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Human Influences on Biodiversity

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the decade, $42.6 billion had been flowing to developing countries.) Between 1986 and 1993 developing countries paid $1253 billion to serve a growing foreign debt that reached around $1550 billion in 1994 (IMF, 1994). If the developing countries continue to be shut out of markets, deprived of access to technology, and burdened with debt, they will have neither the means nor the incentive to conserve their resources for the future.

11.2.4 Conclusions

The major cause of biodiversity loss in recent historical times is human action, primarily land use that alters and degrades habitat to serve human needs (Pimm and Gilpen1989; Freedman 1989). Yet the ability to forecast the impact of specific actions on biodiversity is not yet well developed, and practical techniques for conducting such analyses are at only a very preliminary stage (OTA 1987; Soulé and Kohm 1989). Machlis and Forester (1992) have pointed out that while a large number of conceptual and predictive models of the interactions between humans and nature exist, explicit models of biodiversity loss are sparse and incomplete. While many of the generic models treat 'environmental change' or 'ecosystem alteration' as the dependent variable, it is not at all clear that biodiversity loss can simply be substituted for these more general factors. Biodiversity loss is a special case of environmental change, and the socioeconomic factors that influence it may not have generic impacts. For example, biodiversity loss measured as a reduction in species richness may be so dependent upon the original number of species at a specific locale that certain generic models will fail to explain, much less predict, even the most dramatic levels of biodiversity loss. The importance of habitat in the preservation of biodiversity may suggest that spatial relationships at the local scale will play a more significant role in biodiversity models than, say, models of climate change.

However, it seems apparent that the issue of scale is crucial, as biodiversity loss is embedded in a complex human/environment system that operates at several hierarchial levels; socioeconomic factors important at one scale may be less important at another, and at each different scale, new variables and relationships may emerge as critical driving forces.

The driving forces of human-induced change will vary with the type of change involved, and forces that drive some changes may lessen others (Meyer and Turner 1992). For example, rising agricultural prices may provide an incentive for clearing forests, while also providing an incentive to adopt soil conservation measures. Second, the same kind of land-cover change can have different sources in different areas, with deforestation in some areas primarily for timber extraction, in others for shifting cultivation, and in others for establishment of plantations. In the dynamics of underlying causes, no agreement yet exists on the level at which adequate explanation is achieved. For example, some may consider that deforestation by agricultural expansion is driven by population growth, while others would contend that agricultural expansion helps to cause population growth; others will suggest that population growth needs to be explained in terms of the socio-political and economic conditions that promote it. Ehrlich and Ehrlich (1990) have attempted to provide a single comprehensive approach to the question of driving forces, using the equation $I = PAT$ where I represents environmental impact, as the product of P (population), A (affluence) and T (technology). Thus, human impact is a product of the number of people, the level at which they consume, and the character of material and energy flows in production and consumption. Meyer and Turner (1992) have pointed out that this formula suffers from the handicap of a mismatch between its categories of driving forces and the categories customarily used in the social sciences. Neither 'affluence' nor 'technology' is associated with a substantial body of social science theory.

Today's pressures on the natural world mean that the genetic diversity of many species is being reduced because the total sizes of populations are decreasing and they are often being split into small, widely separated, subgroups which cannot interbreed. Others might argue that this is one of the processes of speciation, with humans serving as a new isolating mechanism.

11.3 Information requirements for the sustainable use of biodiversity

11.3.1 Introduction

Effective action must be based on accurate information, and the more widely shared the information, the more likely it is that individuals and institutions will agree on the definition of problems and solutions. However, the current state of knowledge is still largely inadequate to evaluate precisely what are the impacts of human activities in different ecosystems, and to understand what are the relationships between economic activities, development and conservation of biodiversity. Gaps in knowledge may have at least three origins.

First, the lack of information resulting from an insufficient research effort, especially for the inventory of species and ecosystems (see 11.3.2.4), for understanding how components of ecosystems fit together and interact with one another, for information on traditional use and knowledge of biodiversity, and for changes in ecosystem use. A significant increase in funding and man-power could fill most of these gaps. However, while some scientists argue that until we understand the natural environment, it will be difficult to understand how human societies interact with these systems, it is not realistic to wait for many years for conservation action. What to do in a situation of uncertainty?

The second major source of gaps derives from the complexity of the natural environment and the complexity of the interactions between human societies, their activities and the natural world. Natural and social sciences evolved independently, but better interaction between them is needed to understand the nature and strength of their relationships. The long-term preservation of biodiversity depends on management strategies and modes of development, but it is very difficult to forecast changes in human behaviour. This uncertainty makes it difficult to predict changes in the environment and the expected consequences for biodiversity, and it reinforces the need to monitor biodiversity carefully in order to respond with corrective action.

The third set of gaps involves access to information and how to use what we already know. How can technological solutions be applied on a large scale? While useful concepts such as 'sustainable development' and 'integrated management' are available, we need guidelines for action, supported by reliable observations and experiences. The effective implementation of biodiversity action plans relies on improved methodologies and tools.

In general, research must be expanded and strengthened to improve our understanding of biodiversity and its potential role in building sustainable human societies. We need to understand a great deal more about how, why and where human activities affect biodiversity, in order to provide accurate information to politicians and decision-makers. Research must serve to inform, supplement and improve conservation efforts, but it should not be a substitute for immediate action. However, even with a complete inventory of the status of global biodiversity, and a perfect understanding of the relationship between human activity and biodiversity, we will still face the problem of how to control destructive human behaviour.

11.3.2 Monitoring biodiversity, its use, and changes in natural and managed ecosystems

Different parts of the world are being subjected to varying degrees of transformation. Some areas have been altered by humans over long periods, while in other regions human influence has been moderate. The response to disturbance varies greatly from one ecosystem to another, so we need to monitor and document changes in biodiversity resulting from climatic changes or human activities in a variety of natural and managed ecosystems, and in different climatic zones (Solbrig 1991). To detect, measure and assess changes in the status of biological diversity, appropriate monitoring methods should employ specific indicators of biodiversity attributes, as well as indicators of socioeconomic changes. One of the greatest difficulties is to distinguish the effects of natural fluctuations and changes from the effects of human-made disturbances. Another question still partly unanswered is what exactly should be monitored. Distribution and abundance of selected species? Changes in ecosystem structure, species composition, functions and processes? Distribution and area of different land-use classes, habitats, biotopes, ecosystems?

11.3.2.1 Long-term monitoring

Most of the questions asked of scientists by managers concern our ability to detect changes in the physical, chemical or biological state of the environment, and to distinguish cause from effect. We need data sets from good, regional, long-term monitoring to provide decision-makers with convincing data on environmental changes due to adverse impact (see Section 5). The selection of sites for long-term monitoring depends on the questions to be investigated, but in selecting sites, a good knowledge of their management history is most relevant to an understanding of the processes of change. However, long-term data collection programmes face problems of the continuity of the variables measured, continuity of funding, and comparability of data as analytical methods change.

Monitoring programmes are also faced with major difficulties in the interpretation of data. For example, species extinctions and ecosystem changes do not always result from a single disturbance but rather from the cumulative effects of many different disturbances, and it is not always easy to determine the relative importance of the different factors. Moreover, some environmental factors change gradually over time, while others create short-lived but major disturbances (such as acute pollution, volcanic eruption, or occasional extremes in climate) that could be very important determinants of long-term changes. If they are not recorded, the subsequent data sets will probably be difficult to understand. Moreover, ecological processes operate at a broader range of temporal and spatial scales than is typically addressed in ecological studies, and long-term research reveals processes and events that have often been invisible in the short term. Such is the case for slow changes occurring over years or decades, which are hidden in the so-called 'invisible present' (Magnuson 1990), i.e. we frequently observe the response of an ecological system to a cause that occurred before monitoring began, and in most impact studies we are seeing the transition of the system rather than the new state it is likely to reach.

A major issue in monitoring programmes, as well as in designing restoration programmes, is to identify a baseline reference situation with which to compare the collected data. Any impact study should refer to a standard 'natural' or 'non-perturbed' ecosystem. However, the 'natural community' has in fact already been disturbed virtually everywhere and trying to ascertain its original characteristics is a risky task. What is a 'healthy' system which should serve as reference (Loehle 1991), and how to evaluate its 'integrity', are key questions for ecologists and managers (Woodley *et al.* 1993). The relevant normative goal of human–environmental relationships is to maintain the integrity of combined natural/cultural ecosystems. Natural and social scientists should collaborate in the design and execution of long-term pilot studies of ecosystem integrity in catchment areas that include human settlements, and not only relatively simple 'natural' ecosystems which have usually only recently excluded human occupation.

11.3.2.2 Monitoring the rehabilitation of degraded ecosystems

As populations increase, the proportion of modified land is likely to rise, and in areas of severe land shortage, the management of such lands will become a matter of significant concern. However, lands degraded by overexploitation have received little attention compared with natural systems, and there is now a growing need to improve the scientific understanding on which the effective management of degraded ecosystems can be based.

Rehabilitation describes a management strategy designed to arrest the degradation of landscapes. It includes restoration, which aims to reinstate entire communities of organisms closely similar to those occurring in idealized natural systems. Research needs can focus on describing alternative methods for rehabilitation, including re-seeding of native species, plantations of exotics, etc. More information is required about the genetic structure, biology and ecological requirements of many plants or animals, and their potential for rehabilitating degraded sites. Research is needed on what species attributes would ensure successful invasion of degraded systems, and what is the most cost-effective way of screening the native or exotic flora and fauna to locate candidate species for (re)introduction (Soulé and Khom 1989). We also need to study and compare the rate of ecosystem recovery when submitted to natural and anthropogenic disturbance regimes, and to identify the impacts of different prior land uses on restoration potential, identifying the principal factors that affect restoration in different systems (USNRC 1992).

11.3.2.3 Species introductions

The devastating effects of introduced rats, pigs, cats or rabbits to oceanic islands are widely documented, but in most cases we know little about the impact of introductions on native communities and ecosystems when they do not result in ecological catastrophes. The list of plant and animal introductions is enormous and the future promises a continuing spread of exotic species. However, while the introduction of species has been encouraged all around the world for centuries, both by managers and by scientists, many ecologists today are increasingly worried about their impacts.

