method as defined in their respective disciplines. The representatives of the various disciplines must accept that their knowledge and their research will not be completely incorporated into interdisciplinary work, which will retain only the bare minimum necessary for addressing the problems at hand.

This is the price that must be paid for a truly interactive process which will lead to the development of a truly integrated research instrument. Participants in such projects must exhibit a willingness to be open to other disciplines, a readiness to engage in discussion and exchange and a real ability as teachers, with a view to creating an atmosphere favourable to collective work which requires significant intellectual investment. Avoiding these "human" issues because they seem to be "non-scientific" risks entangling the process in a series of conflicts which will inevitably lead to breakdown.

Interdisciplinary work must therefore be recognised as a truly social process (Callon et al., 2001; Rouwette et al., 2002; Vennix, 1996, 1999), calling for a number of procedures: the adoption of rules which both encourage collective work and regulate power relations based on specific status and informational asymmetrie[52]; the use of mediation instruments which facilitate negotiation and create a common language around the problems under investigation; and the selection of an organiser-mediator, acceptable as such to the parties concerned, who will make the interdisciplinary work both "efficient" and "fair", by ensuring that the rules of the game which sustain it are adhered to.

The interdisciplinary approach does not mean that areas of specialisation will cease to exist. With respect to the issue of the conservation of biodiversity, many topics can be addressed only by biologists: the assessment of extinction crises, the viability of population dynamics, the adaptive responses of populations to pressures, the ecological functions of ecosystems, etc. Others will be addressed by the social sciences: the creation of income, the distribution of benefits related to the conservation of ecosystems, land tenure problems, the services connected with ecological functions, questions of interpretation and conflict, etc. However, in this context all these issues should give rise to the pooling of research and highlight the interdependence which exists between societal and ecological dynamics.

If we look again at Figure 10, we can see that the emergence of conservation science based on the integration of the various disciplines is not sufficient by itself to bring about the adaptive management of biodiversity. It is also necessary to introduce procedures for the interactions between conservation scientists and the "managers" of biodiversity. The diversity of the people who co-exist in the same ecosystem then becomes a central issue, which is why some writers prefer to replace the concept of adaptive management with that of adaptive co-management (Lal et al., 2002), adaptive governance (Dietz et al., 2003), or community-based natural resource management (www.cbnrm.net), which can all be grouped under the heading of adaptive co-management. Co-management means "sharing of knowledge and power". The only difference between adaptive management and adaptive co-management is that in the latter's case the primary uncertainty to be addressed has to do not with ecological interactions but with human interactions. From this perspective, managing biodiversity requires above all managing the interactions between people in order to co-ordinate their activities in the area of biodiversity (Lal et al., 2002).

52 Interdisciplinarity is in effect meaningless if it means the dominance of one discipline over the others.

This assumes that "the meaning of management has moved from 'the administration, relying on experts, of a well-defined entity in order to keep it in something close to its actual state', to 'the management, including and pulling together the diversity of the people involved and their expectations, of an only partly known and inherently changeable entity in order to preserve its capacities for change over the long term evolution' .... The point is thus not to replace one reality with another and to dream of a new kind of (ecologically) enlightened technocracy, but to 'manage management', that is, to intervene in a network of 'distributed intelligence[53]' in order to improve its global functioning" (Chevassus-au-Louis, 2002).

In this respect it should be stressed that "the problem presented by global risk in terms of social choices is precisely that of the nature of the connections between expertise, public decision-makers and public opinion" (Trannoy and Van Der Straeten, 2001, p. 83). In particular, relations between experts and decision-makers are often seen as exclusive, with the first group proposing "recommendations for public action" to the second group (Trannoy and Van Der Straeten, 2001). Under these conditions, political decisions appear to derive from the opinions of experts, which thus replace citizen preferences. The role of expertise becomes a normative one, thanks to which "unopposed, the expert smuggles in an ideology, the ideology of the expert: the absolute validity of compartmentalised knowledge, asserted as infallible truth" (Morin, 1996, p. 256). This does not pose a real problem as long as the collective preferences of the decision-makers and experts match the collective preferences of the citizens. But that would presuppose a world of certainty in which the preferences of the citizens are homogeneous. What adaptive co-management presupposes is precisely that these preferences are heterogeneous, and that this is the chief problem to be addressed if we are to understand accurately the complexity both of the contexts in which decisions are made and of the collective choices with respect to biodiversity.

We must thus shift our focus to the institutions which contribute to the fair organisation of societal interactions: these interactions underlie the societal compromises we must accept if we are to make collective choices about the conservation of biodiversity. Democracy is the first of these institutions.

Democracy is "that form of government in which the sovereign power resides in the people, and is exercised either directly by them or by officers elected by them" (*Shorter Oxford English Dictionary*, 1970, p. 478). Representative (indirect) democracy is the dominant institutional system. "Representative democracy is in principle parliamentary democracy: parliaments are assemblies of men and women, more often of men, chosen for their wisdom, whose deliberations are supposed to lead to the best possible decisions" (Delacampagne, 2000, p. 19, quoted by Callon et al., 2001, p. 327).

Beyond these formal definitions, democracy is a very flexible institution which develops through an ongoing learning process (North, 1999), because it recognises that:

- Political choices and opinions are based on fallible conjectures.
- Opinion results from an interactive process of learning and discovery.
- The central feature of these processes is not the supremacy of one single opinion but the ability to dispute the majority opinion.

This makes democracy, according to Jacques Sapir (1998, p. 215), "a combination of freedom of debate and a decision-maker's responsibility to those who implement the decisions".
Democracy implies a number of shared higher principles:

- a principle of tolerance which allows all the citizens the freedom to express their beliefs and ideas;
- a principle of separation of powers which secures a state based on rights and protects the citizens from abuses of power;
- a principle of social justice whose goal is to reduce inequality (Acheson, 1994; North, 1999; Delacampagne, 2000).

53 "Capacities of perception and understanding of the environment and of adaptation to changes in it".

As well as being an equitable system, democracy is an effective institutional system. Historically, democracy is the only form of government under which no identifiable famines have occurred[54] (Sen, 1981). Its appearance is accompanied, in the short or medium term, by a body of institutional innovations (recognition of the right to own property…), organisational innovations (development of an independent press…) and technological innovations (introduction of an objective system of measurement…) which help significantly to reduce a society's transaction costs (North, 1999).

All these features explain why democracy provides the context needed for any attempt at the introduction of adaptive co-management. This context can be viewed on three geographical levels.

