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5.3.2 Human-induced perturbations biodiversity

5.3.2.1 Introduction

Human perturbations affect biodiversity both directly and indirectly through changes in land and water use (Figure 5.3-1). Such changes have a direct impact through habitat destruction and over exploitation of resources such as occurs in overfishing and overgrazing, and an indirect impact through their effects on the composition of the atmosphere and the climate, both of which directly affect biodiversity. Changes in biodiversity in turn modify the functioning of populations, ecosystems and landscapes. Finally, these changes feed back into land-use patterns, atmospheric composition and climate, accelerating or decelerating the rate of global change and the impacts of human activities. Here we focus on the effects of land use, atmospheric composition, and climate on the different components of biodiversity whereas most of Sections 5 and 6 of the GBA analyse the effects of changes in biodiversity on ecosystem functioning.

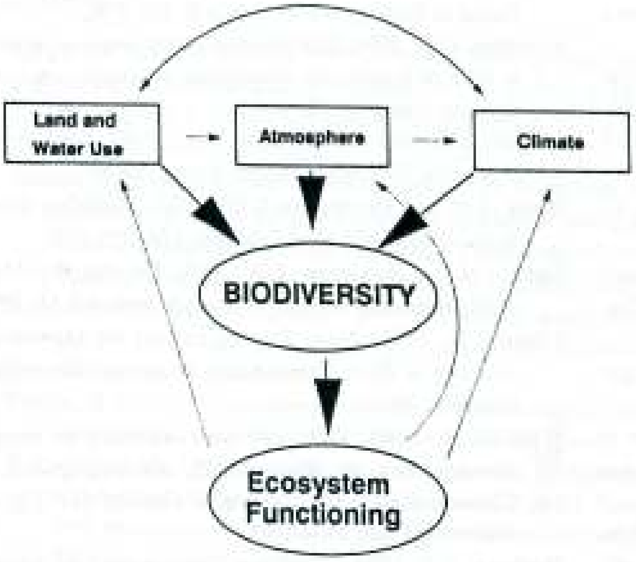

Figure 5.3-1: Conceptual model of the effects of human-induced perturbations on biodiversity and ecosystem functioning. Changes in land and water use directly affect biodiversity and simultaneously modify the composition of the atmosphere and the climate. The alterations of land and water use include the overexploitation of resources such as in overfishing or overgrazing as well as drastic transformations such as the conversion of forests into croplands. Changes in climate and in the composition of the atmosphere also directly alter biodiversity.

5.3.2.2 Changes in land and water use

Forests, grasslands, savannahs, and deserts have been altered drastically by human activity. Over the last three centuries, forests have decreased by 1.2 billion ha or 19%, and grasslands by 560 million ha or 8% (Richards 1993). This is mainly the result of increase in croplands of 1.2 billion hectares and the growth of urban areas. The rate of land-use change is accelerating very rapidly, as is demonstrated by agricultural expansion which was greater during the period 1950–80 than during the entire 150-year period between 1700 and 1850 (Richards 1993). Land-use change also includes changes associated with the over exploitation of resources which are ubiquitous and more difficult to quantify. For example, livestock overstocking has resulted in severe degradation of rangelands (referred to as desertification), bush encroachment or brush invasion altering large areas of North America, Africa and Australia (Buffington and Herbel 1965; Walker *et al.* 1981; van Vegten 1983; Archer 1989).

Marine environments have been and still are being drastically modified by human action. Changes in water use are usually not reflected in qualitative shifts like those we observe in terrestrial environments but in steady and quantitative changes of their chemical, physical and biological properties. Anthropogenic additions of nutrients are most obvious in relatively shallow coastal seas such as the Baltic or the North Sea in Europe, or Puget Sound along the open coast of the state of Washington in North America (Jickells *et al.* 1993). As a result of the discharge of wastes from heavily populated and industrialized areas, the nutrient content of the oceans has increased significantly. For example, phosphate concentration in the Baltic increased by a factor of 3 in the period 1958–80 (Jickells *et al.* 1993). Increases in nutrient availability stimulate the growth of plankton which in turn consumes dissolved oxygen as it decomposes (Lancelot *et al.* 1987). Simultaneously with the increase in nutrient availability, dissolved oxygen in the deep waters of some parts of the Baltic Sea decreased from 3 ml/l at the beginning of the century to almost zero at present (Jickells *et al.* 1993). Besides pollution, humans also drastically alter marine environments by over-exploitating resources. Overfishing has resulted in the elimination of substocks of herring, cod, ocean perch and salmon in several regions of the world (Ludwig *et al.* 1993).