Are introductions really a game of chance? Probably not, but we do not know the rules of the game. Many ecologists, more or less intuitively, claim that the introduction of exotics is risky, and Chapters 11.1 and 11.2 have mentioned cases that may be considered ecological disasters. Conversely, there are also examples of assumed success, and managers are very cautiously optimistic of using new species to improve agriculture or fisheries production, especially using biotechnology to produce genetically modified organisms.

However, one of the major problems with species introductions is their irreversibility, at least at human time-scales. Once introduced and established, it is almost impossible, given current technology, to eradicate an exotic species from a large ecosystem. Therefore, there is great need for a careful assessment of past experiences to provide general, scientifically based guidelines and policies about species introductions, taking into account both the potential ecological values and the economic values of these introductions. It is also essential to evaluate the potential long-term detrimental effects of introduced exotic species, under controlled conditions, and before their release.

Introducing genetically modified organisms presents unique risks because laboratory results alone provide a poor guide to their behaviour, ecological impacts and potential socioeconomic effects. Accordingly, strict Codes of Conduct related to the release of such organisms are urgently needed in all countries and at the international level (WRI *et al.* 1992).

11.3.2.4 Inventory and data bases

To assess long-term changes in biodiversity, a basic prerequisite is a good knowledge of species and their distributions in space – the task of biogeography. However, the inventory and descriptive phase of biodiversity is far from complete, and present-day estimates of the number of species on Earth is a matter of debate, because our knowledge of the species and their distribution is inadequate. The world database is still of variable quality, and there is a shortage of data for many taxonomic groups. There is an urgent need to accelerate collection along with description of organisms, particularly those that are ecologically important and threatened by human activities. A global network of systematists should be established to accelerate the inventory of global biodiversity through improved systematic practices (Solbrig 1991; Bisby 1994).

An effort should also be made to develop new and innovative ways of exchanging biological information, such as the use of computerized relational biological databases, so that it is possible to establish in-country user-friendly biodiversity databases for use in decision-making and for analysis of trends. This is already under way by groups such as the World Conservation Monitoring Centre, and many of these efforts are discussed in Bisby *et al.* (1993).

11.3.3 Strengthening social science research and the connections between biological and social processes

The fundamental causes of the observed attrition of natural biological systems are rooted in the contemporary human condition, involving interactions between social and ecological processes. Therefore, the conservation of biodiversity must focus largely on economics, sociology and political science. Soulé (1991) recognized seven key factors to which our present knowledge does not allow definite answers:

- Population growth: what is the relationship between population growth and impact on biodiversity?
- Poverty: what is the impact of poverty on biodiversity? Conversely, what is the impact of wealth on biodiversity?
- Misperception of time scale: what is the impact on biodiversity of the short-term mentality of many governments and businessmen?
- Anthropocentrism: if a new ethic and a revolutionary change in human consciousness are necessary to support conservation purposes, why is there a general lack of support for non-utilitarian causes, and why are current cultural values usually human-centred?
- Cultural transitions: which socio-cultural situations foster loss of biodiversity and which foster conservation?
- Economics: what kinds of economic instruments foster the loss of biodiversity and which foster conservation?
- Policy implementation: what is the impact of social and political instability on biodiversity?

Another causal factor, not mentioned by Soulé, is the lack of responsiveness of decision-makers at the national and international levels to local indicators of environmental degradation, including indigenous knowledge and observation of user groups.

11.3.3.1 Knowledge, innovations and practices of indigenous and local communities

Faiths, cultures and traditions give people their basic orientations toward the natural world and guide their actions. Nature has been considered (and is still considered) by many people as an obstacle to human purposes as well as the direct or indirect source of all the material necessities and comforts of human life. For instance, aquatic ecosystems are considered both as a reservoir of biological resources (fish, shrimps) to be preserved, and as a reservoir of diseases (malaria, schistosomiasis, etc.) to be eradicated. This dilemma may explain why human attitudes to nature differ from culture to culture, and have changed over time. Their importance is often overlooked in conservation programmes, while people's commitment to conserving and sustainably using biodiversity springs from the human 'sense of place'. There is a need to understand better how ethical norms and religions condition human behaviour toward biodiversity.

During the last two decades, the link between biodiversity conservation and sustainable socio-economic development has been recognized. It appears that the interests of some human groups have been strongly linked to the prudent use of their resource base, and that they have evolved appropriate conservation practices based on some simple and approximate rules that have tended to ensure the long-term sustainability of the resource base. These rules may have been developed by a process of trial and error, with acceptance of practices that appeared to keep the resource base secure coupled with rejection of those practices that appeared to destroy the resource base.

There is a need to recognize the value of traditional knowledge, and subsequently to develop a mechanism for the appropriate protection of, and compensation for, such knowledge (UNEP 1994). This can be achieved through (1) a better knowledge of biological resources being exploited, as well as the full range of uses and values of these resources, and (2) compilation of available information with the support of a group of specialists. We must also identify and develop means to maintain traditional knowledge and to strengthen and develop indigenous and local community strategies for conservation and sustainable use of biodiversity, fully respecting their intellectual and cultural integrity and their own vision of development. This research should build a greater understanding of the relationship between biodiversity and local systems of knowledge and resource use, and should translate this understanding into useful policy (USNRC 1992).

11.3.3.2 Legal aspects

The position of biological diversity in national legal systems is one of the important judicial problems of today (de Klemm and Shine 1993). Plants and animals are objects whose degree of protection depends on the value they represent for human beings. Although well intentioned, this specifically anthropocentric view leads directly to the subordination of biological diversity, and to its sacrifice in spite of modern understanding of the advantages of conservation.

One major concern is the implementation of legal instruments developed nationally or internationally. Most treaties and conventions are not obligatory for the countries, and their application is usually delayed. Attention must be given to structural problems that contribute to biodiversity loss, such as unequal trade relations that might conflict with the conservation of biodiversity, or the impact of debt on the exploitation of biodiversity (IUCN 1994).

To strengthen the position of biological diversity in our societies we should provide the guidelines of legal procedures and ethical considerations. We should accept biodiversity as a legal subject, and supply it with adequate rights. This could clarify the principle that biodiversity is not available for uncontrolled human use. However, this non-availability should not turn into an unrealistic conservation. Contrary to current custom, it would therefore become necessary to justify any interference with biodiversity, and to provide proof that human interests justify the damage caused to biodiversity.

To realize the objectives of the Biodiversity Convention, biodiversity concerns must be integrated into mainstream public policy and law governing the natural resource-based production sectors, such as forestry, fisheries and agriculture. Many existing legal frameworks, issues, obstacles, strategies and prospects are associated with this integration (Glowka *et al.* 1994). The precautionary principle is increasingly seen to be of great importance to the conservation of biological diversity. In international environmental soft law, it has emerged as a recognition of the uncertainty involved in impact assessments and management, and in the determination of the future consequences of present decisions. However, its translation into binding rules of law is particularly difficult, and a number of legal problems will have to be resolved (de Klemm and Shine 1993). Its implementation in fisheries management has been suggested and FAO is currently developing Guidelines for Responsible Fishing (García 1994).

A whole new area in the legal world is the question of intellectual property rights. While the convention affirms the right of states to require payment for the commercial use of genetic resources obtained from their territory, the formalization of such rights, equitable as it may seem, gives rise to considerable practical difficulties. How will it be possible to determine the true country of origin when the resource has a distribution range overlapping many countries? What sort of recourse will a country of origin have if the genetic material has been smuggled out of the country? (de Klemm and Shine 1993). Disputes are therefore bound to occur and difficult problems of proof may arise.

11.3.3.3 *Economics and biodiversity*

Natural resources are crucial to human welfare so there are strong interactions between ecological systems, economies and social systems (Arom *et al.* 1993). Biologists have in general displayed concern for the health and persistence of ecosystems as a foundation for human well-being, but usually oversimplify the economic side of the relationship. Conversely, many economists ignore natural systems and resources while many of the critical questions at the ecology–society interface involve economics (Ehrlich 1989).

Despite past neglect of environmental problems and externalization of environmental costs, a few economists since the 1970s have taken a broader interest in environmental issues. Growing environmental problems have not abandoned the idea that maximizing human welfare is an inherent goal of economics, but the goal has been deprived of its exclusivity. This change was due largely to scientists who argued that there were limits to human population and development (Goodland *et al.* 1991). Fortunately, the pessimistic scenarios foreseen for instance by the 'Club of Rome' and others (Goldsmith *et al.* 1972), have not occurred, but the decisive question raised by debates about the 'limits to growth' is still unanswered: How large can the human population become and how long can it be sustained with the available resources? To achieve global sustainability, economists must extend their theoretical horizons and consider the environment in production costs (Hohl and Tisdell 1993).

A major challenge is to evaluate the biological consequences of economic activities and to develop appropriate economic models for the sustainable use of natural resources.

11.3.3.3.1 Contribution of wild species to local economies and to international trade. A central question in the effort to conserve biodiversity is how local people affect the biological diversity of the ecosystems they inhabit (USNRC 1992). In other words, how do local people use biological resources? Why? And what is the overall contribution of wild species to local economy? What are the incentives of local people to use ecological resources sustainably and how can these incentives be transferred from the ecosystem to the biosphere? The screening of plants and animals for features of potential use to mankind should also be accelerated, in order to identify organisms of potential benefit in agriculture and in the provision of environmental services. Particularly important in this regard are traditional drugs which can be used to treat diseases in communities that lack access to modern medicine because of its expense (USNRC 1992). However, results of this screening should benefit local people directly where traditional knowledge leads to the identification of a resource with broader value, and it should be protected through local control from non-sustainable exploitation.

International trade in wild species deals with living specimens (ornamental plants, ornamental fish, snakes, parrots, etc.) as well as dead specimens for collections (shells, insects, etc.). It also includes the trade in ivory, rhino horns, skins, furs, bones, etc. Recent estimates put the annual turnover in the wildlife trade at US$5 billion (Le Duc, 1990) (as mentioned in 11.2.3.4). In recent years serious efforts to control this trade have been made through the Convention in International Trade in Endangered Species of Wild Fauna and Flora (CITES), which came into force in 1975. However, as controls have become tighter and more effective, they have encouraged the development of sophisticated illegal networks.