The level of reference of democracy is the state: national parliaments form the basis of democratic systems. However, this level has lost importance as a result of globalisation: today national decisions are largely dependent on higher-level decisions. But there are no democratic institutions on an international level. There are of course international organisations which are supposed to manage relations at this level, but these organisations do not function democratically. The World Bank and the International Monetary Fund use a contributory voting system in which quotas are in proportion to the sums paid to the organisation: in these two organisations the United States has nearly 17 % of the vote while the Sub-Saharan Africa has approximately 2,5%. The World Trade Organisation functions in theory on the principle of "one country one vote", but as the United States and the European Union refuse to become minorities, the voting system has never been used to make decisions within the organisation, which in the end functions by way of a principle of consensus whose rules are undefined. Only the UN observes the "one country one vote" rule, but this is rendered null and void by the Security Council, which gives the decision-making power to its five member states. Consequently, introducing adaptive co-management of biodiversity is difficult at the country level, if a country is structurally dependent on international relations (Trommetter and Weber, 2005). In this situation, the rules of the game are in effect not those of a democracy but of an almost unregulated market.

The third level (in addition to the individual state and the world as a whole) is the ecosystem or territory, that is, the local level. Democracy has become an increasingly important issue on this level, as criteria of good local governance have been implemented by international organisations responsible for development and conservation. This is why participation, consultation, dialogue, deliberation, negotiation, mediation, etc. have in recent years become "opportune" concepts for responding to the need for renewed local democracy and hence to the problems of conservation and development.

But beyond this "idealised" vision presented by the international organisations, there are several reasons in favour of adopting the local ecosystem level as the geographical level of reference for the adaptive co-management of biodiversity.

Firstly there are theoretical reasons: the ecosystem is a relatively homogeneous geographical entity (though it can vary enormously in size) defined in terms of interactions between living beings (among which humans have a central place) and their environment. Managing biodiversity thus requires knowing and understanding, at least partially, ecological interactions as well as society-nature interactions. These interactions can be identified only on the basis of a local, or ecosystemic, grasp of the dynamics concerned, that is, on the level of human perceptions. Even if processing large amounts of data enables us to identify statistical correlations between various parameters on a large scale, the interactions described by the data exist on the local level.

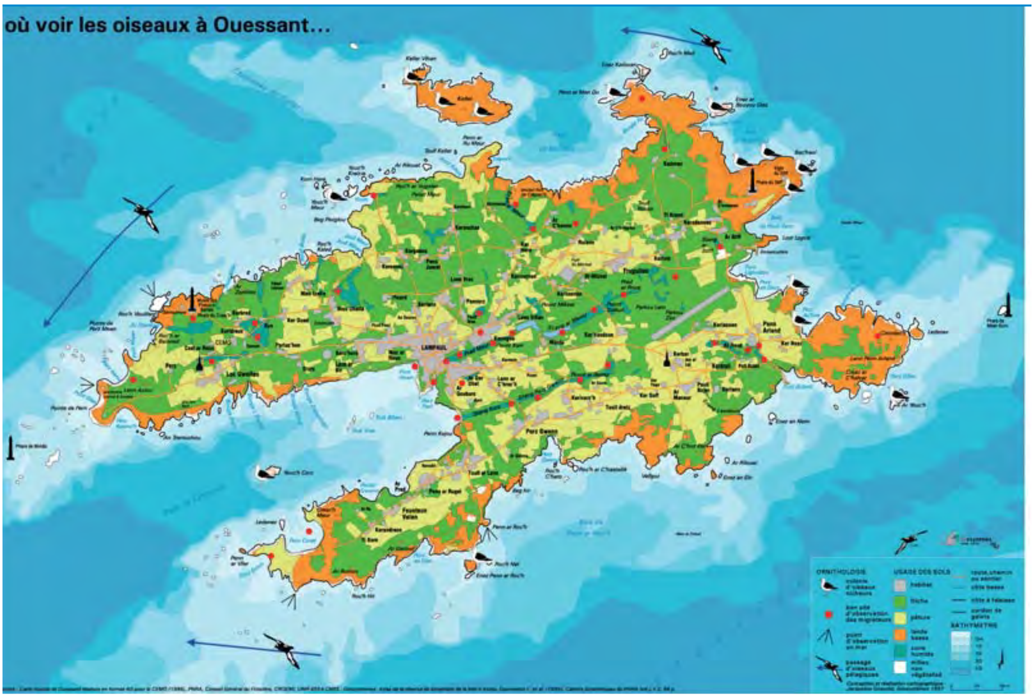
Next, there are practical reasons. Adaptive co-management is anchored locally because this is the geographical level on which information asymmetries are least important and where opportunistic behaviours can quickly be identified and penalised. It is also at this level that we can best describe the contexts which make it possible to identify the services provided by biodiversity to human beings; the direct and indirect drivers of changes in the state of biodiversity; the

54 However, the connections between democracy and human development are hard to determine. Partha Dasgupta (2001, p.57) found positive correlations between human development and civil and political rights for 1980 (using a sample of 46 developing countries), but negative ones for 1995-96 (using a sample of 36 developing countries). He then pursued a third, dynamic, assessment of correlations between changes during the period 1970-80. Here he found a positive correlation between civil and political rights on the one hand and life expectancy and GDP on the other, but a negative correlation between rights and literacy rates.

agents responsible for these changes; and the political responses best adapted to the ecological and social context. This is also the level on which human interactions are most intense, and thus where substantial social capital can be mobilised and where institutional systems for co-operation between local people on shared problems, such as the conservation of biodiversity, can be devised (Ostrom, 1990; Pretty, 2003). This is thus the desirable level on which to initiate discussions and negotiations leading to the devising and testing of institutional, technological, or organisational innovations for the management of biodiversity.

Finally, there is an institutional reason to adopt an ecosystemic approach: this is the geographical level chosen by the Millennium Ecosystem Assessment, the Convention on Biological Diversity and UNESCO's Man and Biosphere programme[55].