Changes in land use are the major causes of habitat destruction and fragmentation, and these in turn are the major causes of recent extinctions, and constitute a major threat to biological diversity (WCMC 1992; Skole and Tucker 1993). A clear indication of the importance of habitat destruction in accounting for changes in biological diversity is that one way of estimating current and predicted losses of species diversity is based solely on combining information on current and projected deforestation rates with information on species richness per unit area in tropical forests (Ehrlich and Wilson 1991; see also Section 4.4). The assumption that global terrestrial species extinction rates can be assessed from tropical forest extinction rates is justified on the assumption that most terrestrial species occur in tropical moist forests. Independent exercises using different approaches have estimated extinction rates to be of the same order of magnitude as those estimates based on species–area relations and the rate of habitat loss (Smith *et al.* 1993; Heywood *et al.* 1994).

Although drastic changes in land use such as large-scale transformations of forests into grasslands or grasslands into croplands usually result in reductions in global species diversity, more subtle human-induced changes sometimes increase local species diversity. For example, some grasslands that evolved under low grazing pressure have shown increases in species diversity as a result of the introduction of livestock and the consequent increase in grazing intensity (Sala *et al.* 1986; Milchunas *et al.* 1988). This pattern is accounted for mainly by the introduction of alien species better adapted to grazing conditions, without the disappearance of native grasses. Further increases in grazing intensity have reduced diversity as introduced grazing-tolerant species have become dominant. Human activity is mostly neutral or negative with respect to genetic or species diversity. Only recently – by means of biotechnology – have humans increased diversity. However, at the community and landscape levels human activity may either increase or decrease diversity. Naveh (1971) suggested that human-induced livestock grazing has increased plant, community and landscape level diversity in the Mediterranean Basin.

5.3.2.3 Changes in atmospheric composition

Recent changes in the composition of the atmosphere are a clear indication of the major disruption of biogeochemical cycles that have occurred as a result of human activities (Schlesinger 1991). First, scientists pointed out the perturbations of the carbon cycle and the resulting sharp increase in the concentration of carbon dioxide in the atmosphere (Keeling 1986). Next in importance is the disruption of the nitrogen cycle as evidenced by the magnitude of human-induced nitrogen fixation, the increase in nitrous oxide emissions, and the high values of nitrogen deposition over most of the developed world (Matson and Vitousek 1990; Vitousek 1994). These alterations of biogeochemical cycles have always resulted in ecosystem enrichment and, in most ecosystems, nutrient enrichment results in a sharp reduction in species diversity. Experimental fertilization of shortgrass steppe, tallgrass prairie, tundra and deciduous forest has always resulted in decreases in plant species richness (Lauenroth *et al.* 1978; Schulze 1989; Tilman 1993).

The increase in atmospheric CO_2, and the corresponding CO_2 fertilization effect, results in an ecosystem carbon enrichment which is modulated by nutrient and water availability (Mooney *et al.* 1991). Carbon enrichment can be expected to have effects on biodiversity similar to those that have been demonstrated for the enrichment of ecosystems with nutrients. Because our ability to perform CO_2 enhancement experiments in whole ecosystems is relatively recent, there is no experimental evidence to assess the effect of CO_2 fertilization on biodiversity. Experiments under controlled environmental conditions support the hypothesis that CO_2 enhancement changes plant–plant interactions, and alters the competitive balance among species, which might lead to a decrease in plant species diversity. Elevated CO_2 field experiments based on open-topped chambers showed a distinction between the response of C3 and C4 species in a salt-marsh (Curtis *et al.* 1989). Morse and Bazzaz (1994) also exposed two species with different photosynthetic pathways to elevated CO_2 concentrations and found that the C3 species (*Abutilon theophrasti*) showed a larger response than the C4 species (*Amaranthus retroflexus*). Based upon experiments under controlled environmental conditions, Polley *et al.* (1994) suggested that the invasion of the C4 grasslands in the southwestern United States by woody C3 mesquite (*Prosopis glandulosa*) during the past 150 years can be related to the observed 27% rise in atmospheric CO_2. Species-specific differences among CO_2 responses of forest trees have been reported for temperate zones (Williams *et al.* 1986; Norby *et al.* 1992) although not for tropical ecosystems (Körner and Arnone 1992). Phillips and Gentry (1994) speculated that increased CO_2 may favour vine growth in tropical forests, which may explain the observed increase in tree mortality.