While we have a substantial amount of data for some charismatic species, they are far from complete, and for many other species we have little information about the number of species and the individuals collected by such trade. We know that a significant trade exists, but the usual lack of customs expertise for the identification of imported specimens makes regulation difficult. Also, for most species, we do not know the consequences and long-term effects of massive harvesting on either the genetic diversity or the abundance of heavily exploited wild populations. Indeed, we do not know how to predict with accuracy the level of exploitation possible for many species before serious genetic erosion or species endangerment occurs.

Nevertheless, there is evidence that over-harvesting is the principal threat to certain species (the illegal trade in rhino horn has been almost entirely responsible for the drastic decline of the black rhinoceros in Africa during recent decades according to Cumming *et al.* 1990), and a significant contributory threat to many others, especially rare species and those of limited distribution. The rareness of a species adds dramatically to its value in this trade, and several species have been driven close to extinction by collectors (Jenkins and Oldfield 1992). Appendix I of CITES lists over 600 threatened species of animals and plants that are, or might be, affected by trade (Burgess 1994).

11.3.3.3.2 How to value what we have? Natural ecosystems have been considered as unproductive areas whose benefits could be realized only by conversion to some other use. Decisions on land and water uses, for example, have a great impact on biodiversity but political considerations are often paramount in these decisions when the value of biodiversity is introduced as a major component in the evaluation of alternative land/water uses. Many systems have been greatly altered because their value to society was not adequately demonstrated, and because evaluations favoured short-term benefits.

Valuation is therefore a fundamental step in informing planners and resource managers about the economic importance of biodiversity in national development objectives, and in demonstrating the importance of different areas for the biological resources they contain (Ehrenfeld 1988). Current methods of evaluation used in decision-making, such as cost-benefit analysis, inadequately reflect the true environmental and socioeconomic values of natural resources and ecosystems. The economic values of natural biological resources are poorly understood and a variety of methods have been devised for assigning values (de Groot 1992; Desaigues and Point 1993; Pearce and Moran 1994). Some methods have been developed to enumerate values of individual species, but not entire ecosystems. Moreover, the methodologies for economic valuation of environmental functions are not universally agreed. Economists have developed various techniques to capture direct use values, indirect use values and option values, but techniques for reflecting the non-use values involving bequest, cultural and heritage attributes are in early stages of development. Empirical problems include the difficulty of estimating the costs of environmental trends (such as the accumulation of greenhouse gases) in the presence of great uncertainty over their predicted impact (see Section 12 for a detailed review).

Another need is to determine how to protect an area and its species and how much it will cost. For example, conserving biodiversity in its present condition would require more funds than are assumed to be available in the near future. The need to provide economic incentives for the conservation of biodiversity is generally recognized – at the international or national level (by transfer of resources), or locally by ensuring that local communities benefit from the biological diversity of their regions (McNeely 1988). To achieve this goal, it would be useful to document and publicize cases in which incentive systems have successfully conserved biodiversity; determine how to adjust incentive systems to achieve a more efficient and sustainable allocation of resources; determine how incentives can be used in biodiversity restoration efforts in degraded systems; identify institutional constraints on the implementation of incentives systems at the local and national level, and develop strategies for the elimination or mitigation of these constraints (USNRC 1992). If we assume that environmental awareness evolved gradually in different countries, then studying the way these changes occurred, and working out how they could be enhanced in developing countries, is probably the type of research that is at the right level of resolution (global conservation) and could have far-reaching ramifications.

A major problem is therefore to find approaches, agreeable to economists and non-economists alike, on valuation methodologies that capture across cultures the consumptive and non-consumptive values of biological diversity. Research in environmental economics needs to be strengthened. Uncertainty over the local, national and international economic value of biological resources and biodiversity invites policy-makers to discount both and to avoid conservation investments when other budget priorities offer more readily quantifiable benefits. If the costs of resource degradation and the benefits of saving and using biodiversity were better understood, better conservation incentives for resource users could be designed (WRI, IUCN and UNEP 1992). Moreover, while the valuation of the economic contribution of regulatory environmental functions, particularly in developing countries, is still in its infancy, findings to date indicate that the indirect benefits of these functions are of a magnitude that may rival even the direct benefits of sustainable use of natural systems (Aylward and Barbier 1992; de Groot 1992).

11.3.3.3.3 Managing trade and having biodiversity too. Never before has human society engaged in trading such a diversity of commodities, on such a geographical scale and volume, as currently occur. Further, as a result of liberalization measures contained in the recently concluded GATT negotiations, trade is likely to expand. The overall impact on biological resources from increased production, consumption, exchange and transportation of goods and services is difficult to foresee.

A major question is how much increase in consumption and production we can allow without compromising the sustainability of the biosphere. What is the optimum core of biological wealth necessary to maintain the present state of global production without impairing future options? For these questions, there is presently no definite answer.

Another major concern is that of how the global community can direct international trade to deliver economic progress without impairing economic sustainability (Goodland *et al.* 1991). Trade is market-driven, and markets function best when the regulator's 'command and control' measures are supportive of the development of free trade rules, practices and related infrastructures. However, trade in itself is environment-blind. The invisible hand of the market does not have any adequate self-corrective mechanism to consider biological losses and reduction of biological diversity. This would imply that some degree of 'command and control' will be necessary. Ecologically fragile wetlands can be transformed into shrimp farms in the short run, but without enlightened management, care and regulatory supervision, these areas may be destroyed. Individual nation states have considerable experience in using regulatory and market-based instruments to promote environmental objectives. However, there is no prior experience of fusing global trade and environmental goals.

11.3.4 Toward sustainable use of resources and ecosystems: the need for new management options

Modern societies seem unable to halt, much less reverse, the ongoing depletion of resources and degradation of the environment. Resource management has not always been designed for the sustainable use of resources, but for their efficient utilization as if they were boundless. Ecosystem management according to ecological principles alone, is not sufficient. Increasing pressure to use natural resources for a variety of purposes, combined with the increasing democratization of resource allocation decisions, has made social values an important component in the management process. There is an urgent need to improve the link between ecological science and public perception and values. We must develop a new resource and ecosystem management science that is better adapted to serve the needs of ecological sustainability. Sustainability concepts are increasingly important to policy-makers around the world, but it is not easy to devise better development models because poverty is a major cause of habitat and biodiversity loss in developing countries. Actions to alleviate the loss of biodiversity must address the socioeconomic causes of poverty (Schweitzer 1992).

11.3.4.1 Ecosystems management

It is likely that one of the major environmental concerns in the 2000s will be the preservation of biodiversity in the context of sustainable development, and that is closely related to future options for the management of lands and waters.

A major factor of success in designing sustainable exploitation systems is the cooperative capacity of the local community, and its ability to design and implement management plans. Research is needed to help communities obtain the greatest benefit from any land or water over which they have legal rights, and to identify ways to integrate the knowledge, innovations and practices of indigenous and local communities into modern management practices. How do different land management systems, such as individual property and common property, affect the use and protection of natural resources? What combinations of extensive and intensive land and water use achieve satisfactory sustainable returns to people while conserving biological diversity? For instance, at the level of the forest people, more research is needed to determine how they and their traditional land-use practices are affected by different forms of rain forest management, e.g. alternative logging practices, introduction of plantations, conversion of cleared areas to intensive agroforestry. This also emphasizes the need to assess local perceptions of preposed modes of development (Schreckenberg and Hadley 1991). There is a major gap in our knowledge of the effectiveness of alternative use/management strategies for biodiversity conservation.

11.3.4.2 Living resources management

The well-being of human populations depends on the availability of a variety of renewable resources which may be utilized either sustainably, at rates that permit harvests at a given level over a long time, or exhaustively, at rates which in the long run lead to a decline in the total stocks. Recognition that our natural resources are not currently managed on a sustainable basis may lead to the conclusion that further loss of biological diversity will reduce our future options for sustainable biological resource management (Cairns and Lackey 1992).

Resource management options have ecological, socioeconomic and political constraints (Clark 1989). Conflicts, or at least competition, between protection of biodiversity and production of resources are likely to occur; and what might be in the interest of society is not always in the best interest of individuals. There is a conspicuous paucity of examples showing how both traditional and modern societies perceive, value and conserve biological diversity while successfully using natural resources in a sustainable manner (exceptions include a number of cases documented in Johannes 1978; McCay and Acheson 1987; Berkes 1989; Bromley 1992). Achieving a balance between resource use and conservation, accepted as mutual goals in technological societies, has largely failed. Ethnobiological research is needed to design more effective and locally acceptable conservation and management plans (Soulé and Khom 1989). In fact, rural populations have had the capacity throughout their history to manage their resources for a sustainable yield while the ability of primitive humans to exterminate a vast array of prey species is also well documented. It is only in recent times (beginning in the colonial period but greatly accelerated after 1950) that traditional systems for managing resources have been replaced by government agencies and have proved to be less efficient, or at least not as successful as they should be.

This situation can be illustrated by fisheries management in inland waters. After the Second World War, the European ideas of rational fisheries management were assumed to be the only universal solution for sustainable use of fish stocks. Most policies for the sustainable management of fish stocks derive from the concepts of equilibrium population dynamics and stock assessment, and aim to achieve a level of fishing effort at which the stock or population is conserved at its level of maximum sustainable yield. Although the principle of Maximum Sustained Yield has been challenged, it is still accepted as one of the main bases for management. Despite the apparent capacity to determine the levels of harvest needed to conserve fish stocks, there has been an almost universal failure to do so. This failure may lie in part in the shortcomings of scientific advice, but for the major part lies in the difficulties of applying coherent management strategies for political and sociological reasons (Welcomme 1992). Efforts at central fisheries management during the last few decades have not been especially cost-effective, and serious consideration therefore needs to be given to reinstating community-based, traditional-type management structures.