Apart from the requirement of democracy, it is difficult to identify the institutions which best facilitate exchanges between people and stimulate innovation in the implementation of effective adaptive co-management of biodiversity. Most of these institutions are informal in nature and have a contextual character (North, 1999). Thus, the reasons for the success of a local method for managing biodiversity are not necessarily obvious. "Knowing how" and "knowing why" go hand in hand, but it is often difficult to grasp them simultaneously (Sapir, 1998). We often observe that some method has led to good management of biodiversity, and we hypothesise that this success is tied to some number of interactions between some number of parameters. But there is generally much uncertainty as to the real origins of the success of the method



55 It seems, however, that the demand for instruments for managing biodiversity, such as indicators, cannot be created artificially at the local level using a top-down approach (d'Aquino, Seck and Camara, 2002), and that the indicators of sustainable development never survive past the end of the participatory programs which initiated them at this level (Garcia and Lescuyer, 2006). The problem is that international organisations often confuse their needs with those of the populations they address. Sustainable development and the conservation of biodiversity are technocratic concepts which generally have no concrete meaning for local populations.

in question. We may recall that Arun Agrawal (2001) identifies 33 significant parameters relevant to good local governance of commonly owned renewable natural resources, and that there are many interactions between them. This is why the "winning" local methods are not necessarily generalisable, all the more so because the environment in which they were developed is complex and only partly understood.

However, Carl Folke (2003) identifies four primary conditions for the emergence of systems for adaptive co-management:

1) *Learning how to live with uncertainty and change*. This is how our ancestors lived, and we need to recover some of their practices: frugality, risk management based on management of diversity, decision-making using the precautionary principle. All these behavioural traits share the goal of minimising risk.
2) *Making diversity a keyword* in an international context in which the modes of consumption and production are becoming standardised. Societal and ecological diversity is a source of creativity, a form of insurance against unpleasant surprises, the ecological and societal memory of planet Earth.
3) *Constructing new systems of knowledge*. Adaptive behaviours are always a function of levels of knowledge, past experience and the comprehension of the dynamics concerned. There must thus be an exchange between expert knowledge about the complex dynamics of systems and lay knowledge derived from local management of systems. Data relating to adaptive dynamics must be integrated into societal institutions for the management of biodiversity, then passed on by societal networks, since they are better adapted for this than are inflexible organisations of experts.
4) *Creating opportunities for auto-organisation*. Creativity and diversity have to be allowed expression, so as to make room for the joint development of societal and ecological systems.

Technology democracy and the co-construction of indicators

The co-construction of instruments for the management of biodiversity is a first stage in its adaptive co-management. This co-construction is based on the principles of "technology democracy".

Technology democracy is visible today in socio-technological debates with the emergence of hybrid forum[56] in which minorities can express their opinions and their preferences on questions hitherto restricted to experts (Callon et al., 2001). It relies on the same principles of tolerance, separation of powers and social justice as democracy.

Technology democracy stresses the sharing of knowledge, which is the corollary of power-sharing. Here it relies on two assumptions. There exists a *symmetry of ignorance* among all those concerned with any one issue (Arias and Fischer, 2000). This assumption implies that no agent - individual or collective - has sufficient knowledge and legitimacy to solve alone a problem of a collective nature: "Most of what any individual 'knows' today is not in her or his head, but is out in the world (e.g., in other human heads or embedded in media)" (Arias and Fischer, 2000, p. 1). Knowledge is dispersed in reports, practices, institutions, skills, memories. Consequently (this is the second assumption), procedures must be put in place to facilitate an *unlocking* of knowledge, to involve all those concerned with a common problem, and to enable exchanges of information so that a maximum number of people can profit from dispersed knowledge (Dietz et al., 2003).

56 "Forums, because these are open spaces where groups can come together to discuss technological choices which affect the community as a whole. Hybrid, because these committed groups and the spokespersons who claim to represent them are heterogeneous: they include experts, politicians, technologists and concerned citizens. Hybrid also because the questions addressed and problems raised belong to a variety of different registers" (Callon, Lascoumes and Barthe, 2001, p.36).

Two elements in particular must help us to face uncertainty and to establish dynamic procedures for collective learning (Callon, Lascoumes and Barthe, 2001): the *exploration of possible worlds* and the *exploration of the collective world*. These two modes of exploration aim to supplement the dual delegation of authority (to the political decision-makers and to the experts) practised in traditional democracies, in order to bring about a true sharing of power and knowledge.

The exploration of possible worlds is characterised by the move from a *system of expertise* to a *system of co-operation between various sources of knowledge*. This does not mean casting doubt on the specific knowledge and skills of experts, but simply that these need to be shared and opened up to debate. This co-operation is founded on the idea that scientific knowledge and lay knowledge must be complementary and nourish each other in order to improve the quality of collective information about a complex problem such as the management of biodiversity[57]. This mutual enrichment is easily understood if we think of the assumptions of Condorcet's jury theorem (Trannoy and Van Der Straeten, 2001). Scientists and lay people concerned with the same question are respectively more "expert" and more "close to the ground" than the average. Now, both these qualities are essential factors in reducing the risk of error when an opinion is formulated. From this perspective, a diversity of perceptions and experiences, related to the diversity of the communities of practice concerned with the question of biodiversity, is a source of collective learning and information gathering, not only of conflicts of interpretation. These communities possess specific knowledge about biodiversity which deserve to be brought into a relationship of reciprocity.

For lay knowledge and expert knowledge to be reciprocal, the differences between them must first be identified.

The principal difference between lay knowledge and expert knowledge derives from their respective origins: tacit knowledge[58] for the former and explicit knowledge for the latter (Cowan and Foray, 1998). The difference between these two forms of knowledge is related to the degree of "codification" that they rely on. Explicit knowledge relies on a significant degree of codifica-

57 There are various levels of co-operation (Callon, Lascoumes and Barthe, 2001, p. 175). Simply going back to the place where laboratory research was carried out is the first level. Then there is the collective work done by scientists and laypersons on scientific problems. This is a more significant form of co-operation, but the lay knowledge remains merely instrumental. This is why there must be a third form of co-operation, corresponding to technology democracy, which begins from the moment a problem is formulated and thus makes it possible to intertwine scientific and societal questions. The formulation of the problems develops from that point onwards through discussion and negotiation designed to determine which aspects the different parties concerned will find most interesting to address.

58 Tacit knowledge is defined as "what we know" but "what we cannot always say". It is knowledge which is difficult to express and which can appear at first glance to be useless because individuals are unaware of its value.

tion - books, statistical data, mathematical models - through which it is formalised. Tacit knowledge often belongs to the world of everyday perceptions, practical know-how and experience. It is thus difficult to formalise and regarded as "subjective"[59] .

Three other characteristics define the difference between lay knowledge and expert knowledge (Adams et al., 2003):

- The way in which the reality of a phenomenon is empirically grasped. This will be connected to personal experience in the case of local people and to standardised research - monitoring, surveys, statistics - in the case of scientists.
- The institutions of reference which individuals appeal to in arguing for the relevance of a particular type of knowledge. For scientists these are national and international institutions, while local people focus mainly on traditional institutions and societal conventions.
- The beliefs which lead to viewing an item of information as significant or insignificant. Experts place great faith in formal data while local populations rely more on "good sense".