5.3.2.4 Climate change

The indirect effects of changes in the composition of the atmosphere and changes in land-use patterns occur via changes in climate. Changes in land-use and atmospheric composition have already been detected and will affect ecosystems and humans sooner than changes in climate. However, climate change has been the first global change phenomenon to attract the attention of scientists and policy-makers. Scientists agree that an increase in the atmospheric concentration of greenhouse gases such as CO_2 and methane will result in an increase in global temperature and a change in the global distribution of precipitation. Current uncertainties are related to the geographical patterns of those changes and the speed with which they will occur (Mitchell *et al.* 1990). Predicted changes in climate for a doubling of atmospheric CO_2 are quite significant for most regions in the world. Models that relate average climatic variables to the distribution of vegetation types are ideal tools for assessing the potential effect of climate change

Box 5.3-2: Management for sustainable biodiversity.

To manage and exploit the environment effectively, and sustainably, scientific information must be translated into management plans and actions. However, promoting the wise use of ecological concepts in managing the Earth's biodiversity is neither simple nor straightforward. It requires not only specific scientific skills, but also considerable leadership qualities in co-ordination, integration and advocacy. On the other hand, the challenges and opportunities for a decisive involvement of the ecological sciences in environmental management are greater than ever, given that the Convention on Biological Diversity and the *Agenda 21* document signed at the UNCED Rio summit in 1992 provide ample political support at the highest level. How do we translate ecological research into management? Here, some key aspects of the research/management interface are discussed.

1. *The available options are limited.* The options available to managers are restricted by practical feasibility, environmental acceptability, economic desirability, and in many cases political advantage (Saunders and Burbidge 1988). Time is a key constraint. Decisions need to be made within a given (and usually short) time horizon, and typically with only incomplete information available. In the case of biodiversity, for example, the rate of loss of both species and habitats is growing exponentially, leaving less and less time for detailed, long-term studies (Meadows *et al.* 1992).

2. *Management for sustainable biodiversity must be based on the precautionary principle.* The precautionary principle, and the associated notion of reserved rationality (Perrings 1991; see Section 12), apply to those decision-making problems in which both the level of fundamental uncertainty and the potential costs are high. Examples include the use of environmental resources in novel ways and at high levels of magnitude. Both principles imply the need to proceed cautiously to safeguard against the possibility of unexpectedly severe future costs when there is ignorance as to the probability distribution of the magnitude of the negative impacts. In other words, when dealing with decisions that have the potential to destroy crucial life-supporting systems, it is prudent to have some margin for error (on the conservative side) as one learns the outcomes of a given management policy. It is also prudent to make allowances for the potential, although uncertain, future losses associated with the resulting use of environmental resources and services. By necessity, the precautionary principle implies a high value-driven judgment about the responsibility borne by present generations toward future generations (Perrings 1991). Therefore, and acknowledging that at present we do not have all the answers we need, the only prudent policy to assume today is that while there is clearly redundancy in the role of species in delivering some services, there may also be an extinction threshold which, if crossed, will result in unacceptable deterioration of ecosystems services (see 5.1). Accordingly, the precautionary principle indicates that extreme care should be taken before labelling any species as 'redundant'. Since the precautionary principle entails a cost for human societies, decisions need to be made about how much the precautionary principle would have to be stretched or how much insurance different societies can afford to buy. These kinds of decisions will be greatly aided by a better understanding of the relationship between biodiversity and ecosystem functioning.