For tropical forests, agroforestry is a collective name for land-use systems and technologies in which woody perennials (trees, shrubs, palms, bamboos, etc.) are combined on the same management unit with herbaceous crops and/or animals, in some form of spatial arrangement or temporal sequence (Schreckenberg and Hadley 1991). Agroforestry is not a new technology and it has often been used traditionally in different ways in many parts of the world, but farmers have abandoned such forest use because of inappropriate land or forest tenure systems. Combined with modern agricultural and forestry techniques, traditional agroforestry is often stated as one of the most successful approaches to producing tropical hardwood in a sustainable way, but it cannot be an answer to the demand in the developed world. At present, additional research is needed to allow a progressive change in land use from traditional shifting cultivation or extractive forestry to more intensive agroforestry (Schreckenberg and Hadley 1991). Several initiative are also under way to develop systems for sustainable forest management in all types of forest in the world, and to agree on a system of labelling sustainably produced timber.

To achieve the sustainable use of environmental systems, there is an increasing need for new resource management systems. Should they be based on the resource management techniques of the industrialized countries, or should they be developed by rehabilitating and adapting 'indigenous' resource management systems and upgrading traditional local-level institutions? Is there any way to integrate the scientific and traditional systems? These are the central questions that must be answered in order to propose development models that take care of the environment and serve the needs of the people who use its biological resources. The only answer to this type of problem is to test different systems and discover what works. This is a new challenge because, until recently, scientists and policy-makers knew little about traditional management systems and accorded them little credibility.

We therefore need to conserve the diversity of traditional resource management practices and systems if we want to construct a new resource management science better adapted to the real world. The rejection of the monolithic scientific vision of resource management does not mean the overall rejection of science. The task is to develop a flexible approach by conserving what is useful in science. Ecology is in a unique position to be the cornerstone of a new science of resource management that synthesizes the best of the old and new wisdom towards a more sustainable future. But ecology would first have to extricate itself from the older utilitarian, 'control over nature' tradition of resource management (Gadgil and Berkes 1991).

What would be the reaction of a system in a case of reduced pressure on biological resources? We have little experience in this field, even if a great deal of experience has been gained in nature management systems during the last decade.

11.3.4.3 The question of common property of natural resources

The use of the term 'common property' has been controversial. For some scientists it means resources that are not amenable to private appropriation: they are free goods, not owned by anyone, such as marine resources, including fisheries. As a result, they are open-access and freely available to any user. An alternative view considers that the term 'common property' should be restricted to communally owned resources that are managed through communal arrangements for allocation among co-owners.

The 'tragedy of the commons' model (see 11.1.7 and 11.2.3) still persists in the conventional wisdom of many resource managers, and is also dominant in models of development exported to Third World countries. It led a generation of fishery managers and other resource managers to believe that absolute governmental controls needed to be established over both the resource and the user, and blinded them to the possibility of managers and resource users working together, rather than against one another. However, valuable natural resources are almost never open-access but are managed under traditional rules. Many case studies indicate that co-operation for communal interest more frequently occurs (Berkes 1989). Recent literature on common property rejects a deterministic 'tragedy of the commons' (Ostrom 1990; Stevenson 1991). The common property approach reverses the traditional emphasis of resource management, which has been on the resource rather than on the people, and starts with an analysis of the local property rights regime.

For some authors, appropriation is not property (Weber and Reveret 1993). The appropriation of a resource or an ecosystem may be understood under five components: (1) *representations*: the way each society perceives nature; part of the group culture; (2) *uses*: the use of natural resources is not always dictated by economic purposes; taboos exist everywhere; (3) *access to resource and control of access*: access is often regulated by customary institutions, myths, historical rights or traditional regulations, and may be individual or collective, permanent or temporary; (4) *transfer modalities*: that is, the way rights are transferred from one generation to another; (5) *re-partition and sharing*: the resource, or the benefit of the resource, may be distributed amongst all individuals or according to social status.

More research is needed on a global analysis of appropriation and use regimes. They are not well known partly because of the confusion between common resources and open access, though analyses of the management of common resources are becoming more numerous (Berkes *et al.* 1989; Bromley and Cernea 1989). However, before we consider new resource management systems we need to know the extant systems and understand the choices behind them.

11.3.4.4 Predicting the consequences of social and economic changes on biological diversity

One of the major challenges is to understand and adapt ourselves to natural, economic and political variabilities (Henry 1990), and to develop a flexible and adaptative approach to management. We can have a greater impact on the way people are using resources than we can on the resources themselves. An increasing population pressure is likely to occur, but we do not know to what extent. What kind of changes should we expect in consumption? How do groups extrapolate the future use of biological resources, and how do use rates change as biological, social, economic and cultural factors change? Is it possible to forecast future social behaviour and political options and/or is it feasible? There are so many unanswered questions about the future of humanity that it is difficult to forecast the future of biodiversity in relation to human needs and expectations. However, we need urgently to reinforce collaborations between social and biological sciences to gather at least enough information not to be unprepared.

11.3.4.5 Knowledge-based systems

Models of the dynamics of biodiversity under the impacts of natural and human-induced disturbances might provide a better way of managing ecosystems and resources. However, models built for explanation or prediction have not been very successful when applied to whole ecosystems.

A subsidiary goal of modelling activities could be to combine the various rules and generalizations developed through the long experience of ecologists and resource managers to make them available in a systematic way. They could then be applied to situations where less experienced managers may be faced with problems of making decisions with inadequate data. Such 'expert' systems do not provide definitive answers, but may act as a reminder of some of the principles that need to be considered and some of the interactions that might occur.

11.3.4.6 Development and transfer of technologies relevant to the sustainable use of biological diversity

One of the most consistent of the Agenda 21 themes, and one of the most intractable of issues, concerns access to technology (Rath and Herbert-Copley 1993). Among the proposals under consideration are: to increase the flow of information about environmentally friendly technologies; to increase industrial self-regulation; to increase the importance of markets in allocating values; and to promote improvements in environmental performance of industry in the South. This issue was widely discussed during the intergovernmental meeting of scientific experts held in Mexico in 1994 (UNEP 1994). It ranges from environmental impact assessment techniques to ecosystem management techniques and integrated land use, biotechnologies, new and renewable sources of energy techniques, less wasteful lifestyles, consumption and production patterns, family planning techniques and economic and financial instruments.

The issue of access to technologies is about how to develop endogenous capacity to assess, adopt, manage and apply environmentally improved technologies. However, there are difficulties in identifying appropriate kinds of 'clean' or environmentally sound technologies to promote in developing countries. Environmental sustainability has not been a major consideration among mainstream innovation policy and management researchers (Winn and Roome 1993), and the literature on 'green' innovation policies is relatively small and dispersed among the literature on environmental management, environmental economics, risk assessment and economics of innovation.

Much of the literature on environmentally sound industrial innovation suffers from the difficulty of identifying and describing those variables linking the technical and social dimensions that are accessible to management, policy or political interventions. Mechanisms and instruments of deliberate social choice, especially ones that are feasible under regimes of democratic governance, are a relatively unknown part of the non-market selection environment.

11.4 Future prospects

11.4.1 Introduction

The world is an uncertain place. A strong interest remains in understanding what might take place in the future, although science has largely assumed the role of fortune-teller. However, with our limited understanding of the biotic and abiotic systems of the Earth and our even more limited understanding of human behaviours and cultures, forecasting is at best an inexact science. In fact, it is unclear to what extent our evolving understanding of systems can accurately 'back-cast' (*sensu* Kates *et al.* 1990), let alone forecast. Furthermore, predictions of the future vary depending on the forecaster's culture, religion, experience and temperament.

Modern fortune-tellers can be distributed along a spectrum with the 'Malthusian pessimists' at one end and the 'technological optimists' at the other (Goodwin 1994). The Malthusians tend to think it very likely that human civilization will collapse and human life, if it goes on at all, will return to the sort that Thomas Hobbes characterized as 'solitary, poor, nasty, brutish and short'. According to this position, no group of inventions or investments can permit us to continue living in the style, and at the level of material affluence, taken for granted by industrial societies today. We have so harmed the natural environment that ecological and economic collapse are inevitable, resulting in the collapse of populations and civilizations, and perhaps followed by a regrouping at a much lower level of resource use and civilization. The Club of Rome report *The Limits to Growth* (1972), for example, predicted that population growth, resource exhaustion and pollution would bring about the collapse of human society by the early twenty-first century.

At the other extreme, technological optimists speculate that technological advances will rescue us, and that an ever-improving base of material well-being will continue to provide humanity with the option of continuing its experiments in freedom, justice and understanding. Many see no need to tamper with consumer behaviour, believing that any shortcomings of today's energy economy can be modified on the supply side. Simon and Kahn (1984) argue that the twenty-first century will indeed bring higher living standards and reduced human impacts on the environment as a result of technological advance and policy innovation.

Given the many possible and feasible views of the future, Goodwin (1994) suggests that a sensible course of action would be the following:

1. Given the lack of credibility attached to the predictions of either end of the spectrum, we need to prepare for many kinds of futures simultaneously – including that predicted by the pessimists and that to which the optimists look forward.
2. We should try to maximize the possibility that our preferred set of possibilities is realized, while taking steps to ensure against even a small probability of the most pessimistic scenarios being realized.
3. We should continue to refine our understanding of the competing predictions, both by adding to our knowledge about the events that will determine the relevant characteristics of the future, and by familiarizing ourselves with the terms of debate over why these events should lead one way or the other.

Speculation about and preparation for the future have necessarily taken place on two related but distinct dimensions. The first involves understanding the degree to which past human actions have set in motion irreversible and on-going change in the natural and physical environments, altering the range of options faced by human communities. The second involves the capacity of human societies to understand, adapt and respond to environmental change, a function of the cultural, social, economic and political contexts in which they operate.

11.4.2 Trends

11.4.2.1 Population and resources

Optimistic as well as pessimistic forecasters of the world's future recognize increasing demand by expanding human populations as a source of immense stress on biotic and abiotic resources and systems. A key factor in assessing future demand is our ability to predict accurately population size decades in the future. The remarkably accurate prediction of today's population by demographers in the early 1970s is a tribute to their technical skill (McNeely and Ness 1995) and should give us some confidence in current estimates of global population over the next few decades.