Methodologically, exploring collectivity requires moving from the *aggregation of individuals* to the *composition of a collective*. What is needed is not the assemblage of a number of discrete representative agents but the creation of processes of social interaction, discussion, or negotiation among emerging identities. From this perspective, "interests are plastic, identities are negotiable, claims are open to question: not only can no solid and constraining tradition be called upon, but problems appear contingent and solving them does not seem insurmountable. In the hybrid forums, minorities raise questions which can be answered without too much difficulty, provided that those involved agree to do everything in their power to find the answers" (Callon, et al., 2001, pp. 329-330). The participants are not there to defend the interests of a pre-existing body (which traditionally might be trade unions, elected officials, NGOs), but to work on a shared issue on a local level. The people concerned are not spokespersons but "experience-persons", which enables them to overcome conflicts of principle and to stick to concrete local issues.

From the perspective of technology democracy, the supply and demand of socio-technological instruments - such as indicators - will converge. In fact, the distinction between supply, controlled by experts, and demand, controlled by decision-makers, is no longer valid. The goal now is to develop an instrument collectively, based on a collective expression of needs.

In concrete terms, the co-construction of instruments is an interactive activity during which participants put forward proposals, formulate criticisms, express doubts and sharpen definitions, in accordance with their individual interpretations. Co-construction thus means establishing interactions between heterogeneous cognitive maps and interpretations. This results in the construction of collective interpretations of shared issues. The process is not static but develops out of the observations, experiments, discussions, etc.

We can propose a categorisation of co-construction processes by identifying various levels of approaches to scientific investigation, going from a more "constricted" approach to a more "grounded" one (Callon et al., 2001; Mirault et al., 2006): bibliographic compilations and standard ecological modelling which do not take demand into account; discipline-based observation on the ground, still not taking demand into account (or very little); experts' statements in response to potential demand; experts' observations and/or statements in response to an expressed demand; co-construction with the agents who present the societal demand.

59 This tacit knowledge, which is difficult to represent quantitatively, is usually neglected when information systems are being instituted. However, it can be rich in information when the populations who possess this knowledge interact with their ecosystems over a long period of time. In particular, local populations often use tacit indicators for the dynamics of their environment (Levrel et al., 2006).

Table 10: The different levels of co-construction

	Demand	Supply	Requirements
Scenario 1	Construction based on expert response to potential demand	Development of a supply of expert responses	Good knowledge of the terrain by the scientific "experts"; formats for reporting back on indicators in institutional forums will be needed
Scenario 2	Co-construction of demand	Development of a supply of expert responses	Good knowledge of the terrain by the scientific "experts"; analysis of the use of the indicators produced will be needed
Scenario 3	Formulation of demand by the agents concerned	Co-construction of a supply of indicators	Relationship of trust between agents "on the ground" and scientists
Scenario 4	Co-construction of demand	Co-construction of a supply of indicators	Methods ensuring this construction will take place in a reasonable period of time

Source: Mirault et al., 2006, p.71

This categorisation of the response to demand must be seen in conjunction with the categorisation of cross-disciplinary work which we proposed earlier - the discipline-based approach; the multidisciplinary approach which proposes proceeding discipline by discipline but does not require a community of interest focused on a common problem; the interdisciplinary approach which seeks to define scientific questions collectively and to create a community of interest around the co-construction of common problems. The more the approach tends towards interdisciplinarity and the involvement of all concerned, the more supply and demand will converge (Table 10).

Adaptive Decision-Making Process proposes an operational version of technology democracy using a method based on a number of stages through which a society-nature system, an analysis of the problems involved and the appropriate instruments for addressing them in a complex collective context can all be co-constructed (Lal et al., 2002):

1) The identification of a sub-system, to include
    - Identification of the key agents
    - Identification of the key resources for these agents
    - Identification of the key institutions for these agents
    - Identification of uses
2) The initiation of a process of reflection, involving
    - The construction of a shared vision of the dynamics concerned
    - Researchers who play the role of mediators
    - The integration of dispersed knowledge
    - The establishment of procedures for iterative practical learning
3) Proposals for collective action based on
    - Proposals for strategies which create respect for collectively defined ecological and societal requirements
    - The use of decision-making methods which will
        - > Integrate ecological, economic and societal data
        - > Perform simulations based on "what-if" scenarios of interest to all disciplines
        - > Propose interfaces which make sense to all the parties concerned
        - > Enable local agents to reach a better understanding of the interconnections between societal, ecological and economic dynamics
        - > Put into perspective the various value-systems which co-exist in the society-nature system
        - > Support the emergence of a shared world
    - Processes of negotiation, conciliation and mediation to deal with conflicts of interest.

4) Practical learning
   - Instrumental, concerning the appropriateness of the instruments used
   - Societal, concerning the construction and resolution of problems
   - Collective, concerning negotiation and the sharing of information.

The goal of technology democracy is, ultimately, to reconcile the goals of *effectiveness* and *justice* by seeking for synergies. Technology democracy thus is both an end and a means. As an end, it gives the public an opportunity to access information previously guarded by "experts", to discuss the problems which interest them the most, to confront differing interpretations of shared problems and to negotiate agreements. As a means, opening up the methods of experts to the lay public's forms of knowledge makes it possible to improve information systems by reducing transaction costs and to launch dynamics of collective practical learning.

This dynamics of practical learning are founded on *freedom of debate*, which lies at the root of any democracy. "Through debate, we conceive and test projects and solutions which integrate multiple perspectives, demands and expectations. This modus operandi, which goes through successive negotiations and compromises, generates a process of practical learning" (Callon et al., 2001, p. 56). Technology democracy is also an effective method from a scientific viewpoint, since it functions as an ongoing sequence of refutations and justifications through which discussions move forward and collective questions can be addressed in a more precise way.

The primary requirement when it comes to setting up these methods is to put in place procedures that any democratic system must include, that is, to make negotiations as equitable as possible. Debates must be transparent and founded on principles of equity with regard to who is represented, the length of time each person is allowed to speak and the free expression of opinions, so as to maintain a balance among the power relations involved.

It is possible to move from individual knowledge to collective knowledge only when a principle of equity is in place. A belief in the reciprocal value of their contributions is what encourages those concerned to share their individual experiences and specific knowledge. This belief is directly related to their understanding of the nature of the collective which they are to become part of, and in particular to their trust in the procedures used to organise debates (Favereau, 1994; Biencourt et al., 2001).