3. *The relationship between science and management is a two-way process.* There is no such a thing as a definite, prescription regarding environmental management. Management is a continuous, dynamic and interactive process involving research, implementation and monitoring. Therefore, a continuous feedback between researchers, managers and users is clearly necessary. Accordingly, the following basic steps are required in a well planned project: (a) planning and developing goal-orientated research, (b) dissemination of results, (c) implementation of management practices and policies, and (d) monitoring and feedback.

An important component of this two-way process is the adaptive management approach, i.e. using management practices as a research tool to obtain information and insight to fine-tune management practices. Use of management as a research tool has considerable potential, providing access to semi-experimental situations at a scale and degree of realism well beyond the possibilities of 'traditional' experiments (Holling 1978). Furthermore, the management project itself can be used as an experimental probe as, for example, when manipulating grazing pressure as a way of understanding vegetation dynamics in savannas or grasslands. The adaptive management approach is particularly useful when decisions need to be made in situations where data are incomplete and uncertainty is great, requiring an ongoing, flexible, and sometimes opportunistic process. A particularly important challenge for researchers on the functional role of biodiversity is the need to develop sustainable management models for each of the Earth's biomes, in which both ecological services and human use are made compatible (see for example Milton *et al.* 1994 for a discussion on savannas). Furthermore, involvement in real-world situations favours interdisciplinary work, while providing a better insight into the constellation of factors (biological, economic and social) affecting the system under management.

under equilibrium conditions. One of the earliest models of this kind is the one developed by Holdridge (1947) (see Section 2.3). Analysis of the distribution of vegetation in equilibrium with the new climatic conditions showed big shifts of vegetation types under a double CO_2 climate (Emanuel *et al.* 1985; Kramer and Leemans 1993). The main result is a poleward shift of vegetation patterns. Approximately 30% of the vegetation of the Earth will experience a shift as a result of the predicted climate change. Although the climate change is expected to be significant, the major threat for biodiversity is the speed with which this change will occur. Changes of the magnitude predicted for a doubling of CO_2 have occurred during the Earth's climate shift from glacial to interglacial periods. However, while these changes occurred over millennia, the expected human-induced changes will occur in less than a century (Watson *et al.* 1990). The rapid change in climatic conditions will hamper the ability of individual species to migrate to regions with climatic conditions similar to those of the present. Moreover, in some cases such as the Arctic, the area favourable for the survival of an individual species will be largely reduced. The reductions of suitable areas for a large number of species, and a change in climate faster than the migration rate of most species, is certain to result in a drastic reduction of global species diversity.

5.3.2.5 Conclusions

Human-induced perturbations differ quantitatively and qualitatively from natural perturbations. Humans have increased the frequency and severity of natural disturbances to the extent that their impact is now greater than that of most natural ones (Likens 1991). The duration of human disturbances is also usually much longer, and the frequencies are much higher, than natural ones (Reiners 1983; Woodwell 1983). Among the major threats to species diversity are the qualitatively new kind of disturbances for which no specific adaptations have yet evolved. Humans have synthesized new chemical substances which have reduced the stratospheric ozone layer at higher latitudes in the Southern Hemisphere as well as at mid-latitudes (Farman *et al.* 1985; Stolarski *et al.* 1991). A reduction in the ozone layer allows increased quantities of short wave radiation (UV) to penetrate through the atmosphere. There is evidence that increased UV results in major negative effects on primary producers as well as on the next trophic level (Caldwell *et al.* 1989; Smith *et al.* 1992; Bothwell *et al.* 1994). Equally new is the ability of humans to exchange floras and faunas which has resulted in rapid and major invasions of exotic plant and animal species (Drake *et al.* 1989). Increases of some insect, plant pathogen and weed pests may be associated with the increase in CO_2 and temperature (Pimentel *et al.* 1992).