The world population in 1990 has been estimated as 5.29 billion, 78% occurring in LDC (less developed countries, effectively all countries excluding Europe, North America, Japan, Australia and New Zealand). The significant increases anticipated in total world population in the coming decades are largely uncontended and two sophisticated analyses arrive at similar 'middle' scenarios: by 2025 world population will stand at 8.5–9.0 billion people (UN figures, quoted by WRI, UNEP, UNDP 1990; Lutz *et al.* 1993). The latter authors used three components of population change – fertility, mortality and migration – and using various estimates of the range that these three components could realistically take, developed nine population scenarios. Although these resulted in a wide range of possible outcomes, three conclusions were consistent:

- World population will continue to grow and by 2030 will have increased by at least 50%, and may even have doubled in size. The 'central' scenario suggests an increase of 80% with a population of 9.5 billion (Table 11.4-1).
- Developing countries will account for a greater share of the world population and by 2030 will have increased from 78% of world population in 1990 to 86%. Under all scenarios, Africa's share of the population will increase most rapidly (the central scenario estimates Africa's population will increase from 12% of world population in 1990 to 19% in 2030 and 26% in 2100 (Table 11.4-1).
- All populations will become older and the more rapidly fertility declines the faster populations will age.

The world's population is likely to double in the next 60 years, even if fertility rates fall in virtually every developing country (Jolly and Torrey 1993). If the demographers' consensus holds true, we are about half-way towards a level population of between 8 and 12 billion people, barring a major catastrophe (Kates *et al.* 1990).

Rising human populations mean an inevitable expansion in human demands on the resources of the planet. Moreover, per capita demand for biotic resources has also increased, so that the increase in direct exploitation has been exponential rather than linear. The human species now appropriates some 40% of the net primary productivity of terrestrial systems (Vitousek *et al.* 1986), much of it as a result of food production (Brown 1994). Between 1950 and 1984, per capita grain production increased by 40%. Between 1950 and 1990, per capita supply of beef and mutton increased by 26%. In addition, world fish catches underwent a 4.6-fold increase between 1950 and 1989, doubling per capita production of seafood. World consumption of wood also increased 2.5-fold between 1950 and 1991, per capita consumption increasing by a third during this period (Durning 1994). As with food consumption, most of the growth in total and per capita wood consumption has occurred in the developing world.

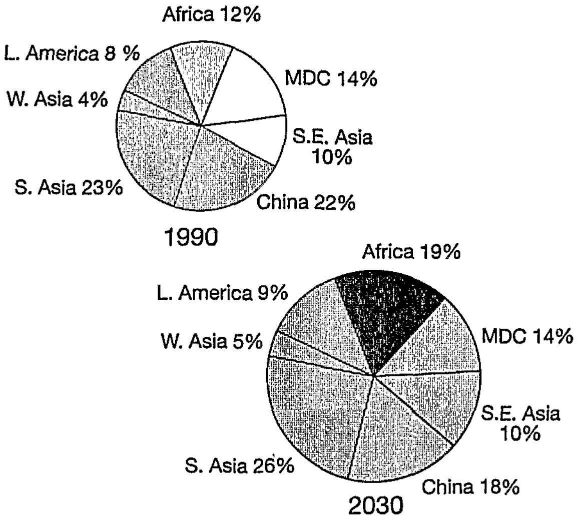

Figure 11.4-1: Regional distribution of world population under the central scenario (Population Network Newsletter No. 23, 1993).

Some indicators suggest that ecosystem and resource limits are already being reached. World fish harvests peaked at 100 million tonnes in 1989, and by 1993 had declined 7% from 1989 levels. Growth in grain production has slowed since 1984, with per capita output falling 11% by 1993. World economic growth has slowed from over 3% annually in the decade 1950–60 to just over 1% in the decade 1980–90 and less than 1% from 1990 to 1993. The Worldwatch Institute, extrapolating from historical data, forecasts that 'If current trends in resource use continue and if world population grows as projected, by 2010 per capita availability of rangeland will drop by 22% and the fish catch by 10%. The per capita area of irrigated land, which now yields about a third of the global food harvest, will drop by 12%. And cropland area and forestland per person will shrink by 21% and 30%, respectively' (Postel 1994).

The potential for further expansion of cropland area is thought to be small. Current figures show that roughly one-third of global land area is used in food production, 1.5 billion ha of this being used as arable land (Kendall and

Pimental 1994; Doos 1994). This current land area will decline as expanding global populations compete with agriculturalists for land for urban and industrial purposes and as land degradation takes its toll. The above authors, in agreement with WRI (1994), conclude that while there is a further potential for conversion of land to cropland (in the order of 1.5–1.7 billion ha) the areas with the best potential for cropland are already being used in this way; to realize any further expansion of arable land will involve the conversion of marginal areas such as tropical forests, steep hillsides and semi-arid regions which have relatively fragile resources – and a great deal of the world's biodiversity. These areas are inherently unsuitable for crop production due to various physical and chemical soil constraints or unreliable rainfall.

Current trends in resource use and population growth are not, of course, perfect predictors of the future. Indeed, population growth is expected to level off by the end of the twenty-first century, and growth in food production has slowed in the last decade, with much of the remaining growth achieved by increasing output per area. Another disturbing trend, however, has been the rising concentration of income world-wide. From 1960 to 1989, the share of world income going to the poorest 20% of its population declined from 2.3% to 1.4%, while the share of income going to the richest 20% increased from 70.2% to 82.7% (United Nations Development Programme 1992). In other words, while per capita consumption is actually declining in many parts of the developing world, 83% of world income is concentrated in the hands of 'biosphere people' whose disproportionate share of disposable income allows them access to increasing quantities of consumer goods.

11.4.2.2 Changes in terrestrial and aquatic ecosystems

Humans have already greatly modified the Earth's surface. Ecosystems that have been substantially transformed, managed and utilized constitute about half the land surface of the ice-free Earth. Moreover, the rate of global land-use and land-cover change is accelerating. Conversion to cropland contributes to much of this land cover change; half of the area of cropland world-wide was added during the last 90 years, with croplands in the tropics doubling in area in the last 50 years. Rates of forest loss in the tropics are currently increasing by an estimated 4% to 9% annually (Houghton 1994).

Although land-use change outside the tropics is relatively limited, changes in characteristics other than area continue to occur, including loss of biomass and carbon storage (Houghton 1994; Ojima *et al.* 1994). Habitat disturbance and other anthropogenic factors may also contribute to species invasions or successful introductions of exotic species. The addition of species may have wide-ranging effects on community composition and dynamics, and alter productivity, soil structure, nutrient cycling and water chemistry (see discussion in Chapter 11.2).

Table 11.4-1: *Total population size (in millions) in 12 world regions under the central scenario.*

	Year					
Region	**1990**	**2010**	**2030**	**2050**	**2070**	**2100**
Northern Africa	140	226	332	440	529	595
Sub-Saharan Africa	502	924	1 499	2,097	2 561	2 700
North America	277	325	376	420	475	577
Central America and the Caribbean	147	219	289	342	370	371
South America	294	407	516	604	667	727
Western and Central Asia	197	312	442	553	632	682
South Asia	1 191	1 806	2 428	2 874	3 065	2 855
China and Hong Kong	1 159	1 469	1 722	1 873	1 945	1 968
Southeast Asia	518	735	937	1 076	1 129	1 082
Japan, Australia and New Zealand	144	158	160	158	154	151
Eastern Europe	345	368	380	385	392	427
Western Europe	377	368	380	385	392	427
Developing regions	4 149	6 097	8 167	9 859	10 897	10 980
Industrialized regions	1 142	1 255	1 333	1 378	1 437	1 582
World total	5 291	7 352	9 499	11 238	12 334	12 562

Biotic communities are also modified by the removal of animal and plant species (as noted in 11.2.3.4). The size of the this trade is staggering. At present, nearly 22 000 species are already threatened, including about 10% of all birds and mammals (McNeely *et al.* 1989); direct exploitation is one of the most important threats (WCED 1987). Although many areas of apparently natural vegetation remain, large animals on which many plant species are ecologically dependent may have been hunted out by humans (Redford 1992), The result may well be the eventual ecological collapse, or at least profound change, of these areas.

Not only will land areas continue to be affected, but so too will marine and freshwater areas. Marine ecosystems are increasingly affected by logging of forests and mangroves, siltation, dredging and channelization, pollution, shoreline development, oil and gas development and other human modifications, as well as introduction of exotic species and direct offtake of fisheries (Norse 1993). As L'vovich and White (1990 in Wolman 1993) have shown, human activities have also significantly altered the global distribution of runoff in rivers. They estimate an increase over a period of 300 years of about 20% in base flow and a decrease of 16% in surface runoff as a result of anthropogenic activities. More dramatic is a 300% predicted increase in consumptive use of water in irrigated agriculture over that of the last 300 years.

Habitat loss, modification and fragmentation are widely considered the most important causes of loss of biological diversity, with most current attempts to estimate and project the rate of species loss based on reductions in habitat area (WCMC 1992). Recent work (Tilman *et al.* 1995) has documented what the authors refer to as the 'extinction debt' associated with habitat destruction, in which the rate of extinction increases as a function of the area of habitat that has already been destroyed. For instance, destruction of an additional 1% of habitat causes the extinction of eight times more species if 90% versus 20% of a region has already been destroyed. Furthermore, an unanticipated effect of this habitat destruction may be the selective extinction of the best competitors – those species that are often the most efficient users of resources and major controllers of ecosystem functions. Thus, this extinction debt may have dramatic effects on the ecosystems of the future and the ability of these ecosystems to deliver vital services to human populations.

Human-induced change has shifted from the agricultural transformation of the surface of the Earth to industrial mobilization of materials and energy, to the current mix of agricultural, industrial and advanced-industrial transformation. As this range has expanded, so has the secondary interaction among the changes and hence the complexity of the problems that they pose for biological systems. The impacts of human-induced change are no longer local or regional, but rather global, adding to the difficulty of assessing the human impacts on biodiversity and predicting the future.