Whether participants in the hybrid forums will play this "exchange game" or not is also related to the requirements which any collective discussion process in a public arena imposes on the participants. The dynamics of controversy which this type of process involves must encourage the participants to bring forward arguments and counter-arguments, to clarify points that are unclear, to refute or support whatever claims are made. In this context, those who refuse to participate in debate - either by not taking part in discussions or not responding to questions - are badly served by their obstructive strategies. The eventual outcomes will represent their perspectives very inadequately.

The ultimate goal of technology democracy is, through these exchanges, to create a community of interest around a shared issue such as the management of biodiversity. As we have said, this requires the convergence of heterogeneous perceptions of a shared problem. We therefore need to reach a deeper understanding of the underlying cognitive processes responsible for the construction of beliefs and interpretations.

Some principles based on the inclusion of individual perceptions in assessing the quality of the indicators of biodiversity and of interactions

To better grasp the needs of the people concerned with respect to biodiversity indicators, we have to come to understand their perceptions of biodiversity and their cognitive capacity to use indicators.

A basic problem, as we stressed earlier, is that the organisations responsible for the construction of indicators assume that these indicators must control a system of interactions between society and nature. The use of traditional indicators often presupposes complete rationality and a decision-making process based on computation. A guide - usually called the manager or decision-maker - will use a "control panel" of indicators to master the system of society-nature interactions and keep it in balance (Bouleau, 2006). On this assumption, a system of economic, ecological and societal indicators would control the interactions between these various spheres, with no need to see the actual environment they relate to, like the pilot of a plane using instrument flying: the altimeter, anemometer, variometer and GPS provide all the input needed to select an optimal heading for flying from point A to point B. However,

- The indicators related to sustainable development and biodiversity management contain large areas of uncertainty.
- The indicators are not of much use unless we know how to process the data contained in the "signals" they send.
- The indicators are usually ambiguous and must be interpreted before they can be applied in decision-making.
- There is no one rational decision-maker to fly the plane, but rather a multitude of heterogeneous individuals who do not want to go to the same place or even to fly the plane in the same way.

In other words, the reality on the ground is quite different. Decision-makers and managers never actually see themselves as controlling a system (Mirault, 2006), but as individuals among others who try to influence the dynamics of the situation. There are many heterogeneous individuals who make use of all the different signals appropriate to their specific needs - without ever referring to them as "indicators" (Levrel et al., 2006). Only the inventors of indicators imagine that they are producing a "control panel" for piloting a system.

Paying attention to the actual models of cognition and learning processes which individuals adopt enables us to reframe the question of the quality of the indicators in a more realistic way, and to identify five additional principles which complement the criteria used by statistical organisations (Table 11): a principle of contextualisation, a principle of hierarchisation, a principle of feedback, a principle of exploration and a principle of interaction.

The principle of contextualisation

It is of primary importance to understand that individual rationality is *procedural* and that the signals sent by the indicators always carry information whose meaning has to be extracted via interpretation and then supplemented by specific knowledge. To understand the connections between the individual agents' knowledge and the knowledge conveyed by the indicators, we can make use of the concepts of codified knowledge and tacit knowledge described above (Cowan and Foray, 1998). These two forms of knowledge are complementary: without tacit knowledge it is impossible to use codified knowledge, which conveys only incomplete information. This is why differences in individuals' tacit knowledge result in interpretations that differ from the signals sent by the indicators (Batifoulier and Thévenon, 2001). At the same time, the use of codified knowledge will influence the tacit knowledge which individuals possess, while conversely these implicit interpretations will play a role in the simplified representations of the world furnished by the indicators. The identity of the decision-makers to whom the indicators are addressed, their ability to process information and their interpretations must thus be taken properly into consideration when we assess the relevance of indicators of biodiversity and of interactions.

Every individual constructs a virtual world in which interpretations interact. Indicators must be positioned in relation to these interpretations of the world. There must be a good fit between the "worlds" created by the indicators and the "shared worlds" which communities of practice draw upon when they act.

One subject of particular interest in this connection is individuals' abilities to process the signals sent by indicators. These abilities are much weaker than the inventors of information systems assume (North, 1999), and they become weaker yet in proportion to the remoteness of the communicated information from an individual's own culture, knowledge and practices. To improve these processing abilities, it is possible to *contextualise* the indicator. This enables cognitive models to process more quickly the data contained in the signals. The context creates a situation in which indicators can "speak", supplementing the codified knowledge they send and making their own relevance self-evident. This context is related to a number of other things.

Firstly, it is related to the interface. For indicators to reach their targets and to be relevant to them, the interface used must be suited to their audience (Levrel et al., 2006). For example, it would be completely ineffective to seek to communicate with illiterate African hunters using indicators representing changes in the rates of growth of the animal populations of a wildlife reserve. On the other hand, geographically-based indicators of changes in the abundance of game will probably be accepted by these communities of practice. Conversely, a scientist would rather look at curves, ratios and indices which relate to precisely defined entities. A second major requirement for contextualising indicators is that the information they transmit can be expressed in terms of concrete events in people's lives (North, 1999). Thus, "the development of knowledge depends on its expected impact on everyday life" (Douglas, 1999, p. 70). This means especially that indicators can change over relatively short time-frames and still represent long-term trends, but also that these trends are connected to parameters which affect the daily lives of the communities of practice in question[60]. A third requirement relates to the presentation of the system to which the indicator belongs. The real range of the indicator and its limits have to be clearly stated, otherwise its meaning is liable to be ambiguous.

One example of an indicator of society-nature interactions which fits this criterion successfully is the eco-efficiency indicator described in Section Two. This indicator enables us to measure the efficiency with which resources are used to produce goods and services. In concrete terms, the measurements can be performed at the level of a whole society or country, by calculating the value added or the GDP, de-linked from energy consumption. This indicator of sustainable development "speaks" to the industrialised world, in which efficiency is recognised as a general principle (Boltanski and Thévenot, 1991) and it is normal to set performance goals. It relates to concrete modes of production, and it is easy to calculate the costs and benefits of technological change. This instrument must, however, be used cautiously because, like all instruments which depend heavily on interpretation, it can easily be manipulated to reach a desired conclusion (Hukkinen, 2003).