All the human-induced perturbations described here result in reductions of global species and genetic diversity, although some human manipulations may result in local increases in genetic, species, community, ecosystem and landscape diversity. Human-induced perturbations under the term 'global change' directly affect ecosystems, and humans who depend on ecosystem services (Ehrlich and Mooney 1983). Global change reduces species diversity which in turn (as described in Sections 5 and 6) may affect ecosystem functioning. The truly irreversible nature of the loss of genetic and species diversity is what it makes it so important for humans (Vitousek 1994). In contrast, the changes in atmospheric composition and climate and to a large extent land use are reversible. Reducing of 'human forcing' will result in a slow return of the atmosphere and the climate to approximately original conditions. In contrast, the loss of population and species diversity is permanent. The combination of genes that results in a variety of morphologies and behaviours will be lost for millions of years or even forever. The issue of how to satisfy the increasing demands of human societies for goods and services and simultaneously to ameliorate the rate of species and populations loss, is discussed in Box 5.3-2.

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5.4 Conclusions

5.4.1 Background

Fundamentally, we wish to answer the simple question: Does biodiversity matter in the functioning of ecological systems? This question should be addressed with respect to the four major principles introduced in Section 5.0: (1) the levels of biological and ecological organization and their interactions, (2) the numbers of different biological units within each level, (3) the influence and degree of similarity in the traits or roles that biological and ecological units within each level play, and (4) the spatial configuration of the units within any level. We have thus summarized the conclusions of the chapters in Section 5 with respect to these four principles. We then proceed with a synthesis of these conclusions with respect to the influence of human actions and implications for management. The summary and synthesis take the form of several simple questions.

5.4.2 What are the influences of genetic diversity on ecosystem functioning?

Ehrlich (5.1) and Templeton (5.2.1) both point out that intraspecific genetic variation can be, and has been, exploited to change quantitative aspects of ecosystem functioning, e.g. by increasing crop yields. In addition, intraspecific genetic variability confers some adaptive capability to those species, and thus increases the possibility that their functional roles can continue to be expressed in ecosystems that are undergoing environmental variability or stress. There is very little information on whether the genetic similarity of populations influences ecosystem functioning. Templeton (5.2.1) points out that the phenomenon of local adaptation of populations to their environment is well known, and thus the spatial configuration of genetic variability might be important. Reintroduction of species to areas from which they have been lost is generally most successful if the reintroduced individuals are from populations that originated close to the original area. It is not unreasonable to suppose that there are ramifications of these observations for ecosystem functioning, but direct experimental evidence or observations are lacking.

5.4.3 What are the influences of species diversity in ecosystem functioning?

In many cases, species clearly matter. This is primarily because the species plays an important and unique role in its ecosystem. Removal or addition of the species results in a dramatic and obvious change in the other species in the ecosystem or in a key ecosystem process. The evidence for this conclusion is compelling; the number of examples is increasing as more systems are examined; and these keystone species (Chapin *et al*., 5.2.2) have been reported from a wide range of ecosystem types. However, in spite of the widespread existence of the phenomenon, no species characteristics have emerged that allow prediction of which species will play keystone roles. In fact, some small or cryptic species have been found to play a keystone role.

In many other cases, however, there appears to be substantial overlap among species with respect to their functional roles. Their removal or addition appears to have little demonstrable effect either on other species or on an ecosystem process. Other species compensate for the absence of the target species, at least in the short term. However, it is not known with certainty if all functions of the species in question are compensated for (in fact, it is rarely understood what the full range of functions is for each species). For this reason, it is probably inappropriate to say that species are 'redundant'.

Ecosystems with greater overlap among species with respect to any particular process will be more resistant to change than otherwise comparable systems characterized by little compensatory potential. This stability is predicted to be a direct result of the fact that species that overlap with respect to a particular function probably differ with respect to their responses to environmental changes such as temperature, salinity, ultraviolet radiation (UV-B), or explosure to toxic compounds. Compensatory overlap is thus suggested to provide 'insurance' in the sense that key functions are more likely to continue despite changes that result in the loss of some species. There is some evidence for this prediction, but it is a very difficult phenomenon to demonstrate. There is no evidence that contradicts the predictions. This is an area where further research is needed.

The above conclusions focus on particular traits of species and the extent to which the traits are unique to a