Most global-scale impacts of human-induced change have been quite recent, particularly those dealing with biogeochemical cycles. For example, high-temperature industrial emissions alone now multiply the annual natural releases of arsenic by a factor of 3, of cadmium by 7, of mercury by 10 and of lead by 25 (Kates *et al.* 1990). Galloway *et al.* (1994) predict that by 2020, emissions of fixed nitrogen from fossil fuel and biomass burning are expected to increase over 1980 levels by 25% over North America, by more than half over the oceans of the Northern Hemisphere, and by at least 100% in the developing areas. Less than one-third of this increase is accounted for by population growth; the remainder will be achieved through greater per capita emissions, particularly in the developing world. These increases in nitrogen deposition have a number of effects, including fertilization of terrestrial and marine ecosystems, acidification, and increases in emissions of nitric oxide and nitrous oxide (see also Section 6).

Chameides *et al.* (1994) found that three regions of the northern mid-latitudes, which they termed 'the continental-scale metro-agro-plexus' currently dominate global industrial and agricultural productivity. Although they cover less than a quarter of the Earth's land surface, they account for most of the world's commercial energy consumption, fertilizer use, production of food crops and food exports. They also account for more than half the world's atmospheric nitrogen oxide emissions and, as a result, are prone to ground-level ozone pollution during the summer months. On the basis of a global simulation of atmospheric reactive nitrogen compounds, it is estimated that about 10% to 35% of the world's grain production may occur in parts of these regions where ozone pollution may reduce crop yields.

Exposure to yield-reducing ozone pollution may triple by 2025 if rising anthropogenic nitrogen oxide emissions are not abated. Although the current loss in crop yields from ozone pollution appears to be only a few per cent of the total loss, this may well change in the coming decades. Nitrogen oxide emissions predicted for 2025 not only intensify pollution but also enhance pollution in agricultural regions of the developing world. For 2025, they estimated that as much as 30% to 75% of the world's cereals may be grown in regions with ozone above the 50 – 70 ppbv threshold, which suggests that the agricultural losses may increase significantly. Further, this increased pollution effect will be occurring at a time when growing populations in developing countries will be straining food production capacities.

11.4.2.3 Climate change

The most complex manifestation of human-induced global change is that of the Earth's climate. The debate over the effects of ozone depletion and airborne particulates (producing a cooling influence) and greenhouse gases (producing a warming influence) has produced a plethora of scientific material on the subject (summarized and assessed in Houghton *et al.* 1990). In an attempt to deal with the uncertainty in the prediction of the effects of climate change, IPCC has brought together a group of statements on various climate change issues which represents the degree of consensus on these issues (Table 11.4-2). Many climatologists believe that the 'greenhouse effect', caused by the observed accumulation of carbon dioxide, methane, nitrous oxide and chlorofluorocarbons in the atmosphere, is likely to raise mean world temperatures by about 2 °C by 2030 and mean sea levels by around 30–50 cm on a comparable time scale (Warrick *et al.* 1988). By the end of the next century, global average surface temperatures are predicted by the IPCC (1992) to increase by 2–6 °C with an attendant rise of sea level of 0.5–1.5 m. Such a change could be 10 to 50 times as fast as the natural average rate of temperature change since the end of the last glaciation (Schneider 1989). These changes could bring increased frequency and destructiveness of hurricanes (Emanuel 1987); more protracted droughts, longer and hotter heatwaves, and more severe rainy periods; and significant changes in the area of the great ice sheets of Antarctica (Frolich 1989).

Although the nature and causes of the greenhouse effect remain hotly contested (e.g. Bryson 1993), the scale and complexity of potential changes has led to a desperate scramble to foresee the future. Large-scale extinctions have occurred in the past as a result of major climatic changes, cataclysmic disturbances and human activities (Crowley and North 1988; Gates 1993). Although there is little scientific consensus on the impacts of apparent current changes, it appears highly likely that global warming and associated disturbance events, particularly when coupled with human population growth and accelerating rates of resource use, will bring further losses in biological diversity (IUCN 1986; Gates 1993).

If predictions of a rapid temperature rise are realized, the effects of global change on patterns of human settlement, production and resource consumption will be dramatic. The effects of increased concentrations of atmospheric carbon dioxide and other greenhouse gases on climate will be particularly evident in northern latitudes. Rising temperatures are expected to bring about a poleward shift of cereal cropping in the major grain-producing – and exporting – areas of the Northern Hemisphere and an overall decline in grain production, and may reduce livestock production as a result of heat stress. Impacts on agriculture in the tropics are more difficult to anticipate because they are more vulnerable to the unknown effects of warming on the amount and distribution of precipitation. Agricultural pests and diseases may increase their geographic ranges, severity or both, as temperature and humidity rise (Parry and Jiachen 1991; Gates 1993).

Sea-level rise may also result in the loss of farmlands directly and through increased saltwater intrusion in coastal regions. For each centimetre rise in sea level, beaches may

Table 11.4-2: Degree of consensus on various climate change issues (WRI 1994).

Issue	Statement	Consensus
Basic characteristics	Fundamental physics of the greenhouse effect	Virtually certain
	Added greenhouse gases add heat	Virtually certain
	Greenhouse gases increasing because of human activity	Virtually certain
	Significant reduction of uncertainty will require a decade or more	Virtually certain
	Full recovery will require many centuries	Virtually certain
Projected effects by mid-21st century	Large stratospheric cooling	Virtually certain
	Global-mean surface precipitation increase	Very probable
	Reduction of sea ice	Very probable
	Arctic winter surface warming	Very probable
	Rise in global sea level	Very probable
	Local details of climate change	Uncertain
	Tropical storm increases	Uncertain
	Details of next 25 years	Uncertain

Virtually certain: nearly unanimous agreement among scientists and no credible alternative view.
Very probable: roughly a 9 out of 10 chance of occurring.
Probable: roughly a 2 out of 3 chance of occurring.
Uncertain: Hypothesized effect for which evidence is lacking.

erode a metre landward and storm surges, a major erosional force, will increase. For every 10 cm rise, saltwater wedges in estuaries and tidal rivers may advance a kilometre; and any sea-level rise will increase salinity intrusion into coastal freshwater aquifers (NAS 1987; Parry and Jiachen 1991). In addition, these changes will affect human settlements through changes in the availability of nearshore and brackish water organisms (Ray *et al.* 1992), important food sources for humans and other species.

Changes in cropping and crop location, livestock husbandry, irrigation, fertilizer use, pest control and soil management may enable human societies to maintain global levels of food production. However, it is likely that the frequency of both short-term and long-term crises in regional food supply will increase (Parry and Jiachen 1991). Moreover, the direct and indirect feedback effects (Ojima *et al.* 1994) of change of land use and technology on climate change are impossible to predict.

Major changes in global vegetation cover are also expected to occur in response to global climate change, primarily as a result of changing temperature and precipitation (Gates 1993). Schlesinger (1991), for example, predicts that rising temperature and precipitation will result in the expansion of boreal forests, but overall forest area is expected to contract, with grasslands and deserts increasing in extent. In North America, Europe, Asia and southern Africa, desert and other areas of sparse vegetation may expand at the expense of grasslands, shrublands and prairies. On the other hand, shrubby vegetation may spread into areas of sparse vegetative cover in southern Africa, Saudi Arabia and Australia (Woodward 1992).

More difficult to predict are the multiple interactions among changes in temperature and precipitation, soil quality and nutrients, and increase carbon dioxide. Although researchers know very little about the responses of vegetation to an increase in CO_2, laboratory studies increasing CO_2 concentrations have produced higher yielding wheat, larger sugar beets, and faster-growing radishes (Fajer *et al.* 1989). On the other hand, plants fertilized with CO_2 may be larger and grow faster but are less nutritious, so that insect pests must consume more to achieve their normal rate of growth and may pose a greater threat to crops and vegetation (Pain 1988a). Other observations suggest that plants respond to high CO_2 concentrations and may become more efficient in their use of water, thus contributing to the spread of shrubby vegetation into more barren regions of east and south Africa, Saudi Arabia and Australia (Fajer *et al.* 1989). In three sub-alpine conifers (*Pinus flexilis, P. longaeva, P. aristata*), greatly increased tree growth rates observed since the mid-nineteenth century exceed those expected from climate trends but are consistent in magnitude with global trends in CO_2 concentrations, especially in recent decades (LaMarche *et al.* 1984). The IPCC (Schlesinger 1991) concludes that the growth effects of increased CO_2 will be greatly outweighed by the effects of temperature change, but few laboratory or field experiments have been conducted to evaluate such interactions.

A growing body of research has also examined the possible effects of climate change on individual species and biotic communities. This research suggests that biological communities will change and shift in complex and unpredictable ways as the geographical distributions of species are altered individually rather than in community units (Conner 1986). Further, because species are interrelated, any advantage falling to a given species in a closed system will affect other species in ways that are not always predictable. The rate of species invasions and extinctions is likely to accelerate further, bringing about complex changes in species compositions and interactions (Lodge 1993). Thus, rather than causing a simple northward or uphill shifting of ecosystems with all of their inhabitants intact, climate changes will serve to reorganize biological communities. For example, small changes in temperature alone may differentially alter the spacial distribution of predator and prey species in marine ecosystems (Murawski 1993). The 1982–3 El Niño event gave Galapagos increased rainfall by a factor of ten, with a resultant increase in seed production and caterpillar abundance. Ground finches responded to the increase in food supply by producing up to ten egg clutches instead of the usual one to five, increasing population size by a factor of four (Gibbs and Grant 1987). On the other hand, oceanic productivity was low, so that many seabirds did not breed. The Galapagos penguin and the flightless cormorant populations were reduced by 49% and 77%, respectively (Valle and Coulter 1987).

In forest ecosystems, rainfall and seasonality as well as temperature may be influential, particularly if they cause major changes in fruit or seed production. Further, the responses of forests to climate change may depend as much on the indirect effects of climate and vegetation on soil properties (Pastor and Post 1988). The ability of animal and plant species to shift their ranges in response to climate change also depend on dispersal mechanisms. Significant changes in temperature could occur during the life-time of some long-lived tree species; trees that disperse light, wind-blown seeds or drop seeds carried by animals may be able to disperse more than others (Peters 1992). On the other hand, tree species dependent on animals for pollination or seed dispersal may be affected by the changing ranges of animal species.