The principle of hierarchisation

National and international organisations' experience of introducing sustainable development indicators over the last fifteen years or so has led them to identify one constant: an "overkill effect" in connection with the sets of indicators of society-nature interactions (Lavoux, 2006). The majority of reports on sustainable development indicators seek to present a fairly exhaustive account of the subject, in order to emphasise its multidimensional character and also to incorporate the great diversity of interpretations it generates. With this aim in view, by 2001 the Institut Français de l'Environnement had identified 307 sustainable development indicators (IFEN, 2001a). As we pointed

60 This does not mean that events which are difficult to incorporate into indicators which affect daily life should not be included (these issues should be managed in the first place by political decision-makers who can adopt long-term strategies), but that problems of global dimensions will be addressed all the more strongly if this can be done in a way that relates to aspects of daily life which individuals are already aware of.

out in Section Two, this overkill effect is also related to the proliferation of programmes for developing indicators of society-nature interactions within many organisations in recent years.

The large number of indicators and the proliferation of programmes have caused three major problems (Lavoux, 2006). Firstly, they create the phenomenon of information *saturation*. In effect, the indicators send so many signals that it becomes impossible to make decisions. While a lack of signals increases the degree of uncertainty in decision-making, an excess of signals also creates a problem because using them would require superhuman perceptual and processing abilities. Thus, introducing too many indicators can increase uncertainty rather than reducing it. This is all the more true because indicators do not change in sync in the "control panels", and the meaning of any such changes for synthetic indicators is often ambiguous. Interpreting these systems of indicators is therefore difficult.

Along with saturation appears the problem of *hierarchisation*. The indicators are presented in the form of non-hierarchical sets. However, the co-existence of several non-hierarchical indicators can function to destabilise the information environment and produce uncertainty and inconsistency in the individuals who work within it. It is very often difficult to recognise clear signals in the trends described by sustainable development indicators. Finally, these sets of indicators create an effect of *repulsion*. A great deal of time is required to read, understand and interpret these sets of indicators, which often do not "speak" to the user. All of these problems can hardly encourage people to use indicators.

Symbolic systems create abstract hierarchies by giving meaning to things and by classifying them via orders of magnitude (Boltanski and Thévenot, 1991). Just as representations are ordered hierarchically within a symbolic system, indicators must be ordered hierarchically before they can be used effectively. This hierarchisation applies to the systems of preferences developed by individuals, communities of practice and whole societies.

We may note that many organisations are paying more and more attention to the overkill effect and the need for hierarchisation in their sustainable development indicator "control panels". Several examples can be mentioned. The United Nations Development Programme (UNDP) uses an emblematic "headline" indicator - the Human Development Indicator (HDI) - to encourage users to go on to consult other indicators of human development included in the Global Report on Human Development published every year: indicators of education, gender inequality, access to natural resources, etc. Other synthetic indicators specific to the subject of an annual report (the gender HDI in 1995 or the Human Poverty Indicator in 1997, for example) are added to the global HDI. The UNDP's strategy is to build interest among the general public and to encourage potential users to explore their other subject-based indicators, which may be less visible in the media but are more precise as instruments.

Another example is that of the European Environment Agency, which proposes three key indicators addressed to the general public, ten to fifteen headline indicators addressed to political decision-makers and thirty subject-based indicators addressed to direct users of the environment. A final example is that of two emblematic indicators of global warming: change in the date of the grape harvest over the last hundred years and projected change in the distribution of vineyards over the next hundred years (Bovar and Pennequin, 2006). These indicators are much touted by the media and speak directly to French audiences because they reflect the hierarchy of preferences expressed by the public. But many other indicators can be brought into play if there is a call for more precise information on the reality of global warming (such as temperature change, glacier mass, composition of the air bubbles imprisoned in ice cores, etc.).

The principle of feedback

Today, change at the level of individual behaviour often appears to be a necessary condition for the establishment of sustainable development. We may conclude from this that a good indicator of sustainable development is one whose development produces feedback in the behaviour of individuals. It is only then that there will be any interaction between change in the indicator and change in the behaviour of the users. One of the sources of behavioural change is practical learning, especially learning by doing. This implies that one of the main functions of the indicators of sustainable development is to provide a pedagogical tool for learning by doing; a major advantage of this tool is that it reduces the costs of learning from real-world experience.

In this context the Ecological Footprint is a particularly appropriate indicator of society-nature interactions. As we emphasised in Section Two, the interactive dimension of this indicator has been one of the major reasons for its success with a wide audience, but it is also an effective tool for stimulating reactive change in individual behaviour.

Symbolic systems create possibilities for reactivity by helping individuals to develop new and permanent reinterpretations of their experience via an ongoing process of practical learning. The degree of reactivity achieved is a function of the cognitive dissonances which form the motor force driving practical learning[61]. On this analysis, good indicators ought to provoke surprise, so as to create the cognitive dissonance which stimulates individual and collective processes of practical learning about issues of sustainable development. Surprise will be caused especially by changes in the geographical, temporal and symbolic-system levels. It is the transition from an indicator of final consumption to an indicator of consumption of units of biosphere - that is, a change in both geographical and symbolic-system levels - that produces the impact of the Ecological Footprint on the user. Another source of surprise is the transition from indicators that are of interest to one specific community of practice to those that are of interest to other communities of practice concerned with the sustainability of the same system. This gives a community the opportunity to better understand the constraints and goals of its "neighbours". The transition from indicators relating to the plot of agricultural land - a very small-scale unit - to indicators relating to the whole of the ecosystem provokes surprise among farmers. For managers of protected areas, the reverse holds true: it is the transition from the geographical level of the protected area to that of the agricultural plot that will raise their awareness of the impact of particular site developments on other groups or individuals (Etienne et al. 2003).

This in turn brings up the question of which tools are most appropriate for the construction of a multilevel picture of the sustainability of a system and for connecting indicators of different kinds functioning on different geographical levels. It is especially important to make use of spatially defined models of sustainability which are flexible and educationally useful, and to connect them with indicators functioning on heterogeneous geographical and symbolic-system levels (Boulanger and Bréchet, 2005).

The principle of exploration

As well as being able to interpret the world around them, human beings have the ability to *anticipate change in the world*. They can thus act today in accordance with their expectations about tomorrow's events, a fact which is of major importance for sustainable development.

However, the question of our real ability to recognise signals about future events is seldom raised. In fact, we experience great difficulty in interpreting signals relating to parameters with slow rates of change, such as the resilience of systems (Westley et al., 2002). It is hard even to imagine what these might be, since changes can often seem unlikely to the general public but be entirely probable from a scientific point of view. Belief in the improbability of certain changes is reinforced by platitudes about the uncertainty of current knowledge.

61 When individuals make choices, they draw on a cognitive model which leads them to expect a causal connection between an action and its outcome. If the actual outcome matches the one expected, it reinforces the cognitive model. In contrast, if the outcome does not take place, or is different from the one expected, that is, if the consequences of an action do not match expectations, this creates cognitive dissonance in the form of surprise and may require a reorganisation of the cognitive model, since otherwise the same action is liable to result in the same error in future.

Moreover, it is difficult to connect micro-level with macro-level processes of change, since they do not take place over the same time-scales, so the role of changes in behaviour can be ignored or its impact minimised. But in reality it is short-term micro-level changes which are at the root of the loss of resilience of society-nature systems at the macro level (Gunderson and Holling, 2002).

We must therefore be able to use indicators of society-nature interactions to project individuals into various possible futures, so as to connect short-term practices with global long-term changes. We need to explore these futures in order to grasp the dangers inherent in present-day dynamics (Callon et al., 2001). In particular, the indicators must enable us to connect parameters of slow change with those of rapid change, and thus to highlight the risks of collapse which these changes pose to a system when its resilience is eroded too far.

The concept of "critical natural capital" is one good response to the principle of exploration just described. The concept of CNC is based on a principle of strong sustainability, which implies that natural entities are not substitutable by physical capital, as we emphasised in Section Two (Ekins, 2003). Using the concept of CNC, indicators functioning on heterogeneous time-scales can be connected and "what-if scenarios" can be elaborated.

The principle of interaction

Economic, ecological and societal indicators must be able to be interconnected and thus represent the dynamics which drive society-nature systems. Only if this is done will we possess integrated indicators which highlight the interdependence between parameters belonging to the economic, social and ecological spheres.

From the cognitive perspective, some connections between perceptions presuppose the existence of causal relationships between them. Individual responses to issues of sustainable development are a function of the causal links which individuals' symbolic systems establish between various parameters. But even if causal connections are demonstrated scientifically, that does not necessarily mean that these interactions will be taken into consideration by political decision-makers. We need only think back to the asbestos case to see how scientific knowledge established on the basis of causal connections can take a great deal of time to become generally accepted, even when it affects the health of millions of people[62].

A key lesson of the environmental and health crises that the OECD countries have experienced in the last twenty years is that we cannot view causal connections as unambiguous (Beck, 1986). In complex systems dynamics of change are a function of multiple non-linear interactions; it is therefore important to give priority to the adaptive management of these dynamics based on practical learning (Arrow et al., 2000; Kinzig et al., 2003).

But here too the problem is that we as humans have limited capacities to grasp the complex dynamics generated by society-nature interactions (Gunderson and Holling, 2002). The human cognitive system finds it very difficult to manage several goals simultaneously and to take all the relevant interactions into account at once. This difficulty in grasping the connections among multiple causal links leads people to suppose that unambiguous relations obtain between the phenomena they observe, and to avoid concern for the indirect effects their choices might produce. This largely explains the success of the "command and control" approach, in spite of the problems created by its short-sighted focus on parameters such as economic output or species conservation.

62 Identified as cancer-causing by doctors in 1976 and by a resolution of the European Parliament in 1978, it was not banned in France until 1997.

Table 11: Synthesis of the criteria for quality of indicators of sustainable development (ISD)

Principle	Cognitive problems	Issues for the creation of ISDs	Goals of the ISDs	Example of an ISD
Contextualisation	The absence of contextualisation of the ISD creates problems of interpretation	To position ISDs with respect to specific shared worlds	To provide one or more common languages which will facilitate debate	Eco-efficiency (refers to the "industrial world")
Hierarchisation	Overkill effect due to the large number of ISDs: saturation, confusion, repulsion	To take into account the users' own priorities	To offer effective signals organised by order of importance	Human development indicator ("headline" indicator generating activism)
Feedback	ISDs seen as tools for planning rather than practical learning	To identify signals which will get people to change their preferences	To be a source of surprises which will create cognitive dissonance and practical learning processes	Ecological Footprint (educational tool based on changes in scale)
Exploration	Limited ability to grasp long-term time-scales	To find data that will connect short-term and long-term dynamics	To connect micro-level short-term activity with long-term global change	Critical natural capital (takes account of resilience and threshold effects and enables the construction of simulations)
Interaction	Limited ability to grasp non-linear interactions	To find data about society-nature interactions	To help grasp the complexity of society-nature dynamics	Multi-agent system or models of system dynamics (takes numerous interactions into account)

The indicators must thus help to increase individuals' aptitude for interpreting the interactions which drive the society-nature system they belong to. This requires adopting systemic models which incorporate a large number of interactions (Boulanger and Bréchet, 2005). Here the development of the processing capacities of computer-based models offers an interesting way to grasp complex dynamics.

Conclusion

Biodiversity indicators pose two initial technical questions: How composite should they be, and which criteria for weighting them should be adopted? These questions create a significant problem for inventors of indicators: the more parameters an indicator is composed of, the better the integrated information it will provide about biodiversity (Living Planet Index), but at the same time, changes in an indicator with many parameters will be more difficult to interpret and it will be more essential to establish methods for weighting the parameters in question. Conversely, the construction of single-parameter indicators (indicator species) provides information that is targeted but poorly integrated and subject to being affected by random phenomena.

Even if there is no miracle solution, we can agree that a composite indicator which provides a good compromise from a technical perspective is one that focuses on species diversity and abundance within a taxon. This approach has three advantages.

> Firstly, it reduces the problem of stochastic effects via averaging.
>
> Secondly, it produces targeted information by regrouping species on the basis of functional criteria such as their sensitivity to human activities or changes in their habitats.
>
> Thirdly, it offers a common unit of reference (as in the example of the common birds) which facilitates interpretation and makes it possible to avoid the problem of weighting to a certain extent.

With regard to the indicators of interactions, the question of interpretation is even more complicated, for two reasons. Firstly, the degree of integration is higher. Secondly, the conversion matrices needed to establish the parameters of the interactions are often not very transparent (the Ecological Footprint) nor very rigorous (the Index of Sustainable Economic Welfare) and are dependent on expert opinion (the Biodiversity Intactness Index or the Natural Capital Index), because of a chronic lack of information about these interactions.

This is why the Pressure-State-Response indicators and those derived from them have met with great success among the organisations responsible for introducing indicators of interactions. These indicators connect together heterogeneous indicators of society-nature interactions, without having to deal with the issue of aggregation. However, as we emphasised in Section Two, this category of indicators poses other problems which make them rather ineffective as tools of persuasive communication.