Peters and Lovejoy (1992) identify a number of mechanisms through which species and communities are likely to be affected as a result of the direct and indirect impacts of climate change. Populations located near the edge of a species' range, narrowly endemic species, and endangered species that exist only in reserves or other extremely limited habitats, are especially vulnerable to global vegetation shifts. Species that are already threatened by direct exploitation and habitat loss and degradation are likely to be particularly susceptible to new threats. Coastal communities may be inundated as sea levels rise, while altitudinal shifts brought about by increased temperatures would reduce or even eliminate the ranges of montane and alpine species, many of which are already relictual, having been isolated by past climate changes. In hybrid zones such as those reviewed by Barton and Hewitt (1989), where genetically distinct populations meet, mate and produce hybrids, climate change may favour some species but cause the extirpation of others.

Because climate change is expected to be greatest at high latitudes, Arctic communities are also expected to undergo particularly rapid changes. Many of Europe's most productive wildlife habitats are in the far north, where algae, bacteria and other microscopic organisms grow on the undersides of sea ice during the spring. As the ice breaks up with the approach of summer, the organisms are released into the water, where they support a series of food webs that include large species such as whales, polar bears and seals. An increase of 5 °C over the next 50 years could melt even the permanent Arctic ice (Pain 1988a), bringing fundamental changes to polar ecosystems. Alexander (1992) notes that the melting of sea ice could also affect marine mammals that use ice floes for rest, travel and reproduction. If the ozone hole over the North Pole becomes firmly established, these impacts could be greatly magnified: El Sayed (1988) predicts that observed damage to the sensitivity of some plankton species by increased ultraviolet radiation would occur.

Severe temperature changes at northern latitudes may also have negative implications for species dependent on the timing of ice melt. Under normal conditions, snow and ice melt in Northern Europe over a period of several weeks, with the acidic meltwater draining through the soil, neutralizing it before it runs into lakes and rivers. An earlier and faster melt would cause the meltwater to run over the soil and into rivers, introducing a flood of acid water at a time when many animals are at their most vulnerable stage (e.g. eggs or fish fry). In addition, less water would be available in the following months, and with the warmer summer, water is likely to be in short supply. The pools and shallow lakes of the taiga and tundra – home to large populations of migratory water-birds – may become a far less productive habitat (Pain 1988).

Temperature change will also affect animal species directly. Dawson (1992) notes that animals that react to thermal stress by evaporating water may be negatively affected by rising temperatures and decreased water availability, while ectotherms are likely to experience extreme changes in metabolic and other bodily functions in response to relatively small temperature changes. Rising ambient temperature may result in decreased fertility and fetal survival in mammals. Fish, reptiles and invertebrates that are subject to environmental sex determination may also be affected directly by rising temperatures. For example, higher temperatures produce more males of alligators and crocodiles and more females of some turtles, thereby enabling sex ratios to be adjusted in response to particular environmental conditions (Head *et al.* 1987).

Migratory species dependent on climate and prey availability throughout their migratory pathways are also acutely sensitive to the direct and indirect effects of global change (Pain 1988; Myers and Lester, 1992). In the Western Hemisphere, for instance, shore-birds such as sanderlings and plovers spend the winter in South America and travel north to breed in the Arctic in summer, stopping in Delaware Bay to feed on the eggs of horseshoe crabs that arrive and lay their eggs at the same time each year. If the timing of horseshoe crab egg-laying were to be disrupted, then the effects on the migrants could lead to a late arrival in the Arctic, missing the summer population explosion of the Arctic insects that is required to provide the hatchlings with sufficient food (Pain 1988).

11.4.2.4 Implications of global change

The role of change in ecological systems is increasingly recognized by natural scientists. The current paradigm, termed the 'flux of nature' or 'non-equilibrium paradigm', emphasizes process rather than end points, in contrast to the previous 'balance of nature' or the 'equilibrium' paradigm. The flux of nature acknowledges constant change, contending that natural communities have multiple stable states (Pickett *et al.* 1992). This approach is endorsed by plant ecologists such as Primack and Hall (1992), who concluded from their research in Asia that the forests they studied were characterized by unstable local populations of some common species and a rapid turnover of rare species. Condit *et al.* (1992) concluded that all biotic communities undergo constant flux as populations or individual species expand, contract, go extinct locally and re-migrate in response to endogenous ecological and evolutionary change and exogenous forcing.

Holling (1986) points out that the constant change occurs on an infinite number of spatial scales – from tree falls to the impacts of meteors, and temporal scales – from continental drift to sunrise and sunset. Variability and instability are indeed the traits necessary to retain the resilience of ecosystems, or their ability to adapt to disturbance through rapid shifts to alternate stable states or through evolutionary organizational change. An important implication of this view is that reductions in natural variability lead to fragility and lessen the likelihood that disturbance will bring about a transition to an alternate equilibrium.

Anthropogenic factors are of course among the exogenous forcing agents prompting change in ecological systems. Indeed, not only has the rate and scale of human-induced global change increased dramatically, but it is often acknowledged that human activity has modified the environment from a set of systems characterized by flexibility and constant flux, toward one that is more fragile and increasingly vulnerable to cataclysmic events. For example, tree species differ in their genetic variability, and those that have more variable populations might be able to respond with greater facility to changing climates (Davies and Zabinski 1992). Yet human-induced change through harvesting, habitat alteration or climate change tends to reduce the genetic diversity of individual species. Successful adaptation to climate change may also depend to a great extent on the ability of species to disperse to new areas, but this ability is increasingly impeded by human-induced landscape change (Peters 1992; Ryan 1992; Quinn and Karr 1993).

Human populations have already exerted fundamental influences on biological diversity and the Earth's capacity to support and maintain such diversity. It appears inevitable that changes already wrought will bring further losses of biodiversity in the future. However, changes are also integral to human populations, and in turn are often a response to shifts in biotic and abiotic systems. The following sub-chapter will assess current viewpoints on the ability of individuals, institutions and societies to evolve and adapt in response to the changes already under way in natural systems.

11.4.3 Human adaptations

Since the 1970s, an expanding body of literature has heightened awareness of the ecological impacts of economic development, and of their increasing severity. However, it is also increasingly recognized that environmental change is not only a consequence of affluence; it is also a cause and effect of poverty (WCED 1987). Malthusian forecasts indeed often present a scenario in which ecological collapse hits the poor first and hardest, causing famine and disease in developing countries on a scale surpassing anything yet experienced by the human species. In an era of global ecological and economic integration, the impacts of the crisis will be felt world-wide, inevitably affecting industrialized countries as well (Kaplan 1994).

Optimistic forecasts typically begin with a recognition that the needs of the developing world are tremendous, and those needs must be met, for humanitarian even more than for political reasons (MacNeill *et al.* 1991). It is therefore clear that continuing development will be necessary to meet the basic needs of present and future human populations (IUCN, WWF and UNEP 1980; WCED 1987). Optimistic scenarios envision several possible mechanisms for averting global crisis, including continued technological development in response to growing population and resource constraints, sacrifice of future growth in consumption on the part of wealthy nations in order to allow future growth in the developing world (Goodland *et al.* 1991), and direct transfers of resources and technology to developing countries (Pearl 1989). Less clear is whether appropriate changes can and will be made in the policies and institutions that will determine patterns of growth and development.

11.4.3.1 The benefits of technology

Technological optimists often argue that even given recent evidence of the pace and scale of environmental change, human societies can continue to achieve quantitative and qualitative economic development through advances in science and technology. Technological optimism is typically linked to the economic arguments, for as Daly (1991) points out, in an era in which natural capital is the limiting factor to economic development, logic dictates that we maximize its supply and productivity. Environmental investment makes good economic sense; for example, Dogse and von Droste(1991) note that a US$4.5 billion per year investment in soil protection world-wide would reduce annual agricultural losses by some US$26 billion over a 20-year period. Furthermore, the world's shift from command to market economies offers greater opportunities for research and investment, since market economies are generally more open to change in response to signals of ecological distress (MacNeill *et al.* 1991; Ausubel 1993).

Technological innovation undoubtedly has the potential to stretch dramatically the limits of existing resources and systems in order to meet the needs of present and future human populations, and to alleviate many of the ecological and economic stresses caused by growing human populations and rising per capita resource consumption. Crop improvements and continuing developments in irrigation and pest control are likely to allow rising productivity as well as reducing known environmental impacts; for example, research is now under way to develop drought-resistant cassava and crops suitable for production on acidic soils (El-Sharkawy 1993; Rao *et al.* 1993). Continuing increases in food supply can also be maintained through increased aquacultural production as well as diversification of seafood consumption. Timber consumption can be reduced dramatically simply by further development of technologies to reduce waste or to mass-produce woodless paper (Postel 1994).

The effects of industrial emissions can also be reduced. For example, Goodland (1991) points out that the technology is available to reduce greatly the energy requirements of industry and other economic activity, so that carbon emissions can be reduced without necessarily implying a reduction in standards of living. To illustrate this point, he notes that since 1973, Japan has increased its output by 81% without increasing energy use. Mills *et al.* (1991) conclude that even allowing for continued economic growth, by the year 2000 global greenhouse gas emissions can be reduced by 10% from current levels, at significant net economic benefit, through implementation of available energy-efficiency improvements. The impacts of ozone pollution on crop production can also be reduced by cutting the use of fossil fuels, limiting losses of nitrogen fertilizers from soils, implementing nitrogen oxide emission controls, and developing ozone-resistant crops. Enhanced networks for monitoring air quality throughout the world to assess the extent and severity of ozone pollution on continental scales will aid in evaluating the benefits of these mitigating strategies (Chameides *et al.* 1994).

As the rate and scale of global change has increased, so has the technological response. In the future, resource frontiers may expand beyond the Earth itself (e.g. Louis *et al.* 1993). In the shorter term, one of the most dramatic manifestations of technological response to resource limitations is biotechnology. Biotechnology, for example, offers the prospect of boosting crop yields with lower inputs of energy, water and pesticides. In the short term, potential advances include modification of food crops to increase resistance to insects, viruses and fungus; to improve processing quality or reduce spoilage; and to improve nutritional content. Fermentation and enzyme technology are already used in the manufacture of animal growth hormones to increase milk production or induce faster growth and production of leaner meat. In the long term, biotechnology may help to offset the impacts of global change on food supply, for example by producing staple crops that are resistant to drought, heat and other environmental stresses. New reproductive techniques for livestock, such as embryo transfer to stimulate production of multiple eggs for artificial insemination or cloning, could boost the reproductive rate of desirable species and reduce susceptibility to disease (Teale 1993; WRI 1994).

Biotechnology also offers the possibility of new production techniques that reduce emissions of chemicals and metals into the environment. Researchers have discovered that a completely biodegradable natural plastic is produced by some types of bacteria, which can be grown in large batches to harvest the plastic. Eventually, it may be possible to insert the genes into crop plants from which plastic could be harvested. Mass production of natural plastics could replace petroleum-based products in the market-place as well as easing problems of solid waste disposal (WRI 1994; Frederick and Egan 1994). Production of ethanol from waste materials, microbial coal desulphurization, and algae-fuelled combustion could reduce emissions to the atmosphere of chemicals contributing to acid rain and the greenhouse effect.

Biological elements are also used to detect organic chemicals, pesticides and mercury in the environment, while bioremediation is increasingly used as a technology for cleaning polluted sites of metals and pesticides and treating acid drainage from coal mines. Biofilters are used to remove volatile organic compounds from industrial emissions, while bioleaching can lessen the environmental impacts of mining by enhancing recovery of minerals and reducing the release of metals into the environment (Frederick and Egan 1994).

It is becoming increasingly clear, however, that even rapid advances in productive and environmental remediation may not be sufficient. For example, increasing aquacultural output on the scale needed would require vast amounts of water and feed, and accelerate loss of coastal mangrove habitat (WCMC 1992; Brown 1994). Furthermore, the energy use and habitat modification associated with aquaculture also contribute to changes in the Earth's atmosphere and climate, which will in turn bring about dramatic changes in coastal ecosystems.

Biotechnology also brings its own set of problems and issues. In the past, human activities have resulted in biodiversity loss through the introduction of exotic species, a problem that could recur on a grander scale with the introduction of transgenic species. Altered organisms may out-compete other species in the environments in which they are released, or spread their altered genes by reproducing with native species (Pimental *et al.* 1989; Hoffman 1990; WRI 1994). Just as the Green Revolution was accompanied by hidden economic and environmental costs, it is possible that the Biotechnology Revolution will bring with it environmental consequences that have not yet been anticipated.

11.4.4 Constraints on human adaptations

11.4.4.1 Problems of uneven development

Technological solutions are also limited by their uneven availability. Not only is access to resources and skills unevenly distributed in the present, but the costs of new technology are likely to be prohibitive for many developing countries, so that future development will preserve the existing international economic structure for decades to come (Theys 1987). The first products of biotechnology research, for example, are just becoming available after 20 years of research, but research and development are concentrated in industrialized nations. Furthermore, much of the work in this area is directed toward high-value crops cultivated in developed nations, rather than the subsistence crops of tremendous importance to the developing world. Many of the products of biotechnology are likely to compete with tropical export commodities, further weakening the position of developing countries in international markets (WRI 1994).

The developed world is also much more likely to absorb successfully the economic costs associated with global climate change, and to have access to the benefits of biotechnology and other mitigative technologies that will allow the maintenance of high standards of living. Although there have been few attempts to date to compare human responses to climate change in developed and developing countries, Mooney *et al.* (1993) point out that high incomes in North America will facilitate mobility and adaptation in response to global change. By contrast, Fuentes and Muñoz (1993) hypothesize that climate change will force small-scale Chilean agriculturalists to intensify agricultural production on steep slopes and increase secondary activities such as logging and mining, thus intensifying the environmental impact of current land-use practices. Indeed, land-use and land-cover change are expected to outweigh the effects of climate change in South America. Low-income agricultural households in the developing world will be particularly vulnerable to the increasing frequency of extreme climatic events as well as temperature change, although forecasting of the effects on agricultural production has primarily been conducted in developed countries (Parry and Jiachen 1991).

11.4.4.2 *Prices, politics and alternative models of development*

Many observers argue that increasing supply from available resources, mitigating ecological damage associated with human activities, and developing adaptive technologies depend in large part on the ability to reform economic pricing and markets. Markets and prices must not only account for the environmental costs of production and consumption, but also compensate economic factors for the environmental benefits of resource conservation (McNeely 1988; Von Droste and Dogse 1991). Brenton (1994) considers that sustainable development will not emerge from 'dense webs of regulation' or the old command and control approach to environmental conservation, but only when conditions create more democracy, greater economic prosperity and a market that works for, rather than against, the interests of biodiversity. However, it is increasingly clear that the process of market reform and 'getting prices right' involves much more than simply freeing the market. Markets are the creation of human cultures, policies and institutions and are therefore subject to the many limitations of human understanding and politics.

The problem of scientific uncertainty is almost universal in the development of appropriate economic and environmental policy. According to Ludwig *et al.* (1993), the complexity and natural variability of biological and physical systems mean that levels of resource exploitation must be set by trial and error, with over-exploitation often not detectable until it is severe or even irreversible. Scientific consensus on the impacts of exploitation is seldom achieved, even after the resource has collapsed. Furthermore, even when considerable scientific evidence exists that a given practice or technology will prove ecologically destructive, certainty has not proved sufficient to prevent the unsustainable use of resources. 'Resource problems are not really environmental problems: they are human problems that we have created at many times and in many places, under a variety of political, social and economic systems' (Ludwig *et al.* 1993: 549).

The development of appropriate economic and environmental policies to deal with biodiversity problems is thus hindered not only by problems of scientific certitude, but also by lack of understanding of the driving forces underlying individual and collective human behaviour and the relationships among human behaviour and global change. For example, only relatively recently has a body of evidence emerged on land-use and land-cover change that attempts to identify the social, economic and political forces that determine land-use patterns, and the understanding of relationships between land-use and global environmental change (Ojima *et al.* 1994). One of the contributions of this multidisciplinary research is the recognition that the fundamental causes of land-use and land-cover change may originate far from the ecosystem, or even region, affected. Regional and local responses to these causes vary widely depending on available resources and on local political, social and economic conditions, and further research is needed to determine local and regional variations in the human dynamics of global change (Kummer and Turner 1994; Skole *et al.* 1994; Collier *et al.* 1994).

One of the problems that this raises for appropriate environmental policy is 'scale mismatch', in which human responsibility does not match the spatial, temporal or functional scale of natural phenomena (Lee 1993). Adjustment of short-term, specialized human behaviours to account for their broader long-term ecological consequences depends in part on improved understanding of those consequences, but ultimately depends on politics (Holdgate 1991) – developing the institutions, management styles and policies that link individuals with their impacts on the global environment. Another growing body of research focuses on the development of diverse and context-specific institutional arrangements that correct such mismatches of scale and reduce the human conflicts they produce (Ostrom 1990; Bromley 1992; Haas *et al.* 1993).

11.4.4.3 *Building the capacity to adapt to change*

In the short term, policy-makers may be forced to respond to calls to limit human impacts on the Earth in ways suggested by the best available information and technology, even in the absence of consensus on human and natural systems. Given the scale of expected human-induced global change and the limitations of natural and social science in predicting the future, some observers suggest that the major challenge in decades to come will be to adjust to the unexpected (Theys 1989). Planning methods for the uncertain and the unexpected involve adjusting the values for which ecosystems are managed, and adjusting the management styles adopted to achieve those values.

First, successful human adaptation to global change may depend on ecosystem management for the values of variability and resiliency, rather than for predictability, as has been the trend in the past. The maintenance of biological diversity is itself an important contributor to variability and resiliency, and many of the methods proposed for biodiversity conservation have important implications for global change. Walker (1989) suggests, for example, that conservation areas should maintain the elements of heterogeneity and variability that allow for change. Efforts to stabilize an ecosystem or to preserve an individual plant or animal species may be counterproductive, since ecosystem processes are the most critical value in conservation. Ryan (1992) applies this concept to intensively managed systems as well, noting that diversification of products and production methods within a management area also improves the capacity to adapt to change.

Second, several researchers have argued that planning for the uncertain and the unexpected can best be achieved by adopting a management style that is flexible, adaptive and experimental (Holling 1986). Holling argues that political decisions typically involve quick fixes for quick solutions, designed to maintain an imperfectly understood system in a constant state. The result is greater ecosystem fragility and higher stakes for future policy and management. The alternative of adaptive management is designed explicitly for decision-making in the face of uncertainty.

The principles of adaptive management may be described as follows: 'consider a variety of plausible hypotheses about the world; consider a variety of possible strategies; favour actions that are robust to uncertainties; hedge; favour actions that are informative; probe and experiment; monitor results; update assessments and modify policy accordingly; and favour actions that are reversible' (Ludwig *et al.* 1993: 549). Holling (1994) suggests a number of research strategies for experimentation in short-term change variables and monitoring of long-term shifts in ecosystem processes: experimentation and monitoring that combine perspectives from both the natural and social sciences may contribute greatly to our understanding of the human impact on global ecosystems.

Social and institutional learning is often an extremely slow process, and the scale and pace of changes in global biodiversity are increasing rapidly. However, the possibility also exists for rapid change in human behaviour. For example, smokeless fuel regulations were adopted in response to killer smogs in London in the 1950s, and strong energy conservation measures were prompted by the oil crisis of the 1970s (Western 1989). More recently, abrupt shifts in management policies in response to ecological crises in a number of settings, from North America to the Baltic Sea, are also described by Gunderson *et al.* (1995; cited in Holling 1994). Thus while the unexpected may characterize the future, there are precedents for rapid leaps in the evolution of human capacity to modify human impacts on global ecosystems.

11.4.4.4 Uncertainty

The future is uncertain. We do not understand how little we know, nor what future citizens will value. H.G. Wells (1902), writing just before the Wright Brothers' first powered flight, was prescient regarding high-speed highways but could not imagine that airplanes might be important a dozen years later in World War I. Today we may be making similar errors in our valuation of ecosystems. Arguments for preservation of ecosystems such as rain forests include their use as a resource for medicinal chemicals, for preserving species, and for preserving indigenous cultures and knowledge systems. Additional arguments may emerge. For example, computer scientists are starting to explore adaptive, evolutionary, neo-biological designs based on close observations of ecosystems (Kelly 1994).

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