Finally, it is worth highlighting a pronounced trend in the area of the indicators of interactions: the transition from a situation where the primary goal of these indicators was to stress either the threats that human activity poses to biodiversity (the ecological perspective) or the resources which biodiversity can provide (the economic perspective), to a situation in which the primary function of the indicators is to emphasise the interdependence between the state of biodiversity and levels of well-being.

Beyond these observations, it is important that we not limit the assessment of the indicators of biodiversity and of interactions to technical concerns. Biodiversity indicators are societal tools as well as technical tools. They ought to foster public debate about the major societal problem that the conservation of biodiversity represents. Thus a "good" indicator must always be doubly sensitive - to the dynamic that it seeks to describe and to the public which it seeks to reach. However, while the technical issue has been studied by specialists in biodiversity and by statisticians concerned with indicators, it appears that the issue of the meanings that indicators have to create for their potential users has not really been addressed. This is to be measured, as we have shown, by way of the standards of quality employed to assess the indicators.

A major consideration in addressing the subject of the indicators of biodiversity and of interactions is thus the identification of the needs of the potential users of these tools. The process of identification cannot be limited to questioning managers, because that assumes that they can control systems of society-nature interactions autonomously, without concerning themselves with the other agents within these systems. However, managers - and more generally those we call decision-makers - are members of a society on which they have little influence. They must make compromises with a collective entity in which each of them is only one individual among others. From this viewpoint, the question of the function of indicators can be posed thus: are they tools for controlling a system, or for co-ordinating the heterogeneous agents who constitute this system?

To answer this question, we can point to the fact that the conservation of biodiversity has two implicit goals. The first is to change individual behaviour so as to inculcate sustainable practices and bring about concrete action on the global changes which threaten the majority of species on our planet. The second is to co-ordinate heterogeneous individuals with respect to the conservation of biodiversity, so as to implement collective choices through which regulatory systems will be introduced which encourage individuals to adopt sustainable practices.

The indicators of biodiversity and of interactions, viewed from this angle, must fulfil two functions:

- First, they should be meaningful for potential users and facilitate practical learning at the individual level. Only if this condition is met will there be interaction between change in the indicators and change in behaviour.

- Second, they should help to clarify the issues related to the conservation of biodiversity and encourage debates on the subject. In particular, they should demonstrate the connections between heterogeneous interpretations of shared problems and they should explore possible futures, so as to create a convergence of perceptions of questions of conservation and sustainable development.

Indicators will be more successful at fulfilling these functions if they take into account the five principles we described in Section Three (Table 11):

- the principle of contextualisation, which means thinking about the indicators from within specific symbolic systems
- the principle of hierarchisation, which means limiting the risk of information saturation due to too many indicators
- the principle of feedback, which leads to viewing indicators from the perspective of the dynamics of practical learning which it can give potential users
- the principle of exploration, which stresses that a function of the indicators is to project possible futures and to connect them with parameters changing at different rates
- the principle of interaction, which stresses that the indicators must enable a better grasp of the complexity of society-nature dynamics

The principles of contextualisation and hierarchisation are closely connected: they embody the requirements that have to be adhered to in order to develop "speaking" indicators, that is, indicators suited to the understandings of the potential users. In the same way, the principles of feedback, interaction and exploration form a complementary group, as these three characteristics mutually reinforce one another and result in dynamic indicators which encourage practical learning about society-nature systems.

However, this list of "principles" should not be viewed as the list of standards of quality which all the indicators of biodiversity should adopt, but as a list that complements the "technical" principles proposed by statistical organisations.

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Tables

Figures

Acronyms

BII : Biodiversity Intactness Index

CDB : Convention on Biological Diversity

CNC : Critical Natural Capital

CNRS : Centre National de la Recherche Scientifique

CRBPO : Research Center (Centre de Recherche sur la Biologie des Oiseaux, MNHN)

CSD : Commission on Sustainable Development

CSI : Community Specialisation Index

DP : Developing Country

EE : Eco-Efficiency

EEA : European Environment Agency

EF : Ecological Footprint

ETCBD : European Topic Centre on Biological Diversity

EU : European Union

FAO : United Nations Food and Agriculture Organisation

GDP : Gross Domestic Product

GFCF : Gross fixed capital formation

GNP : Gross National Product

GPI : Genuine Progress Indicator

GS : Genuine Saving

HDI : Human Development Indicator

IFB : Institut Français de la Biodiversité

IFEN : Institut Français de l'Environnement

IFN : Inventaire Forestier National

ISD : Indicator of Susainable Development

ISEW : Index of Sustainable Economic Welfare

IUCN : World Conservation Union

LPI : Living Planet Index

MAB : Man And Biosphere Programme

MAS : Multi-Agent System

MEA : Millennium Ecosystem Assessment

MEDD : French Ministry for Ecology and Sustainable Development

MNHN : Muséum National d'Histoire Naturelle

MTI : Marine Trophic Index

NCI : Natural Capital Index

NGO : Non-Governmental Organisation

OECD : Organisation for Economic Co-operation and Development

ONF : Office National des Forêts

ONCFS : Office National de la Chasse et de la Faune Sauvage

PSR : Pressure – State – Response Indicators

PCI : Principles, Criteria and Indicators Model

RLI : Red List Index

SDI : Sustainable Development Indicators

SEEA : System of Economic and Environmental Accounting

SEBI : Streamlining European 2010 Biodiversity Indicators

SNA : Systems of National Accounts

STOC : French Museum programme (Common bird census)

UN : United Nations

UNDP : United Nations Development Programme

UNEP : United Nations Environment Programme

UNESCO : United Nations Educational, Scientific and Cultural Organization

WWF : World Wild Fund for Nature

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Selecting indicators for the management of biodiversity

In 2010, nations around the world will have to assess the state of their progress in preserving biodiversity, within the framework of the Convention on Biological Diversity adopted in Rio in 1992. To do so, they will need to make use of monitoring mechanisms. The indicators of biodiversity, as multi-purpose instruments appropriate for addressing hybrid questions (that is, those which concern both the scientific and the political arenas), have rapidly emerged as the best means for monitoring this progress.

This book has two goals :

- to report briefly on the status of the existing indicators and to see in what way they enable us to better describe, understand and manage the dynamics which underlie biodiversity ;
- to address new methods for the construction of indicators of biodiversity and new criteria for evaluation of the indicators thus produced.

Through its Cahiers, IFB aims to build up a set of short syntheses meant for well informed people : researchers as well as managers and policy makers, civil society organization leaders and activists, and staff from the corporate sector involved in biodiversity management.

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